Visualising the Aurora: Embodied and Instrumental Sensing throughout the International Polar and Geophysical Years (1880-1960).

Fig. 1. Harald Moltke, 'Aurora toward the northwest, Akureyri, Iceland, 11 November 1899, in the foreground is a spectrometer on a pillar', oil painting (60 x 60), *Danish Meteorological Institute (DMI).*

Fiona Alexandra Amery

Selwyn College, University of Cambridge

December 2022

This thesis is submitted for the degree of Doctor of Philosophy

Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text. I further state that no substantial part of my thesis has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text. It does not exceed the prescribed word limit for the relevant Degree Committee.

Abstract

Fiona Amery, *Visualising the Aurora: Embodied and Instrumental Sensing throughout the International Polar and Geophysical Years (1880-1960).*

This thesis traces the various ways in which the aurora was imaged, visualised and understood during the International Polar and Geophysical Years of 1882-1883, 1932-1933 and 1957-1958. I explore the depiction of the phenomenon, from hand-drawings to radio echoes, while paying heed to what was occluded from portrayals, the imaginative and aesthetic considerations involved in rendering the aurora and the epistemological problems of capturing a transient, unpredictable and intangible atmospheric object. Photography, spectroscopy, radio imaging and the introduction of the all-sky perspective were integral technological developments, influencing the ways in which the aurora was presented and viewed. Nevertheless, experiential knowledge of the phenomenon, gained through watching the affective light displays and occasionally listening for its potentially illusive sounds, remained crucial to each of the endeavours. With a focus on the practices of Polar research, I trace the shifting balance between reliance on embodied and instrumental registration of the phenomenon. This perspective reveals the significance of amateur participation to the Polar Years and the centrality of outdoor, situated practices of knowledge creation, complicating our understanding of the spaces of the nineteenth and twentieth century physical and geophysical sciences. The project to perfectly reproduce the aurora, and thus come to know it, was from the outset an impossible task. This thesis is, therefore, a story of incremental learning, of the calibration and standardisation of the phenomenon across vast distances, of bringing together fragments of the aurora's ontology to create a fuller, more complete picture of the phenomenon, and of both fallibility and success.

Acknowledgments

First and foremost, I am indebted to my supervisor, Richard Staley, and my advisor, Simon Schaffer, for their boundless encouragement, invaluable feedback and generous guidance throughout the duration of my doctoral studies. I always leave meetings with each of you inspired and excited to get to work and explore whatever we have discussed. It has been a real privilege and a great joy to work with you both.

I would like to extend my sincere gratitude to friends and colleagues who have read drafts of chapters included within this thesis and provided exceedingly helpful comments and constructive suggestions. Thank you Helen Curry, Josh Nall, Emilie Skulberg, Amelia Urry, Claire Oliver, Harriet Mercer and members of the 'Outside Sciences' group: Katy Duncan, Daniel Belteki, Miguel Ohnesorge and Floris Winckel. For the insightful exchanges and the opportunity to present and discuss my research, I am very grateful to members of the University of Regensburg Astrophotography Reading Group. In particular, I would like to thank Omar Nasim, Kelley Wilder, Katharina Bick and Chaokang Tai. Discussions with Emilie Skulberg and Miles Kempton on scientific images have similarly been extremely valuable.

Many thanks are owed to Joe Martin for his encouragement and formative conversations about my PhD project during my MPhil. I am also indebted to archivists at the Royal Society, Cambridge University Library, Churchill College, the University of Aberdeen, The Shetland Island Museum, the University of Manchester, the University of Bergen and Oslo National Library.

For the many excellent reading recommendations and kind hospitality on my visit to the Tromsø Geophysical Observatory, I would like to thank Magnar Johnsen and the late Chris Hall. I have also benefited greatly from conversations with Charles Deehr about his work at the University of Fairbanks, Alaska in the years surrounding the International Geophysical Year and Unto Laine about current auroral sound investigations.

I have been extremely fortunate to have the unwavering support of my parents and my partner, Noah Havers. Thank you Gillian Amery for your tireless proofreading and thank you Noah for your helpful suggestions and technical support, including helping me to build a computer during the first UK lockdown of 2020.

I am grateful for the work of Michael Bravo and Charlotte Bigg in examining this thesis. I would also like to thank the administrative and support staff at the Department of History and Philosophy of Science and at Selwyn College. Lastly, this thesis would not have been possible without the Cambridge Trust Vice Chancellor's & Selwyn Littlefield Scholarship funding and the Lisa Jardine Royal Society Travel Grant, which funded a trip to visit three archives in Norway.

Table of Contents

List of Figures

Introduction

Chapter 1

Chapter 2

Abbreviations

The following abbreviations are used:

- Atlas of Auroral Forms, Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae
- BAA, British Astronomical Association
- C, Coronas
- CSAGI, Special Committee for the International Geophysical Year

- DMI, Danish Meteorological Institute
- FIDS, The Falkland Island Dependencies Survey
- G, Feeble Glows
- HA, Homogenous Arcs
- IBC, Internal Brightness Coefficient
- IBMs, Interim Ballistic Missiles
- IGY, International Geophysical Year
- IMO, International Meteorological Organisation
- IPY, International Polar Year
- IUGG, International Union of Geodesy and Geophysics
- NOSWE, The Norwegian Centre for Space Weather
- RB, Bands with Ray Structure
- UAF, University of Alaska Fairbanks
- WMO, World Meteorological Organisation

Introduction

The aurora, that fleeting, enigmatic, brilliant light phenomenon seen in northern and southern skies, has inspired awe and contemplation for centuries. Alluring and unearthly, it has enchanted those who have witnessed it and drawn observers from across the globe. Above the icy landscape of the polar regions, spaces that have long been ascribed a mystical ethos themselves, the aurora takes on an iconographic power which is both deeply affective and peculiarly transcendental.[1] 'It paints my simple spirit with taints of majesty', Emily Dickinson writes in her poem, 'Of Bronze and Blaze'.[2] Dickinson refers to another recurring motif of auroral description with the lines, 'so preconcerted with itself, so distant to alarms, an unconcern so sovreign to universe or me'.[3] The aurora is portrayed here as aloof, unfeeling, distant, and almost otherworldly. Indeed, its characteristics as an intangible, remote, and inert phenomenon presented problems for the epistemological project of coming to understand and know the aurora.

The nature of the lights and the mechanism by which they operate had puzzled observers for centuries. In the eighteenth century, Jacques Philippe Maraldi (1716) contended that the aurora originated from sulphurous gases emanating from the earth, Edmond Halley (1716) asserted that the lights were caused by vapours affected by the earth's magnetic field and Leonhard Euler (1746) suggested that particles in the earth's atmosphere were pushed by the sun's rays.[4] It was in 1753 that John Canton noted that the aurora might be stimulated by an electrical charge, possibly generated from clouds and the vapours passing through them. Yet, by the twentieth century, the phenomenon 'remained, in many respects, mysterious', according to one of Britain's leading geophysicists, Sydney Chapman.[5] Nevertheless, capturing and therefore understanding the aurora was a prominent objective

[1] For literature on the projection of the Arctic as a 'spectral' and spiritual space, see: Michael Bravo, *North Pole: Nature and Culture* (London: Reaktion Books, 2019); Shane McCorristine, *The Spectral Arctic: A History of Dreams and Ghosts in Polar Exploration* (London: UCL Press, 2018); Francis Spufford, *I May be Some Time: Ice and the English Imagination* (London: St Martin's Press, 1999).

[2] Emily Dickinson, 'Of Bronze and Blaze', *Emily Dickinson Museum*, 319.

[3] Ibid.

[4] J. Morton Briggs, Jr., 'Aurora and Enlightenment: Eighteenth-Century Explanations of the Aurora of the Aurora Borealis', *Isis* 58, no. 4 (1967): 491-503; Edmund Halley, 'An account of the late surprising appearance of the lights seen in the air, on the sixth of March last; with an attempt to explain the principal phenomena thereof'', *Philosophical Transactions* xxix (1716): 406-428.

[5] Sydney Chapman, 'The Audibility and Lowermost Altitude of the Aurora Polaris', *Nature* 127, no. 3201 (1931): 341-342.

of several nineteenth and twentieth century endeavours. On the largest scale, the International Polar (IPY) and Geophysical Years (IGY), of 1882-3, 1932-3 and 1957-8 respectively, included auroral programmes which sought to scrutinise, reproduce and reveal the phenomenon's ontology.[6]

The process of constructing visual knowledge of the aurora during the International Polar and Geophysical Years is the subject of this thesis. With a focus on the practices of polar research, I trace the shifting balance between reliance on embodied and instrumental sensing across transnational projects, analysing how these two different paths to knowledge informed, underpinned and sometimes contradicted one another. I explore the depiction of the aurora, from hand-drawing in the late nineteenth century to radio imaging during the Cold War, while paying heed to what was occluded within portrayals, the imaginative and aesthetic aspects of rendering the aurora and the epistemological problems of understanding a transient, unpredictable and intangible atmospheric object. This thesis is a story of incremental learning, of the calibration and standardisation of the phenomenon across vast distances, of bringing together fragments to create a more complete picture of the aurora's nature, and of both fallibility and success.

As an object of repeated investigation across temporal and spatial boundaries, the aurora becomes a lens through which we can view the intricacies and unevenness of international collaboration during the IPYs as well as how visual replication formed the basis of new understandings of the phenomenon. Indeed, taking the aurora as the central organising subject reveals the significance of the outdoor realm to such observational projects and brings to light what counted as convincing evidence of atmospheric phenomena across the late nineteenth and twentieth centuries. While the aurora acts as a probe into the institutional and epistemological history of the Polar Year programmes, I also use the Polar Years as anchor points to explore changes and developments in the field of auroral science between the 1880s, 1930s and 1950s. From this perspective we gain an appreciation of the position of amateur observers in an emergent field within the (geo)physical sciences and learn much about the instrumentation and practices of using such devices to analyse the aurora in the cold conditions of the Arctic and Antarctic.

Influenced by the framework set out in Peter Galison's *Image and Logic* (1997), which traces the changing material culture of twentieth century microphysics from an instrumental perspective, my research is organised both temporally and thematically, with two chapters devoted to each of the Polar Years and each of these six chapters exploring a different method of reproducing the aurora.[7] The theme of scale was important for Galison's history and so too is it an important prism through which to view the history of auroral observation, though its implications are different when looking at the

[6] I will refer to these three programmes collectively as the Polar Years or IPYs for simplicity.

[7] Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997).

hemispheric planetary scale rather than the microscopic. Whilst Galison is interested in the connections between experiment, instrument and theory, this thesis will instead chart the practices of situated knowledge creation at multiple polar sites through the production of images to bridge the gap between the intangible atmosphere and the observer on the earth's crust. Comparable to the lengthy period surveyed in *Image and Logic*, this is a history which spans from 1880 to 1960.

Chapter Synopses

'If one were to try to describe each of these three events by a single word, appropriate choices would be: sublime for the First Polar Year, courage for the Second Polar Year, and audacity for the International Geophysical Year'.[8]

The International Polar Years were twelve or eighteen-month periods wherein a transnational co-ordinated effort to understand the geophysics of the polar regions in the realms of oceanography, geomagnetism, atmospheric electricity, meteorology and glaciology was undertaken. There have been four such Polar Years, in 1882-3, 1932-3, 1957-8 and 2007-8. The most recent event did not focus to a great extent on auroral investigations and thus this thesis concentrates on the first three programmes.

The first chapter of this thesis explores the aurora as it was conceived of as an ineffable phenomenon in the literature produced as part of the First International Polar Year of 1882-3. The phenomenon's apparent indescribability caused ontological problems for an international programme dependent on written communication and the 'virtual witnessing' of an object situated in an inaccessible area of the globe. Because the phenomenon could not be captured through language or imagery in a way that was perceived as faithful, emphasis was placed on first-hand embodied observation. Nevertheless, language was also deployed purposefully by the scientists of the IPY to navigate the relationship between the aurora's power as an imaginative resource and a topic of scientific study. At the limits of common registration techniques, the language of obscurity and occlusion became part of the aurora's visuality. Indeed, it emerged as a way of underpinning the sublime nature of the aurora itself.

Hand-drawings of the aurora produced during and immediately after the First IPY form the focus of the second chapter of this thesis. By surveying the aesthetic lineage of auroral reproduction stretching back to the eighteenth century, it is clear that the IPY drawings departed from the iconographic traditions of past renderings. The aurora was portrayed with an earnest faithfulness to all of its irregularities and asymmetry, it was deterritorialised in schematics and, significantly, was

[8] Nicolet Marcel, 'The International Geophysical Year (1957-1958): Great Achievements and Minor Obstacles', *GeoJournal* 8 (1984): 303-320, 305.

presented in a specific rather than a general register, set next to precise temporal and spatial signatures. The move toward naturalistic modes of portrayal can be interpreted as a reflection of the popular precept of 'mechanical objectivity' in the late nineteenth century, albeit operating in an altered form with rigorous practices of observation and drawing standing in for the 'mechanical' element in the system. Pastel drawings, sketches and watercolour paintings were used as direct evidence of the various formations of aurorae seen across the Arctic during the winter of 1882-3, intervened in debates about the altitude of aurorae and were employed in a visual performance of persuasion to substantiate the veracity of artificial aurora observations.

The third chapter of this thesis takes as its focus the standardisation of auroral photography during the Second IPY of 1932-3. It explores the influence of *The Photographic Atlas of Auroral Forms and Visual Scheme for Aurorae* (1930) on the practices and conventions for capturing the phenomenon through the camera lens at the British, Norwegian, Canadian, US and Dutch Polar Year stations.[9] The atlas's codes were largely followed, although in some important cases the protocols of the reference text were altered, demonstrating that even though the atlas was ideally positioned to direct the practices of auroral science, it could not entirely pre-empt the complexities that the field presented. Furthermore, the camera introduced a distinct temporality to capturing the aurora; it placed images of the lights into sequential series and presented the phenomenon as a set of stationary moments rather than a flowing and rapidly changing display. The immense volume of photographs produced during the programme facilitated reassessment of 1932-3 auroral appearances years after the programme had ended, thus bearing new knowledge and introducing a different type of temporality to the discipline.

The 'spectral' life of the aurora during the Second International Polar Year is the subject of the fourth chapter of this thesis. In other words, I explore embodied and instrumental investigations of the aurora's chromatic and audible qualities during the programme. Extensive spectroscopic analyses were carried out to assess the elements responsible for the various colours witnessed within auroral displays, and thus reveal the conditions and composition of the upper atmosphere. Standards were put in place to calibrate spectroscopic research in a similar vein to the work carried out by astrophysical spectroscopists, as discussed by Charlotte Bigg.[10] Spectroscopy, however, was considered only a partial way of rendering the aurora. I argue for the recognition of the importance of experiential knowledge within chromatic investigations of the phenomenon. The significance of accurate colour and brightness observations gave rise to particular gestures and performances of viewing as well as the act of training the eye to see beyond auroral illusions and adjust to the ambient darkness.

---

[9] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930).

[10] Charlotte Bigg, 'Spectroscopic Meteorologies', *Nuncius* 18 (2003): 765-777, 776.

Moreover, the debate regarding the veracity of auroral sound reports, which had been building in number since the beginning of the century, galvanised considerable speculation within the auroral research community as to whether the apparent noises were imagined or illusory, connected to discussions about the possibility of low-altitude aurorae. Crucially, this debate reveals an unexpected faith in the corporeal senses and the essential role of amateurs.

The fifth chapter of this thesis focuses on the physical and social networks constructed to examine the aurora by means of radio echoes during the International Geophysical Year. I explore the themes of communication and correspondence, taking the Jodrell Bank Observatory as a central node in the international network. The antithetical theme of interference arose on multiple intersecting scales, from the individual reading spurious results within auroral echoes to the havoc aurorae could wreak in both hemispheres by disrupting communications. Disagreements about the practices of the programme took place between the various research stations and visitors to Jodrell Bank were explicitly discussed using the discourse of disruption and snow static interfered with the signals recorded from radio echo devices placed at Halley Bay in Antarctica.[11] I investigate the ways in which the aurora itself was viewed as a threat to communication, its effects even mirroring the onset of nuclear attack, while it's interference was also harnessed as a way of learning more about the phenomenon.

The sixth and final chapter of this thesis surveys the International Geophysical Year's all-sky camera photography project and its aim to capture the aurora from a synoptic perspective. All-sky cameras have a field of view of 500km from horizon to horizon. Chains of such cameras facilitate a more complete view of the patterns of aurorae from a planetary perspective, giving rise to new knowledge about the shape of the maximum auroral frequency zone and development of aurorae from their formation to their eventual disappearance. Researchers involved in the International Geophysical Year also saw themselves as situated at the culmination of auroral science, uniquely positioned at the climax of their field, able to take stock and reflect on the previous Polar Years. In such a way the synoptic power of the chain of all-sky cameras was two-fold: it was both *planetary* and *historical*.

What was at stake with these various ways of imaging and investigating the aurora was the very way that the phenomenon was defined throughout the nineteenth and twentieth centuries. The aurora was initially understood to be present if it was visible to the human eye in the night sky. Then, with the introduction of photography and spectroscopy, the criteria for auroral appearances changed. The phenomenon existed if it could be imprinted on the photographic plate or if the 'auroral green line' could be recorded by the spectroscope. Aurorae invisible to the human eye were detected and thus the senses no longer constituted a reliable measure of the presence of the phenomenon. When

[11] Jon Agar, *Science and Spectacle: The Work of Jodrell Bank in Postwar British Culture* (Abingdon: Routledge, 1998).

daytime aurorae were recorded with radio echo apparatus in the 1950s, the definition was altered once again. The aurora came to be defined as a pattern of atmospheric ionisation drifting overhead. Lastly, the all-sky camera inverted the perspective, emphasising that the aurora was a planetary phenomenon, best captured by the combination of remote sensing camera data to form hemispheric charts. One key argument of this thesis is that the aurora was defined in increasingly instrumental ways throughout the International Polar Years. This does not, however, mean to say that the embodied component of knowledge construction was no longer an important part of the epistemic process towards the 1950s. In fact, it remained crucial to the project to understand the aurora.

Sensory Histories:

The sensory turn began in the 1990s, with such figures as Alain Corbin, Constance Classen and Roy Porter exploring sensory perception in their works.[12] It remains a 'vigorous mainstream enterprise'.[13] Vision has been studied through the lens of visuality since the late 1980s, following the publication of Hal Foster's seminal edited collection, *Vision and Visuality* (1988).[14] Visuality, according to Klaus Hentschel, can be defined as, 'the variegated bundle of social factors involved in the process of seeing'.[15] As such, the act of seeing needs to be understood in relation to the technological, cultural and embodied factors on which it depends. Visualising the aurora was a two-fold process. It involved the corporeal witnessing of the phenomenon in situ as well as the construction of images for the imaginative project of conjuring the aurora at a distance, either temporal or geographical, from the display. In 1996, W. J. T. Mitchell argued that images 'exhibit both physical and virtual bodies; they speak to us, sometimes literally, sometimes figuratively'.[16] The material component of visual representations, their technical construction, the operations applied to them and their circulation as well as their conceptual messages must all be studied in order to gain an understanding of their significance for a particular community of researchers.

---

[12] W.F. Bynum and Roy Porter, *Medicine and the Five Senses* (Cambridge: Cambridge University Press, 1993); David Howes and Constance Classen, 'Introduction: Ways and Meaning', in David Howes and Constance Classen (eds.), *Ways of Seeing: Understanding the Senses in Society* (Abingdon: Routledge, 2013): pp. 1-17; Alain Corbin, *Time, Desire and Horror: Towards a History of the Senses* (Oxford: Blackwell Publishers, 1995).

[13] Martin Jay, 'The Senses in History', in David Howes (ed.), *Senses and Sensation: Critical and Primary Sources Volume 2 History and Sociology* (London: Bloomsbury, 2018): pp. 63-70, p. 66.

[14] Hal Foster, *Vision and Visuality: Discussions in Contemporary Culture* (Seattle: Bay Press, 1988).

[15] Klaus Hentschel, *Visual Cultures in Science and Technology: A Comparative History* (Oxford: Oxford University Press, 2014), p. 25.

[16] W. J. T. Mitchell, 'What Do Pictures Really Want?' 77 (1996): 71-82, 72.

Histories of scientific images have their roots in the work of art historians of the late 1980s and 1990s. James Elkins published his influential essay, 'Art History and Images that are Not Art' in the *Art Bulletin* in 1995, arguing that scientific images should be recognised as representations full of meaning and expression which have their own aesthetic lineages and conventions of representation.[17] While recognising that the images surveyed in this thesis have their own traditions, I also argue that the late nineteenth century iconography of the aurora engages with artistic movements and the work of such impressionists as Edvard Munch.

One central theme of this thesis is the interplay between objectivity and subjectivity and how it manifested in the literature and imaging techniques of the IPYs. Photography was widely considered to be a method of producing 'mechanically objective' scientific images in the early twentieth century, by eliminating the subjective human element from the production process.[18] As Johnathan Crary writes in his influential article, 'Techniques of the Observer' (1988), photographs 'seemed to be a continuation of older 'naturalistic' pictorial codes', giving the impression that they could transmit the reality of the natural world.[19] The notion of photography as an inherently objective technology, however, is challenged in the third chapter of this thesis and other ways of negotiating subjectivity and visual illusions are evaluated throughout. Contemporary and modern debates about photography are just one of the ways that this thesis will seek to unravel notions of objectivity and subjectivity embedded within auroral research.

Despite the success of the sensory turn, Martin Mahony and Samuel Randalls argue that, 'corporeality has often been missing from, or unevenly present in, our spatial histories of science'.[20] Moreover, while the historical hegemony of vision in the west has been well documented, other means of perception have received considerably less scholarly attention.[21] Research in the fields of cultural geography and anthropology has confronted this discrepancy most wholeheartedly. Deborah Dixon illuminated the significance of haptic perception in the 'grasping of new information' and Paul Stoller galvanised the sensory turn within anthropology with his 1989 work, *The Taste of*

[17] James Elkins, 'Art History and Images That Are Not Art', *The Art Bulletin* 77, no. 4 (1995): 553-571.

[18] Lorraine Daston and Peter Galison, *Objectivity* (Cambridge: Zone Books, 2007), p. 131.

[19] Jonathan Crary, 'Techniques of the Observer', *October* 45 (1988): 3-35, 34.

[20] Martin Mahony and Samuel Randalls, 'Introduction', in Martin Mahony and Samuel Randalls (eds.), *Weather, Climate, and the Geographical Imagination: Placing Atmospheric Knowledges* (Pittsburgh: University of Pittsburgh Press, 2020): pp. 3-21, p. 7.

[21] Howes and Classen, 'Introduction: Ways and Meaning', p. 1; Chris Otter, *The Victorian Eye: A Political History of Light and Vision in Britain, 1800-1910* (Chicago: University of Chicago Press, 2008).

Ethnographic Things.[22] The history of auroral science provides a particularly rich example for the exploration of a phenomenon configured in regard to experiential knowledge acquired through the human senses and particular spatialities. The aurora of the nineteenth and twentieth centuries was affective, often overwhelming the senses and thus providing an experience of the sublime, while also registered visually, audibly and in extreme latitude spaces where considerations of temperature, intangibility, and patience needed to be taken into account.

Atmospheric aesthetics have recently been the subject of sociological and empirical studies.[23] Mădălina Diaconu has written on the aesthetic appreciation of fine weather as influenced by art, literature and science.[24] In a recent paper Diaconu traces the aesthetic features of weather phenomena at the limits of representation and the connection between personal atmospheric experiences and ecological responsibility.[25] Jeff Diamanti, Lynn Badia and Marija Cetinić co-edited a collection on the aesthetic category of realism in relation to the Anthropocene, arguing that 'every weather event constitutes the climatic forces that are as much social, cultural and economic as they are environmental, natural and physical.'[26] This thesis charts the aesthetic experience of the aurora along several different paths. Most significantly, I trace the ineffability and sublime nature of the aurora as it was conceptualised in the literature of the First IPY.

Interestingly, it was not only the bodies of researchers visiting the polar regions who were trusted with registering and recording the aurora. The standard history of the physical sciences tells us that there were few practicing amateurs involved in the discipline by the mid-1800s. The history of auroral science provides a rich counter narrative as a discipline involving lay observers and local

---

[22] Deborah Dixon, 'Geographies of Touch/Touched by Geography', *Geography Compass* 4, no. 5 (2010): 449-459; Paul Stoller, *The Taste of Ethnographic Things: The Senses in Anthropology* (Philadelphia: University of Pennsylvania Press, 1989).

[23] Tonino Griffero, 'Is there such thing as an 'atmospheric turn'? Instead of an introduction', in Marco Tedeschini and Tonino Griffero (eds.), *Atmosphere and Aesthetics* (Berlin: Springer International Publishing, 2019): pp. 11-62; Juhani Pallasmaa, 'The Atmospheric Sense: Peripheral and the Experience of Space', in Marco Tedeschini and Tonino Griffero (eds.), *Atmosphere and Aesthetics* (Berlin: Springer International Publishing, 2019): pp. 121-132; Gernot Böhme, *The Aesthetics of Atmospheres* (Abingdon: Taylor & Francis, 2016).

[24] Mădălina Diaconu, 'Longing for clouds – does beautiful weather have to be fine?', *Contemporary Aesthetics* 13, no. 16 (2015): 1-13; Another related example is: Ronald W. Hepburn, 'The Aesthetics of Sky and Space', *Environmental Values* 19, no. 3 (2010): 273-288.

[25] Mădălina Diaconu, 'Rescaling the Weather Experience: From an Object of Aesthetics to a Matter of Concern', *Environmental Values* 31, no. 1 (2022): 67-84.

[26] Jeff Diamanti, Lynn Badia, and Marija Cetinić, 'Introduction', in Jeff Diamanti, Lynn Badia, and Marija Cetinić (eds.), *Climatic Realism: The Aesthetics of Weather and Atmosphere in the Anthropocene* (Abingdon: Taylor and Francis, 2020).

indigenous inhabitants. Even during the IGY, when the scope and number of expeditions sent to the Arctic and Antarctic were at their fullest extent, researchers welcomed the engagement of the general public and depended on their input to maintain a complete record of the aurora's appearances. As Patrick McCray writes with regard to the IGY Moonwatch programme, 'historians have not fully examined or appreciated the role of amateur scientists… in IGY activities'.[27] By including the knowledge of laypeople and probing its often-uneasy relationship with what has been termed 'cosmopolitan' knowledge, I follow Jeremy Vetter's lead in *Field Life* (2016). He argues that the 'epistemic rift' between these two types of knowledges is 'one of the most important conceptual frameworks for understanding the practice of field science'.[28]

Spaces of Research:

As Gillian Rose argues in her 2017 essay in *The Handbook of Visual Culture*, 'practices of looking… are also about the practising of places'.[29] The concepts of space and place have been important to the study of the history of science for what they reveal about the environmental factors involved in the construction of knowledge as well as the ways in which knowledge has been transported, translated and exchanged. Moreover, through the lens of place, we learn much about the configurations of particular sites as 'truth-spots', to make use of Thomas Gieryn's phrase, with the authority to export universal knowledge.[30] The aurora, as a phenomenon resulting from the interaction of planetary forces which can span 10,000km in length while also being seen from below by individuals observing the night sky, poses the question as to how 'placeless' knowledge arises from information gathered from multiple sites particularly sharply.[31]

Although the dichotomy between the laboratory and field has received relatively minor treatment in histories of the physical and geophysical sciences, the spaces of the biological sciences have been explored more thoroughly. As Robert Kohler and Jeremy Vetter argue, the biological sciences experienced a gradual shift in locus from the field to the laboratory from the 1840s to the

[27] W. Patrick McCray, 'Amateur Scientists, The International Geophysical Year, and the Ambitions of Fred Whipple', *Isis* 97, no. 4 (2006): 634-658, 635.

[28] Jeremy Vetter, *Field Life: Science in the American West during the Railroad Era* (Pittsburgh: University of Pittsburgh Press, 2016), p. 17.

[29] Gillian Rose, 'The Question of Method: Practice, Reflexivity and Critique in Visual Culture Studies', in Ian Heywood and Barry Sandwell (eds.), *The Handbook of Visual Culture* (London: Bloomsbury Publishing, 2017): pp. 542-558, p. 549.

[30] T.F. Gieryn, *Truth-Spots: How Places Make People Believe* (University of Chicago Press, 2018).

[31] The ideal of 'placeless knowledge' is discussed in: David N. Livingstone, *Putting Science in its Place: Geographies of Scientific Knowledge* (Chicago: University of Chicago Press, 2003), p. 3.

1870s, in what has been termed the 'laboratory revolution'.[32] Historians including Kohler and Vetter have nevertheless drawn attention to field sites and fieldwork as essential to the projects of nineteenth century biology and the environmental sciences.[33] Henrika Kuklick and Bruce Hevly have evaluated the virtue of heroism and the experience of hardship in the field.[34] Stuart McCook has analysed the influence of individuals with (or without) authority in the field and Gieryn has noted the possibility of unexpected but promising surprises through immersion in a field site.[35]

In terms of disciplinarity, auroral research was positioned within the realm of the physical sciences and the emergent discipline of geophysics, with prominent researchers employed at universities as Professors of physics, the use of instrumentation and methods from the physical sciences, and its aim of understanding the connection between the solar wind and the earth's atmosphere at the level of atomic particles. While the laboratories of the earlier nineteenth century were sometimes indistinguishable from kitchens, workshops, museums and domestic spaces, 'the rather different notion of the laboratory as a place for rigorous experimental training was imported from chemistry to physics in the 1860s and thence to engineering in the 1870s'.[36] What we learn from traditional histories of the physical sciences is that the laboratory was understood as the *exemplary site*, from which universal knowledge could be exported.[37] The auroral work of the nineteenth century moves us beyond the dualistic narrative of the laboratory field dichotomy, blurring the lines between these spaces while also complicating our understanding of what it meant to create atmospheric knowledge from a handful of research stations on the earth's crust.

---

[32] Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-field Border in Biology* (Chicago: University of Chicago Press, 2002), p. 6; Vetter, *Field Life*, p. 24.

[33] Robert E. Kohler, 'History of Field Science: Trends and Prospects', in Jeremey Vetter (ed.), *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (New Jersey: Rutgers University Press, 2011): pp. 212-231; Henrika Kuklick and Robert E. Kohler, 'Introduction', *Science in the Field* 2, no. 11 (1996): 1-16; Jeremy Vetter, 'Introduction', in Jeremy Vetter (ed.), *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (New Jersey: Rutgers University Press, 2011): pp. 1-16.

[34] Henrika Kuklick, 'Personal equations: reflections on the history of fieldwork, with special reference to sociocultural anthropology', *Isis* 102, no. 1 (2011): 1-33; Bruce Hevly, 'The Heroic Science of Glacier Motion', *Osiris* 11 (1996): 66-86.

[35] Thomas F. Gieryn, 'City as Truth-Spot: Laboratories and Field-Sites in Urban Studies', *Social Studies of Science* 36, no. 1 (2006): 5-38, 6; Stuart McCook, 'It May be Truth but it is not Evidence: Paul Du Chaillu and the Legitimation of Evidence in the Field Sciences', *Osiris* 11 (1996): 177-197.

[36] Graeme Gooday, 'Placing or Replacing the Laboratory in the History of Science?', *Isis* 99, no. 4 (2008): 783-795, 792.

[37] For an explanation of the rise of the physical science laboratory see: Iwan Rhys Morus, *When Physics Became King* (Chicago: University of Chicago Press, 2005).

The work of auroral researchers was intrinsically connected to the emergent discipline of geophysics, with the journal of *Terrestrial Magnetism* founded in 1896 and the International Union of Geodesy and Geophysics founded in 1919. As Gregory Good outlines, 'geophysics, like physics, was kaleidoscopic' in its traditions, methods, instrumentation and theories, and still in the process of discipline formation at the end of the nineteenth century.[38] The discipline was unstable and the places where the study of geophysical phenomena were carried out varied significantly. In terms of how historians of the geophysical sciences have dealt with the spaces in which their actors carried out research, Victor A. Ramos and Suryakanthie Chetty have discussed Alexander du Toit's fieldwork in Argentina and South Africa in the 1920s and his support of Hans Keidel's concept of continental drift.[39] The Magnetic Crusade of the 1840s and 1850s is a notable example project with geophysical aims taking place at a multitude of outdoor spaces in the mid-nineteenth century before the discipline had been assembled.[40] Remote sensing technologies have become a prominent means of data collection for current research within the geophysical sciences but Casey Allen argues that despite common assumptions, fieldwork remains important to the discipline in the modern era.[41]

Numerous historians have moved beyond the analytic framework of the laboratory field dichotomy, presenting a more nuanced picture of the practices which make up scientific endeavours in particular spaces. Vanessa Heggie argues that many wild spaces, and the polar regions in particular, were perceived as 'natural laboratories' in the twentieth century – places which could provide standardised conditions and unique experiences to aid in the process of knowledge creation.[42] Echoing Heggie's remarks, Charlotte Bigg, David Aubin and Philipp Felsch assert that mountaintops can be conceptualised as nature's laboratory, 'at the intersection of laboratory, observatory and field sciences'.[43] Indeed, mountains and 'high places' have long been considered to be pure, sublime

[38] Gregory A. Good, 'The Assembly of Geophysics: Scientific Disciplines as Frameworks of Consensus', *Studies in History and Philosophy Part B: Studies in History and Philosophy of Modern Physics* 31, no. 3 (2000): 259-292, 272.

[39] Victor A. Ramos, 'Hans Keidel and Alexander du Toit's relationship and its impact on Wegener's continental drift hypothesis', *Geological Society, London, Special Publications* 531, no. 1 (2023); Suryakanthie Chetty, *Africa Forms the Key: Alex Du Toit and the History of Continental Drift* (Berlin: Springer Nature, 2021).

[40] J. Cawood, 'The Magnetic Crusade: Science and Politics in Victorian England', *Isis* 70 (1979): 493-518.

[41] Casey D. Allen, 'Why Fieldwork?', in Mary J. Thornbush, Casey D. Allen, and Faith A. Fitzpatrick (eds.), *Developments in Earth Surface Processes* (Amsterdam: Elsevier, 2014): pp. 11-29, pp. 11-13.

[42] Vanessa Heggie, *Higher and Colder: A History of Extreme Physiology and Exploration* (Chicago: University of Chicago Press, 2019), p. 6.

[43] Charlotte Bigg, David Aubin, and Philipp Felsch, 'Introduction: The Laboratory of Nature – Science in the Mountains', *Science in Context* 22, no. 3 (2009): 311-321, 317.

locations which can give rise to clear, unencumbered thinking within the western imaginary.[44] Cosmic ray physics, in particular, has been understood as a product of its spatial location, carried out at mountain observatories. For example, mountains in Bolivia and Italy provided particularly useful sites for cosmic ray research and high energy particle interactions.[45] The IGY also played a significant role in formalising co-operative research into cosmic rays.[46]

Marianne Klemun and Ulrika Spring use the heuristic of expeditions as experiments to assert that 'expeditions are also a variation of the laboratory where different practices can be carried out, where the transformation from uncertain knowledge to verified knowledge can be tested and where different discourses of knowledge can be juxtaposed'.[47] Expeditions transform spaces temporarily, by adding new individuals and equipment and therefore altering the dynamics of the site, from which different layers of meaning can be derived. Moreover, it was not just objects within the field which were studied and constructed in relation to the parameters of the space, but the field itself was configured through the technologies which captured it. One such example is presented within the work of Kathryn Yussoff, writing on the unique temporality bestowed upon the Antarctic landscape by the photographic method as part of the Terra Nova expedition of 1910-1913.[48]

In his work on the use of electromagnetic fields in the Social Mind and Body (SOMBY) Lab at the Central European University, Cameron Brinitzer aptly argues that the conceptualised opposition between laboratories and fields is neither stable nor useful as a historical tool.[49] Multiplicities of 'fields are always variably generated' by their participants and dependent on their own contexts, even to the extent that the clothes one wears and the gestures one performs construct a field space through

---

[44] Denis Cosgrove and Veronica della Dora, 'Introduction', in Denis Cosgrove and Veronica della Dora (eds.), *High Places* (New York: I.B. Tauris & Co, 2009): pp. 1-18, p. 12; William Fox, 'Walking in Circles: Cognition and Science in High Places', in Denis Cosgrove and Veronica della Dora (eds.), *High Places* (New York: I.B. Tauris & Co., 2009): pp. 19-32.

[45] A Zanini, M. Storini, and O. Saavedra, 'Cosmic Rays at High Mountain Observatories', *Advances in Space Research* 44 (2009): 1160-1165; Serge A. Korff, 'High Altitude Observatories for Cosmic Rays and Other Purposes', in Yataro Sekido and Harry Elliot (eds.), *Early History of Cosmic Ray Studies: Personal Reminiscences with Old Photographs* (Berlin: Springer Science & Business Media, 2012): pp. 171-186.

[46] Peiter H. Stoker, 'The IGY and Beyond: A Brief History of Ground-Based Cosmic-Ray Detectors', *Advances in Space Research* 44 (2009): 1081-1095, 1081.

[47] Marianne Klemun and Ulrike Spring, 'Expeditions as Experiments: An Introduction', in Marianne Klemun and Ulrike Spring (eds.), *Expeditions as Experiments: Practising Observation and Documentation* (New York: Springer Publishing, 2016): pp. 1-26, p. 9.

[48] Kathryn Yusoff, 'Configuring the Field: Photography in Early Twentieth-Century Antarctic Exploration', in Simon Naylor and James R. Ryan (eds.), *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century* (London: Bloomsbury Publishing, 2009): pp. 52-77.

[49] Cameron Brinitzer, 'Generating Fields', *Isis* 113, no. 1 (2022): 144-150, 150.

the inheritance of traditions, while the implementation of infrastructure cements the categorisation of a 'field site'.[50] Field sites may appeal to different rhetorical ideals than those pursuits which have traditionally been labelled as 'laboratory sciences', but can overlap physically, materially and conceptually. As Dorinda Outram asks, one important question is: 'what were the interactions *between* these different sorts of spaces?'[51]

It must not be forgotten that much analysis of the visual materials captured during the Polar Years, the traces of the aurora, or docile objects in Michael Lynch's terminology, was carried out back in the laboratories and institutes from where scientists ventured.[52] As Karin Knorr Cetina points out, often the objects of study in laboratories do not equate to how those particular objects appear in nature – they can be substituted and subsequently transformed through experiment.[53] Crucially, knowledge created in the unstable outdoor realm needed to be documented and subsequently communicated to other researchers and the public. This, Felix Driver argues, requires the labour and mobilisation of trust, which he evaluates through the analytic of 'disturbance' in the late nineteenth century.[54] The aurora, evading usual registration techniques, provides a particularly useful example for understanding the problems of knowledge transferral and exchange, at the limits of communicable experience.

The material that I will be working with is especially well positioned to shed light on the question of how to conceptualise practices which do not fit into the traditional laboratory field dichotomy. The places where the aurora was studied were a combination of indoor and outdoor spaces, involving the mixing of practices of the natural historian in the field and the physicist in the laboratory. Auroral researchers attained credibility based on the blended attributes of the research stations; the sites were remote and perceived as pristine but also unpredictable and wild, encompassing all aspects of the natural landscape of the polar regions as well as the subject of study. The aurora brings us to polar spaces and allows us to chart the impact of multi-sited research on the conclusions drawn about a planetary-scale atmospheric phenomenon. Intervening in debates about space and place within the geophysical sciences of the nineteenth century, I also want to emphasise

---

[50] Etienne Benson, 'The Post-Heroic Field', *Isis* 113, no. 1 (2022): 114-120; Brinitzer, 'Generating Fields'; Erika Lorraine Milam, 'Making Place in the Field', *Isis* 113, no. 1 (2022): 121-127.

[51] Dorinda Outram, 'New Spaces in Natural History', in N. Jardine, J.A. Secord, and E.C. Spary (eds.), *Cultures of Natural History*, vol. 249–265 (Cambridge: Cambridge University Press, 1996), p. 253.

[52] Michael Lynch, 'Discipline and the Material Form of Images: An Analysis of Scientific Visibility', *Social Studies of Science* (1985): 37-66, 43.

[53] Karin Knorr Cetina, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge: Harvard University Press, 1999), p. 27.

[54] Felix Driver, 'Distance and Disturbance: Travel, Exploration and Knowledge in the Nineteenth Century', *Transactions of the Royal Historical Society* 14 (2004): 73-92.

the significant, entangled function of the field site for the production of atmospheric knowledge, while recognising its messiness and often unclear boundaries.

The research presented here is also well placed to answer the call for greater attention to be paid to the category of verticality in spatial histories. One major critique of the spatial turn is that it operates with broad brush strokes, lacking in fine grained texture.[55] As Michael Reidy argues, 'science was not done in the 'field'. Rather, science was carried out on the land, under its crust, beneath the ocean, and on the side of mountains'.[56] Emphasis on verticality, 'a material condition of knowledge production and an object of scientific enquiry itself', brings into sharp relief 'the epistemic, technical, and bodily challenges of producing knowledge of vertical spaces; and the history of collecting and visualising data at a distance, through new technologies'.[57] The aurora and its position at 100km altitude provides a distinct vertical perspective on the field as an intangible and distant territory.

The Literature of the Polar Years and the Aurora

Nineteenth and twentieth century atmospheric sciences have received uneven attention. As James Fleming notes, 'there are relatively few twentieth-century histories of atmospheric research and its supporting technologies'.[58] Gregory Good, an eminent historian and director of the American Institute of Physics Centre for the History of Physics, remarked more specifically in 2011 that 'the interesting and complicated history of the people and organisations who investigated the upper atmosphere in the 1920s and 1930s is just beginning to be explored'.[59] Apart from specific and isolated exceptions, the atmospheric sciences of the early twentieth century is largely a neglected field of historical research.

In terms of the historiography of the International Polar and Geophysical Years, excellent research has addressed the organisation and political legacies of the various programmes.[60] The

---

[55] Michael S. Reidy, 'The Most Recent Orogeny: Verticality and Why Mountains Matter', *Historical Studies in the Natural Sciences* (2017): 578-587, 587.

[56] Ibid., 586.

[57] Wilko Graf von Hardenberg and Martin Mahony, 'Introduction – Up, down, round and round: Verticalities in the history of science', *Centaurus* 62 (2020): 595-611, 596-597.

[58] James Rodger Fleming, *Inventing Atmospheric Science: Bjerknes, Rossby, Wrexler, and the Foundations of Modern Meteorology* (Cambridge: MIT Press, 2016), p. 12.

[59] Gregory A. Good, 'Measuring the Inaccessible Earth: Geomagnetism, In situ Measurements, Remote Sensing, and Proxy Data', *Centaurus* 53, no. 2 (2011): 176-189, 185.

[60] Harold Bullis, *The Political Legacy of the International Geophysical Year* (Washington D.C.: U.S. Government Printing Office, 1973); Robert W. Smith, 'Large-Scale Scientific Enterprise', in Stanley Kutler (ed.), *Encyclopedia of the United States in the Twentieth Century*, vol. 2 (New York: Scribner's, 1996): pp. 739–

collection of essays in, 'Globalising polar science: Reconsidering the International Polar and Geophysical Years', edited by Roger D. Launius, James Rodger Fleming and David H. DeVorkin, takes international co-operation and the financial and practical organisation of the IPY and IGY programmes as its focus.[61] 'The History of the International Polar Years', edited by Susan Barr and Cornelia Lüdecke, deals with the logistics, aims and achievements of the polar years in broad-brush strokes.[62] Nevertheless, as Aant Elzinga, one of its contributors points out, there are still significant gaps in the histories of these events.[63] Most starkly, as Michael Bravo has called to attention, 'there exists at present no satisfactory historical, political or cultural analysis of the International Polar Year events… This is by no means to overlook the importance of research by historians and geographers on the history of specific polar year events.'[64] Echoing Gregory Good's remarks, Elzinga argues that the Second International Polar Year has received much less scholarly interest than the First IPY and IGY.[65] Similarly, although the IGY has been much discussed by historians, the historiography has been overshadowed by interest in the International Space Race and the launching of the first artificial earth satellite, Sputnik 1.[66]

765; Walter T. Sullivan, *Assault on the Unknown: The International Geophysical Year* (New York: McGraw Hill, 1961); Lisbeth Lewander, 'Swedish Polar Policies from the First International Polar Year to the Present', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (London: Palgrave Macmillan, 2010): pp. 107-122.

[61] Roger D. Launius, James Rodger Fleming, and David H. DeVorkin, *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (London: Palgrave MacMillan, 2010).

[62] Susan Barr and Cornelia Lüdecke, *The History of the International Polar Years* (Berlin: Springer Science and Business Media, 2010).

[63] Aant Elzinga, 'Through the Lens of the Polar Years: Changing Characteristics of Polar Research in Historical Perspective', *The Polar Record* 45, no. 245 (2009): 313-336, 313.

[64] Michael Bravo, 'Preface: Legacies of Polar Science', in Jessica Shadian and Monica Tennberg (eds.), *Legacies and Change in Polar Sciences: Historical, Legal and Political Reflections on the Polar Year* (London: Routledge, 2009): pp. xiii-xvi, p. 15.

[65] Elzinga, 'Through the Lens of the Polar Years', 313.

[66] Robert A. Divine, *The Sputnik Challenge: Eisenhower's Response to the Soviet Satellite* (New York: Oxford Univ. Press, 1993); Roger D. Launius, John M. Logsdon, and Robert W. Smith, *Reconsidering Sputnik: Forty Years since the Soviet Satellite* (New York: Routledge, 2000); Walter A. McDougall, *The Heavens and the Earth: A Political History of the Space Age* (Baltimore: Johns Hopkins Univ. Press, 1997); Veronica della Dora, 'From the Radio Shack to the Cosmos: Listening to Sputnik during the International Geophysical Year (1957-1958)', *Isis* 114, no. 1 (2023): 123-149.

The organisation of the First IPY has received some historiographical attention.[67] William Barr's seminal work, *The Expeditions of the First International Polar Year, 1882-83* (1985), provides a particularly valuable overview.[68] Yet, relatively little of the IPY literature addresses the research outcomes of the programme, in no small part because the publication of results was inconsistent, leaving incomplete records of the scientific activity undertaken.[69] Indeed, in 2006 Kevin Wood and James Overland published, 'Climate Lessons from the First International Polar Year', seeking to correct for the lack of analysis of IPY data by interpreting the information from a synoptic twenty-first century perspective. There are some works which focus on the scientific contributions of individuals or the longer histories of research within nation-states, which include sections on the First IPY. For example, in terms of auroral historiography, K. Moss and Peter Stauning discuss the contribution of Sophus Tromholt and Peter Stauning examines the development of Danish auroral science from the sixteenth to the twentieth centuries.[70] Nevertheless, the historiography of the First IPY lacks analysis from the vantage point of its research programmes.

The specific research programmes of the Second IPY and the IGY suffer from the same sparsity of historical attention. It is well documented that 'there is neither a sophisticated literature of the IPYs and the IGYs, nor of the major questions these activities engendered' as Roger D. Launius puts it.[71] That being said, Aant Elzinga has traced the scope and philosophy of each of the Polar Years (including the fourth International Polar Year of 2007-8) and James Fleming and Cara Seitchek have

---

[67] F. W. G. Baker, 'The First International Polar Year 1882-1883', *Polar Record* 21 (1982): 275-285; Reinhard A. Krause, 'Neumayer's Ambitions for Polar Research and his Role in the Establishment of the First International Polar Year 1882-3', *Transactions of the Royal Society of Victoria* 123, no. 95 (2011): 95-115; Cornelia Lüdecke, 'The First International Polar Year (1882-83): A Big Science Experiment with Small Science Equipment', *Proceedings of the International Commission on History of Meteorology* (2004): 55-64.

[68] William Barr, *The Expeditions of the First International Polar Year, 1882-83* (Calgary: Arctic Institute of North America, 1985).

[69] Philip N. Cronenwett, 'Publishing Arctic Science in the Nineteenth Century: The Case of the First International Polar Year', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years*, vol. 2010 (New York: Palgrave Macmillan, 2010): pp. 27-46, p. 42.

[70] K. Moss and P. Stauning, 'Sophus Peter Tromholt: An Outstanding Pioneer in Auroral Research', *History of Geo and Space Sciences* (2012): 53-72; P. Stauning, 'Danish Auroral Science History', *History of Geo and Space Sciences* 2 (2011): 1-28; Alv Egeland and William J. Burke, *Kristian Birkeland: The First Space Scientist* (Heidelberg: Springer Netherlands, 2005).

[71] Roger D. Launius, 'Toward the Poles: A Historiography of Scientific Exploration during the International Polar Years and the International Geophysical year', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan, 2010): pp. 47-84, p. 48.

analysed meteorological and climate science initiatives within each of the programmes.[72] Despite this beginning, the scientific programmes of these enormously ambitious events still deserve much more complete historical treatment. In focusing on the aurora, this thesis seeks to redress the lack of research into the practices and results of specific scientific endeavours within IPY and IGY historiography.

More specifically, as Launius contends, ‘major themes not fully addressed in what does exist in the scholarly [IPY] literature include the place of the poles in the human imagination’.[73] In the wider realm of Polar studies, significant attention *has* been paid to the construction of the Arctic and Antarctic within the popular imagination.[74] Michael Bravo’s *North Pole: Nature and Culture* explores the place of the poles within western culture, connected to utopian mythologies and early modern notions of its cosmological relationship with the heavens. Peter Davidson’s *The Idea of North* explores the imaginative concept of the ‘north’ in literature, mythology and art.[75] Moreover, scholars such as Shane McCorristine and Francis Spufford have investigated the polar regions as dreamlike, spectral, literary spaces built up from intangible assumptions, responses to landscapes and fantasies in the nineteenth century.[76]

In terms of historiography written specifically on the topic of auroral science, there exist several excellent publications. For example, Helge Kragh’s 2009 article entitled, ‘The Spectrum of the Aurora Borealis: From Enigma to Laboratory Science’, traces the early twentieth century search for the element, or multiple elements, responsible for the characteristic green light of aurorae.[77] Marc Robert Friedman explores the position of scientific hegemony over the potent symbol of the aurora in the making of Norwegian national identity at a time when promoting autonomy from the Swedish crown was a prominent and self-conscious objective.[78] Intellectual possession of the aurora is a theme

---

[72] Elzinga, 'Through the Lens of the Polar Years'; James Rodger Fleming and Cara Seitchek, 'Advancing Polar Research and Communicating its Wonders: Quests, Questions and Capabilities of Weather and Climate Studies in International Polar Years', in Igor Krupnik, Michael A. Lang, and Scott E. Miller (eds.), *Smithsonian at the Poles: Contributions to International Polar Year Science* (Washington: Smithsonian Institution Scholarly Press, 2009): pp. 1-12; Aant Elzinga, *Achievements of the Second International Polar Year* (Berlin: Springer Science and Business Media, 2010).

[73] Launius, 'Toward the Poles', p. 48.

[74] Bravo, *North Pole*; A.S. Thompson, J.M. MacKenzie, and R. David, *The Arctic in the British imagination 1818–1914* (Manchester University Press, 2017).

[75] P. Davidson, *The Idea of North* (London: Reaktion Books, 2005).

[76] McCorristine, *The Spectral Arctic*, p. 6.

[77] Helge Kragh, 'The Spectrum of the Aurora Borealis: From Enigma to Laboratory Science', *Historical Studies in the Natural Sciences* 39, no. 4 (2009): 377-417.

[78] Robert Marc Friedman, 'Making the Aurora Norwegian: Science and Image in the Making of Tradition', *Interdisciplinary Science Reviews* 35, no. 1 (2010): 51-68.

also taken up by Patricia Fara in a 1996 article, which surveys the ways in which scientific practitioners as well as historians have claimed authority over the phenomenon in projects of national myth-making from the eighteenth to the twentieth century.[79]

Ulrike Spring analyses the symbolic power of the aurora in the aftermath of two Austro-Hungarian Polar expeditions in 1874 and 1883 respectively, finding that the First IPY expedition was overshadowed by the advent of artificial electric light and events such as the International Electrical Exhibition in Vienna.[80] Henrik Knudsen's chapter, 'Battling the Aurora Borealis: The Transnational Coproduction of Ionospheric Research in the Early Cold War Greenland' traces the competition between the US and Denmark for supremacy in radio ionospheric research in Greenland.[81] These perspectives interrogate different ways of conceptualising the aurora by reference to its technological, folkloric and national significance in different contexts. This study follows these themes but focuses on the construction of the aurora through visual images and its significance within the Polar Years.

For the most part, however, the historical literature of auroral research has been written by the practitioners of the discipline themselves. The two most broad-ranging accounts of the field of auroral science are *The Northern Light: From Mythology to Space Research* (1979) and *Majestic Lights: The Aurora in Science, History and the Arts* (1980), both published over forty years ago.[82] Asgier Brekke and Alv Egeland, the authors of *Northern Light*, are both Norwegian physicists. Robert Eather, the author of *Majestic Lights*, has specialised in auroral and space research during his career. As for nineteenth century scientists, Sophus Tromholt, a key figure during the First Polar Year, published on the organisational history of the First IPY and the mythology of the aurora in northern Norway.[83] John Rand Capron, a British amateur astronomer and expert in spectroscopy, recounted prior notions of the mechanism of the aurora borealis in his treatise on the phenomenon in 1879.[84] As discussed more

[79] Patricia Fara, 'Northern Possession: Laying Claim to the Aurora Borealis', *History Workshop Journal* 42 (1996): 37-58.

[80] Ulrike Spring, 'Between Spectacle and Science: The Aurora in Central Europe, 1870s-1880s', *Acta Borealia: A Nordic Journal of Circumpolar Societies* 29, no. 2 (2012): 197-215.

[81] Henrik Knudsen, 'Battling the Aurora Borealis: The Transnational Coproduction of Ionospheric Research in Early Cold War Greenland', in Ronald E. Doel, Kristine C. Harper, and Matthias Heymann (eds.), *Exploring Greenland: Cold War Science and Technology on Ice* (New York: Palgrave Macmillan US, 2016): pp. 143-165.

[82] Asgeir Brekke and A. Egeland, *The Northern Light: From Mythology to Space Research* (Oslo: Grondahl and Son Forlag, 1979); Robert Eather, *Majestic Lights: The Aurora in Science, History and the Arts*, vol. 18 (Washington D. C.: American Geophysical Union: Special Publications Series, 1980).

[83] Sophus Tromholt, 'A Note Relating to the History of the Aurora Borealis', *Nature* 32 (1885): 89-90; Sophus Tromholt, *Under the Rays of the Aurora Borealis: In the Land of the Lapps and Kvæns, vol 2* (London: Sampson Low, Maston, Searle, and Rivington, 1885) (trans. Carl Siewers).

[84] John Rand Capron, *Aurorae: Their Characters and Spectra* (London: E. & F. N. Spon, 1879).

extensively in chapter six, researchers of the IGY took pains to write historical accounts of the previous Polar Year endeavours. While there is thus much primary literature to be consulted, there are few accounts of the development of auroral science over the past two centuries from a twenty-first century vantage point. The research presented in this thesis provides a new perspective, providing a history of auroral research while paying heed to the temporal complexities of capturing and understanding the aurora as well as the tensions exposed by the historical and literary projects of its researchers.

Auroral Visual Culture: Precedents

Countless attempts have been made to capture the essence of the aurora, situated within the liminal space of the atmosphere, in pencil, etching, pastel and even by mechanical contrivance throughout history. Images of the aurora were instilled with meaning, symbolic and descriptive, for centuries before the First International Polar Year. Just as Denis Cosgrove argues in *Geography and Vision* that 'representations of new geographical spaces were embedded with imaginative ideas', so too were

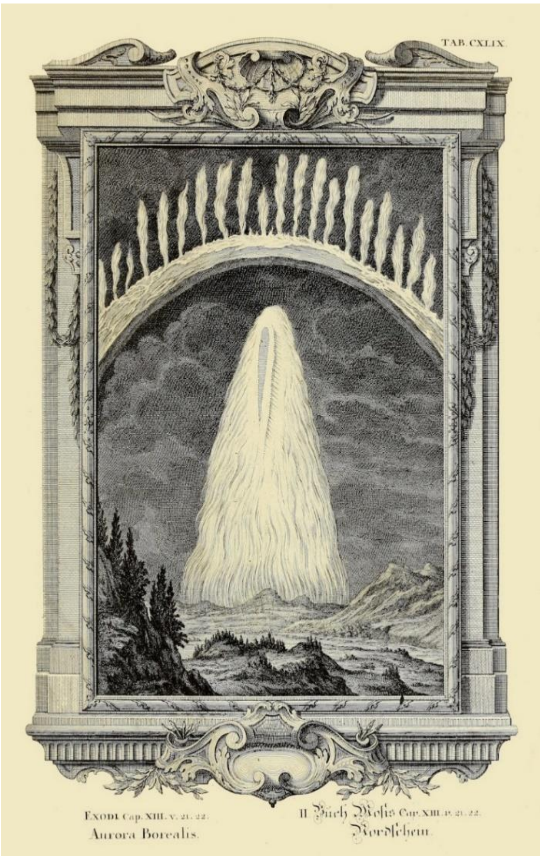


Fig. 2. Johann Jakob Scheuchzer, 'Aurora Borealis', copper engraving in *Physica Sacra* (1733), vol. 3, Tab. CXLIX, p. 160.

depictions of the aurora, relatively rarely seen at lower latitudes, imbued with fantastical elements and presented with highly stylised iconography for particular religious and aesthetic purposes.[85]

Bearing little resemblance to the subsequent drawings produced during the First IPY, the copper engraving, shown in fig. 2, was printed in *Physica Sacra* (1733), a commentary on the King James Bible filled with hundreds of remarkable illustrations of the natural world. It was written by Johann Jakob Scheuchzer, a Swiss physician and scholar, with the images produced by Johann Melchior Fussli, a well-regarded Zurich engraver. Accompanying a description of the aurora's forms and significance as a portent, the phenomenon is portrayed as a great column of light surrounded by a fiery halo.[86] The emphasis on the glory, magnitude and incomprehensibility of nature furnished the *Physica Sacra* northern lights display with deeply religious overtones. This represents a broader category of auroral imagery of the eighteenth century, which characterises the phenomenon as a striking object and bad omen.

Samuel Triewald, a Swedish poet and statesman, published an article in 1744, relating his attempt to reproduce the northern lights within his laboratory.[87] He detailed his experiment, which saw a ray of light let into a darkened room, striking a prism before passing just over a cup filled with common grain spirit, and then finally hitting a screen. As Triewald asserted, with this apparatus 'one

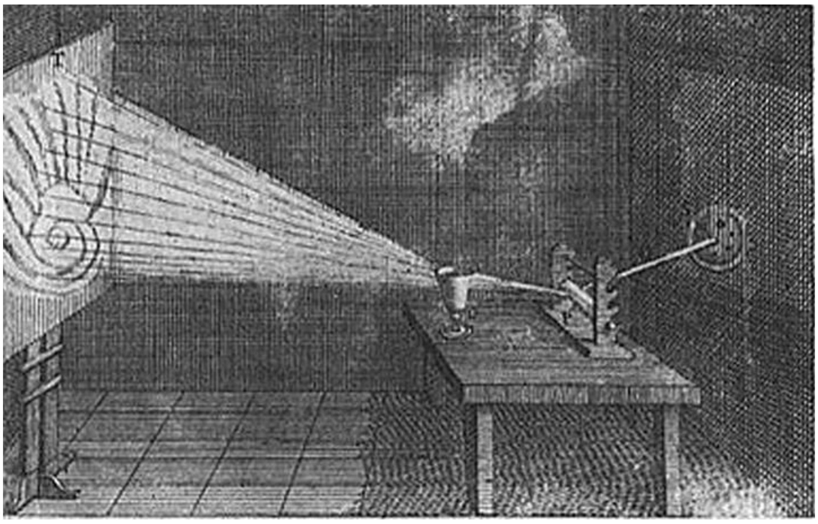


Fig. 3. Samuel Triewald, 'experimentum aurorae borealis artificialis', *Kungl. Vetenskapsakademiens Handlingar* (1744), plate III.

[85] Denis Cosgrove, 'Introduction', in Denis Cosgrove (ed.), *Geography and Vision: Seeing, Imagining and Representing the World* (London: I.B. Tauris, 2012): pp. 1-12, p. 8.

[86] Johann Jakob Scheuchzer, *Physica Sacra*, vol. 3 (Ausberg: Christian Ulrich Wagner, 1733).

[87] Samuel Triewald, 'Experimentum aurorae borealis artificialis', *Kungl. Vetenskapsakademiens Handlingar* (1744): 115-117.

sees all the phenomena that the natural northern lights display and as changeable as the same'.[88] The image that accompanied his text (fig. 3) shows the aurora as a swirl of straight lines emanating from a central spiral, shining in the dark and hinting at movement. This is one of the first recorded attempts to replicate the aurora and demonstrates a fascination with its dancing motions.

Fig. 4. Frederic Edwin Church, 'Aurora Borealis' (1865) *Smithsonian American Art Museum*.

Later depictions, including the famous oil painting, *Aurora Borealis* (1865) by Frederic Edwin Church, retained the majestic characteristics of previous portrayals, although shorn of their explicit religious connotations. Based on two sketches drawn by Church's friend, the American Arctic explorer Isaac Hayes, on his Arctic voyage of 1860, the painting depicts a peak named 'Church's Peak' by Hayes, memorialising the artist. Hayes's ice-locked ship, the *United States,* is small and insignificant against the immensity of the Arctic landscape. *Aurora Borealis* seems to exaggerate the intricate colours of the lights shining over Ellesmere Island, although Hayes recounted, 'blue and yellow streamers were playing in the lurid fire; and, sometimes starting side by side from the wide expanse of the illuminated arch, they melt into each other, and throw a ghastly glare of green into the face and over the landscape.'[89] Church's painting represents the romantic era of auroral portrayal and has also been interpreted as a divine omen in response to the American Civil War.

John Rand Capron, a well-regarded amateur astronomer, became fascinated with the aurora after witnessing two displays from his home in Guildford in the early 1870s. Primarily engaged with early spectroscopic investigations of the phenomenon, he measured the wavelengths of auroral light

[88] Ibid., 116.

[89] Isaac Israel Hayes, *The Open Polar Sea: A Narrative of a Voyage of Discovery Towards the North Pole* (London: Sampson Low & Marston, 1867), p. 195.

on 24 October 1870 with a 5-prism direct vision spectroscope. As Capron detailed in a letter to the editor of *Nature* (1870), the sky was filled with a 'rosy-coloured light' and gave a distinct red spectroscopic line.[90] He was inspired to go beyond his spectroscopic analyses by painting a watercolour version of his first sighting of the northern lights. The image (fig. 5) was then

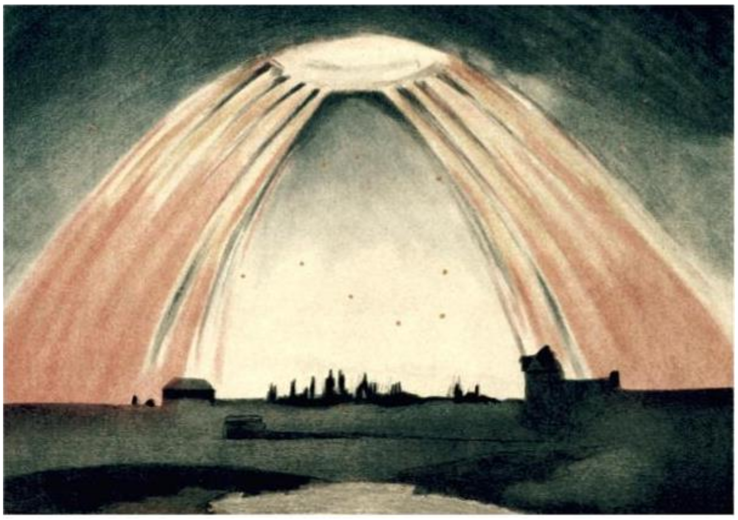


Fig. 5. John Rand Capron, 'Lithograph from water colour of aurora at Guildford, 24 Oct. 1870', in *Aurorae: Their Characters and Spectra* (London: E. & F. N. Spon, 1879), Plate 3, p. 19.

lithographed and published in 1879.[91] Capron's stylised painting, evoking the halo-effect apparent in *Physica Sacra,* lends a spiritual, almost protective quality to the display. The aurora is symmetrical, flowing to the surface of the earth and neatly surrounding Guildford.

Following the pattern of balanced, regular, ethereal imagery, Étienne Léopold Trouvelot created a pastel drawing of the 1 March 1872 northern lights display (fig. 6). It was published among fourteen other pastel depictions of celestial and atmospheric objects in 1881, one year before the IPY, in *The Trouvelot Astronomical Drawings* (1882).[92] Trouvelot worked at the Harvard College Observatory from 1872 and was appointed astronomer at the Meudon Observatory in Paris in 1882. His dual capacities, as a self-described 'lithographer' and latterly a professional astronomer, reflected his enchantment with both technological and creative ways of engaging with astronomic and

[90] John Rand Capron, 'The Aurora Borealis', *Nature* 3 (1870): 28.

[91] Capron, *Aurorae: Their Characters and Spectra,* p. 160.

[92] Étienne Léopold Trouvelot, *Aurora Borealis, The Trouvelot Astronomical Drawings* (New York: C. Scribner's Sons, 1881).

atmospheric phenomena.[93] As Trouvelot himself pointed out in the first pages of *The Trouvelot Astronomical Drawings Manual*, ‘while my aim in this work has been to combine scrupulous fidelity and accuracy in the details, I have also endeavoured to preserve the natural elegance and the delicate

Fig. 6. Étienne Léopold Trouvelot, ‘Aurora Borealis’, *The Trouvelot Astronomical Drawings* (New York, C. Scribner’s Sons, 1881).

outlines peculiar to the objects depicted’, two aspirations at first glance not incongruent be it for the syntax which belies the tension.[94] His projection of the 1872 aurora speaks to this dichotomy; Trouvelot employed the now familiar tropes of symmetry and halo-effect while working to construct a realistic auroral entity.[95]

In 1895 and 1896 Kristian Birkeland, a Norwegian auroral scientist and polar explorer, conducted terrella experiments in order to investigate the reason for the aurora’s common position surrounding the poles. He simulated an auroral display by directing cathode rays at a magnetised terrella in a vacuum chamber. Because the terrella was painted with a phosphorescent substance, its two poles began to glow when bombarded with the negatively charged electrons (known as cathode rays), as magnificently demonstrated in fig. 7 and fig. 8. Birkeland’s photographs of his experiments

93 Brenda G. Corbin, 'Etienne Leopold Trouvelot: The Artist and Astronomer', Conference Presentation, *Library and Information Services in Astronomy V ASP Conference Series*, 18-21 June 2007, vol. 377, Cambridge, Massachusetts, USA: 352-360, 352.

94 Étienne Léopold Trouvelot, *The Trouvelot Astronomical Drawings Manual* (New York: Scribner’s sons, 1882), p. 1.

95 Robert J. Spear, *The Great Gypsy Moth War: A History of the First Campaign in Massachusetts to Eradicate the Gypsy Moth, 1890-1901* (Amherst: University of Massachusetts Press, 2005), p. 10.

present the aurora in a different guise, as streams of charged particles swirling around his simulated earth sphere. The images produced prior to the 1880s tended to depict the horizon and render the aurora as an object set firmly within the landscape, tending towards the artistic mode of romanticism. The commonality between these images is that they did not presume to emulate the aurora exactly or precisely but rather they evoked the witnessing experience in an interpretation which laid claim to the aurora's affective capacities. Chronologically though, they do reflect a growing attention to accuracy, Capron emulating the rosy glow emanating from the phenomenon and Trouvelot self-consciously treading the line between stylisation and verisimilitude on the eve of the Polar Year.

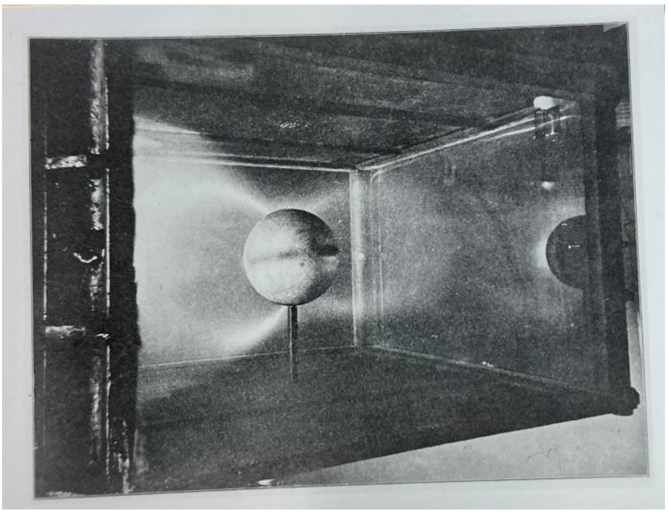


Fig. 7. 'Birkeland's terrella experiments', Ole Andreas Krogness papers, *Observatoriet på Haldde and Nordlysobservatoriet 1912-1973, Tromsø State Archives.*

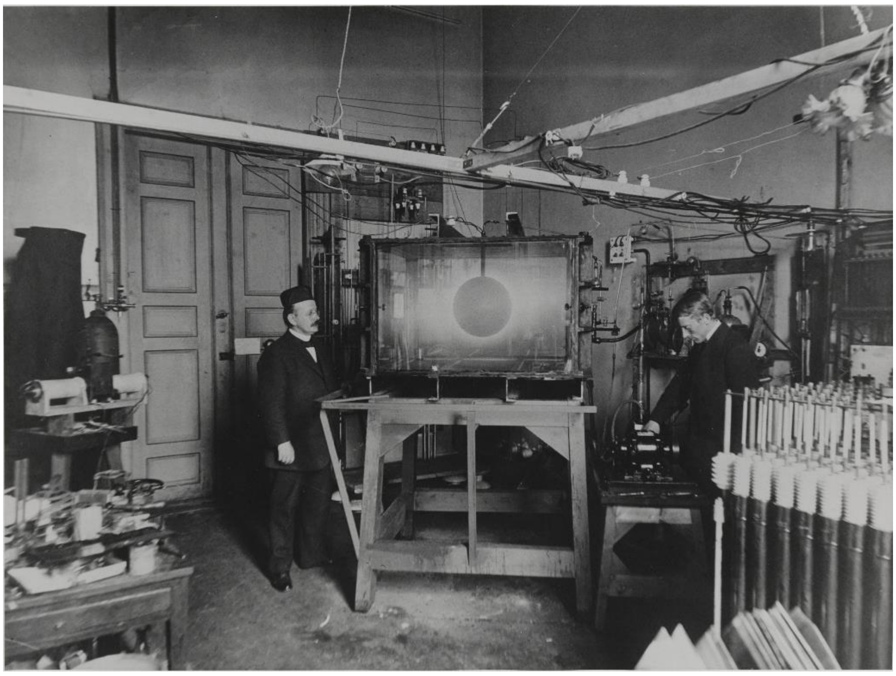


Fig. 8. 'Kristian Birkeland experiments with the northern lights in a vacuum vessel, 1912', *Oslo Nasjonalbiblioteket* https://urn.nb.no/URN:NBN:no-nb_digifoto_20160304_00236_bldsa_fPORTRETT_0034.

Parallel Fields

A whole host of varying, unstable and fleeting phenomena tested the limits of late nineteenth century imaging techniques. In tracing the visual history of auroral reproduction, it is also worth evaluating graphic trends within parallel research fields including the study of nebulae, the solar corona, lightning and clouds in the same period. Astronomical and atmospheric objects evaded simplistic representation, but with the advancement of photographic technologies, could more easily and reliably be captured by the turn of the twentieth century.

Whilst the aurora was difficult to observe because of its faint and transitory nature, nebulae were imperceptible in the sense that they could only be viewed through a telescope. From Omar Nasim's account, *Observing by Hand* (2013), we learn that nebulae imagery moved from generalities to peculiarities between 1820 and 1890.[96] George Chambers, the English barrister and amateur astronomer, published his *Handbook of Descriptive and Practical Astronomy* in 1861. Within it, he included a rendering of the M51 nebula, drawn by William Parsons, the Third Earl of Rosse, in 1848

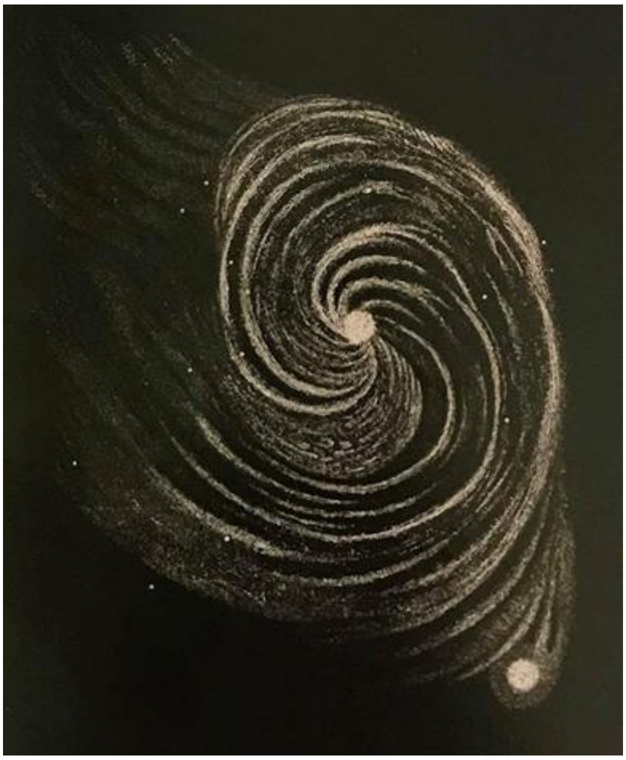


Fig. 9. 'George Chambers, 'new reproduction of Rosse's M51 'nebula' image', *A Handbook of Descriptive and Practical Astronomy* (1861).

[96] Omar W. Nasim, *Observing by Hand: Sketching the Nebulae in the Nineteenth Century* (Chicago: Chicago University Press, 2013), p. 229.

after his detection of the spirality of the galaxy in 1845.[97] Reproductions of the M51 nebula contributed to the stabilisation of the object and the creation of the conceptual category of the spiral form.[98] The drawing (fig. 9) comprises a multitude of swirling lines around a central point. Most striking is the image's strong sense of motion, both in terms of centrifugal force and as an object travelling through the universe. This dynamic tendency, along with the simplicity of the line drawing and its contrast of bright light against dark, are common themes of later nineteenth century auroral imagery.

The aurora and solar corona are fleeting in different ways: the corona is briefly witnessed during rare eclipses, whereas the aurora may appear nightly but constantly varies and cannot be predicted with the same accuracy. As Alex Soojung-Kim Pang argues, in the 1860s and 1870s, drawings and photographs of the solar corona had roughly equal status, with both amateurs and professional scientists imaging the phenomenon.[99] The greater brilliance of the sun compared to its surroundings meant that capturing an eclipse photographically proved challenging. Before the invention of the gelatin dry plate process in 1875, the Kew photoheliograph, designed by Warren De la Rue, was used to photograph the eclipse of 18 July 1860 from Rivabellosa in northern Spain and aided in the discovery of the origin of prominences, or red flames, observed with solar eclipses.[100] Yet, during the transit of Venus of 1874, photography proved unreliable and was not officially employed for the 1882 transit.

By the later 1880s and 1890s, however, the situation had changed. Depictions of the corona produced by hand were replaced with photographs, limiting human interference in accordance with the growing appeal of 'mechanical objectivity'.[101] The development of collotype printing, popular between the 1870s and 1920s, meant that astronomers increasingly favoured photographic reproductions. Furthermore, synchronous with the Polar Year, between June and September of 1882, respected astronomer William Huggins experimented with photographing the solar corona without an

---

[97] Wolfgang Steinicke, 'The M51 Mystery: Lord Rosse, Robinson, South and the Discovery of Spiral Structure in 1845', *Journal of Astronomical History and Heritage* 15 (2012): 19-29, 27.

[98] Omar W. Nasim, 'Observation, working images and procedure: the 'Great Spiral' in Lord Rosse's astronomical record books and beyond', *The British Journal for the History of Science* 43, no. 3 (2010): 353-389, 378.

[99] Alex Soojung-Kim Pang, 'Victorian Observing Practices, Printing Technology, and Representations of the Solar Corona (1): The 1860s and 1870s', *Journal for the History of Astronomy* (1994): 249-274, 250.

[100] Holly Rothermel, 'Images of the Sun: Warren De la Rue, George Buddell Airy and Celestial Photography', *The British Journal for the History of Science* 26, no. 2 (1993): 137-169, 152; Jimena Canales, 'Photogenic Venus: The "Cinematographic Turn" and its alternative in Nineteenth-Century France', *Isis* 93 (2002): 585-613, 611.

[101] Daston and Galison, *Objectivity*, p. 124; Pang, 'The Solar Corona (1)', 249.

eclipse, overcoming the impermanent nature of the phenomenon and thus solidifying the camera as the investigative instrument of choice.[102]

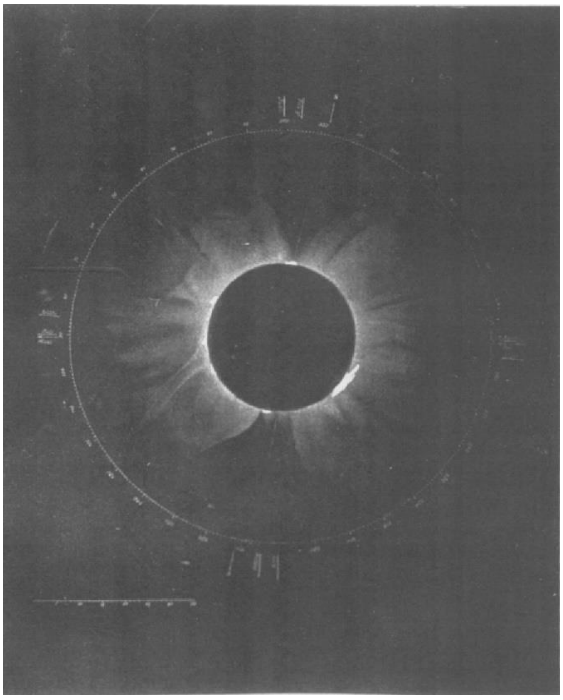


Fig. 10. William Henry Wesley, ‘Lithograph of the eclipse of 1871 sent to the Astronomer Royal George Airy’, *Cambridge University Library,* RGO 6/135 f204r.

The case of auroral imagery provides a different narrative because no photographs were captured of the aurora until 1892. This was not, however, for want of trying. In a letter to *Nature*, Tromholt, who produced many hand-drawings of the aurora during the First IPY, stated, ‘I have several times attempted to photograph the aurora borealis, but without success.’[103] Additionally, Sergeant Rice of the ill-fated Lady Franklin Bay expedition attempted to expose a sensitised dry photographic plate to the light of the aurora ‘without any effect’.[104] The camera simply could not reliably capture the transient, rapidly moving and colourful aurora in the 1880s. Nevertheless, there is little indication within the community of auroral scientists that hand-drawings were perceived as any less useful than photographic renderings.

---

[102] William Huggins, 'On a Method of Photographing the Solar Corona without an Eclipse', *Proceedings of the Royal Society of London* 34 (1883): 409-414, 412.

[103] W. Littleton, 'Dr. Tromholt’s Auroral Observatory at Kautokeino', *Nature* 28 (1883): 397-398.

[104] Adolphus Washington Greely, *Three Years of Arctic Service: An Account of the Lady Franklin Bay Expedition of 1881-84, and the Attainment of the Farthest North* (New York: C. Scribner's sons, 1894), p. 140.

The first daguerreotype photograph of lightning is recognised to have been taken on 18 June 1847 by T. M. Easterly working in the American Midwest.[105] Later, concurrent with the first IPY, William Jennings produced several photographs of lightning from his home in Philadelphia. These photographs represented a step change in the ambitions for the presentation of intangible atmospheric phenomena. They eschewed any subjective intervention by the human hand, capturing the electrical phenomenon with a type of 'blind sight'.[106] The series of lightning photographs captured in the nineteenth century revealed the irregularity of the phenomenon's path, travelling in a wavy rather than a zigzagging direction, 'as drawn and painted by almost all our artists and painters' prior to 1882.[107] 'The blow photography dealt to artistic representations of lightning was seen as its major contribution to meteorology', Jennifer Tucker argues.[108] The aurora was likened to 'a flash of summer lightning conceived as permanent' by Karl Weyprecht in his 1877 record of the 1872-74 Arctic expedition, being as it was elusive, short-lived and atmospheric.[109] This statement hints at the frustration of auroral researchers who hoped to overcome the aurora's transient nature by capturing it on a photographic plate.

Fig. 11. William Jennings, 'September 2, 1882 photograph of lightning', *Franklin Institute*.

[105] Jennifer Tucker, *Nature Exposed: Photography as Eyewitness in Victorian Science* (Baltimore: JHU Press, 2005), p. 144.

[106] Daston and Galison, *Objectivity*, p. 120.

[107] William N. Jennings, 'Lightning Photography', *Scientific American* 53, no. 10 (1885): 149.

[108] Tucker, *Nature Exposed*, p. 142.

[109] Weyprecht quoted in: Julius Payer, *New Lands Within the Arctic Circle: Narrative of the Discoveries of the Austrian Ship 'Tegetthoff' in the Years 1872-1874*, vol. 1 (New York: D. Appleton and Co., 1877), p. 202.

Clouds, argues Richard Hamblyn, are inherently unreliable, while also acting as screens on which thoughts, feelings, myths, ideas and dreams are projected.[110] Lorraine Daston analyses the disputed classificatory systems of cloud physiognomy, beginning with Luke Howard in the early nineteenth century and moving to the making of the *International Cloud Atlas,* organised by Hugo Hildebrand Hildebrandsson and published by the International Meteorological Committee in 1896.[111] Hildebrandsson slimmed down the categories of cloud formation which proliferated in the earlier nineteenth century to three fundamental types with the help of Scottish meteorologist Ralph Abercromby. Crucially, the *International Cloud Atlas* prioritised photographs as the most exact way to construct its ontology. Auroral scientists faced comparative difficulties in making northern lights research coherent and commensurable. Yet, there was less discord among the auroral communal practice, presumably because Norwegian hegemony was firmly established.

Posing similar problems to the scientific photographer as the northern lights, noctilucent clouds were first captured on a photographic plate in 1887 at the Berlin Astronomical Observatory and in Potsdam by Dr Stolve and Otto Jesse respectively. Noctilucent clouds consist of ice crystals and are only visible in the stratosphere at astronomical twilight. A direct aesthetic lineage can be

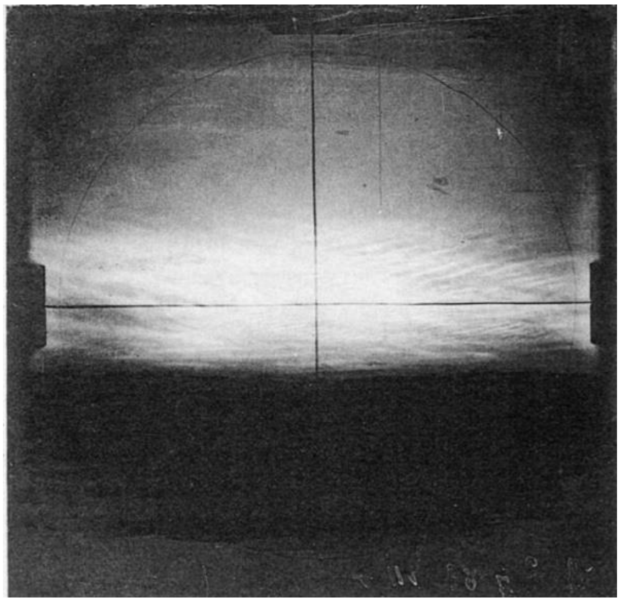


Fig. 12. 'One of the first noctilucent cloud photographs taken by Jesse on 2 July 1889', in Wilfred Schöder, 'Otto Jesse and the Investigation of Noctilucent Clouds 115 Years Ago', *Bulletin of the American Meteorological Society* (2001), 2469.

[110] Richard Hamblyn, *Clouds: Nature and Culture* (London: Reaktion Books, 2017).

[111] Lorraine Daston, 'Cloud Physiognomy', *Representations* 135, no. 1 (2016): 45-71, 58; Hugo Hildebrand Hildebrandsson, A. Riggenbach, and L. Teisserenc de Bort, *International Cloud Atlas* (Paris: Gauthier-Villars et fils, 1896).

traced between the cloud and auroral images because the camera used by Jesse was borrowed by Otto Baschin and Martin Brendel in 1892 to produce the first auroral photograph.[112] Photography acted as a bridging platform between the direct observation of cloud formations and the later nineteenth century mimetic experiments to reproduce clouds in the laboratory, according to Galison and Alexi Assmus.[113] It was with the cloud chamber, invented by Charles Thomas Rees Wilson, that the complex and unpredictable pathways of charged particles could be visualised.[114] The apparatus made visible the subvisible.[115] Also in the laboratory, concerning the sequencing of electrical discharge in the late nineteenth century, figures such as Warren De la Rue, Huge Müller and John Fletcher Moulton endeavoured to 'bring order to the unruly variety and challenging temporality of the stratified discharge in vacuum tubes'.[116]

Where the aurora differs from these other unstable phenomena is in its inaccessible position at the poles and its vivid chromaticity. Significantly, the visual technologies of auroral science lagged behind methods for making images of eclipses, lightning and clouds. The history of auroral science, then, throws into particularly sharp relief the problems of communicating and 'virtually witnessing' an uncapturable atmospheric object. Following from this, embodied registration remained crucial to the auroral scientific endeavour throughout the nineteenth century and well into the twentieth century, despite increasingly instrumental ways of visualising and therefore understanding the phenomenon. One of the major contributions of this thesis is that it will provide a history of auroral research, anchored by the Polar and Geophysical Years, from a thematic and chronological perspective, detailing the ways in which the phenomenon was interpreted in negotiation between the impressions it left on individuals and the impressions it left on measurement devices in the nineteenth and twentieth centuries.

---

112 O. Baschin, 'Die ersten nordlichtphotographien, Aufgenommen in Bossekop (Lappland)', *Meteorol* Z, no. 17 (1900): 278-280, 278; Alexander McAdie, 'What is an Aurora?', *The Century Magazine* (1897): 874-878, 874.

113 Peter Galison and Alexi Assmus, 'Artificial Clouds, Real Particles', in David Gooding, Trevor Pinch, and Simon Schaffer (eds.), *The Uses of Experiment: Studies in Natural Sciences* (Cambridge: Cambridge University Press, 1989): pp. 225-274, p. 262.

114 Ibid., 252.

115 Galison, *Image and Logic*, p. 66.

116 Chitra Ramalingam, 'Natural History in the Dark: Seriality and the Electric Discharge in Victorian Physics', *History of Science* 48 (2010): 371-398, 374.

'No pencil can draw it, no colours can paint it and no words can describe it': The Aurora Borealis as an Ineffable Phenomenon in the First International Polar Year, 1882-83.

'Once more it becomes clear over the ice, and the whole phenomenon has disappeared with the same inconceivable rapidity with which it came, and gloomy night has again stretched her dark veil over everything. This was the aurora of the coming storm—the aurora in its fullest splendour. No pencil can draw it, no colours can paint it, and no words can describe it in all its magnificence. And here below stand we poor men, and speak of knowledge and progress, and pride ourselves on the understanding with which we extort from Nature her mysteries. We stand and gaze on the mystery which Nature has written for us in flaming letters on the dark vault of night, and ultimately we can only wonder and confess that, in truth, we know nothing of it.'[117]

Karl Weyprecht, initiator of the First International Polar Year (IPY), diagnosed the tension at the heart of the nineteenth century endeavour to capture and make knowable the aurora: the phenomenon cannot be extracted or reproduced and therefore our understanding is always destined to be incomplete. To invert Bruno Latour's concept, the aurora appears here as a 'mutable immobile': an infinitely varying, culturally contingent entity, uninscribable and intangible in the atmosphere.[118] Inevitably, this caused ontological problems for a scientific landscape based primarily on the direct inspection of material objects in the laboratory. Not only did Weyprecht argue in his account of the 1872-1874 Austro-Hungarian North Pole expedition that 'we know nothing' of the aurora, but he maintained that it was fundamentally unknowable unless one had witnessed it: 'nature displays before us such an exhibition of fireworks as transcends the powers of the imagination to conceive.'[119] All the while, despite himself, he urged that the aurora be documented and imaged during the IPY as part of the project to bring the otherworldly polar regions into the realm of western scientific understanding.

[117] These words are printed in Julius Payer's account of the Austro-Hungarian North Pole expedition (1872-74) but are attributed to Karl Weyprecht with the lines 'in spite of the extreme difficulty of describing the appearances of those fitful and changing lights, I believe that the following description by Lieutenant Weyprecht will be found equally faithful and effective', p. 206, the quote in the text is from Payer, *New Lands Within the Arctic Circle*, p. 209.

[118] Bruno Latour, 'Visualization and Cognition: Thinking with Eyes and Hands', *Knowledge and Society* 6 (1986): 1-40, 7.

[119] Payer, *New Lands Within the Arctic Circle*, p. 209.

The First IPY, running from 1 September 1882 to 31 August 1883, was an unprecedented, co-ordinated international endeavour set up to investigate the geophysics, meteorology, and environmental conditions of the polar regions. At the January 1875 meeting of the Academy of Science in Vienna, Weyprecht expressed his disappointment in polar expeditions to date, which had produced little in the way of standardised scientific results. By the time of the 1879 International Meteorological Conference, Weyprecht and Count Hanz Wilczek, an Austrian Arctic explorer and main sponsor of Weyprecht's 1872-74 expedition, had planned a detailed schedule for a potential Polar Year. Responses to their proposal were positive and a special commission was created, with the first International Polar Conference taking place in Hamburg in October 1879 and the final preparatory conference in St Petersburg in August 1881.[120] Twelve nations participated in the programme, operating twelve stations in the Arctic and two in Antarctica. The aurora was named as one of seven key areas of focus within the IPY, with hourly auroral observations and drawings taken at most northern sites. The German and French expeditions to South Georgia and Cape Horn did not encounter the Aurora Australis because they approached the Antarctic continent from a position far removed from the magnetic pole. Hence this chapter and the next will concentrate on the Arctic expeditions.

The 1880s was a period in which the mechanism underpinning auroral displays was still disputed and its connection to geomagnetism in the process of being investigated. The First IPY thus encompassed a concerted push to understand the patterns of auroral appearances and correlate them with other atmospheric and astronomical processes. The act of creating visual likenesses was a process fraught with challenges deriving from the aurora's extreme location, its faintness, changeability and transcendental nature. At the time of the First Polar Year, the aurora had entirely evaded photographic technologies, despite the camera being used to image phenomena which posed similar problems, including lightning, clouds and eclipses.[121] The first attempt to photograph the solar eclipse occurred in 1851, for example, with the method becoming increasingly popular towards the end of the century, whereas the first photograph of the aurora was taken as late as 1892.[122] Hand-

[120] For more details regarding the organisation of the First International Polar year see: Niels H. de V. Heathcote and Angus Armitage, 'The First International Polar Year', in Sam Stuart (ed.), *The Histories of the International Polar Years and the Inception and Development of the International Geophysical Year: Annals of the International Geophysical Year*, vol. 1 (Oxford: Pergamon Press, 1959): pp. 7-100.

[121] Jennings, 'Lightning Photography'; Alex Soojung-Kim Pang, 'Victorian Observing Practices, Printing Technology and Representations of the Solar Corona (2): The Age of Photomechanical Reproduction', *Journal for the History of Astronomy* 26, no. 1 (1995): 63-75, 249; Tucker, *Nature Exposed*, p. 142.

[122] Baschin, 'Die ersten nordlichtphotographien', 278; McAdie, 'What is an Aurora?', 874; Alex Soojung-Kim Pang, *Empire and the Sun: Victorian Solar Eclipse Expeditions* (Redwood City: Stanford University Press, 2002), p. 91.

drawing and linguistic description therefore underwrote the endeavour to learn and communicate about the aurora during the First IPY.

Despite Weyprecht's protestation that 'no words can describe it', researchers spent a great deal of time using narrative, emotive and illustrative textual strategies to constitute the aurora as a single, knowable entity. Observers involved in the programme shifted between viewing the aurora as an object which eluded the viewer and one which needed to be stabilised. There exists no such thing as a single auroral object – an argument put forward most convincingly in Robert Friedman's work on the phenomenon as varying over time and in different national contexts.[123] Nevertheless, I argue that language, as it was deployed in the IPY national reports and tales of exploration, contributed to the visuality of the aurora in the late nineteenth century, complicating our historical understanding of what constitutes the term *visuality*. The two threads so far drawn out are not in contradiction; indeed, they build upon one another. Where the evasive qualities of the aurora eluded IPY researchers and visual imagery failed to capture the aurora as an experiential phenomenon, language was ushered in to fill the gap. As has been argued by French anthropologist David Le Breton, 'words capture perception in their prisms of signification and provide the means of formulating meaning'.[124] Similarly, language, and particularly the slippery language of occlusion, was an important part of the aurora's visuality, as codified by the scientists of the First IPY.

Scrutinising the tensions and anxieties involved in describing ineffable experiences has not been a major priority within the history of science. Thus, I draw on literary analyses which have forged a path in examining the interplay between language and the inexplicable or abstract to inform this study. Dora Zhang has explored the limits of linguistic description in connection with ordinary, everyday occurrences within the writings of Virginia Woolf and the philosophical writings of William James.[125] Additionally, the Victorian fascination with the threshold between the visible and invisible within Romantic literature and culture has been investigated by Sophie Thomas, albeit in a period prior to that of the International Polar Year.[126]

It is well documented that 'there is neither a sophisticated literature of the IPYs and the IGYs, nor of the major questions these activities engendered.'[127] More specifically, as Roger Launius contends, 'major themes not fully addressed in what does exist in the scholarly literature include the

[123] Robert Marc Friedman, 'Introduction: The Aurora in History', *Acta Borealia* 29, no. 2 (2012): 115-118, 117.

[124] David le Breton, 'Sensing the World in Cross-Cultural Perspective', in David Howes (ed.), *Senses and Sensation: Critical and Primary Sources* (London: Bloomsbury Academic, 2018): pp. 43-53, p. 47.

[125] Dora Zhang, 'Naming the Indescribable: Woolf, Russell, James and the Limits of Description', *New Literary History* 45 (2014): 51-70.

[126] Sophie Thomas, *Romanticism and Visuality: Fragments, History, Spectacle* (New York: Routledge, 2008), p. 7.

[127] Launius, 'Toward the Poles', p. 48.

place of the poles in the human imagination'.[128] No systematic analysis exists of the language and imaginative techniques employed by the multitude of expedition teams researching the aurora borealis in the Polar and Geophysical Years. This chapter seeks to remedy this omission, and in doing so reveal the ways in which statements of ineffability and aesthetic registration can constitutively construct an elusive atmospheric object.

Auroral Taxonomy

'Words crystalise perception, invoke it' we are told by Le Breton; language and experience are intimately related.[129] Unpredictable, chaotic and always viewed at a distance, the aurora presented serious challenges of calibration to observers. Each light display was unique and continuously varying. As Daston contends, 'variety and variability flummox description.'[130] Auroral displays had both in abundance and thus resisted simple systematisation. In preparation for the Polar Year, Weyprecht attempted to implement a taxonomic classification system to mediate the problem of indescribability and make auroral reports commensurable in a short book entitled, *Practical Instructions for Observing the Northern Lights and the Magnetic Phenomena at High Latitudes*, printed in the year of his death, 1881.[131] The fact that Weyprecht wrote in highly aestheticised terms as well as in a more systematic register is reflective of the fact that 'the boundary between literary and scientific language is porous and more or less continually transgressed', as Spring contends in direct response to Weyprecht's prose.[132] He introduced specific types, dividing the aurora into arches, which were almost entirely regular, often reaching the horizon on both sides; bands, also known as streamers, which were irregular in shape; threads, characterised by extremely fine light beams of different lengths; corona, sometimes known as 'crown aurorae', which constituted auroral bands converging at a central point near the magnetic zenith; northern light haze, which accounted for formless accumulations of auroral light; the aurora segment, an apparently darker segment located in the magnetic north; and finally polar light or shine, which referred to faint aurorae seen in mid-latitudes.[133]

---

[128] Ibid.

[129] le Breton, 'Sensing the World in Cross-Cultural Perspective', p. 47.

[130] Daston, 'Cloud Physiognomy', 47.

[131] Karl Weyprecht, *Praktische Anleitung zr Beobacktung der Polarlichter und der magnetischen Erscheinungen in hohen Breiten* (Wien: Verlag von Moritz Perles, 1881).

[132] Ulrike Spring, 'Materialising the Aurora Borealis: Carl Weyprecht and Scientific Documentation of the Arctic', in Marianna Klemun and Ulrike Spring (eds.), *Expeditions as Experiments: Practising Observation and Documentation* (New York: Springer Publishing, 2016): pp. 141-162, p. 154.

[133] Weyprecht, *Praktische Anleitung zr Beobacktung der Polarlichter*, p. 39.

Weyprecht's nomenclature was taken up by many of the IPY research stations, including the British Fort Rae station in northern Canada, where a numerical system was developed to indicate the types of aurorae Weyprecht had outlined.[134] The taxonomy, however, drew criticism, precisely because it could not account for the aurora's infinite variability. Lieutenant Adolf Bóbrik von Boldva, leader of the Austro-Hungarian expedition, noted that the system did not encompass some of the forms witnessed at the Jan Mayen IPY station, within the Svalbard archipelago. As a way of mediating this problem, observers stationed in Jan Mayen relied on their own personal strategies for describing the phenomenon. As Boldva wrote, 'the expressions and comparisons occurring in the observations but not contained in the Weyprechtian classification were originally chosen by every observer arbitrarily, according to subjective impressions.'[135]

Hugo Hildebrand Hildebrandsson, a Swedish meteorologist who became a fellow of the Royal Meteorological Society of London in 1880 and in the same year was commissioned to prepare *The International Cloud Atlas*, rejected Weyprecht's classification system outright.[136] Dating back to Luke Howard's 1802 lecture on cloud taxonomy, much disagreement existed surrounding the collective assigning of labels to cloud forms.[137] *The International Cloud Atlas*, edited by the International Meteorological Organisations' Cloud Commission and published in 1896, implemented visually specific types to codify the study of clouds on an international scale.[138] Ten categories were chosen, which could be further divided into three kinds. In comparison to his own scheme, Hildebrandsson argued that the aurora of Weyprecht's system was divided by different projections, not true types.[139] He supposed that there were only two fundamental forms of auroral light: horizontal layers and arches composed of distinct rays. What was at stake for Hildebrandsson in 1888 was the status of atmospheric classification systems, since these would explain the variance in observers' reports in his own field of cloud physiognomy. Weyprecht's ordered taxonomy of the aurora then, was largely deemed to have failed to capture both the infinite variety of auroral displays as well as its fundamental types. Personal, subjective impressions of the aurora were understood to be a more

---

[134] Sam Stuart, *The Histories of the International Polar Years and the Inception and Development of the International Geophysical Year: Annals of the International Geophysical Year*, vol. 1 (Amsterdam: Elsevier, 1959), p. 27.

[135] International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen, ausgerüstet durch Graf Hanns Wilczek, geleitet vom Emil Edlen von Wohlgemuth. Beobachtungs-Ergebnisse, hrsg. von der Kaiserlichen Akademie der Wissenschaften', vol. 2 (Wien: In Commission bei K. Gerold's Sohn, 1886), *Gerstein Science Information Centre, University of Toronto (scanned December 2008)*, Plate VIII, p. 3.

[136] Hugo Hildebrand Hildebrandsson, 'The Aurora in Spitzbergen', *Nature* 38 (1888): 84-85, 84.

[137] Frances J. Pouncey, 'A History of Cloud Codes and Symbols', *Weather* (2003): 69-80, 70.

[138] Hugo Hildebrand Hildebrandsson, 'Studies of Clouds', *Nature* (1906): 416-417, 416.

[139] Daston, 'Cloud Physiognomy', 58; Hildebrandsson, 'The Aurora in Spitzbergen', 84.

faithful form of registration in place of the reductionism of a numerical system in the years directly preceding the Polar Year.

Experiential Knowledge

The type of seeing inculcated within the IPY programme was a form of vision which *presupposed* that the experience would be communicated to an audience who would likely never witness an aurora. Indeed, the literary prose demanded use of the reader's imagination. In tension with this, one consistent trope of the IPY literature was the underlying argument that one had to witness the phenomenon oneself to come close to understanding it, for the very reason that its nature could not be communicated effectively. Another way of understanding this problem is by repatterning it in terms of the *traveling* of knowledge, in response to Steven Shapin's question, 'if science is indeed a local product, how does it – or rather some versions of it – travel with what seems to be unique efficiency?'[140] How can one communicate the witnessing of a visual phenomenon which is largely regarded as indescribable? Prior to the Polar Year, Alexander Von Humboldt, whose work established the scientific tradition which promoted precision in observation as well as a sensitivity to aesthetics, referenced the aurora's indescribable nature in *Cosmos* (1849). He characterised the auroral streamers he witnessed as uniting 'in a quivering sea flame, the splendour of which no description can reach, for every instant its bright waves assume new forms'.[141] Attesting to the aurora's transience and mutability, Humboldt indicated that linguistic registration could not keep pace with the rapid movements of the phenomenon.

Tromholt was a Danish auroral researcher stationed alone at Kautokeino in northern Norway for the Polar Year. The Danish government did not fund Tromholt's IPY expedition, but he received support from the Norwegian Parliament and two private sponsors, Captain I. C. Jacobsen and Norwegian businessman, C. Sundit. Tromholt observed and recorded the northern lights in accordance with a co-ordinated plan, pre-arranged with his Norwegian colleagues at Bossekop. He constituted the aurora as a poetic phenomenon fully embedded within the cultural landscape of the Arctic in his narrative, *Under the Rays of the Northern Lights: In the Land of the Lapps and Kvæns* (1885). Resonating with Weyprecht's 1877 remarks regarding the state of knowledge of the phenomenon, he asked, 'Will man ever decipher the characters which the aurora borealis draws in fire on the sky? Will his eye ever penetrate the mysteries of creation which are hidden behind this dazzling drapery of

---

[140] Steven Shapin, 'Placing the View from Nowhere: Historical and Sociological Problems in the Location of Science', *Transactions of the Institute of British Geographers* 23, no. 1 (1998): 5-12, 7.

[141] Alexander von Humboldt, *Cosmos: Sketch of a Physical Description of the Universe*, vol. 1 (London: Longman, Brown, Green and Longmans… and John Murray, 1849), p. 182.

colour and light?'.[142] In doing so, Tromholt imagined a higher purpose for the aurora: that the phenomenon could conceal the secrets of the universe. He was also being self-referential, lending the aurora agency in reflexively drawing itself on the sky, while it was Tromholt, the observer, who was actually sketching the phenomenon on paper, just as Weyprecht characterised the 'flaming letters' as being *written* on the 'dark vault of night'.[143] Tromholt thus presented his own body as a microcosm of the sublime actions of the universe.

Tromholt also noted the ineffability and affective iconographic power of the aurora, remarking in *Under the Rays*, that 'a lovelier spectacle is not given the human eye to behold. He who has not seen it cannot form an idea of its magnificence – it defies description'.[144] He went further to argue that not only must a researcher have witnessed an aurora to be equipped to discuss the phenomenon, but they must have observed a multitude of differing aurorae. In a rather scathing passage, he disparaged those who constructed theories of the aurora having only witnessed the phenomenon in southern latitudes or having seen the 'wonderful spectacle' only a handful of times.[145] As he emphatically put it, 'one might just as well form a theory of glaciers from seeing an icicle or construct the grammar of a language from the knowledge of a dozen words.'[146] It is interesting that Tromholt constituted the aurora as an entire language, remapping the problem in terms of linguistics and redoubling the frustration of the project to capture the phenomenon with only a limited taxonomy. Nevertheless, his point was that this type of posturing led to false theories, which were subsequently spread within textbooks, manuals and popular scientific works. This is made clear in his lamentation that that 'the real aurora is so very different to the theoretical', divulging a belief in the existence of an intrinsic and essential aurora not captured by superficial discussions or fantastical descriptions.[147]

Tromholt's most withering critique, though, was reserved for auroral illustrations, which he asserted were too often 'wholly the production of the draughtsman's imagination'.[148] This suggests a particular importance bestowed upon visual impressions of the aurora because they possessed the power to deceive seamlessly, intuitively. It is crucial to note the relationship exposed here between words and images as devices used to render the 'mystical' Arctic. In the passage with which this chapter opened, Weyprecht noted that *neither* pencil *nor words* could do justice to the aurora.[149]

---

[142] Sophus Tromholt, *Under the Rays of the Aurora Borealis: In the Land of the Lapps and Kvæns, vol 1* (Boston: Houghton Mifflin Harcourt, 1885), p. 287.

[143] Weyprecht quoted in: Payer, *New Lands Within the Arctic Circle*, p. 209.

[144] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 201.

[145] Ibid., 195.

[146] Ibid.

[147] Ibid.

[148] Ibid.

[149] Weyprecht quoted in: Payer, *New Lands Within the Arctic Circle*, p. 209.

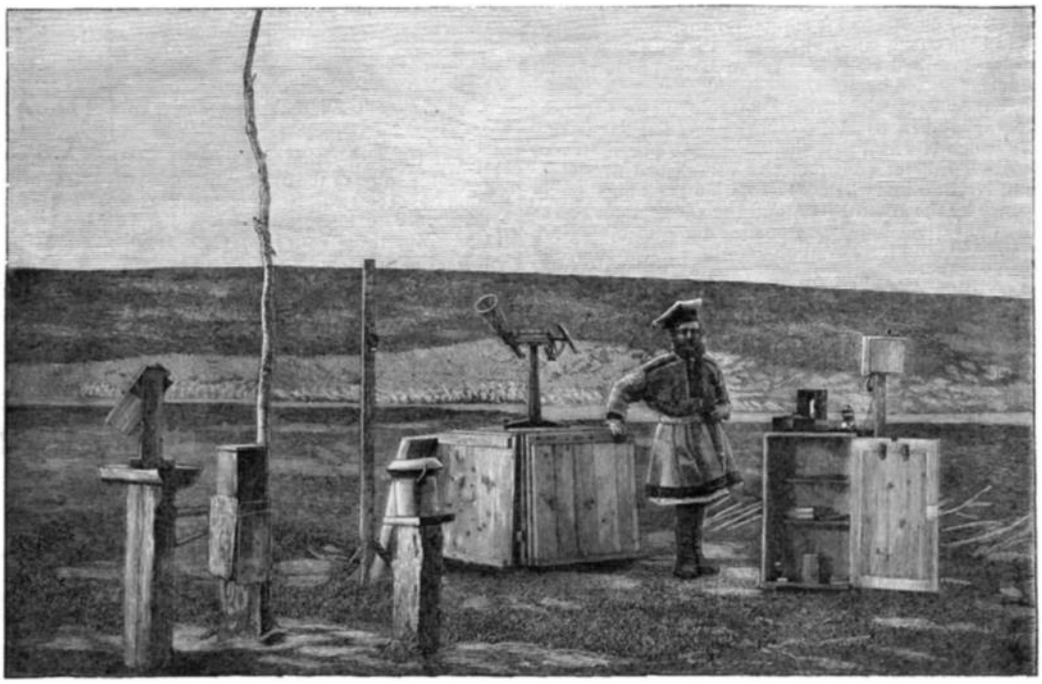


Fig. 13. Sophus Tromholt, 'Sophus Tromholt in Sami costume standing among the instruments in his outdoor observatory at Kautokeino', 1882–3, *University of Bergen Library, ubb-trom-038.*

Language was granted an equivalency with visual portrayal in Weyprecht's scheme, although it is expressed in the negative rather than the affirmative. Weyprecht's agonised statement calls into question the validity of any type of representation and presses on the reciprocal and supplementary relationship between word and image.

The portrait that Tromholt painted of the field of auroral science underscored the normative view that one must see and feel the aurora with one's own senses to gain true knowledge of the mysterious lights, conferring credibility on himself and his fellow IPY researchers. His commentary reinforced the almost shamanistic narrative that those who could 'read' the flaming text of the aurora were those who had lived, worked and endured the hardships of Arctic auroral observation. It is interesting to note here that it was the temporary western visitors who took on the role of the shaman in this scheme. Of course, as McCorristine has shown us, there were circumstances earlier in the nineteenth century when explorers such as William Harvey had consulted an *angakkuq* (or shaman) or John Ross had allowed the Neitchille Inuit to believe that he was a shaman himself.[150] But by assuming the position of the interpreters of the northern lights, researchers of the IPY charged themselves with the complicated task of being communicators of the natural world, repositioning themselves in relation to the local inhabitants of the land.

[150] McCorristine, *The Spectral Arctic*, p. 59.

‘No Words Can Describe it’

Edmund Burke identified language as the best tool we have for conveying the stirring of sentimental emotions in his treatise, *A Philosophical Enquiry into the Origin of our Ideas of the Sublime and Beautiful* (1764), writing, ‘the proper manner of conveying the *affections* of the mind is by words, there is a great insufficiency in all other methods of communication.’[151] Conversely, however, Burke also noted the limitations of language as a precise descriptive tool, stating, ‘the most lively and spirited verbal description I can give, raises a very obscure and imperfect idea of such objects’.[152] This quality of obscurity, though, is taken to be an intrinsic component of the sublime in Burke’s philosophy. Indeed, Burke continued, ‘it is our ignorance of things that causes all our admiration, and chiefly excites our passions.’[153] Just as the darkness heightens our anxieties so too does occlusion feed into our perception of the sublime. When danger is too near and pressing, however, the feeling of the sublime cannot be appreciated; only when set at a safe distance can the sublime be pleasurable.[154]

In Immanuel Kant’s *Critique of Judgment* (1790), the sublime is magnificent and terrible but crucially also elicits a response in us which we recognise. Our senses may be overwhelmed but they are still able to reflexively observe that they are overwhelmed.[155] The mind’s refusal to grasp the boundlessness of an object is exposed, gesturing at a totality which cannot be understood in its entirety. The positioning of the aurora as an ineffable object underscores its sublime nature. An observer is able to experience a brilliant light display and reflect on that fact, while simultaneously failing to fathom what they have just witnessed, let alone put the experience into words. It is precisely this identification of the failings of our own registration techniques which feeds into the perception of the sublime.

Describing the aurora in partial and ineffable language *was* a way of communicating it to an audience even as it escaped common registration techniques. It entailed a recognition that there existed a version of the phenomenon which was whole, even if it could not be made comprehensible on paper. Indeed, the repeated rhetoric of indescribability did more than gesture at a distant splendid and complete display of light; it underpinned and actualised it. The sublime essence of the aurora was made apparent for the very reason that it could only be described in fragments. The aurora followed in the tradition of other atmospheric processes, as Vladimir Jancović makes clear when discussing the ‘irreducibly local character’ of weather phenomena: ‘the history of meteorological ontologies…

---

[151] Edmund Burke, *A Philosophical Enquiry into the Origin of our Ideas of the Sublime and Beautiful* (London: J. Dodsley, 1764), p. 102.

[152] Ibid.

[153] Ibid., 105.

[154] Ibid., 60.

[155] Immanuel Kant, *Critique of Judgement* (New York: Dover Publications, 2012), p. 72.

reveals a tendency towards fragmentation'.[156] As Sophie Thomas argues, from a literary perspective, 'the sublime, properly speaking, refuses all adequate presentation: it disrupts its own presentation so that what it presents is really the inadequacy of presentation.'[157] The language of the invisible, of concealment, of occlusion, became an inherent part of the aurora's visual texture in the late nineteenth century, and a crucial indicator of its sublime nature in the accounts of IPY researchers.

Perhaps the most well-known undertaking of the First IPY, and the focus of much of the existing historiography, is the ill-fated expedition led by Lieutenant Adolphus Greely to Lady Franklin Bay, an Arctic waterway in the Qikiqtaaluk region of Nunavut, Canada.[158] Attempts to resupply and rescue the expedition in the summers of 1882 and 1883 failed, with only seven of the original twenty-five men who set out on the expedition surviving. The magnetic and astronomical reports were brought back to New York, despite considerable personal hardships faced in transporting them.[159] Greely wrote in his subsequent account of his arduous three years in the Arctic that the aurora of 21 January 1883 was 'wonderful beyond description, and I have no words to convey any adequate idea of the beauty and splendour of the scene'.[160] This choice of language may appear as an idiomatic expression, but it reveals a central tension of the project. Language is inadequate in the communication of a 'wonderful' atmospheric event but it must be used to reach people who will never witness the phenomenon themselves. The aurora seen that evening by Greely may have otherwise been considered uninteresting, given that it was 'almost colourless' and produced no movement of the magnetic needle. To Greely, however, its sheer length, lasting twenty-two hours, made it remarkable, demonstrating a subjective element involved in the appreciation of aurorae.

William Healey Dall, the American naturalist and one of the earliest explorers of the Alaskan interior, resided at Point Barrow, the northernmost point of Alaska, for the International Polar Year. Echoing Greely's remarks, he noted that auroral displays 'were always of a character that defies

[156] Vladimir Jancović, 'Introduction', in James Rodger Fleming, Deborah Coen, and Vladimir Jancović (eds.), *Intimate Universality: Local and Global Themes in the History of Weather and Climate* (Sagamore Beach: Science Publications, 2006): pp. ix-xx, p. xii.

[157] Thomas, *Romanticism and Visuality*, p. 106.

[158] Adolphus Washington Greely, 'The United States Arctic Expedition to Lady Franklin Bay', *Proceedings of the Royal Geographical Society and Monthly Record of Geography* 4 (1882): 171-175; Adolphus Washington Greely, 'The Work of the Greely Expedition', *Science* 5 (1885): 168-170.

[159] Adolphus Washington Greely, 'The Magnetic and Tidal Work of the Greely Arctic Expedition', *Science* 9 (1887): 215-217, 215.

[160] Greely, *Three Years of Arctic Service*, p. 139.

description, either by pen or pencil, as they were never for two seconds alike'.[161] This dynamism, the fact that 'the lights were never stationary for a single second', was a feature which only became more prominent as the winter of 1882-3 continued. Here, Dall emphasised an important point for the entire auroral endeavour; he expressed that it would scarcely make sense to describe the lights in one moment, considering it was the flow of the aurora which made the phenomenon so mesmerising and unique. This created a deeper problem for the epistemology at the heart of auroral science, which sought to freeze and capture the aurora at first on paper and subsequently, during the Second IPY of 1932-3, on the photographic plate. What was at stake with these remarks was the extent to which the aurora could possibly be known from a few fleeting moments or snapshots, when it was understood to be a flowing phenomenon, with its constant movement a fundamental characteristic.

Boldva noted that there was a psychological element involved in the challenge of documenting northern light displays. The viewer was often too awestruck by the intricacies of the aurora's morphology to put pen to paper effectively in the couple of minutes allocated for each input of data. As he stated, 'the observer stands in astonishment in front of the enormous splendour of such apparitions and is often unable to find words to describe it'.[162] More specifically, he remarked upon the difficulties involved in the documentation of auroral colour. Boldva noted that the rapid movement of the lights meant 'it was often not possible to give an account of the order or nuance of the colours'.[163] The most common auroral colour, considered to be a whitish-yellow by Boldva, although elsewhere recorded as a yellow-green, was seldom documented because of its prevalence in the Jan Mayen logbooks. Any variation from the norm was most likely denoted by the terms, 'rainbow-coloured' or 'coloured', only a fragmented insight, unhelpful to those researchers who wanted to understand the specific colours of the aurora to match them to elements in the atmosphere using spectroscopic methods.[164]

The practice of describing the colour of the aurora paralleled the activity of documenting various hues within cathode ray tube experiments of the second half of the nineteenth century, albeit in a significantly more controlled environment. As Iwan Rhys Morus has shown, experiments aimed at identifying elements by the specific glowing colours produced in discharge tubes began in the 1850s.[165] J. J. Thompson, working at the Cavendish Laboratory in Cambridge, conducted experiments by passing electricity through various gases within discharge tubes, noting visual changes caused by

[161] William Healey Dall, Asa Gray, John Murdoch *et al.*, 'Report of the International Polar Expedition to Point Barrow, Alaska: In Response to the Resolution of the House of Representatives of 11 December 1884' (Washington: G.P.O, 1885), *Gerstein Science Information Centre, University of Toronto*, p. 23.

[162] International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen', 7.

[163] Ibid., 9.

[164] Ibid.

[165] Morus, *When Physics Became King*, p. 158.

various conditions.[166] For example, in an 1890 paper he noted hydriodic acid appeared brown at low temperatures but a striking purple when it dissociated at higher temperatures. German physicist Eugen Goldstein also spent much time observing the optical process of florescence on the walls of cathode ray tubes. He found that within wide tubes filled with air, the stratified light had a yellow-red colour, whereas narrow cylinders produced a blue light with the same pressure of air when exposed to the same electric current.[167] Both the science of the aurora and that of gas discharge tubes hinged on the accurate perception and subsequent description of colour.

The concern among IPY researchers as to the visual and linguistic challenge of describing the aurora reflects the wider cultural and philosophical moment of the 1880s. In 1884 American philosopher William James addressed the problem of indescribability through the term 'acquaintance' in a paper presented at the Aristotelian society and subsequently published in *The Principles of Philosophy* (1890) and *The Meaning of Truth* (1909). He suggested that there is a contrast between experiencing the world ourselves and knowledge which is derived from any other means. He illustrated his point by asserting 'I know the colour blue when I see it, and the flavour of a pear when I taste it… but about the inner nature of these facts or what makes them what they are, I can say nothing at all.'[168] Following this, he wrote, 'I cannot impact acquaintance with them to anyone who has not already made it himself.'[169] Although speaking of much more everyday experiences for a person residing in the west, James pressed on the problem of translating an intrinsically corporeal experience through language. A parallel exists between the indescribability of the sublime and our inability to precisely name the textures of subjective experiences which we know ourselves intimately, however finely the description is qualified. As Zhang succinctly puts it, 'the ineffable in modernism is what we know *too* well for words', identifying the problem as the inverse of the incomprehensibility of the otherworldly aurora.[170]

Interestingly, James also invoked the aurora borealis in his work, *The Moral Philosopher and the Moral Life* (1891), to denote a disinterested object which exists whether it is observed or not. His main argument was that moral judgements require human consciousness to exist. In his words, they must be 'made flesh by being lodged and concreted in someone's actual perception.'[171] James wrote

[166] J. J. Thomson, 'On the Passage of Electricity through hot gases', *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* 29, no. 179 (1890): 358-366, 364.

[167] Eugen Goldstein, 'On the Electric Discharge in Rarefied Gases', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* xxvii (1880): 173-190, 173.

[168] William James, *The Principles of Psychology*, vol. 1 (Henry Holt and Co., 1890), p. 224.

[169] Ibid.

[170] Zhang, 'Naming the Indescribable', 53.

[171] William James, 'The Moral Philosopher and the Moral Life', *International Journal of Ethics* 1, no. 3 (1891): 330-345, 337.

that a philosophical judgement, good or bad, 'cannot float in the atmosphere, for it is not a sort of meteorological phenomenon, like the aurora borealis or the zodiacal light.'[172] Whether we pay attention to the aurora, or have a visual acquaintance with the phenomenon at all, matters not to the aloof lights which shine in the sky regardless. Unlike a moral judgement, James uses the aurora as the best example of an object which is abstract and cannot be fully understood or made manifest by the power of the mind. This notion of the aurora as entirely separate from our internal thoughts is clearly consequential for the project of describing the phenomenon, which relies upon the virtual witnessing of the light displays.

English language poetry of the nineteenth century played its own role in attempting to express the sentimental and iconographic power of the aurora in a more emotive idiom. Emily Dickinson's poem, *Of Bronze and Blaze*, speaks to the remote and unfeeling qualities of the aurora. Within the poem, Dickinson includes the lines:

'Of bronze and blaze
The north, to-night!
So adequate it forms,
So preconcerted with itself,
So distant to alarms,
An unconcern so sovreign,
To universe, or me,
It paints my simple spirit,
With tints of majesty'[173]

The aurora here is characterised as both aloof and distantly splendid, a common combination of impressions. The wider cultural appreciation of the aurora as a fantastical source of the sublime shaped the narrative elements of the literature put forward by auroral researchers of 1882-3. In turn, their testimonies reinforced common tropes within the popular imagination.

Aestheticised Language

Alex Soojung-Kim Pang has asserted that, 'lurid descriptions of observers' emotions were stock elements of eclipse narrative of the 1860s and 1870s, but had disappeared by the 1880s'.[174] Spring has compared the language used in Weyprecht and Julian Payer's Austro-Hungarian Polar Expedition of

[172] Ibid.

[173] Dickinson, 'Of Bronze and Blaze'.

[174] Pang, 'Victorian Observing Practices (2)', 67.

1872-4 and the Austro-Hungarian Polar Year Expedition to Jan Mayen (1882-3). The aurora, initially representing the bright future of the Austro-Hungarian monarchy, had by 1882 lost its significance as a symbol for state affairs.[175] Spring argues that, during the First IPY the aurora had become 'an object of analysis rather than wonder and marvel'.[176] These two categories, however, are not mutually exclusive. Moreover, highly aestheticised language continued to be a mainstay of 1880s reporting, especially in the literature of the IPY expeditions. It must be remembered that the aurora was an object of the geographical imagination, which occupied a position 'between objective reality and subjective experience, where perceptions of the real and imagined shape each other to produce influential, widely circulated and enduring sets of knowledge and expectation'.[177] The wider community of IPY auroral researchers continued to be awestruck by the northern lights, so much so that they often could not find the words to express their observational experience.

Tromholt's report of his IPY activity at Kautokeino, a place which he described as 'beyond the pale of civilisation' despite being a Sámi settlement, was written in the form of a travel narrative of his year's sojourn, with extensive sections devoted to ethnography. He described his first sighting of the aurora, documenting that, 'during the wonderful night, when the aurora borealis, as if to welcome me, begun to festoon the sky with many-hued draperies, reflected in the deep silent waters, we glided softly in between the jet black, sombre mountains, towering on both sides of the fjord, to our welcome haven.'[178] This aestheticized portrayal of his arrival in Kautokeino acted as a touchstone, setting the scene for Tromholt's superfluous linguistic representations of the aurora later within his narrative. Rich descriptions of 'the loveliest colours of red and green', and streamers 'which hung fairy-like in the air' filled *Under the Rays*, imbuing the aurora with a kind of wonder not attributed to the other features of the polar landscape.[179]

Dall was also particularly taken by the aurora, remarking in his narrative included within the *Report of the International Polar Expedition to Point Barrow, Alaska* that 'every clear night the sky was illuminated by the most beautiful displays of aurora it has ever been my fortune to witness.'[180] Dall differentiated the aurora of Point Barrow from those observed from lower latitudes, waxing lyrical that 'great curtains of light flashing with all the prismatic colours seemed to be drawn across the heavens'.[181] It is possible that Dall's interpretation of the aurora at Point Barrow was skewed towards these more majestic and exciting displays considering that researchers at the station were

[175] Spring, 'Between Spectacle and Science', 206.

[176] Ibid., 207.

[177] Mahony and Randalls, 'Introduction', p. 2.

[178] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 31.

[179] Ibid., 81 & 199.

[180] Dall, Gray, Murdoch *et al.*, 'Report of the International Polar Expedition to Point Barrow, Alaska', 23.

[181] Ibid.

allowed to confine their observations to the most conspicuous examples of the phenomenon, outside of the three days of each month for which observation was compulsory. Dall also made use of more colloquial language in saying that ‘merry dancers, whorls and convolutions followed each other in quick succession’, perhaps hoping to appeal to a wider audience less familiar with the formalised terminology of auroral science.[182]

Boldva of the Austro-Hungarian expedition to Jan Mayen spoke of the aurora in the most overtly aestheticized idiom, characterising the phenomenon as supernatural and using metaphors suggestive of the sublime. He told his readers that gazing on the aurora was ‘as if an omnipotent force granted us a glimpse of the universe, then the phenomenon opened up in the middle and an enigmatic dark eye looked down on us from an infinite distance, soon covering itself again with flowing curtains of light’.[183] Once again, a reflexive tendency can be detected, ascribing the aurora with a type of agency, conducting an activity that actually the Jan Mayen researchers were participating in themselves. While they set about their relentless programme of auroral observation, watching the phenomenon night after night, the aurora, with all its knowledge and secrets, gazed back. Furthermore, Boldva’s narration speaks to the dichotomy of the fragment and the whole. While the viewers only caught a ‘glimpse’ of the workings of the universe, the infinitely distant eye saw the researchers, their station and perhaps in fact, the earth, in its totality. The mind’s ability to only grasp a small part of the phenomenon was positioned in stark contrast to the imagined omniscience of the aurora.

Witnessing an aurora on 17 November 1882 John Rand Capron, British spectroscopist and astronomer, remarked on the aurora’s ‘rare and striking character’. He noted his surprise that scientific journals had taken little notice of the phenomenon.[184] Later, in 1916, when the editors of *The Observatory* were asked to contribute to the 500th edition, Edward Maunder, former editor of the journal, recounted that the aurora of 17 November 1882 was the most ‘striking experience’ of his forty-three years of observation.[185] Ten days later an aurora was observed in Rome by Italian astronomer, Pietro Tacchini, who described the hue as a luxurious ‘lovely azure-greenish colour’, giving a hint of the ostentatious lexicon linked to auroral descriptions.[186]

Despite the recurring characterisation of the aurora as ineffable, it clearly was possible to discuss the phenomenon in the dispassionate language of the natural historian. Discussing the same aurora of 17 November 1882, William Christie, the Astronomer Royal, described it as ‘commencing

[182] Ibid.

[183] International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen', 7.

[184] John Rand Capron, 'XLVII The Auroral Beam of November 17, 1882', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 15, no. 95 (1883): 318-339, 318.

[185] P. Fuller, 'The Life and Times of John Rand Capron', *Antiquarian Astronomer* 8 (2014): 21-45, 31.

[186] P. Tacchini, 'The Aurora', *Nature* 27 (1882): 138.

with a bright glow of red light extending from the north and west beyond the zenith'.[187] While providing a useful account, Christie did not betray any particular excitement for the event. Similarly unemotional descriptions can be found in the records of the British Polar Year Expedition to Fort Rae. Aurorae were described using basic colour and geometric language: 'the lower edge of the arch generally assuming a violet or mauve colour, the upper edge retaining its yellow colour'.[188] This could be accounted for by considering that the aurora at Fort Rae in the winter of 1882-3 'were not of any remarkable brilliancy'.[189] In fact, Henry Dawson, the leader of the Fort Rae expedition, seemed somewhat deflated that his own observations did not live up to the extraordinary accounts of others, stating that, 'the brilliant coloured [aurorae] one reads about are conspicuous by their absence'.[190] Nevertheless, these examples, from both an Arctic expedition and a relatively low latitude observation, demonstrate that the phenomenon could be explained in simple visual terms without reference to the ineffable or the sublime. It was thus a *purposeful* and *conscious* choice to depict the aurora in a more exuberant fashion, as a way of providing an additional layer of meaning.

Auroral Analogies

Harnessing the colourful and lively language of analogy was one way in which participants of the IPY attempted to deal with the sublimity of the aurora and subvert its ineffable nature. As Nasim asserts, 'in the history of science, a customary way to come to terms with the unfamiliar is to connect it to the familiar by analogy or metaphor'.[191] The aurora was an object ripe for symbolic ascription. Patricia Fara has surveyed eighteenth century engagement with the aurora and the subsequent modelling of the atmosphere and sunspot activity based on historical accounts.[192] As she describes, tradition in the Scottish Islands dictated that the lights represented battles. In the Lowlands in the eighteenth century, however, the aurora was named 'Lord Derwentwater's lights' after the execution of James Radclyffe, 3rd Earl of Derwentwater and a popular Jacobite rebel, a few days prior to the prominent red aurora of March 1716.[193] Within northern cosmologies, the aurora has been associated with the spirit world,

---

[187] W. H. M. Christie, 'The Magnetic Storm and Aurora', *Nature* 27 (1882): 82-87, 83.

[188] British International Polar Year Expedition, 'Observations of the International Polar Year Expeditions, 1882-83: Fort Rae' (London: Tribuner & Co., 1886), *MBLWHOLI Library*, p. 253.

[189] Henry P. Dawson, 'Winter Life at Fort Rae', *Nature* 28 (1883): 371.

[190] Ibid.

[191] Nasim, *Observing by Hand*, p. 36.

[192] Patricia Fara, 'Lord Derwentwater's Lights: Prediction and the Aurora Polaris Astronomers', *Journal for the History of Astronomy* 1: Background (1996): 239-258, 241.

[193] Ibid.

whereas in southern latitudes, where it appears far less frequently, the lights have been understood as a bad omen.

Julius Payer, an Austro-Hungarian army officer and Artic explorer who took part in the second German North Polar expedition to East Greenland in 1868 and co-commanded the 1872-74 Austro-Hungarian North Pole Expedition with Karl Weyprecht, put forward a collection of analogies in 1877. He asserted that the aurora 'resembled the uprising of whirling vapours, such as the Geysers might send forth, which generally assumed the form of enormous flames, except that they were transparent and mist-like.' [194] His reference to other geophysical and meteorological terms indicates that Payer wanted to connect the aurora with more familiar natural phenomena, creating a clear and authoritative basis for understanding the phenomenon. He also noted that, 'in many cases the aurora much resembled a flash of summer lightning conceived as permanent'.[195] The connection to lightning is significant, considering that it was only on 2 September 1882 that the first photograph of lightning was taken by William Jennings, just a month into the First IPY programme. The imagined notion of lightning made permanent reflected the frustrations of auroral researchers who attempted to stabilise the perpetually changing aurora through photography, though without success until the following decade.

Commonly, the aurora was likened to fire within the cultural milieu of the Polar Year as a similarly bright and dynamic phenomenon.[196] Payer mused on the inconceivable colours of the northern lights, asking rhetorically in 1877 about its reflection in the ocean: 'is that sea red, white or green? Who can say? It is all three colours at the same moment. The rays reach almost to the horizon: the whole sky is in flames.'[197] It seems that a flame was a convenient descriptor, standing in for the confusion of colours which met Payer's eyes. The portrayal of the aurora as completely enveloping the observable sky plays into its representation as being extreme and arresting. Tromholt, in *Under the Rays*, echoed this depiction, narrating that with an 'almost startling rapidity, the aurora expands westward and shortly after the whole northern sky is a bath of fire'.[198]

Greely also likened the aurora to a 'glowing pillar of fire' on 19 December 1882, 'showing at times a decidedly rosy tint and later a Nile-Green colour.'[199] The colour of the aurora was not captured by the fire analogy, rather the symbol was used to explain the aurora's movements and eerie changeability. Also worth noting is that the aurora australis was witnessed on 2 October 1882 from

---

[194] Payer, *New Lands Within the Arctic Circle,* p. 202.

[195] Ibid.

[196] The analogous connection between aurorae and fire dates back to the literature of ancient Greece. For further information see: Richard Stothers, 'Ancient Aurorae', *Isis* 70, no. 1 (1979): 85-95.

[197] Payer, *New Lands Within the Arctic Circle,* p. 202.

[198] Tromholt, *Under the Rays of the Aurora Borealis (1),* p. 119.

[199] Greely, *Three Years of Arctic Service*, p. 115.

Adelaide, Melbourne, Sydney, Sandhurst and Ballarat in Australia. According to Francis Cole in a publication for *Nature*, several firemen in these cities turned out, literally seeing the aurora as an enormous conflagration due to its rarity at such latitudes.[200] Of course, this was not intended to be emblematic; the aurora clearly did share many characteristics with flames on the horizon. Notorious anecdotes of mistaken aurorae likely fed the literary connection between the light displays and brightly burning fires.

The Jan Mayen IPY report used the metaphor of the aurora as a firework, another common visual trope reflecting the excitement of watching the brilliant lights, their rapid movements and array of colours.[201] Tromholt recorded the aurora 'as if thousands of gold filaments were shot through the sky', conjuring a unique image of the aurora as a luxurious, delicate and ethereal phenomenon.[202] These expressive and very visual analogies crop up in the vast majority of IPY documentation as one possible way of curing the indescribable nature of the aurora. They highlight the problem of translation to lower latitudes and a sensitivity to the fact that the aurora could only be described by close approximation.

The historical use of metaphor informed Tromholt's assertions about the presence of aurorae in Norway from the thirteenth century onwards, put forward in a note published in *Nature* in the same publication year as *Under the Rays* (1885). He drew on *Konungs skuggsjá* (The King's Mirror), an Old Norse text dating from approximately 1250, and the work of Peder Claussön Friis (1566-1614), Minister of Undal in southern Norway, who published a treatise on Greenland in 1600. *The King's Mirror* was written as a dialogue between father and son, where the father provided advice about such matters as good manners and chivalric behaviour. The author of *The King's Mirror* is unknown, although likely resided near the Namsos region of Norway.

Tromholt explicated some of the analogous language used to describe the aurora in these two texts. He quoted at length a passage from *The King's Mirror* in which the phenomenon was likened to 'a luminous blaze' and 'a red-hot iron just taken out of the forge'.[203] When the aurora began to fade, the didactic text referred to the sky 'as if a black smoke or a heavy nebulous cloud had been puffed onto it'.[204] The use of such specific analogies here once again reflects the desire to translate the aurora from an ethereal and mysterious object to something ordinary which could be known. Tromholt asserted that 'the noble unvarnished manner' in which the anonymous author described the phenomenon indicated 'quite plainly that it is based on the author's own observation of the aurora in

---

[200] J. Francis Cole, 'The Aurora', *Nature* 27 (1882): 141.

[201] International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen', 7.

[202] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 207.

[203] Tromholt, 'A Note Relating to the History of the Aurora Borealis', 90.

[204] Ibid.

his native country'.[205] In other words, *The King's Mirror* descriptions were assumed to be written as a first-hand account because of the specificity of the analogies used. Therefore, according to Tromholt, the light display must have been visible from southern Norway during the thirteenth century.

Several powerful and somewhat unusual analogies were included within the Friis text (which itself also quoted *The King's Mirror*). As Tromholt quoted, the aurora was compared to 'a tall slender hedge' and was described as rushing 'up and down in a trice as if many organ pipes were posted beside the other'.[206] The movements of the phenomenon were likened to a 'hopping and dancing with much agitation', a recurring trope which echoed the aurora's colloquial name, 'the merry dancers', commonly used in the Scottish Islands.[207] These 'conspicuous expressions' led Tromholt to believe that Friis must also have experienced an auroral display himself due to their precision and apparent insight.[208]

In revisiting these historical accounts of the Norwegian aurora and printing their testimonies in Nature in 1885, Tromholt situated the Polar Year programme within a tradition of auroral observations, which used the expressive linguistic strategy of analogising to reconstruct the phenomenon on paper. In a lineage dating back to the twelfth century, the aurora was defined to those who would likely never view it as that which it resembled. That the lurid metaphorical descriptions were used as evidence of direct auroral observation reinforces the connection between words and experience; the aurora must have been seen for it to be adequately described and vice versa; descriptions approaching accuracy could only arise from experiential knowledge.

Conclusion

I have made the case for the constitutive power of textual strategies in conjuring and communicating the 'flaming letters written on the dark vault of night', thus complicating and adding to the historical category of *visuality*.[209] Literary performances written in the personal idiom of first-person narrative were deemed crucial to explaining the intricate character of the lights, which could not be made manifest with only a static drawing or any instrumental measurement. The use of analogy, language indicative of the sublime, reference to the corporeal senses and words which registered their own incapacity to render the phenomenon, structured the visibility of the aurora, symbolic of the otherworldliness of the Arctic. In contrast to Spring's findings, here the aurora still retained the ability

[205] Ibid.

[206] Ibid.

[207] Ibid.

[208] Ibid.

[209] Weyprecht quoted in: Payer, *New Lands Within the Arctic Circle*, p. 209.

to stoke the fires of the imagination.[210] It was when discussing the northern lights that lurid and emotional descriptions of the phenomenon and its significance to the individual exploded onto the page of otherwise sober scientific treatises.[211] Albeit techniques reliant on clumsy words always seemed to fall short in the face of the 'wonderful spectacle'.[212]

My argument is that language, and particularly the language of occlusion, constituted an important part of the aurora's visual texture during and after the Polar Year and so too should be considered within the visual histories of other liminal and evasive objects. Describing the aurora as indescribable was *in itself* a means of explaining the experience of witnessing the phenomenon; it was a way of adding another layer of meaning, not just signposting the absence of it. The partial, fragmented accounts of the aurora underscored the sense in which there was a complete and sublime phenomenon, intangible in the atmosphere, which could not quite be grasped, let alone communicated, from the surface of the earth.[213] Words inhabiting the space between visibility and the imagination, the spiritual world and the scientific and what was perceptible and subjectively affective were relied upon to hint at and more directly construct the aurora at the limits of communicable experience in the period.

Elizabeth Kessler characterises the encounter with the sublime as the experience of tension between the senses and reason in her research on the images produced by the Hubble Space Telescope since its launch in 1990.[214] Viewers were encouraged, Kessler argues, 'to experience the cosmos visually *and* rationally, to see the universe as simultaneously beyond humanity's grasp and within reach of our systems of knowledge'.[215] This tension speaks to the dichotomy present within the First IPY of believing the aurora was unrepresentable while also striving to capture it with words and hand-drawings. Nevertheless, the weight of the IPY literature indicates that the aurora was not considered to be an object within the reach of western comprehension, but rather unfathomable and sublime for the very reason that it could not be communicated.

Just as the aurora was understood to be beyond language, so too were the IPY accounts taken beyond the purely visual into the realm of the body. The viewer was physically struck by awe on seeing the phenomenon and was moved to poetics by its affective qualities. Afterall, underpinning all of this was a strong current of belief in the power of experiential knowledge, in seeing the aurora with one's own eyes, without which the phenomenon could never truly be understood. Enduring the

---

[210] Spring, 'Between Spectacle and Science', 206.

[211] Ibid.

[212] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 195.

[213] Weyprecht quoted in: Payer, *New Lands Within the Arctic Circle*, p. 209.

[214] E.A. Kessler, *Picturing the Cosmos: Hubble Space Telescope Images and the Astronomical Sublime* (University of Minnesota Press, 2012).

[215] Ibid.

hardships of the landscape and devoting a year of first-hand study to the aurora were the means by which credibility could be established within the field of auroral science at the end of the nineteenth century.

The project to make the aurora knowable ran counter to the notion that the phenomenon was intrinsically more meaningful than a mere visual manifestation of atmospheric and solar forces. Indeed, its ineffable nature put pressure on contemporary instrumental epistemologies, providing an impetus for the use of novel registration techniques in the later Polar (1932-3) and Geophysical Years (1957-8). The perceived fallibility of the endeavour to capture the aurora as a meaningful whole motivated the later emphasis on representing only fragments of its ontology. In the Second International Polar Year, the use of photography aimed to exhibit only the forms of the phenomenon, spectroscopic analyses were designed to investigate its electromagnetic radiation and radio imaging was used in the International Geophysical Year as a means of scrutinising the aurora's drift sequences in the 'atmospheric ocean'.

This chapter has provided an example of one way in which an enigmatic atmospheric phenomenon escaped conventional registration techniques, while its slippery and evasive nature was simultaneously used for the purposes of representation and definition. The troublesome aurora posed unique challenges to the researchers of the IPY, who could not simply transport it to the laboratory or inspect its inner nature directly. The problem of ineffability, and how it can be squared with scientific projects which, at their foundation, necessitate textual portrayal, categorisation and comparison from multiple sites, may reward greater scholarly consideration within the history of science.

Hand-Drawing the Aurora Borealis During the First International Polar Year, 1882-83: Practices and Performance

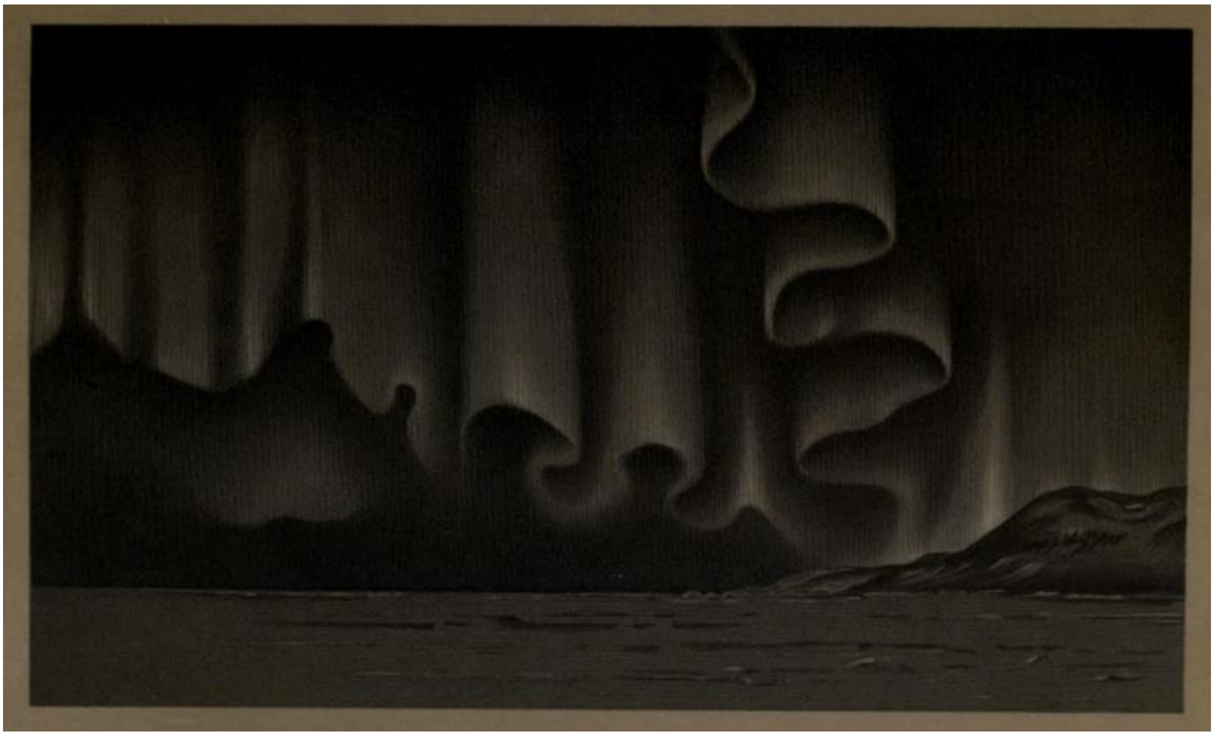


Fig. 14. Edward Adrian Wilson, 'Auroral Curtain, 5th July 1902, 1h am to 2h am, seen in N', in Edward Adrian Wilson, *Album of Photographs and Sketches with a Portfolio of Panoramic Views, British National Antarctic Expedition 1901-1904* (London: Royal Society, 1908), p. 290.

'Unhappily [the aurora] is an impossible thing even to suggest in picture, for as the curtain appears to fold in one direction, it is waved out of sight in another, while the varying intensity of the vertical beams of light which compose it, now brilliant, now vanishing altogether, now stealthily appearing or disappearing imperceptibly, gives the onlooker a strange feeling of expectation and bewilderment, to which is added the conviction that the whole is very beautiful, but quite impossible to represent on paper'.[216]

Thus Edward Adrian Wilson described his attempts to sketch the aurora australis at McMurdo Sound in Antarctica on the British National Antarctic Expedition of 1901-1904. In the now familiar language of occlusion, he lamented that the phenomenon was too changeable and strange to be captured with

[216] Edward Adrian Wilson, *Album of Photographs and Sketches with a Portfolio of Panoramic Views, British National Antarctic Expedition 1901-1904* (London: Royal Society, 1908), p. 290.

any kind of accuracy in his *Album of Photographs and Sketches with a Portfolio of Panoramic Views* (1908).[217] Researchers of the First International Polar Year, which took place twenty years prior between 1882 and 1883, felt similar pressures in attempting to draw the elusive phenomenon in all of its dynamism and variety. In harmony with Wilson's later remarks, they sought not to capture the 'whole' of the aurora but to deconstruct it, delineating specific characteristics and representing the phenomenon as it appeared at one specific point in time.

The researchers of the IPY departed from the guiding principles of romanticism, which idealised and aggrandised the polar landscape, as well as the conventions of symmetry, use of unusual, bright colours and the inclusion of the horizon, which dominated earlier nineteenth century depictions of the aurora. Many of their representations were constructed in the artistic mode of naturalism. Naturalism was a nineteenth century European movement which sought to depict nature true to form, including its imperfections, with the least amount of distortion or idealisation possible. David Summers defines it as the art of portraying 'the elements which are presumed to coincide with the elements of optical experience'.[218] Naturalism was distinct from realism in that the realism movement sought to highlight social inequality through the choice of everyday, working subjects whereas naturalism moulded itself as apolitical and scientific. Realism, as Summers argues, 'is at base a category of subject matter'.[219] The auroral images, as a collection, also spoke to the fine art movements of impressionism and expressionism, responding to the culturally constructed expectations and viewing conventions of the late nineteenth century, or the 'period eye' in Michael Baxandall's terminology.[220]

Many of the IPY images, as naturalist depictions, were constructed in the spirit of the popular precept of 'mechanical objectivity', an epistemic virtue characterised by the self-restraint of the image-maker, displaying specific moments rather than the typical or perfected.[221] Crucially, however, auroral images were constructed by hand; with the procedures which guided researchers standing in for the 'mechanical' element of the system. The act of drawing was a process of configuring the body as an instrument, tasked with capturing what the eyes had witnessed without providing any interpretation.

[217] Ibid., 285.

[218] D. Summers, *The Judgment of Sense: Renaissance Naturalism and the Rise of Aesthetics* (Cambridge University Press, 1990), p. 3.

[219] Ibid.

[220] Michael Baxandall, *Painting and Experience in Fifteenth Century Italy: A Primer in the Social History of Pictorial Style* (Oxford: University of Oxford Press, 1988).

[221] Daston and Galison, *Objectivity*, p. 186.

Drawing, as Omar Nasim argues, is part and parcel of the process of stabilising enigmatic intangible objects.[222] Sketching focuses the attention of the observer and allows the object to be 'virtually witnessed' by others.[223] Furthermore, the process of copying, printing and circulating images influences the way they are received and understood, as Alex Soojung-Kim Pang asserts.[224] Following the work of Nasim on nineteenth century nebulae and Pang on drawings of the solar corona, this chapter explores the materiality of the auroral drawings produced during the Polar Year and the performative purposes to which they were put when published. Embedded within the auroral images are arguments regarding the way aurorae should be viewed and understood. Significantly, several of the researchers surveyed in this chapter preferred to put forward their assertions in the visual mode, rather than by textual or numerical argumentation, demonstrating that scientific images can provide something compelling and distinct from other forms of contention.

The primary aims of auroral research during the First Polar Year were to catalogue appearances of the phenomenon so they could be compared with meteorological and magnetic patterns, examine auroral intensity and to analyse the development of various formations.[225] For these objectives, the practice of hand-drawing from many nights of observation was well suited. There were several aspirations, however, for which the Polar Year was deemed an unfit occasion. Weyprecht, initiator of the First IPY, established the limits of the field of auroral research as well as the most useful techniques in his *Practical Instructions for Observing the Northern Lights and Magnetic Phenomena at High Latitudes* (1881). He advised that exact altitude measurements were impossible with contemporary technology because the shape and position of aurorae changed too frequently to be recorded accurately.[226] Moreover, he urged that brightness intensity readings, while useful, would be difficult to authenticate. Auroral photography, the primary method which underpinned the study of the northern lights in the Second IPY of 1932-3, was in a nascent state in the 1880s while spectroscopic analysis, though employed, made a more significant impact on the field in the 1920s and 1930s. In any case, drawings offered distinct advantages over photographs to the field of auroral imaging. Hand-drawings could capture a wider field of view, could represent the colours of Polar phenomena and would often be based on the detailed and valuable notes of a draughtsman.[227] Despite instrumental limitations, C. J. Taylor, historian of Canada's national parks, recognises the significance of the

[222] Nasim, *Observing by Hand*, p. 240.

[223] Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life* (Princeton: Princeton University Press, 2011), p. 60.

[224] Pang, 'The Solar Corona (1)'; Pang, 'Victorian Observing Practices (2)'.

[225] H. R. Proctor, 'Magnetic and Auroral Observations in High Latitudes', *Nature* 24 (1881): 241.

[226] Weyprecht, *Praktische Anleitung zr Beobacktung der Polarlichter*, p. 40.

[227] John Adam Fleming to Mr Stokes, 10 November 1930, Letter, *Oslo National Library*, Carl Størmer letter archive, p. 115.

auroral work carried out during the First IPY, calling it 'perhaps the clearest contribution' of the entire undertaking.[228]

Practices of Drawing and Visual Argumentation

In an 1881 statement emphasising the importance of hand-drawn images, Weyprecht made auroral researchers aware that, 'drawings of particularly characteristic forms based on nature are very desirable'.[229] The operative words were 'based on nature', by which Weyprecht meant drawn exactly as observed. This directive had already been established at the preparatory Hamburg IPY conference of 1879. For example, Chief Signal Officer of the US army in charge of the National Weather Service, William Babcock Hazen, sent a letter to the commanding officers of the two US IPY stations. In a section titled, 'elective observations', the message from Hamburg was relayed: 'particular attention will be paid to… the aurora borealis, and to drawings of the appearances presented by the phenomenon, as seen by observers situated as far apart as possible.'[230] The instructions further explained that 'in these drawings the auroral phenomena should appear in their proper positions relative to the horizon, meridian and fixed stars', providing spatial contextualisation and reflecting the mapping uses envisioned for such depictions.[231] It is interesting that the drawings were not compulsory, indicating that auroral observations were a peripheral project at the US sites. Furthermore, it is clear from the letter that identifying and recording position was of the utmost significance.

As part of the IPY, the Norwegian government sent five men led by Askel Steen to Bossekop in Finnmark, with Carl Krafft designated to auroral duty. Tromholt's station at Kautokeino was paired with the Bossekop site. Researchers at each station documented meteorological and geomagnetic measurements every hour while logging the appearance of the aurora every fifteen minutes if it was visible between 17:00 and 23:00, and every ten minutes during 'aurora hour' between 20:00 and 21:00.[232] This routine and the metadata included with Tromholt's images imply that the sketches were constructed rapidly, in less than ten minutes. Sketches of the aurora were always made in the plane

[228] Charles J. Taylor, 'First International Polar Year, 1882-83', *Arctic* 34 (1981): 370-376, 372.

[229] Weyprecht, *Praktische Anleitung zr Beobacktung der Polarlichter*, p. 40.

[230] W. B. Brigadier Hazen, Brevet Major-General and Chief Signal Officer US army, 'detailed instructions concerning observations, instruments, at time, by the International Polar Conference, Hamburg 1-5 October 1879', letter in Report of the International Polar Expedition to Point Barrow, Alaska in Response to The Resolution of the House of Representatives of 11 December 1884, vol. 23 (Washington: Government Printing Office, 1885), *Gerstein Science Information Centre, University of Toronto*, 2298, pp. 7-17, p. 13.

[231] Ibid.

[232] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 53.

Kautokeino-Bossekop, drawn on a sheet of paper laid on glass, which formed a box over a lantern, so the page was illuminated.[233] In an inverted, almost mimetic practice of tracing the light in the sky, the paper was inscribed with graphite marks while light shone through in place of the night's darkness.[234] Due to the fast-paced nature of the work and the numbing of the hands in the cold, Tromholt noted that the accompanying auroral notes made using this setup sometimes produced 'the most extraordinary calligraphic puzzles'.[235] Nonetheless, after the Polar Year these records were transformed into legible descriptions and the negative images re-sketched and inverted.

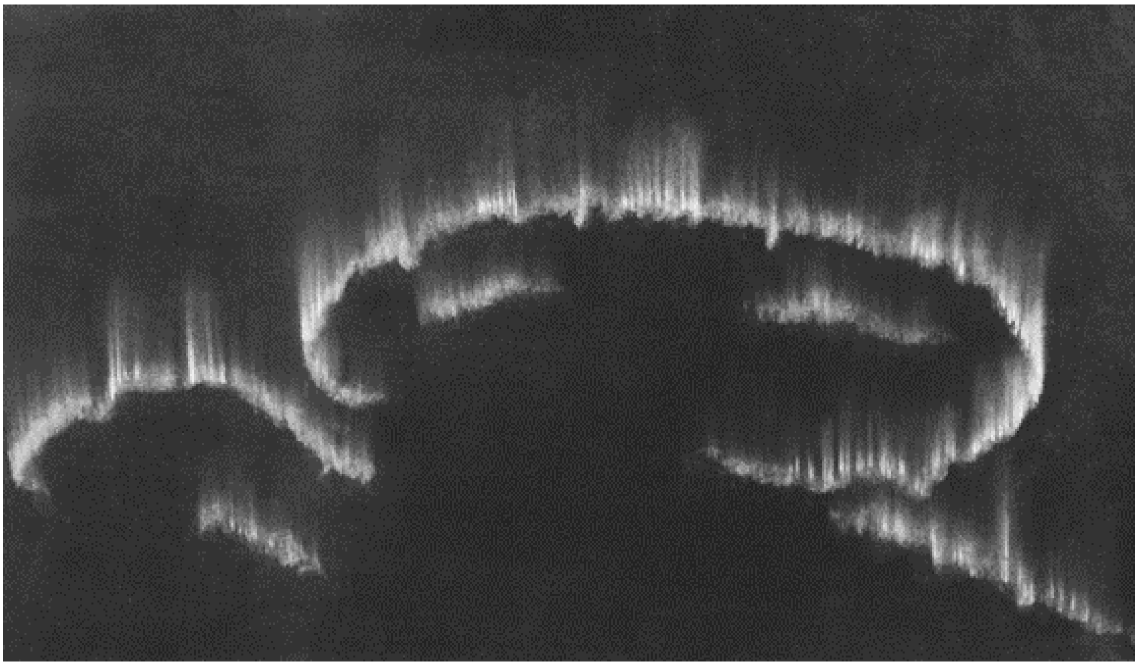


Fig. 15. Sophus Tromholt, 'Northern Lights in Kautokeino 6 Oct 1882, 7h 3m', photograph of a drawing, Sophus Tromholt Collection, *University of Bergen Library, ubb-trom-249*.

The photograph of a drawing, depicted in fig. 15, represents the aurora as seen by Tromholt from his Kautokeino base on 6 October 1882 at 7h 3m. This drawing was one of a dozen which Tromholt subsequently photographed for posterity after the Polar Year. Unlike the auroral imagery produced prior to the IPY, it features an irregular formation of bands and streamers and is situated completely independently of the horizon. Bright rays can be seen against a dark background, with no attempt to include any of the surrounding scenery or even bright stars for reference. Tromholt's drawing was also crucially recorded alongside a precise timestamp, placing it within a temporal scheme and thus furnishing it with a sense of authority. By providing an exact time of capture, down

[233] Ibid.

[234] Here, I follow Peter Galison's use of the word 'mimetic', whereby images 'purport to preserve the form of things as they occur in the world', in: Galison, *Image and Logic*, p. 19.

[235] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 53.

to the minute, Tromholt emphasised that what he was capturing in his sketch was the precise and unique pattern of auroral bands crystallised in one moment, rather than a general impression. Making up for the 'lack of language codes and artistic conventions' for representing the Arctic was Tromholt's own personal and direct experience of the environment, which he put to paper.[236]

Tromholt's drawing is entirely monochrome, indicating that it was the formations rather than the colours of the lights which were deemed important to document in the 1880s. Indeed, the majority of auroral sketches followed the same convention of white pencil strokes against a dark background, similar to the customs of representing nebulae earlier in the nineteenth century. Contrasting with the constitution of the Arctic as 'white, ever white', the sketches emphasised the darkness of the polar night and captured a territory, the night sky, that the camera had yet to conquer.[237] Just as Noelle Belanger and Anna Stenport argue that Frederik Church's *Aurora Borealis* hints at the limits of photography 'while also making a claim for the unlimited capacity for representation in painting' so too did the auroral images document what was 'unseeable' through the camera lens.[238] Embedded within practices of photography is a technological bias towards lightness and whiteness. Most film stocks are calibrated to daytime photography and, as Lorna Roth reminds us, toward white skin tones.[239] The IPY auroral images challenged not only the conventions of landscape painting, but also the expectations of photography.

Tromholt chose to use vertical pencil strokes, drawn in an upwards motion, to create a likeness to auroral bands, each brightest at their lowest point and fading with altitude. He represented the aurora not as one complete phenomenon but a composite of rays reaching down through the upper atmosphere, stopping as if they were hitting an invisible barrier. It is possible that the choice of using fine lines was influenced by the impressionist movement, taking place in Paris during the 1870s and 1880s. Certainly, the impressionists, including Claude Monet with his landscapes and *Woman with a Parasol*, sought to reproduce nature using visible brushstrokes, unusual angles and a focus on movement and light in a way which was authentic to the viewing experience, akin to the project of the auroral observer. The paintings of the impressionists did not include outlines or contours but instead created images composed of single, unblended lines, much like Tromholt's, 'Northern Lights in Kautokeino 6 Oct 1882, 7h 3m'.

---

[236] Robert David, *The Arctic in the British Imagination 1818-1914* (Manchester: Manchester University Press, 2017), p. 12.

[237] Julius Payer, 'An Artistic expedition to the North Pole', *Geographical Journal* 5, no. 2 (1895): 106-112, 107.

[238] Noelle Belanger and Anna Westerstahl Stenport, 'The Politics of Colour in the Arctic Landscape: Blackness at the Centre of Frederic Edwin Church's Aurora Borealis and the Legacy of 19th Century Limits of Representation', *ARTMargins and the Massachusetts Institute of Technology* (2017): 6-26, 9.

[239] Lorna Roth, 'Looking at Shirley, the Ultimate Norm: Colour Balance, Image Technologies, and Cognitive Equity', *Canadian Journal of Communication* 34, no. 1 (2009): 111-136.

The second Danish expedition, funded by the Danish Meteorological Institute (DMI), was led by Professor Adam Paulsen and sent to Godthaab in south-west Greenland. The images produced by Paulsen's team were markedly similar to Tromholt's hand-drawings, portraying the aurora's light rays as vertical bands flowing in irregular shapes. They too were catalogued to the closest minute. There was, however, one significant difference, as shown in the depiction of the auroral display of 15 November 1882, represented in fig. 16; the horizon, or more specifically, the hills towards the south-west of the Godthaab base, were included.[240] This particular image was used to make a visual argument, bolstering Paulsen's claim that aurorae descend to an altitude very close to the earth's surface, in direct conflict with Tromholt's results.

Fig. 16. Adam Paulsen, 'Aurora (multiple rayed-bands) observed to South-West from Godthaab on 15 November 1882 at 00h 30m', drawing in *Observations Internationales Polaires, 1882-83, Expédition Danoise: Observations Faites A Godthaab* (Copenhagen: Chez G. E. C. Gad, Libraire de L'université, 1893), p. 3.

Tromholt announced in 1884 that the northern lights lie at a height of at least 100km above the earth's surface in the Kautokeino-Bossekop plane.[241] Despite Weyprecht's lamentation that height measurements were unreliable, Tromholt spent the years after the Polar Year collecting accounts from nineteen sites close to Bergen of the position in space of auroral arcs to triangulate the aurora and thus calculate its altitude.[242] Paulsen, by contrast, claimed to have measured 8 cases of the aurora between

[240] Adam Paulsen, *Observations Internationales Polaires, 1882-83, Expédition Danoise: Observations Faites A Godthaab* (Copenhagen: Chez G. E. C. Gad, Libraire de L'université, 1893), p. 3.

[241] Sophus Tromholt, 'Measuring the Aurora Borealis', *Nature* 29 (1884): 409-412, 412.

[242] Ibid., 410.

19 and 68km and 14 cases between 0.6 and 9.8km during the IPY.[243] Furthermore, Paulsen asserted that he and his companions had witnessed aurorae below the clouds first-hand.[244] Tromholt noted that such accounts had been ‘greatly doubted as being the result of the imagination or optical illusions’ and for his part, mentioned that, ‘even the most intense development of light, colour and motion occurred always above what seemed to be the very highest-lying clouds’.[245]

The image shown in figure 16, then, acted as an epistemological device, persuading readers with its simplicity and the apparent normalcy of its composition.[246] The text accompanying the drawing is conspicuous in that it does not include any remark on the low aurora’s contentious nature or abnormality, even by Paulsen’s reckoning. Moreover, Paulsen appealed to the auroral visual culture which had emerged earlier in the nineteenth century, wherein the inclusion of the horizon was decidedly unremarkable. His claim, therefore, seemed more plausible because the image was calibrated against what viewers already expected to see. Paulsen also gave no indication of how high the distant hills were or how far displaced they were from the position of the viewer, preferring to put his argument forward through visual insinuation. What this tells us about the rhetoric embedded within images is that visual argumentation does not necessarily only *support* textual or numerical forms of contention, but can stand on its own, with certain advantages for the presentation of theories, including subtlety.

‘No pencil can draw it’

Whereas Paulsen invested his images with specific properties, displaying them as faithful renditions of a scene, Boldva of the Austro-Hungarian expedition believed that the aurora’s ontology consistently evaded depiction. Jan Mayen was the chosen destination for the Austro-Hungarian expedition led by Lieutenant Emil von Wohlgemuth and financed by Wilczek. Boldva organised the resulting auroral report, although six of the fourteen men involved in the expedition shared observational responsibilities. Boldva’s view that the aurora ‘could only be reproduced extremely imperfectly’ was incongruous with Paulsen’s use of drawings as evidence in the auroral height debate

[243] Adam Paulsen, 'On the Height of the Aurora Borealis', *Nature* 29 (1884): 337-338, 377; Stauning, 'Danish Auroral Science History', 12.

[244] Paulsen, 'On the Height of the Aurora Borealis', 377.

[245] Tromholt, 'Measuring the Aurora Borealis', 412.

[246] Klaus Hentschel notes that one can ‘speak of “visual rhetoric” in analogy to the much older discipline of “rhetoric” in: Hentschel, *Visual Cultures in Science and Technology*, p. 51.

but consistent with descriptions in the previous chapter alluding to the fact that ‘no pencil could draw it’.[247]

Early in the book-length Austro-Hungarian IPY report (1886), Boldva remarked that, ‘the drawing and true-to-life pictorial presentation of the aurora is by the way one of the most difficult problems’ faced by the expedition.[248] Speaking directly to the tension embedded within the images, he asserted that ‘all the details of the drawings are not to be taken completely precisely, since only the characteristic moments of the appearances are sensed’.[249] Explicitly making no claims to be entirely representative, this discussion of the Jan Mayen portrayals exposes the competing need for temporal and spatial specificity and the desire to reproduce accurately what was continually experienced throughout constantly transitioning displays. Indeed, Boldva’s unvarnished remarks complicate our understanding of the practice of auroral drawing, revealing the fallibility of the project to capture systematically frozen moments in time and demonstrating the limits of embodied registration of the aurora. In fact, Boldva considered his emotional responses to be a more reliable way of building reproductions of the northern lights. The affective character of the lights is illuminated as the aesthetic erupts onto the page of Boldva’s otherwise relatively sober scientific treatise with the words: ‘beautiful structures appear in the dark night sky as if breathed on’, while ‘every representation, on the other hand, looks plump and stiff’ in comparison.[250] Hand-drawn sketches then, were deficient in a frustrating and obscure way, not quite capturing the visual experience witnessed in the Arctic but simultaneously used as a tool to strive for the replication of the aurora’s forms and patterns. They could not do justice to the delicacy, fragility and transience of auroral displays.

One visual example included within the Austro-Hungarian Polar Year report is that of fig. 17, depicting an aurora which occurred on 6 December 1882. Like the majority of the Jan Mayen drawings, it was constructed at the time of viewing and then copied by the same observer into a journal the following day before being printed in the 1886 Polar Year publication. Boldva pointedly remarked that the images ‘have deliberately not been modified so as not to deprive the collected material of its originality’, playing into a sense of mechanical objectivity whereby credibility is derived from the notion that the images are ‘untouched’ after the moment of production.[251] The body is constructed here as an objective source of knowledge creation by analogy with the mechanical element of an image production system. Adjacent to the image is text which describes the aurora as a

[247] International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen', 13; Payer, *New Lands Within the Arctic Circle*, p. 209.

[248] International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen', 13.

[249] Ibid.

[250] Ibid.

[251] Ibid., 3.

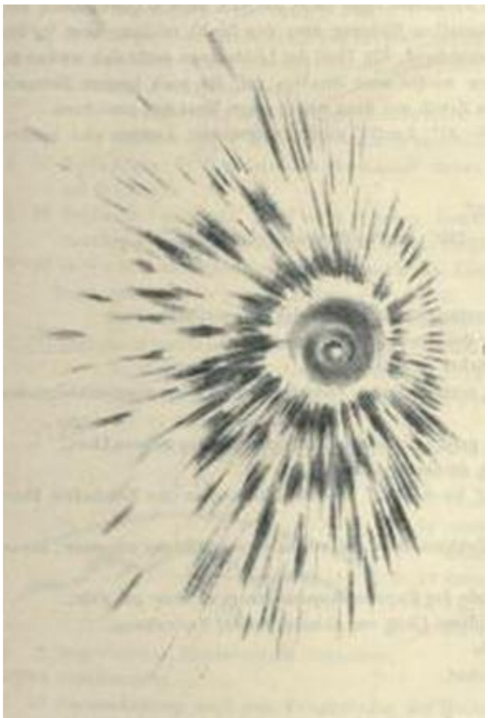


Fig. 17. International Polar Year Expedition 1882-1883, *Die Österreichische Polaristation Jan Mayen, ausgerüstet durch Graf Hanns Wilczek, geleitet vom Emil Edlen von Wohlgemuth. Beobachtungs-Ergebnisse, hrsg. Von der Kaiserlichen Akademie der Wissenschaften – Die Internationale Polartforschung 1882-1883,* vol 2(1) (with 12 plates) (Wien: Commission bei K. Gerold's Sohn, 1886), University of Toronto – Gerstein Science Information Centre, p. 75.

'corona form'.[252] It details how the rays towards the north are shown in a horizontal cross-section whereas those towards the other cardinal points represent 'surface' views, demonstrating a tendency to illustrate the aurora from the observer's perspective rather than perfecting it to make the display appear more symmetrical or familiar.

Documents from the Jan Mayen expedition also teach us that it was difficult to delineate variations in auroral brightness in the short span of time with which one auroral form could be kept in mind while the phenomenon transformed before the eyes.[253] Therefore, notes assigning the intensity of displays were written alongside many of the sketches with brightness encoded as a number from one to four, following Weyprecht's advice.[254] Weyprecht also suggested attaching a small piece of thread to the end of a tube or telescope and then discerning whether the thread could be seen by only the light of the aurora.[255] On the Jan Mayen expedition auroral intensity was estimated using Jaeger eyesight tests: charts with text sizing ranging from 0.37mm to 2.5mm, originally printed in 1867.[256] Held at a fixed distance from the observer's eyes, members of the expedition would trial whether they

[252] Ibid., 75.

[253] Ibid., 8.

[254] Ibid.

[255] Weyprecht, *Praktische Anleitung zr Beobacktung der Polarlichter*, p. 43.

[256] Heathcote and Armitage, 'The First International Polar Year', p. 20; Programme adopted by the St Petersburg conference 1 August 1881: International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen', 9.

could read certain lines of print by the light of the aurora and then relate their legibility to the brightness of the light produced. In this way, the observer's bodies were used to calibrate the intensity of light emitted from the aurora. Uncertainty was nevertheless introduced by the employment of artificial light for notetaking and sketching, treading the line once again between accuracy and the necessity of documenting comparable results.

Culture of Publication and Display

The publication of IPY data represented a 'signal change in the manner in which Arctic science was presented and made available', with particular , attention was paid to documenting the precise instrumentation used across the scientific programmes.[257] The reports all contained charts, tables and illustrations and in theory each participating nation would have a complete set of the published results (although in practice this did not occur). The Polar Commission, the organising body for the First IPY established in 1879, met in Vienna in 1884, after the Polar Year had ended, to discuss the publication of results derived from the programme. It set a deadline of December 1895, an entire decade, for the assemblage and analysis of findings. The particular forums for publication were chosen carefully, with each expedition following the same pattern of publishing short *Nature* articles followed by lengthy national treatises. In 1883 and 1884 articles in *Nature* alluded to the initial findings of each expedition, with a handful of select images included in each. It was by 1886 though, that most of the drawings surveyed in this paper were released, with the exception of those within Paulsen's account, published later in 1893. The notion that this was the proper method in which scientific results should be displayed reinforced the ways of seeing that regarded the auroral images as epistemological devices more so than illustrations.

Significantly, none of the expedition members had access to the drawings sketched during other IPY expeditions before 1886, which may explain the disparity in image-types published. To aid in the evaluation of results it was decided that each national report would be archived together at the Central Physical Observatory in St Petersburg. Nonetheless, no synoptic survey of the First Polar Year results was undertaken in the years following the programme.[258] Later, in the lead up to the Second IPY of 1932-33, the lack of analysis after the First IPY made necessary more robust procedures of circulating and synthesising collected information.

[257] Cronenwett, 'Publishing Arctic Science in the Nineteenth Century', p. 42.

[258] Lüdecke, 'The First International Polar Year (1882-83)', 62; Kevin R. Wood and James E. Overland, 'Climate Lessons from the First International Polar Year', *Bulletin of the American Meteorological Society* 87 (2006): 1685-1698.

With a greater length of time for preparation, some of the images published after the IPY expanded on the direct and imitative style of the rapid sketches constructed during the programme. Tromholt had many of his depictions etched and printed in *Under the Rays of the Aurora Borealis: In the Land of the Lapps and Kvaens* (1885), which was written in the style of a travel narrative with considerable space devoted to ethnographic observations. One striking example from *Under the Rays* is a schematic. Rather than tracing the aurora on a given night, fig. 18 shows Tromholt isolating two auroral forms above two imagined observers, stripping his depiction down to only the critical elements needed for his textual theorising. He used the illustration to explain that although auroral streamers may appear to lie parallel to the surface of the earth, especially when viewed from more southern latitudes, this is in fact an optical illusion.[259] The direction of auroral streamers is instead identical with that of the magnetic inclination needle.

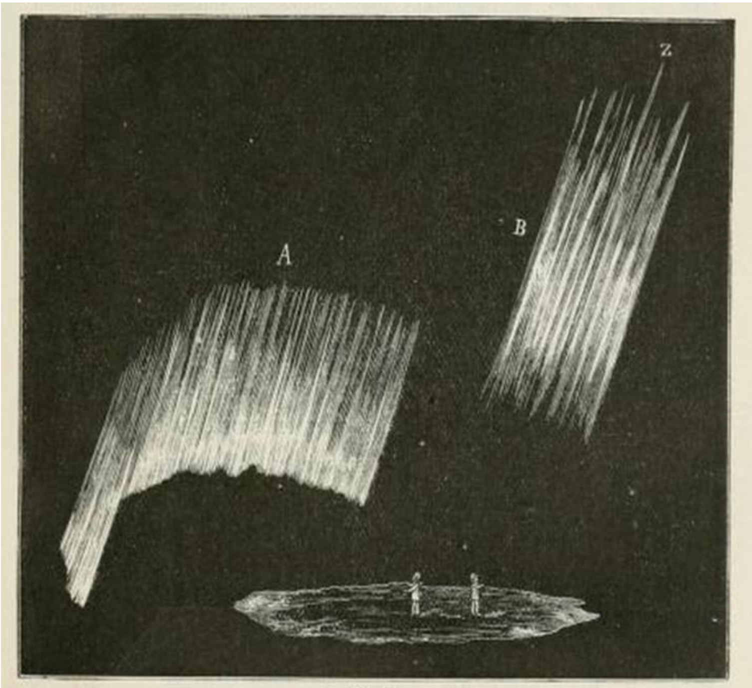
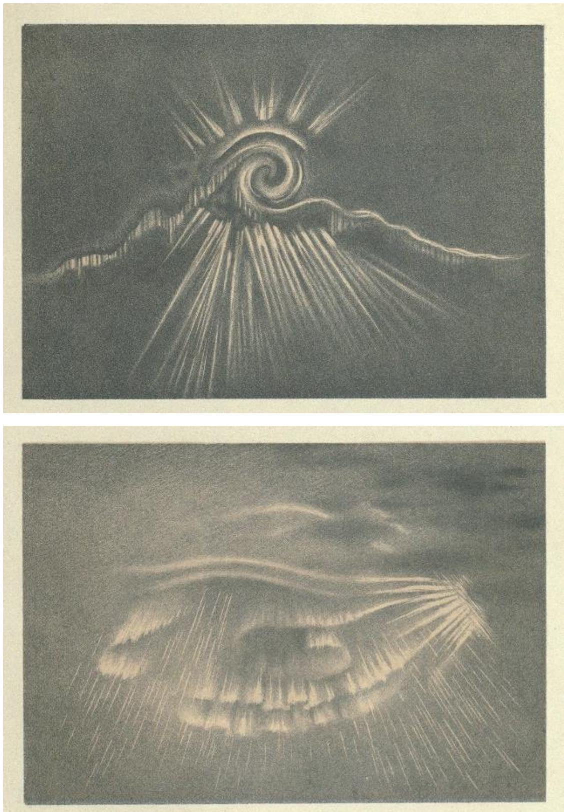


Fig. 18. Sophus Tromholt, *Under the Rays of the Aurora Borealis: In the Land of the Lapps and Kvaens*, vol. 1 (Boston: Houghton Mifflin, 1885), p. 233.

The observer watching aurora A, standing south of the display, will see the ends of the streamers form an elongated arc on the horizon, with its highest point lying in the north-north-west. The angle which the streamers form with the horizon will be approximately 70 degrees. Aurora B, situated between the observer and the magnetic zenith, will appear as an auroral corona, where the streamers converge at point Z. Moreover, Tromholt's explanation refuted Lemström's theory that two

[259] *Tromholt, Under the Rays of the Aurora Borealis (1), p. 220.*

observers ‘do not see one and the same aurora, but each sees only their own arc’, or in other words, that each person witnesses different parts of a diffused luminous layer.[260] Embedded within Tromholt’s schematic is the assumption that a single auroral form could be witnessed simultaneously from different positions on the surface of the earth. Very few simplified schematic views, only representing a specific part of the aurora, appear before the First IPY. Tromholt demystified the position of auroral streamers while de-territorialising the phenomenon by taking it outside of its context as a feature of the Polar landscape. Figs. 19 and 20 reproduce two auroral sketches inspired by observations made during the Jan Mayen expedition. They were likely enhanced for publication as they appear deliberate and polished rather than as hurried working images.[261] Appearing in a lengthy treatise, the purpose of these drawings was to exhibit the various ways in which characteristic light displays could manifest, acting self-consciously as truth-to-nature depictions in Daston and Galison’s terminology.[262] The researchers on the Jan Mayen expedition regularised the spiral corona and corona rather than representing examples of specific displays in the period after the IPY, in contrast to their logbook sketches.



Figs. 19 & 20: ‘Plate VIII: Spiral Corona with Rays and Thread and Corona-like Appearance’, in International Polar Year Expedition 1882-1883, *Die Österreichische Polaristation Jan Mayen, ausgerüstet durch Graf Hanns Wilczek, geleitet vom Emil Edlen von Wohlgemuth. Beobachtungs-Ergebnisse, hrsg. Von der Kaiserlichen Akademie der Wissenschaften – Die Internationale Polartforschung 1882-1883*, vol 2(1) (with 12 plates) (Wien: Commission bei K. Gerold’s Sohn, 1886), *University of Toronto – Gerstein Science Information Centre*.

[260] Karl Selim Lemström, 'The Aurora Borealis 2', *Nature* 28 (1883): 107-109, 108; Tromholt, *Under the Rays of the Northern Lights (2)*, p. 172.

[261] I follow Omar Nasim’s use of the term ‘working images’ in: Nasim, *Observing by Hand*, p. 11; Nasim, 'Observation, working images and procedure'.

[262] Daston and Galison, *Objectivity*, p. 70.

Reminiscent of William Parsons, the Third Earl of Rosse's M51 nebula image produced in 1851 (fig. 9), the swirling auroral form of fig. 19 hints at the phenomenon's movement with shards of light scattering from the centre. The abstract spiral also evokes the patterns presented in Van Gogh's *Starry Night*, painted in the same decade in 1889, reflecting the sky as a dynamic and animated space.

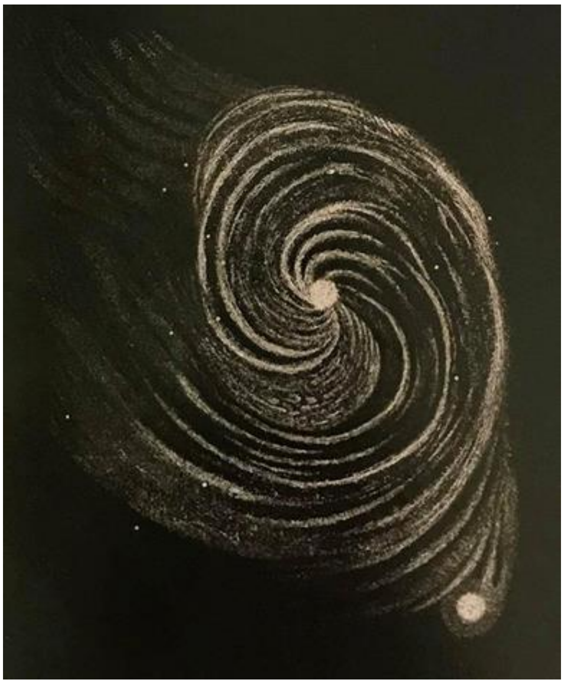


Fig. 9. George Chambers, 'new reproduction of Rosse's M51 'nebula' image', A Handbook of Descriptive and Practical Astronomy (1861).

Fig. 21. Van Gogh, *The Starry Night* (1889), oil on canvas, *The Museum of Modern Art (MoMA).*

The auroral images of the IPY were part of a visual language which included impressionism and post-impressionism, whether or not these artistic movements were purposefully drawn upon. Indeed, in the vein of Baxandall's concept of the 'period eye', there was an interrelationship between cultural practices of representing ever-changing skylines and the iconography of the aurora.[263] The two were in dialogue with one another in the sense that each relied upon visual technologies and ways of viewing to which their audiences were already exposed. Fig. 20 evokes heavenly connotations, appearing as a powerful source of light breaking through the darkness of the night sky, appealing to earlier pictorial conventions for representing the aurora.

[263] Baxandall, *Painting and Experience in Fifteenth Century Italy*, p. 87.

The Swedish IPY expedition, funded by a donation from Mr. L. O. Smith to the Royal Swedish Academy of Sciences, was mounted to Spitzbergen.[264] There, Vilhelm Carlheim-Gyllensköld was responsible for auroral research. The observations made by Carlheim-Gyllensköld at Cape Thorsden have been called the ‘most complete’ of any made throughout the First Polar Year.[265] Within the 1886 report of the expedition, published by L'Académie Royale des Sciences de Suéde, Carlheim-Gyllensköld experimented with portraying the northern lights from a synoptic perspective, by drawing the geographical extent of aurorae upon star charts, as exemplified in fig. 22. Although it is known that several stations were furnished with star charts, Carlheim-Gyllensköld’s series of images is the only example of the publication of such depictions in the years following the First IPY.[266]

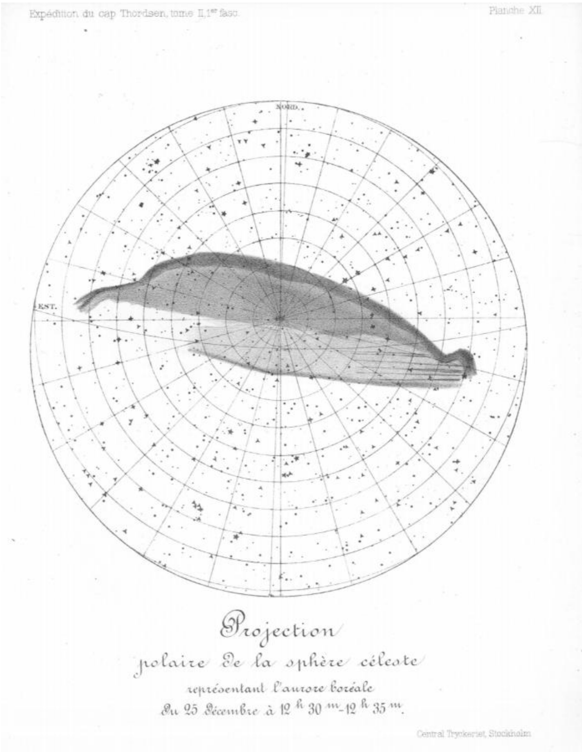


Fig. 22. Vilhelm Carlheim-Gyllensköld, ‘polar projection of the celestial sphere representing the aurora borealis of December 25 at 12:30 m - 12 h 35 m’, *Observations faites au Cap Thordsen, Spitzberg, par l’expedition suédoise publiées par L’Académie Royale des sciences de Suéde, Tome II: 12. Aurora*

[264] Vilhelm Carlheim-Gyllensköld, *Expédition Polaire Suedoise 1882-83*, vol. 2 (Stockholm: L'Académie Royale des Sciences de Suède, 1887), p. 1.

[265] Hildebrandsson, 'The Aurora in Spitzbergen', 84.

[266] Vilhelm Carlheim-Gyllensköld, *Observations faites au Cap Thordsen, Spitzberg, par L'Expédition Suédoise: Observations Astronomiques, Géodésiques et Marégraphiques, Exploration Internationale des Régions Polaires 1882-1883*, vol. 2: Aurora Borealis (Stockholm: L'Académie Royale des Sciences de Suéde, 1886).

Initially, however, the star charts given to the Swedish expedition were deemed to be impractical. The small cards seemed too cramped for plotting the aurora and the large maps could not fit easily on a table. Thus, Carlheim-Gyllensköld had the large maps printed to half the size at Mr Schumburg's studio in Uppsala, and then delivered to the research station.[267] He then traced the zenith, azimuth and shape of the aurora onto a transparent sheet of paper, which would be superimposed onto the celestial projection.[268] Carlheim-Gyllensköld's star chart projections depart from the typical conventions of romanticism in favour of a schematic perspective. Sacrificing romanticism meant giving up on the techniques of colour and perspective used to represent the aurora as it was seen by the human eye. It was hoped that new knowledge relating to the aurora's planetary position could be revealed through this mode of representation.

Stylistic Trends in Broader Publications

Auroral depictions printed in other publications in the years following the IPY demonstrate the endurance of stylistic trends which proliferated in the official reports of the programme. For example, in 1885 William Fairfield Warren printed an image of 'an actual aurora' (fig. 23), with looping folds strikingly similar to the undulating bands of both Tromholt's 6 October 1882 aurora and the Jan Mayen aurora with a 'corona-like appearance'.[269] Warren's work, aligned with the theosophical doctrines of Helena Blavatsky, argued that Atlantis and the garden of Eden were situated in the far north. Thus, his auroral drawing was accompanied by the caption, 'night skies of Eden'. Two years later in 1887, *Our Earth and its Story: A Popular Treatise on Physical Geography,* a more moderate monograph on the geography of the world, was published. Edited by Robert Brown, it included an auroral drawing (fig. 24) akin to Paulsen's 15 November 1882 observation.[270] Although the foreground landscape acts as a focus of the image, the individual pencil strokes and graduated luminosity are particularly reminiscent of Polar Year representations.

Harald Moltke's auroral images, painted at the turn of the twentieth century, demonstrate how the culture of publication developed further beyond the 1880s. Moltke attended the Royal Danish Academy of Fine Arts from 1888 to 1893. It was in this period that the institution was undergoing a transition, in tune with the 'modern breakthrough', a Scandinavian artistic and literary movement which rejected romanticism. The influence of naturalism, with its emphasis on detachment from the artistic subject as well as a move toward impressionism, can be traced throughout Moltke's auroral depictions. Moltke joined Paulsen's second Arctic expedition of 1899-1900 to Akureyri, in northern

[267] Carlheim-Gyllensköld, *Expédition Polaire Suedoise 1882-83*, p. 2.

[268] Ibid.

[269] William Fairfield Warren, *Paradise Found: The Cradle of the Human Race at the North Pole* (1885), p. 67.

[270] Robert Brown, *Our Earth and its Story: A Popular Treatise on Physical Geography* (1887), p. 300.

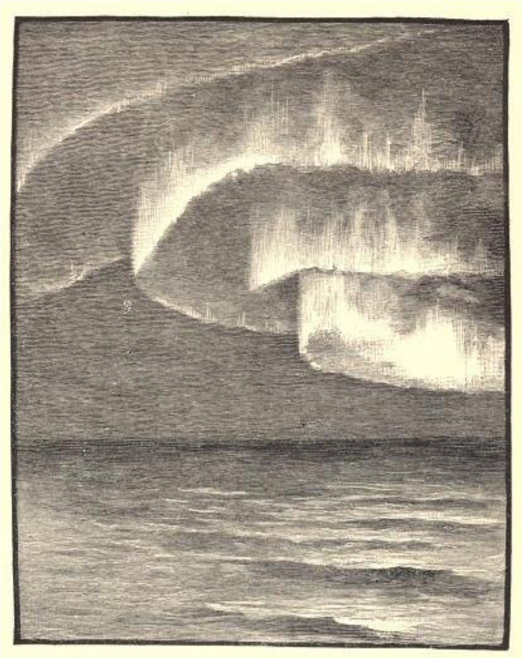


Fig. 23. William Fairfield Warren, 'Night Skies of Eden, An Actual Aurora Borealis', *Paradise Found: The Cradle of the Human Race at the North Pole* (1885), p. 67.

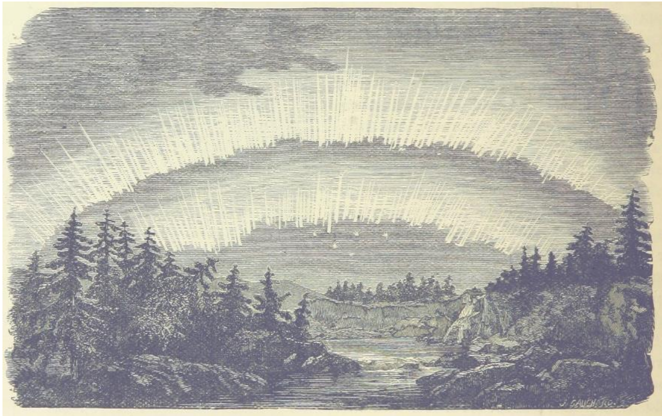


Fig. 24. Robert Brown, 'Double-Arched Aurora with Streamers', *Our Earth and its Story: A Popular Treatise on Physical Geography* (1887), p. 300. *British Library*, catalogue number: 014806127, Digital Store 10006. ff.6.

Iceland. The expedition was funded by the DMI with the express purpose of collecting more data on the aurora. It is crucial to note here that an artist was specifically chosen as the type of person with the most relevant training to capture the aurora. It was Moltke's experience rendering colour and light which made him valuable to the expedition, rather than any knowledge of the science of the aurora.

Moltke observed and sketched the shape of auroral forms with a pencil, marking the stars through which the phenomenon moved and memorising its colours. The following day he would paint it from memory.[271] In this way, Moltke made 19 oil paintings of the phenomenon. The example in fig. 25 portrays a colourful corona, with the irregularity of the auroral streamers depicted using the now familiar line drawing technique. The observer is displaced and seemingly situated close to the phenomenon, while the aurora is pulled out of its natural context of the polar regions. Both Moltke's paintings capturing aurorae on 1 January 1900 (fig. 25) and 1 September 1899 (fig. 26) feature brushstrokes reminiscent of the fluidity of expressionist paintings, including *The Scream*, painted by Edvard Munch in 1893. Incidentally, it has been suggested by University of Oslo researcher, Helene Muri, that Munch's painting was inspired by an unusual meteorological event itself: nacreous clouds, commonly known as mother-of-pearl clouds, which appear to be iridescent.[272] Crucially, each painting

[271] Harald Moltke, *Livsrjsen: Barndom - Ungdom - Rejser. Polarforskeren Knud Rasmussen, forfatteren Mylius Erichsen og maleren Harald Moltke's berømte Grønlandsekspedition 1902-04* (Copenhagen: Herov, O. J., 1965).

[272] Mariëtte Le Roux, 'Weird clouds may have inspired 'The Scream': scientists', *Agence France-Presse* (2017).

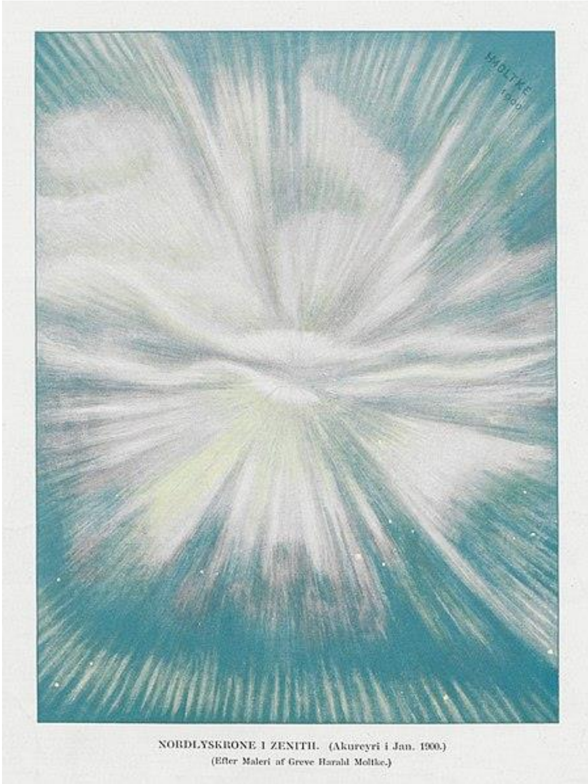


Fig. 25. Harald Moltke, ‘Auroral Corona over Akureyri on 1 January 1900’, *Danish Meteorological Institute* (DMI).

of Moltke’s was dated precisely, sometimes down to the minute, which is a practice likely influenced by the culture of observation brought to the fore in the IPY.

Evidently, Moltke’s images were intended to be scientifically useful as well as aesthetically beautiful. Moltke’s concern for making his paintings faithful to the aurorae he witnessed in Akureyri is revealed by his initial concern that his first paintings were characterised by ‘some confused daubing, which the scientists (and myself first of all) rejected as being completely useless’.[273] Clearly there existed a criteria, dictated by the auroral researchers on the expedition, by which the utility of his images could be measured. Here, Moltke and Paulsen were practising a kind of four-eyed sight in Daston and Galison’s terminology; a type of vision wherein the ‘visions of the naturalist and the artist fused’.[274] Unlike the classic four-eyed sight perspective of the eighteenth century, however, Moltke had considerably more freedom to capture the aurora as he saw fit and would subsequently display his images as artistic pieces.[275] Moltke’s paintings were displayed at the National Museum of Denmark as

[273] Moltke, *Livsrjsen: Barndom - Ungdom - Rejser*, p. 74.

[274] Daston and Galison, *Objectivity*, p. 88.

[275] Ibid., 123.

well as museums in Hillerød and Hesingør before moving to the archives at the DMI, where they remain today.

Fig. 26. Harald Moltke, '*Aurora over Akureyri on 1 September 1899* at 17:45 h', *Danish Meteorological Institute (DMI).*

Lemström's Artificial Aurorae Images

Karl Selim Lemström worked under physicist Erik Edlund on electromagnetic induction in 1867 and became Professor of physics at the Imperial Alexander University (now Helsinki University) in 1878. Two of the most striking images created as a result of the work carried out during the First IPY were Lemström's two watercolours of apparently man-made aurorae. Yet, Lemström's artificial aurorae experiments were by no means the first or last attempts to recreate the phenomenon artificially. Samuel Triewald attempted to replicate the northern lights in 1744 using a prism, common grain spirit and a screen and Kristian Birkeland carried out his magnetised terrella experiments to simulate the aurora using cathode rays in the 1890s. It is noteworthy, however, that Lemström's artificial aurorae research took place outdoors, atop mountains in northern Scandinavia rather than in laboratories or darkened rooms. He sought to reproduce an aurora in its own territory. Indeed, the scale of his experiment itself was part of the performance of his theories.

Lemström travelled with the expedition sent by the Finnish Society of Science to Lapland in 1871, which was tasked with ascertaining whether the aurora 'could be called forth or in any event magnified, by mere mechanical appliances'.[276] During the expedition, Lemström constructed a large device consisting of several hundred metres of electrical wires atop Luossavaara, a mountain rising 520 feet above Lake Enare. According to Lemström, the first aurora after the apparatus had been constructed appeared on 22 November 1871, beginning with a column of light apparently directly

[276] Karl Selim Lemström, 'The Aurora Borealis', *Nature* 28 (1883): 60-63, 60.

Fig. 27. Karl Selim Lemström, 'L'aurore boréale. Étude générale des phénomènes produits par les courants électriques de l'atmosphère', [With coloured plates.] (Paris: Gauthier-Villars, 1886), p. 139.

above Luossavaara.[277] He admitted, however, that it was impossible to tell whether the column was on or behind the mountain from his vantage point.

At the 1881 IPY conference held in St Petersburg, Lemström suggested continuing his research into artificial aurorae by leading an expedition to Sodankylä as part of the Polar Year. The proposal was accepted and the work to be undertaken was chiefly confined to investigations of the aurora, galvanic currents and atmospheric electricity.[278] Lemström erected his newly entitled 'utströmnings' apparatus on the summit of Orantunturi, 1070 feet above the Finnish village of Sodankylä. Since 1871 Lemström had developed his device; it now included several metal poles raised 2.5m in the air, while the copper wire circle covered an area of 900 m^2. Lemström recorded that almost every evening from when the apparatus was constructed on 5 December 1882 a luminous yellow glow could be witnessed surrounding the summit of the mountain, while no illumination was witnessed in the vicinity of other nearby mountains.[279] On 29 December 1882, a great column of light rising 120m into the atmosphere, similar to that seen in 1871, was observed. A spectrum, however, was not taken on the night and the deflexions read from the galvanometer were weak and constantly

[277] Ibid.

[278] Karl Selim Lemström, 'The Results of the Scientific Expedition to Sodankylä', *Nature* 31 (1885): 372-376, 372.

[279] Lemström, 'The Aurora Borealis', 61.

varying. Without these measurements, the burden of relaying details of the man-made aurora fell to Lemström's personal descriptions and images.

The most controversial drawing produced as part of the First IPY was undoubtedly Lemström's image of the aurora of 29 December 1882, published within his *L'aurore boréale: Étude générale des phénomènes produits par les courants électriques de l'atmosphère* (1886), as shown in fig. 27.[280] In presenting the stark visual evidence of his artificial aurora in 1886, Lemström placed his image within the context of the other IPY drawings, earning it validity through connection with such carefully produced and published material. Yet, interestingly, Lemström included the proviso that his images only 'give a faint idea of' the phenomenon because the four observers present, including himself, fell in 'dumb admiration' at the sight.[281]

Within his portrayal, the great column of light, seen as a muted yellow-ish glow directly above the pinnacle of Orantunturi, is represented as an awe-inspiring sight. It is depicted almost as a divine light, although it is clear that the epicentre of the glow is not in fact the heavens but the mountaintop below, with the luminosity dispersing with altitude. The second yellow band of light on the left-hand side of the image represents a 'faint aurora in the sky at the back of the mountain', which Lemström claimed may have negatively influenced spectroscopic readings had he and his team been able to take any.[282] The inclusion of this natural aurora was no accident; it was part of the artifice. Lemström established the mode in which authentic aurorae would be represented and drew a strong visual parallel between the natural and man-made aurorae. In this way, the visual rhetoric of the piece brought experiment and nature together in the mind of the beholder. The Sodankylä base is depicted among the trees at the foot of the mountain; likely included to emphasise the man-made production of the aurora, being as it was, such an unusual feat. Thus, the image was doing epistemological work, aiding Lemström in arguing two main points. First, that aurora 'may be produced in nature by a simple contrivance assisting the electric current flowing from the atmosphere to the earth'.[283] Second, that there exists a belt of atmospheric electricity currents, which manifests the aurora, in a similar vein to the generation of lightning.[284]

So compelling was the research that the Swedish Diet and the Finnish government funded Lemström for an additional year of auroral work during the winter of 1883-4 directly after the Polar

---

[280] Karl Selim Lemström, *L'aurore boréale. Étude générale des phénomènes produits par les courants électriques de l'atmosphère, with coloured plates* (Paris: Gauthier-Villars, 1886), p. 139.

[281] Karl Selim Lemström, *Några resultat af den Finska Polarstationens arbeten i Sondankylä och Kultala åren 1882 - 84 berörande närmast Jordströmmarna och den elektriska strömmen från atmosferen och deras samband med Jordmagnetismen* (Helsingfors: J. C. Frenckell & Son, 1899), p. 33.

[282] Lemström, 'The Aurora Borealis', 62.

[283] Lemström, 'The Aurora Borealis 2', 109.

[284] Lemström, 'The Results of the Scientific Expedition to Sodankylä', 376.

Year.[285] In this additional year, he erected his utströmnings device atop the Kommattivaara mountain, east of Sodankylä. On nights such as 12th of November 1883, Lemström claimed to have witnessed a luminous phenomenon above the apparatus as well as a reaction on the spectroscope, indicating that

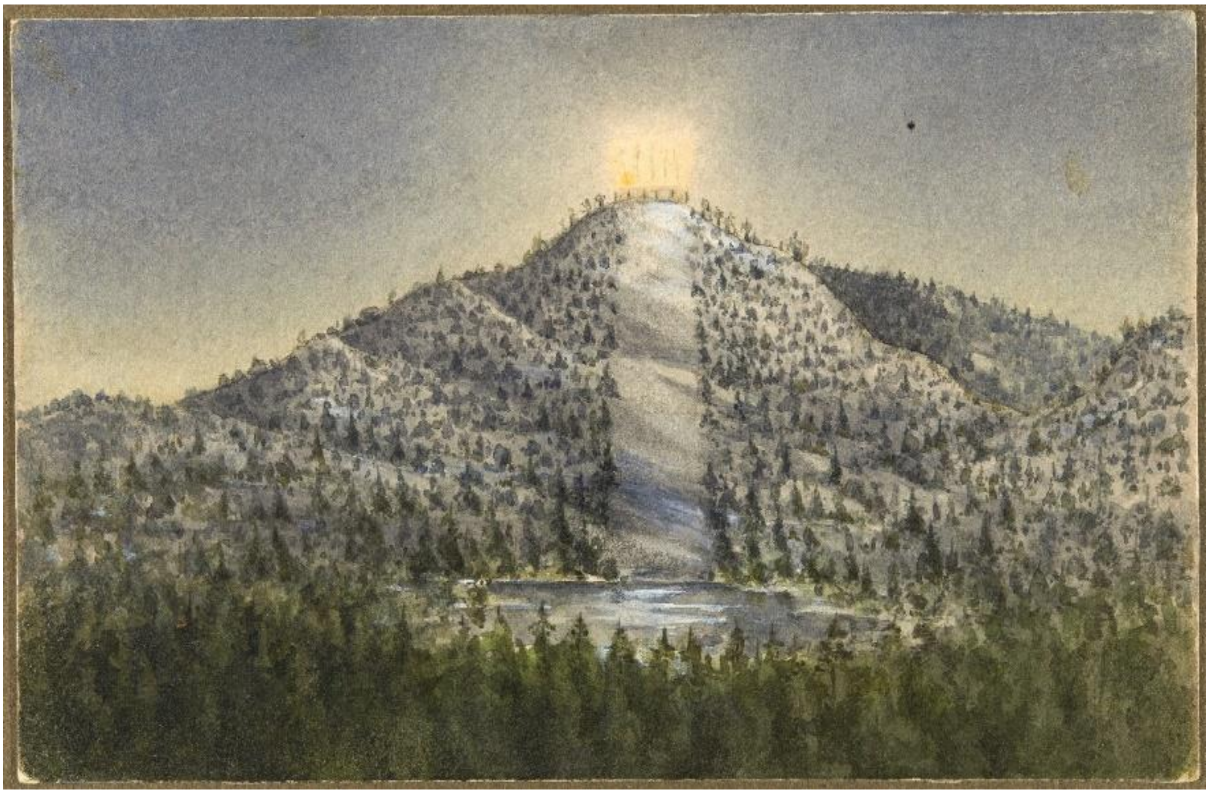


Fig. 28. Professor Selim Lemström, '12 November 1883 aurora atop Kommattivaara, Sodankylä', watercolour, *Finnish Heritage Agency*, Inventory ID: HK19501007:575.

the light was of auroral character.[286] He created a watercolour of this later artificial aurora, presented in fig. 28, which relied more heavily on the conventions of landscape paintings. This image shares many characteristics with that published in 1886, although the glow surrounding the utströmnings apparatus is markedly smaller. Moreover, this watercolour painting remained unpublished. The painting was eventually donated to the Finnish Heritage Society as part of a testamentary bequest made by Mrs Cely Mechelin, a family friend of Professor Lemström's and a relation by marriage.

Lemström made no further artificial aurora experiments after 1884, citing the difficulties of numbed hands and vulnerability of the wires to the cold as reasons for abandoning his project. He later became interested in the effects of atmospheric electricity on the growth of agricultural produce, publishing a treatise on the topic in the year of his death, 1904. Within it, he maintained his belief that

[285] William Barr, 'Geographical Aspects of the First International Polar Year, 1932-1933', *Annals of the Association of American Geographers* (1983): 463-484, 446; John Rand Capron, 'Professor Lemström's Auroral Experiments in Lapland', *The Observatory* 6 (1883): 259-266, 266.

[286] Lemström, 'The Results of the Scientific Expedition to Sodankylä', 375.

'auroras are caused by electric currents in the atmosphere'.[287] Importantly though, he believed that the cause of atmospheric electricity can be found in 'the evaporation which is going on all over the world'.[288] He argued that watery vapours carry electricity to the upper atmosphere, where it meets a layer of rarefied air, at a lower altitude in the polar regions due to lower temperatures, which will then discharge as an aurora or as a current in the atmosphere.[289]

In terms of the wider reaction to Lemström's artificial aurora claims, John Rand Capron visited the South Kensington Museum (renamed the Victoria and Albert Museum in 1899) in 1876 to view Lemström's prototype auroral apparatus, which was on loan for a special exhibition.[290] He had also eagerly read a telegram from Lemström, relayed via the Finnish Meteorological Observatory, dated 11 December 1881, detailing the plans for the auroral experiments in Sodankylä.[291] Having kept himself astride of the advances during the Polar Year, Capron was deeply interested in the possibilities Lemström's experiments presented and wrote in favour of funding being directed towards his continued research after the Polar Year.[292]

Yet, despite hoping for affirmative results, Capron remained cautious of the claims of man-made aurorae. In 1883 in the *Philosophical Magazine*, he put forward the possibility that Lemström may have been deceived during his first expedition by the presence of a concealed natural aurora.[293] Capron also presented a talk at the British Association Annual Conference on 25 September 1883, entitled, 'On some points in Lemström's recent auroral experiments in Lapland', analysing both Lemström's 1871 expedition and that of the Polar Year. He stated that he regretted that the geophysicist had not been able to obtain a wavelength reading for the light which appeared atop Orantunturi and that despite the apparent success of the artificial aurora trial, the electrical nature of the phenomenon remained 'as mysterious as ever'.[294]

Tromholt attempted to reproduce Lemström's artificial aurora results with his own utströmnings device atop Mount Esja in Iceland, just north-east of Reykjavik, directly after the Polar Year. He erected the apparatus on 25 February 1884, once the weather conditions allowed safe passage to the summit. Tromholt then waited patiently to observe any signs of aurorae on the

[287] Karl Selim Lemström, *Electricity in Agriculture and Horticulture* (London: "The Electrician" Printing & Publishing Co. ltd, 1904), p. 7.

[288] Ibid., 6.

[289] Ibid.

[290] John Rand Capron, 'To the Editor of the Meteorological Magazine', *Symons's Monthly Meteorological Magazine* XVII (1883): 55; Fuller, 'The Life and Times of John Rand Capron', 40.

[291] Capron, 'Professor Lemström's Auroral Experiments in Lapland'. p. 259.

[292] Ibid., 266.

[293] Capron, 'XLVII The Auroral Beam of November 17, 1882', 339.

[294] Capron, 'Professor Lemström's Auroral Experiments in Lapland', 264.

mountaintop.[295] He wrote in his 1884 *Nature* article that the device, however, showed 'no signs of life whatsoever'.[296] Tromholt conceded that the lack of aurorae may have been due to the apparently low intensity of electrical forces on the island at the time. Yet, a year later in *Under the Rays*, he was bolder in his assertions, arguing that it was impossible for Lemström to have created an aurora. Instead, he insisted that Lemström must have witnessed an example of the electrical phenomenon known as St Elmo's Fire on both his 1871 and IPY expeditions.[297]

Later, in Lemström's 1899 Norwegian language report of the IPY expedition, he included a new image of the artificial phenomenon, this time from his initial expedition of 1871.[298] This aurora, represented in fig. 29, was observed on 27 November 1871, five days after the initial sighting of the light atop Luossavaara. Remarkably similar to fig. 27, the portrayal includes all the same features, although provides a more distant perspective, serving to emphasise the height of the auroral column.

Fig. 29. Karl Selim Lemström, *Några resultat af den Finska Polarstationens arbeten i Sondankylä och Kultala åren 1882 - 84 berörande närmast Jordströmmarna och den elektriska strömmen från atmosferen och deras samband med Jordmagnetismen* (Helsingfors: J. C. Frenckell & Son, 1899), p. 32.

[295] Sophus Tromholt, 'Auroral Researches in Iceland', *Nature* (1884): 80-81, 81; Sophus Tromholt, 'On the Aurora Borealis in Iceland', *Nature* 29 (1884): 537-538.

[296] Tromholt, 'Auroral Researches in Iceland', 81.

[297] G. J. Symons, 'Artificial Aurorae', *Symons's Monthly Meteorological Magazine* XVII (1883): 33-55; Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 81.

[298] Lemström, *Några resultat af den Finska Polarstationens*, p. 33.

This watercolour image was likely not printed directly after the 1871 expedition because Lemström felt he needed to gather evidence that the vision seen was indeed of auroral character. In 1899, almost three decades after the event, it had become important to produce a persuasive visual rendering of the phenomenon to bolster his artificial aurora theories, which were coming under growing scrutiny at the turn of the twentieth century.[299]

Conclusion

Auroral imagery was transformed during the First International Polar Year, as sketches were drawn with the aim of replicating the phenomenon in all of its irregularity and given precise temporal and spatial signatures to convey the particular rather than the general or aesthetic. No longer beautifully symmetrical and colourful, the streamers and bands of the aurora needed to be documented to replicate the exact, unadorned forms of the phenomenon, sometimes taken entirely out of the context of the polar landscape and frequently depicted in monochrome. Indeed, it was the naturalism movement, with its emphasis on reflecting exactly what was seen with the eye with the least amount of distortion and interpretation possible, which underpinned the way in which the aurora was imaged during the IPY. This contrasted starkly with the romantic auroral portrayals of the earlier nineteenth century.

The shift in the direction of naturalist depictions of specific auroral displays was in keeping with the popular cultural moment of 'mechanical objectivity', at its height during the 1880s and 1890s, albeit in an altered state without the use of technological instruments. In a process of co-ordination between the hand and eye, researchers of the First IPY strove for a rendering ever closer to the instrumental ideal, attempting to remove their own subjective experiences from their work and produce sketches which were precisely faithful to the viewing experience. Paper and pencil *became* instruments for determining the shape and form of the represented aurora and so too did the human body become a means of registering and rendering the phenomenon accurately. It was the rigorous drawing procedures implemented in the Arctic which stood in for the 'mechanical' element within the system, calibrating the image-making process. That being said, there remained a tension at the heart of the project between the impetus to construct accurate drawings and the belief that the aurora would always evade complete representation. This tension likely motivated the exclusive focus on the individual forms of the aurora during the First IPY, rather than its colours or development over time.

[299] Arthur Rindell, 'Prof. Karl Selim Lemström', *Nature* 17 (1904): 129, 129.

No doubt IPY observers stationed at various Arctic sites were influenced by the epistemological work of photographs in the era, especially those capturing bolts of lightning and the solar corona in the same decade of the 1880s. In constructing naturalistic portrayals, observers likely hoped to imbue their images with a sense of 'photo-realism', although the images were exclusively constructed by hand. Additionally, the auroral images appeared to follow visual customs drawn from mid-nineteenth century nebulae drawing, itself a practice moving more towards portraying particulars rather than the general impression of objects.

The drawings created during and as a result of the First IPY were considered to be epistemologically useful images, which could carry meaning in a particularly persuasive manner. Images, I have argued, are capable of holding rhetorical power, offering something distinct and sometimes more convincing than textual or numerical assertions, through their subtle connections with familiar iconographic traditions. Individually, we see that the auroral drawings staged theoretical arguments. Tromholt used a schematic rendering in his 1885 publication to put forward his theory regarding the directionality of auroral streamers while Paulsen depicted a purposefully grounded aurora at Godthaab to emphasise the low altitudes to which he believed aurorae descended. It was Lemström's theory of artificial aurorae and his accompanying illustrative images, however, which provoked the most intense discussion within the community of auroral scientists. With his bold impressions of man-made aurorae atop Orantunturi, Kommattivaara and Luossavaara, Lemström aimed to convince the readers of his 1886 treatise and 1899 account of the IPY expedition of the possibility of calling forth and controlling the phenomenon. That this idea was conveyed visually made it all the more persuasive, although not convincing enough to satisfy some of the leading voices in the field by the end of the nineteenth century.

One reason for the compelling nature of the auroral images was the format in which they were displayed within serious scientific journals and national treatises on the Polar Year. In contrast, auroral depictions which were presented in galleries, such as those of Harald Moltke, tended to be viewed as first and foremost art pieces to be enjoyed but not necessarily believed as representations of reality, despite the fact that Moltke was explicitly employed as a scientific draughtsman. It was thus the positioning and setting of the images which gave them credibility in either the community of atmospheric physicists or the world of art.

Scientific images should be understood as having their own aesthetic traditions, built on precedents and, in turn, able to influence subsequent portrayals. This is what has been argued by James Elkins, Martin Rudwick with reference to the geological sciences, and David Kaiser on the topic of Feynman diagrams.[300] Moving beyond this assertion though, the examples raised in this

---

[300] Elkins, 'Art History and Images That Are Not Art'; D. Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (University of Chicago Press, 2009); Martin Rudwick, 'The

chapter have shown that scientific images are not purely restricted to their own traditions – they are also deeply involved in broader patterns of artistic and technological image-production present in a given period. The auroral images were in conversation with the 'period eye' of the late nineteenth century.[301] Many of the auroral depictions were reminiscent of impressionist and expressionist paintings of the late nineteenth century by such artists as Monet and Munch, possibly influenced by the same techniques and pictorial trends which informed these works of art. Elizabeth Kessler makes a similar argument in the context of the Hubble Space Telescope images and their similarities with nineteenth century Romantic landscape paintings of the American west.[302]

Following the work of both Pang and Nasim, I have taken a perspective not before addressed within histories of the aurora or the historiography of the First IPY. This chapter offers a dissection of a specific research programme, focusing on its ground-level practices and identifying the emergence of a visual culture of auroral representation within its parameters, while contributing to scholarship on the uses of images in the published material of the geophysical sciences. Avenues for further research may include investigations of sketching, rationalising and communicating the features of other Polar phenomena and a close study of the ways in which artificial aurora experiments continued into the twentieth century.

Emergence of a Visual Language for Geological Science 1760-1840', *History of Science* 14, no. 3 (1976): 149-195, 177.

[301] Baxandall, *Painting and Experience in Fifteenth Century Italy*, p. 87.

[302] Kessler, *Picturing the Cosmos*, p. 20.

Capturing the Northern Lights: Standardising the Practice of Auroral Photography During the Second International Polar Year, 1932-33.

Fifty years after the First International Polar Year of 1882–3, the Second International Polar Year was welcomed by the international scientific community in 1932–3. Despite the worldwide financial crisis, forty-six countries participated with twenty-three establishing stations either within their borders or abroad. The aurora was included as one of four key research areas because, as Chapman, one of Britain's foremost geophysicists acknowledged in 1931, it remained 'in many respects mysterious'.[303] The International Union of Geodesy and Geophysics (IUGG), working in close co-operation with the International Meteorological Organisation (IMO), put forward a special committee, led by Professor Carl Størmer, to oversee IPY auroral research. Størmer's deputation produced the *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae*, published by the IUGG in 1930 and used by every station researching the northern lights during the IPY, in what was to be the most ambitious international survey of auroral morphology and verticality ever undertaken.

This chapter explores the ways in which *The Atlas of Auroral Forms* standardised research practices during and after the thirteen-month Polar Year. With concrete instructions and its more subtle introduction of conventions, the atlas set a standard for viewing and capturing the phenomenon through the camera lens, which was followed closely, although altered in some important cases, by IPY researchers. Here, habitual scientific practice is delineated as not only the act of releasing the shutter to capture the aurora on a photographic plate but also all the preparatory expeditionary considerations which resulted in IPY researchers being in a position to take said photographs, as well as the development, measurement and reconsideration of the glass plates, sometimes long after the IPY had finished. It is reconstructed through national IPY reports, correspondence between key researchers, an expedition journal, notes written at the various stations, logbooks and of course, the auroral photographs themselves. In many of the book-length IPY reports, the rigorous practices employed were minutely detailed, although the unpublished material provides an insight into some of the complications and discrepancies involved in the chosen methods.

Daston and Galison argue that atlases 'provide a rare glimpse of ways of seeing in the making.'[304] Yet, in their monumental work, *Objectivity* (2010), they assume that atlases define scientific fields, with the implication that research follows inexorably from the reference text. Although they recognise the importance of researching ground-level practices, or 'objectivity in

---

303 Chapman, 'The Audibility and Lowermost Altitude of the Aurora Polaris', 341.

304 Daston and Galison, *Objectivity*, p. 369.

shirtsleeves' in their words, analysis of habitual scientific activity is not entirely achieved in *Objectivity*.[305] As Jennifer Tucker noted in her 2008 review, the broad approach of *Objectivity* occludes from view 'the specificity, disorder and unpredictability of things on street level'.[306] Indeed, Tucker raises the valid point that a valuable historical project should take into account both the production *and* use of atlas texts.[307] This chapter seeks to do just that; the auroral IPY photography programme provides a prime example for investigating to what extent, and more importantly *how*, instrumental protocols and practices of seeing laid out in an atlas were made manifest within the realm of twentieth century Arctic fieldwork.

Responding to a call for greater emphasis on verticality in histories of modern atmospheric science, this chapter engages with the concept to reveal the ways in which the project of standardising the aurora was contingent on constant intangibility, the construction of a visuality against the night sky and various bodily positionings and gestures. Verticality is understood as 'a material condition of knowledge production and as an object of scientific enquiry'.[308] A vertical approach sheds light on the construction of the atmosphere, and understandings of the aurora specifically, not simply in 'the field' but within the extreme Arctic environment, on the thin contact zone of the crust, looking upwards, always at a distance from the subject of study.[309] Significantly, the 'atmospheric field' is mobile, changeable and open to reinterpretation.[310] As Vanessa Heggie argues in relation to the science of physiology, many wild spaces on earth, and the polar regions in particular, were perceived as 'natural laboratories' in the twentieth century—places that could provide standardised conditions and unique experiences to aid in the process of knowledge creation.[311]

The dry plate process was invented by Richard Maddox in 1871 and astronomical researchers began using it to capture such events as eclipses in the 1880s and 1890s. The use of photography was aligned with the wider move towards 'mechanical objectivity', or the use of technologies which were heralded as eliminating human interference and interpretation.[312] Yet, the faint and fleeting aurora

---

[305] Ibid., 52.

[306] Jennifer Tucker, 'Objectivity, Collective Sight and Scientific Personae', review of Objectivity by Lorraine Daston and Peter Galison, *Victorian Studies* 50, no. 4 (2008): 648-657, 654.

[307] Ibid., 655.

[308] von Hardenberg and Mahony, 'Verticalities in the history of science', 595.

[309] Reidy, 'Verticality and Why Mountains Matter', 586; Adriana Minor, 'Up-and-down journeys: The making of Latin American's uniqueness for the study of cosmic rays', *Centaurus* 62, no. 4 (2020): 698-719, 699.

[310] Mahony and Randalls, 'Introduction', p. 7.

[311] Vanessa Heggie, 'Extreme Acts: Narratives of Balance and Moderation at the Limits of Human Performance', in M. Jackson and M. D. Moore (eds.), *Balancing the Self: Medicine, Politics and the Regulation of Health in the Twentieth Century* (Manchester: Manchester University Press, 2020): pp. 219-249, p. 6.

[312] Pang, 'Victorian Observing Practices (2)', 63.

presented unique challenges for the technology. The first successful photograph of the phenomenon was taken as late as 1892 by Martin Brendel on an expedition accompanying Otto Baschin to Bossekop.[313] Further, it was only in 1909 that Størmer began testing different lenses and glass plates to refine the gelatin dry plate process for auroral photography.

Fig. 30. The first published photograph of the aurora taken by Brendel on 1 February 1892 in Alexander McAdie, 'What is an Aurora?', *The Century Magazine* (1897), 874.

During the Second IPY, it was Norway, Britain, Canada, the United States, and the Netherlands which were most actively engaged in auroral photography. Owing to their traditional pre-eminence in the field, Norway became the organisational core, leading and arranging the IPY programme, providing camera equipment for every station studying the phenomenon and producing the atlas.[314] An executive committee consisting of Lars Vegard and Størmer, as President and Vice President respectively, was established to oversee Norway's IPY activity. Størmer became a Professor of Mathematics at the Royal Frederick University in Kristiania in 1903, his interest in the aurora beginning with mathematically modelling the motion of charged particles around a magnetised terrella. Having developed an amateur interest in photography during his undergraduate days, Størmer became the world's leading auroral photographer in the twentieth century, researching the phenomenon from southern Norway during the IPY.

313 Baschin, 'Die ersten nordlichtphotographien', 278; McAdie, 'What is an Aurora?', 874.

314 Størmer received numerous letters of support in the lead up to the Polar Year, establishing his central supervisory position within the programme. For example, one letter sent from Dr Boyle to Størmer on 24 October 1930 stated that 'you may be assured that the scientists in Canada will be in accord with your proposal', with the clear inference that the IPY would be planned and carried out according to Størmer's direction. See: Dr. Boyle to Carl Størmer, 24 October 1930, letter, *Oslo National Library*, Carl Størmer Letter Archive, p. 115.

A national committee consisting of members from the Royal Societies of London and Edinburgh as well as the Royal Meteorological and Geographical Societies was created to organise the British effort. Six scientists led by James Stagg, a British meteorologist who became a group captain in the Second World War and was influential in providing weather forecasts and recommendations for the date of the D-day landings, re-occupied the Fort Rae station on Great Slave

Fig. 31. 'Carl Størmer Photographs the Northern Lights', at home in the garden at Huk Aveny, Bygdøy, *Nasjonalbiblioteket*, Norway.

Lake in north-west Canada, established during the First IPY.[315] Lerwick Observatory, situated in the south-east of Shetland mainland, was employed as part of the British effort. A Canadian station was established in Chesterfield Inlet, on the western shore of Hudson Bay, similarly isolated but close by to inhabited areas. This station was directed by Balfour Currie and Frank Davies, both members of the department of physics at the University of Saskatchewan. Thomas Alty also led a research group in Saskatoon. In November 1929, a photographic station was set up at the Alaska College and School of Mines in Fairbanks, under the auspices of the United States Coast and Geodetic Survey with the help of a $10,000 Rockefeller grant. Similarly, a station was established at Point Barrow, the northernmost part of the United States, directed by C. J. McGregor.[316] Lastly, the Dutch Polar Year expedition was spent at Angmagssalik in east Greenland, with auroral photographs taken by Dr Van Zuylen, the leader of the expedition, and K. Van Schouwenburg. It should be noted that the territorial politics of

[315] Fort Rae was situated in a relatively isolated area, but near to local settlements of the Dog Rib, Bear Lake and Yellow Knife indigenous tribes.

[316] US Weather Bureau, *Photographic Report of Aurora at Point Barrow, Alaska 1932-1933*, vol. 7 (Washington: Carnegie Institution of Washington Department of Terrestrial Magnetism Archives, 1931-1936).

the research sites reproduced colonial dichotomies, wherein knowledge created within the western scientific model was favoured over local knowledge. This chapter shows how an atlas was used to calibrate the rendering of aurorae on a transnational scale, while speaking to broader debates about the vertical modes of viewing that the camera establishes in the Arctic and the visuality of retrospection inherent in viewing photographs.

The Photographic Atlas of Auroral Forms: Guidelines and Conventions

Atlases serve as normative guides, offering instructions on how to visualise and work with unruly scientific objects and it must be highlighted that they constitute a unique genre.[317] Many of the atlases explored in *Objectivity*, such as Otto Funke's 1853 *Atlas of Physiological Chemistry* and Erwin Christeller's 1927 *Atlas of the Histotopography of Healthy and Diseased Organs*, place emphasis on training the reader to see: to recognise, observe and compare. *The Atlas of Auroral Forms* fulfils this criterion, but also directs the researcher in constructing their own photographic images. Moreover, unlike other reference texts, the auroral atlas was designed with the explicit purpose of directing a small, well-defined research community over a finite period. The built-in purpose of the *Auroral Atlas* only serves to make it more likely that its directions would be actualised in practice. Nevertheless, the work underpinning the IPY auroral programme was flexible in the face of unpredictable circumstances and unforeseen challenges.

The weight *The Atlas of Auroral Forms* afforded to photographs can be inferred from the way its own images were reproduced. The fifteen pages containing auroral photographs were developed in a laboratory and carefully glued into the book between sheets of silk paper. The use of tipped-in prints was a practice commonly associated with the creation of expensive books of art and ambitious scientific catalogues or surveys.[318] For example, in the nineteenth century, it was employed in William Bradford's photobook, *The Arctic Regions, illustrated with photographs taken on an expedition to Greenland* (1873) to showcase the photographs taken by George Critcherson and John Dunmore on Bradford's 1869 expedition.[319] Furthermore, the atlas images represented the positive prints made from the original glass negatives so as to provide a depiction closer to that which an observer would witness on an Arctic night.

The atlas's photographic aims for the IPY were set out as follows: auroral scientists should obtain a statistical survey of auroral morphology as functions of time and place, make a close study of

---

[317] Theodore M. Porter, 'The Objective Self', review of Objectivity by Lorraine Daston and Peter Galison, *Victorian Studies* 50, no. 4 (2008): 641-647, 642.

[318] James R. Ryan, *Photography and Exploration* (London: Reaktion Books, 2013), p. 22.

[319] William Bradford, *The Arctic Regions, illustrated with photographs taken on an expedition Greenland* (London: Sampson Low, Marston, Low & Searle, 1873).

the development of single forms and take parallax photographs from pairs of stations wherever possible.[320] From this data it was hoped that under-researched auroral forms and features could be surveyed, the geographical range of displays determined, and the altitude of the phenomenon established.[321] To this end, Størmer urged that a large number of photographs be taken, increasing the likelihood that some excellent images would be produced, forming the basis of later analyses. Two dozen plates, each containing six photographs, was considered an appropriate number for a night of observations.

To standardise photographic practices *The Atlas of Auroral Forms* established protocols. It stated that photographs should be exposed so that background constellations were visible. The atlas suggested using personal judgement in deciding exposure times but also recommended shutter speeds of between half a second and three seconds for strong aurorae and up to sixty seconds for faint varieties. As such a critical parameter, it is perhaps surprising that exposure times were left up to individual wisdom. Yet, because auroral displays were so variable, it was difficult to create universal rules and made more sense to train IPY scientists in using their own experience with the atlas images as exemplars. The exact time of the exposure, reckoned in Greenwich Mean Time, should be noted and the watch used for this consistently checked against a chronometer and adjusted for error. Latitude, longitude and information about visibility on the night should be recorded. Latitude, longitude, and information about visibility on the night should be recorded.

For parallax photography, the atlas advised that a telephone connection be established between the two participating stations with earpieces and microphones connected to the clothing of the scientists working outside. The two photographers should be in constant contact, agreeing on the portion of the sky they wished to capture, lining up their apparatus and taking photographs simultaneously for the same length of time. Størmer even suggested pinning a watch to the inside of one's hat so the audible ticking could help time the length of the exposure more accurately.[322] Leiv Harang and Einar Tønsberg furthered the atlas's guidelines in a 1931 supplementary publication, having occupied the Tromsø auroral observatory and a station at Tennes in Balsfjord to experiment with dual-station photography throughout the winter of 1929–1930.[323] They emphasised that an agreed constellation of stars should occupy the centre of each photograph to aid in the matching up of the negatives with a magnifying glass. Additionally, a third person should be on the telephone wire to record information for both observers, so their hands could be kept free for camera operation. Their

[320] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*, p. 19.

[321] Balfour W. Currie, 'The Polar Aurora', *The Journal of the Royal Astronomical Society of Canada* 7 (1947): 249-264, 251.

[322] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*, p. 19.

[323] Leiv Harang and Einar Tønsberg, *Investigations of the Aurora Borealis at Nordlys Observatoriet Tromsø 1929-1930* (Bergen: A. S. John Griegs Boktrykkeri, 1931), pp. 4-5.

recommendation of Barnet superior speed ortho glass plates was incorporated into the official supplementary atlas, printed in 1932.[324]

Reducing continuous variety into a taxonomic scheme of finite types is one of the most important powers of an atlas. *The Atlas of Auroral Forms* carved the forms of the northern lights into twelve categories based on their differing brightness, position in the sky, shape, ray structure and diffuseness. In doing so, it created a new visual language with which to speak about the phenomenon. Photographs were placed with each identified formation to provide a visual reference and assist scientists in categorising the structures they witnessed themselves. One of the most common forms

Fig. 32. Example of an HA type of aurora; a homogenous arc without ray structure. Taken by Størmer in Oslo on the night of the 13th of December 1927, *Photographic Atlas of Auroral Forms*, p. 6.

Fig. 33. Example of an RB type of aurora; bands with ray-structure, taken by Størmer at Bossekop on the night of the 3rd of March 1910, *Photographic Atlas of Auroral Forms*, p. 12.

Fig. 34. Example of a G type of aurora; feeble glow. Taken by Størmer at Bossekop on the night of the 14th of March 1913, *Photographic Atlas of Auroral Forms*, p. 10.

Fig. 35. Example of a C type aurora; corona, taken by Størmer at Bygdo on the night of the 22nd of March 1920, near the magnetic zenith, *Photographic Atlas of Auroral Forms*, p. 18.

[324] The International Geodetic and Geophysical Association, *Supplements to The Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae*, vol. 1 (Oslo: Brøggers Boktrykkeri, 1932), p. 5.

was the HA type, a homogenous arc without ray structure. Described as diffuse along its upper border but sharp along the lower edge, the arc could be single or double and could extend across the entire horizon.[325] One photograph used as an exemplar of this form, shown in fig. 32, neatly encapsulates its qualities while also indirectly introducing conventions for capturing aurorae. The image includes faint stars, crucial for situating the structure in the night sky, and silhouetted trees, providing a frame of reference. The inclusion of foreground features was not a novel innovation, but also important to lightning photography of the late nineteenth century to indicate the distance of the lightning flash.[326] Fig. 33, depicting auroral bands with ray structure (RB), provides a sense of scale by including low clouds and is correctly exposed so the parallel rays can be perceived.

Some auroral structures, particularly Feeble Glows (G) and Coronas (C), eluded the conventions put forward in the atlas. Fig. 34 represents a feeble glow, which are generally very faint, 'resembling the dawn, of white or reddish colour.'[327] Often they appear in an elevated position, above the upper edge of an arc and are therefore best represented without the inclusion of foreground elements. Auroral coronas, presented in fig. 35, have long or short rays which appear to converge at the magnetic zenith. They cannot be captured easily alongside ground-level objects because the camera needs to be pointed directly upwards in most cases. In sum, the atlas turned the always vertically distant aurora, an object of visual fascination, into an item to be catalogued, labelled, analysed, and discovered anew through the camera.

The Krogness Camera

Just as observing the solar corona required the use of specially constructed instruments in the latter half of the nineteenth century, so too did auroral imaging.[328] Implicit in the instructions of the atlas was the assumption that all IPY scientists would use the same photographic equipment. This is because the Krogness camera, a product of Norwegian ingenuity, was distributed to every station researching the aurora during the programme.[329] Developed in 1911 by Ole Andreas Krogness, the first director of the Haldde Observatory, the camera was the first built specifically to capture the northern lights. It was trusted within the auroral research community as the most practical apparatus, the reputations of Krogness and Størmer bolstering its authority. Between 1911 and 1935, 300 cameras of this type were sold for international use and the Krogness design remained the most

[325] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*, p. 4.

[326] Tucker, *Nature Exposed*, p. 153.

[327] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*, p. 10.

[328] Pang, 'The Solar Corona (1)', 249.

[329] Herbert H. Kimball, 'The Second International Polar Year, 1932-1933', *Transactions of the American Geophysical Union* 12, no. 1 (1931): 81-82, 82.

effective for auroral photography until the 1950s.[330]

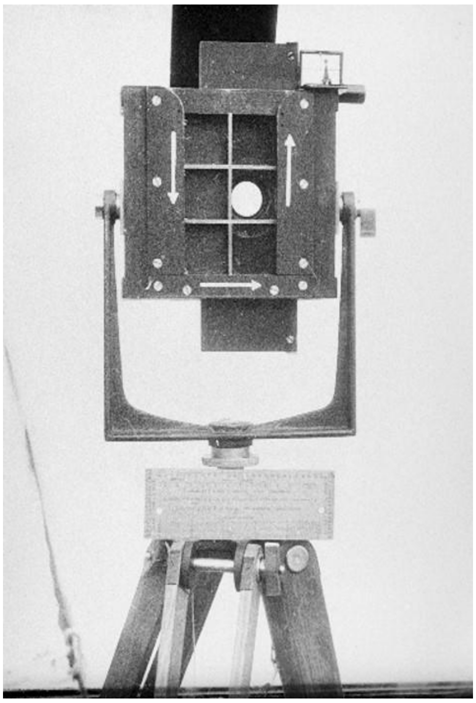


Fig. 36. One of the Krogness cameras that accompanied the British Fort Rae Expedition, 1932-33, *Scott Polar Fort Rae Picture Library Collection*, P82/28/06: Auroral Camera (Rear View).

Just as Henry Rowland's concave diffraction gratings providing a standard map of spectral lines at the end of the nineteenth century, the Krogness camera was an instrument that set the limits of what could be recorded on photographic plates, thus standardising the auroral practice. Yet, unlike Rowland's policy of keeping his procedures of production as a trade secret, the camera was widely discussed and distributed.[331] That being said, some models were more advanced than others. Stagg scribbled a note on a letter he received from Størmer, relating that the latter's apparatus was made entirely of metal and thus the frame could withstand the freezing temperatures without distorting, whereas the frame at Fort Rae consisted of some wooden elements, which were liable to warping with temperature and humidity, slightly changing the focus of the lens.[332]

One of the main advantages of the Krogness design was that each plate could render six photographs by virtue of the mechanical slide system that swiftly shifted the lens into six positions. Six exposures could be taken in quick succession without the need for the fiddly procedure of

[330] Stian Bones, 'Norway and Past International Polar Years – A Historical Account', *Polar Research* 26 (2007): 195-203, 197; Alv Egeland and William J. Burke, *Carl Størmer: Auroral Pioneer* (Berlin: Springer Science and Business Media, 2010), p. 37.

[331] Bigg, 'Spectroscopic Meteorologies', 786; Klaus Hentschel, 'The Discovery of the Redshift of Solar Fraunhofer Lines by Rowland and Jewell in Baltimore around 1890', *HSPS* 23, no. 2 (1993): 219-277, 244.

[332] Carl Størmer to J. M. Stagg, 28 September 1934, correspondence and notes on measurements of auroral plates, *University of Aberdeen Archives*, MS. 3152/25/1/1.

changing the plate in cold conditions. As Nick Hopwood, Simon Schaffer and Jim Secord argue, there is a certain rhetorical power embedded in serial depictions.[333] The sequentiality of a series is linked with conventions of development. Viewed adjacently, upwards from the bottom left-hand corner and then down the right-hand column, the auroral photographs are placed into a temporal scheme and can be easily compared for minute changes. The way the photographs within *The Atlas of Auroral Forms* were formatted on the page, in a pattern of two columns of three, reproduced the arrangement generated by the Krogness camera. This choice was likely made to familiarise the viewer's eye with the six-image convention and demonstrate that auroral photographs ought to be thought of in combination rather than singularly. Another helpful quality of the camera was that it could be pointed in any direction, useful for when it was not known in which portion of the sky the aurora would appear.

Fig. 37. Format of auroral photographs within the atlas in a grid system of 6, *Photographic Atlas of Auroral Forms*, p. 9.

Within the auroral research community, the overwhelming need to suppress the 'scientific self' did not reach the heights that it did within other scientific pursuits of the late nineteenth century. It was not the Krogness camera alone which ensured that the photographic results could be calibrated, but rather the following of instructions. To ensure uniformity in using the camera, Størmer published a paper in December 1932 providing supplementary photographic equipment recommendations five

[333] Nick Hopwood, Simon Schaffer, and Jim Secord, 'Seriality and Scientific Objects in the Nineteenth Century', *Hist Sci.* 48 (2010): 251-279, 257-258.

months into the IPY.[334] Having experimented with 700 *Lumière* plates from France and 240 plates from other manufacturers, Størmer concluded that the *Lumière* plates were preferable, reducing shutter speeds to one second and clearly rendering even faint aurorae.[335] Further tests showed that the *Lumière etiquette violet* plates, with high sensitivities at the blue and ultraviolet end of the spectrum, were best for capturing the broad array of radiation emitted from the phenomenon. The *Lumière* brothers began manufacturing these plates in a factory near Lyon in the 1880s, selling 1.3 million in 1886.[336] Their plates were the height of photographic technology at the time, used by Henri Becquerel to image radioactive emissions from uranium salt in the late 1890s and in capturing Comet Morehouse in the early twentieth century.[337]

Only black and white photography was employed to capture the aurora during the Second IPY, despite colour being a quintessential auroral property. The Lumière brothers developed the autochrome process in 1903 and patented it in 1907. Nevertheless, as Størmer stated in 1932, 'colour plates are so insensitive, that it has as yet been impossible to photograph the aurora borealis with them'.[338] Only in 1951 were colour photographs of the aurora successfully captured by Carl W. Gartlein and William Petrie working at Cornell and the University of Saskatchewan, respectively. In any case, the parallel spectroscopic IPY programme dealt primarily with the hues of the aurora, its main objective being to find the predominant frequencies of auroral radiation.

In terms of lenses, Størmer initially favoured a small light-sensitive objective produced by the Dresden manufacturer, Ernemann, which he found in a photography shop in Oslo as part of a children's motion camera toy. By 1915, however, he realised that he could reduce exposure times by a third using the Astro-RK Berlin camera lens with focal length of 50mm. Harang made an official recommendation on behalf of the IUGG that all IPY researchers use the Astro-RK lens and Størmer

---

[334] Carl Størmer, 'Progress in the Photography of the Aurora Borealis', *Terrestrial Magnetism and Atmospheric Electricity* 37, no. 4 (1932): 475-477, 475.

[335] Carl Størmer to his father, 19 March 1909, letter written while on a boat returning from Bossekop; quoted in: Egeland and Burke, *Carl Størmer*, pp. 43-44.

[336] Bruno Salazard, Christophe Desouches, and Guy Magalon, 'Auguste and Louis Lumière, inventors at the service of the suffering', *European Journal of Plastic Surgery* 28 (2006): 441-447, 442.

[337] A. de la Baume Pluvinel and F. Baldet, 'Spectrum of Comet Morehouse', *The Astrophysical Journal: An International Review of Spectroscopy and Astronomical Physics* XXXIV, no. 2 (1911): 89-104, 91; Kelley E. Wilder, 'Visualising Radiation: The Photographs of Henri Becquerel', in Lorraine Daston and Elizabeth Lunbeck (eds.), *Histories of Scientific Observation* (Chicago: University of Chicago Press, 2011): pp. 349-369, p. 353; Antoine Henri Becquerel, *Recherches sur une propriété nouvelle de la matière: activité radiante spontanée ou radioactivité de la matière, Mémoires de l'Académie des Sciences de l'Institute de France* (Paris: Firmin-Didot, 1903).

[338] Størmer, 'Progress in the Photography of the Aurora Borealis', 475.

gave instructions that eighteen Krogness cameras be equipped with them before the programme began.[339] In their 1931 publication, Harang and Tønsberg also suggested the Kino Plasmat 5mm objective, manufactured by Hugo Meyer, as an appropriate substitute.[340]

Putting the Atlas into Arctic Practice

A copy of *The Atlas of Auroral Forms* was housed at each station participating in IPY auroral observation with an accompanying circular letter from the IUGG urging each research group to familiarize themselves with the methods outlined therein.[341] As the atlas was considered a valuable tool and the number of issues printed was limited, the IUGG requested that copies be returned if observers 'give up' on auroral work during the IPY, so that they could be distributed to others.[342] The atlases were in high demand even after the beginning of the Polar Year. John Adam Fleming wrote to Størmer in October 1932 asking for a new copy of the atlas and its supplements because he had equipped the Mount Washington Observatory in New Hampshire with his own copies.[343]

One of the most compelling powers of photographic evidence was that it appeared to represent the aurora with a greater verisimilitude than was possible through the hand-drawn techniques of the First IPY. In 1929 Størmer explicitly stated that, 'the introduction of photographic methods has rendered the observations much more definite and reliable'.[344] Nevertheless, as Jennifer Tucker argues, the habitual practices of photography expose a rift between the technology's claim to the ideal of mechanical objectivity and the involvement of human thought and influence at every stage of the photographic process.[345] Capturing the northern lights through the camera lens was not a simple and unconsidered task. Photographs were intricately constructed, selectively framed and purposefully produced in the cold and demanding conditions of the polar regions.

The protocols set out in *The Atlas of Auroral Forms* were bound up with specific ways of viewing the northern lights. The camera introduced a temporality to capturing the aurora, making it

339 Ibid., 477.

340 Harang and Tønsberg, *Investigations of the Aurora Borealis*.

341 International Geodetic and Geophysical Union Section of Terrestrial Magnetism to Edinburgh Observatory, 'International Polar Year', October 1930, 1932–3 correspondence, *Oslo National Library*.

342 Ibid.

343 John Adam Fleming to Carl Størmer, 'International Polar Year', 04 October 1932, 1932–3 correspondence, *Oslo National Library*.

344 Carl Størmer, 'International Co-operation for Auroral Research', *The Journal of the Royal Astronomical Society of Canada* 23, no. 1 (1929): 1-7, 1.

345 Tucker, *Nature Exposed*, p. 3.

appear as a series of stationary moments rather than a flowing display.[346] Although this impression was given, because the camera shutter was left open for several seconds and sometimes even a minute, the photographic plate rendered the movement of the aurora rather than a static likeness. Considering that spectroscopic images were often captured over a period of at least an hour, IPY auroral researchers had likely learnt to see the phenomenon with its movement on the photographic plate.[347] Due to the fast-paced nature of the work, the aurora was consistently seen through the camera lens rather than with the unaided eye during intense appearances. This more limited field of vision, only 40 x 40 degrees of the night sky, reduced the viewer's ability to see the whole extent of the phenomenon, focusing the eye on more active or interesting sections. Additionally, at sites such as the Alaska Fairbanks in the zone of maximum auroral frequency, the phenomenon often appeared directly overhead, its vertical nature putting the viewer in an awkward and straining position.

Fig. 38. 'Expedition Member Equipped for a Cold Spell of Auroral Photography', Fort Rae, Scott Polar Fort Rae Picture Library Collection, P82/28/08.

The 13-month British expedition to Fort Rae made auroral photography one of their priorities, using two Krogness cameras to render the phenomenon whenever the lights were bright enough. The party used a Hugo Meyer Kino Plasmat lens of 5mm focal length, in line with the secondary

[346] For an exploration of the temporality the camera established in the Antarctic during Robert Falcon Scott's expedition see: Yusoff, 'Configuring the Field'.

[347] Balfour W. Currie and H. W. Edwards, 'On the Auroral Spectrograms Taken at Chesterfield, Canada, During 1932-1933', *Terrestrial Magnetism and Atmospheric Electricity* 41, no. 1 (1936): 256-278, 265.

recommendations of Harang and Tønsberg in 1931.[348] A logbook was also kept, noting the forms of the aurora according to the atlas's taxonomic scheme.[349] In living and working in the Arctic, they developed embodied ways of feeling, seeing and understanding the phenomenon, although this was always accompanied by a sense of unpredictability, underscored by the phenomenon's intangibility and physical distance from the earth's surface.

The journal of Alfred Stephenson, one of the Fort Rae expedition members, reveals the ways in which the regimented system of hourly observations suggested by the atlas gave rise to specific modes of perceiving the lights. On 25 November 1932 he wrote that he had assumed visibility would be poor and the aurora calm because there was a 'howling wind' and the lights had been quiet all evening. Yet, when Stephenson went outside at midnight, he found the aurora was 'roaring away; the whole sky was filled with brightly coloured rapidly moving stuff.'[350] In contrast, on 12 January 1933, he noted that he enjoyed snowy weather because 'there is something definite about snow, you can sit down in a chair and stay there without bobbing up and down wondering what is going to meet the eye – cloud – no activity – or fleeting curtains.'[351] Unless visibility was very poor, members of the expedition felt a degree of agitation throughout their shift, waiting to know if the lights would appear. This quality of being startling, unanticipated and instantaneous was a fundamental part of the aurora's visuality. The effect of the field was the feeling of being on tenterhooks, swinging between neurosis and uselessness on an aurora shift. Indeed, the pressure of documenting an unpredictable phenomenon was the lack of habitual routine.

Auroral observation and photography were strenuous tasks, requiring active engagement for hours on end in cold conditions. The temperature at Fort Rae reached -39 degrees Celsius in winter and force 6 winds were not uncommon. Stephenson came to dislike his stints outside using the Krogness camera, writing on 17 April 1933 that he was having a 'very lucky week' because the sky was completely covered by nimbostratus clouds, meaning visibility was too poor for auroral observation.[352] He also campaigned for all members of the expedition to have nights off auroral duty together, which Stagg firmly rejected for fear of having gaps in the record. After this episode, Stephenson reflected that Stagg was 'absolutely determined that we shall get no enjoyment out of life

[348] J.M. Stagg 'Auroral photography, various notes, measurements, log of measured plates', typescript, Introduction to Auroral Photography, *University of Aberdeen Archives*, MS. 3152/1/3, p. 3.

[349] Fort Rae Expedition Members, 'Auroral Observations made at Fort Rae, Canada, Aug 1932 – Aug 1933', vol. 2-5, *Aberdeen Archives*, MS 3152/29/2-5.

[350] Alfred Stephenson, 'Journal 14 May 1932 - 04 October 1933', vol. 1 Expedition Materials, Alfred Stephenson Collection, *Scott Polar Research Institute*, GB 15, p. 68.

[351] Ibid., 95.

[352] Ibid., 145.

whatever'.[353] Auroral observation, and the process of following the atlases minutiae, was hard work in the freezing conditions of the Arctic and became mundane rather than awe-inspiring for some researchers.

The photographs produced as part of the Fort Rae Polar Year expedition are relatively uniform and follow the conventions of *The Atlas of Auroral Forms* closely. As fig. 39 shows, they were created in the customary pattern of six, dictated by the Krogness camera. This particular image is overexposed; the bands of the aurora can be seen but little detail discerned. It is worth remarking that fig. 39 is significantly more scratched and imperfect than those represented in the atlas, which is to be expected considering the atlas images were selected for their clarity. Representing a similar morphology, fig. 40 shows slightly more detail and depicts the top of the magnetograph hut, providing perspective on the verticality of the phenomenon. The camera has clearly been tilted downwards to follow the movement of the aurora, revealing an active photographer physically tracing the progress of the phenomenon by repositioning his body and the camera. It was evidently not possible to fit the entire extent of the display into the frame of either photograph or expose to include constellations.

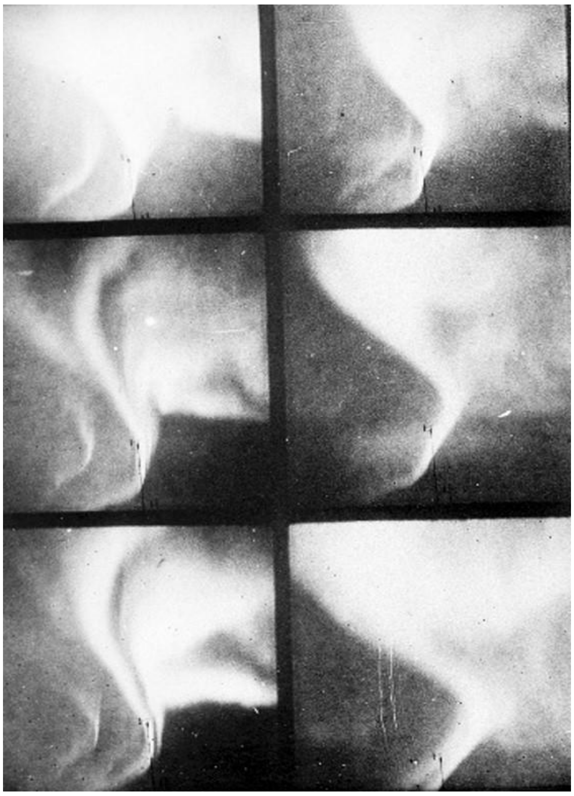


Fig. 39. 'Plate of Six Auroral Photographs', *Scott Polar Research Institute Fort Rae Picture Library Collection*, P82/28/09.

Fig. 40. 'Fort Rae, Auroral Photograph, 1931-1932', Krogness auroral photographs, *University of Aberdeen Archive*, MS. 3152/26/3.

[353] Ibid., 23.

Finding the correct length of exposure was a fine balancing act for IPY researchers. Professor Fuller at the Fairbanks, Alaska station complained of a continual fogging of his developed plates, indicating they had been exposed to too much light. This he blamed on the plateholders of the Krogness camera, which he alleged allowed light to leak in.[354] In reply, Størmer emphatically defended the Krogness camera's efficacy, commenting that 'plates stored as long as three months in the plateholders have been found to be quite good' and suggested that the light leaks must be derived from exposure to the dark-room lantern or reliance on old plates.[355] Nevertheless, the problem of establishing the intensity of displays was mitigated by the atlas's introduction of a scale for estimating their brightness.[356] Known as the internal brightness coefficient (IBC), the scale had 5 intervals with 0 meaning the aurora was subvisible or not present, 1 meaning it was comparable with the milky way, 2 being comparable with moonlit cirrus clouds, 3 comparable with brightly lit cirrus clouds and 4, denoting anything brighter than 3, often representing aurorae which cast discernible shadows. If any colour was distinguishable then the lights must have corresponded with an IBC of at least 2 because below this threshold colour cannot be detected by the human eye.

Although the IBC was a useful tool for auroral photographers, influencing their aperture and shutter speed settings, the system was limited. Stagg criticised IBC methodology in his 1937 report, asserting that the IUGG atlas gave undue weight to brightness. He argued that no scope was given for relaying the activity of the phenomenon. For example, a violent aurora in a dull red colour, which was equally important for concerns of exposure time.[357] Moreover, some forms, such as the corona, only lasted a few seconds and thus needed to be captured before there was time to estimate the IBC. At Fort Rae, these challenges were dealt with in two ways. First, Stagg introduced more gradations to the IBC scale for greater precision. Second, expedition members used the step wedge technique in the darkroom to decipher the correct length of time to expose a negative plate to the developing solution, therefore making the most of the shutter speed chosen on a given night. One such photograph is shown in fig. 41. It reveals the process of examining different lengths of darkroom exposure time on a single plate and choosing the option that provided optimum clarity and least movement of the phenomenon. In this example, a darkroom exposure time of eighteen seconds, closer to the twenty-second section than the exposure at fourteen, was thought to generate the best photograph.

Somewhat surprisingly there was little discussion of the objectivity of auroral brightness during the IPY. Later, in 1947, it was Currie who engaged most intently with this point in question in

[354] John Adam Fleming to Prof. Fuller, (Alaska College School of Mines), 'Correspondence on the International Polar Year', 20 August 1932, letter, *Oslo National Library*.

[355] Størmer quoted in: Ibid.

[356] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms,* p. 12.

[357] J. M. Stagg and The British National Committee for the Polar Year, *Some General Characteristics of Aurora at Fort Rae, N.W Canada, 1932-1933* (London: Percy Lund, Humphries & Co. Ltd, 1937), p. 253.

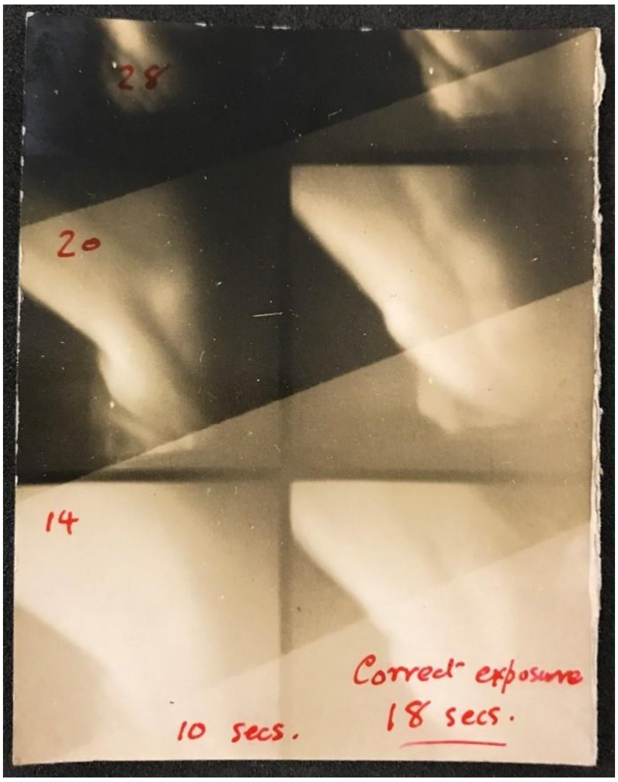


Fig. 41, 'Fort Rae, Exposure Test Auroral Photograph, 1931-1932', *University of Aberdeen Archive*, MS. 3152/26/3, Krogness auroral photographs.

his article, 'The Polar Aurora.' He recalled, from his time working at the Chesterfield station that on occasion, 'bright zenithal displays produce sufficient light to make newsprint readable.'[358] Yet, he also remarked on the illusory quality of auroral brightness stating that, 'the unusual and rapid changes of aurora give the impression of a greater luminosity than actually exists.'[359] Currie voiced concerns over use of the IBC in retrospect, noting that the eye is more sensitive to the common green of aurorae than are photographic emulsions.[360] It is interesting that his consideration of the subjectivity of auroral brightness was only expressed fifteen years after the Second Polar Year. The act of registering the phenomenon in the present and then returning to it retrospectively allowed Currie to reflect on the extent to which the northern lights had been captured objectively with the camera.

There are exceptions to the conformist portrait of the photographic programme, following the model of the atlas. One example is the photographs produced on the Dutch east Greenland expedition.[361] The photographers, Van Zuylen and Van Schouwenburg, each interpreted the guidance differently, creating starkly contrasting images. Van Zuylen's set of photographs taken on 17 March 1934 appear in a pattern of three rather than the usual six, implying that he did not use the Krogness

[358] Currie, 'The Polar Aurora', 258.

[359] Ibid.

[360] Ibid.

[361] Frank Rust, 'The Dutch Polar Expedition of 1882-3', *Journal of the American Geographical Society of New York* (1883): 375-380.

camera. Taken at intervals of 49 and 33 seconds, the images delineate the rays of an extremely fast changing aurora, likely positioned at significant altitude. Van Schouwenburg's photographs resemble other Krogness images more closely but were influenced by landscape photography to a greater extent than other IPY photographs. As fig. 43 exemplifies, his images were atmospheric and panoramic, including the polar environment and traces of everyday life at Angmagssalik. By including the ground, Van Schouwenburg used the camera to construct a vertical representation of the aurora, situating the phenomenon within a terrestrial field of vision. It is significant that such different aesthetic principles underpinned the production of these representations, indicating that the atlas guidelines could be interpreted differently even among closely connected individuals.

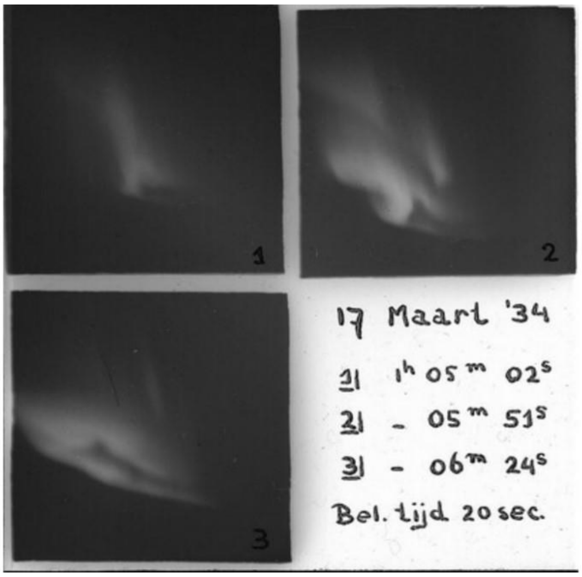


Fig. 42. Jaap Van Zuylen, 'Photograph 17th March 1934, East Greenland', Number: RV-6222-264, Jaap van Zuylen Collection, Rijkmseum voor Volkenkunde, Leiden.


Fig. 43. Dr. Van Schouwenberg, 'Photograph 1934, East Greenland', Jaap van Zuylen Collection, *Rijkmseum voor Volkenkunde, Leiden*, number: RV-A304-2-

The most substantial innovation of the atlas, its instructions for parallax photography, were taken up wholeheartedly by researchers at Chesterfield Inlet, Urafirth and Fort Rae. Davies and Currie followed parallactic photography procedures precisely, with Davies remaining at Chesterfield and Currie travelling to a station at Fort Sik-Sik, 4.3km away. Communicating via radio, Davies would identify a part of the sky to be captured in terms of its constellations and then say 'on' to signal that they should both begin exposing the photographic plate and 'off' as soon as the aurora started to move. In this way, Davies and Currie collected hundreds of parallactic photographs, which were used to find the altitude of Canadian aurorae for the first time.[362] One of their pairs of plates is represented

[362] Frank T. Davies, 'The Canadian Second Polar Year Expedition to Chesterfield Inlet, 1932-33', *University of Saskatchewan Archives & Special Collections*, J. E. Kennedy fonds, MG 102 additionals box 10, pp. 5-6.

in fig. 44. Although the background constellations are not visible, the auroral forms align well. A second Krogness camera was also supplied at Urafirth, located 26 miles north-north-west of Lerwick Observatory in the Shetland Islands, for the purpose of taking simultaneous photographs during the IPY.[363] On the back of the Lerwick photographs, the type of aurora is written, using the vocabulary of the atlas, as well as the constellations which are visible in the image.[364]

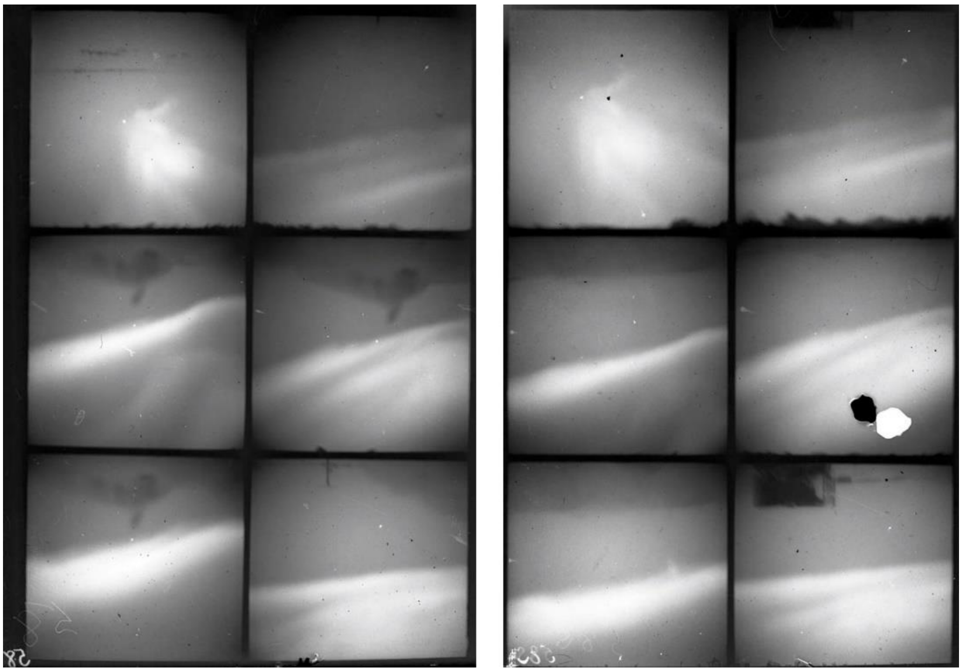


Fig. 44. Frank Davies, Parallactic Photographic Plate: 58 and Parallactic Photographic Plate: 58S, 'The Canadian Second Polar Year Expedition to Chesterfield Inlet, 1932–33', Currie-Davies Chesterfield Inlet Parallactic Plates, *University Archives and Special Collections, Department of Physics fonds, University of Saskatchewan*, RG 2043, 1111-267, Box 4.

Similarly, parallax photographs were captured at the Old Fort and the main Fort Rae base. The two sites were connected via insulated telephone wires, laid by the expedition team, which functioned well apart from the odd occasion when the party's husky dogs managed to chew through them.[365] In the British National Polar Year Committee report published in 1937, Stagg noted that only

[363] Air Ministry Meteorological Office, *The Observatories' Year Book 1932: Comprising the Meteorological and Geophysical Results Obtained from Autographic Records and Eye Observations at the Observatories at Lerwick, Aberdeen, Eskdalemuir, Cahirciveen (Valentina Observatory), and Richmond (Kew Observatory) and the Results of Soundings of the Upper Atmosphere by Means of Registering Balloons* (London: His Majesty's Stationery Office, 1934), p. 38.

[364] 'Lerwick Auroral Photograph', photograph (23 November 1930), Krogness Auroral Photographs Collection, *University of Aberdeen Archives*, MS. 3152/26/3.

[365] Stagg and The British National Committee for the Polar Year, *Some General Characteristics of Aurora at Fort Rae*, p. 11.

photographs captured on 53 nights, out of the total of 273 on which the aurora was witnessed, were satisfactory for parallactic measurement.[366] This figure poses the question as to what constituted a satisfactory pair of parallactic photographs. Presumably, they could be discarded if they did not both reproduce the same portion of the sky or if they were not focused or free from superficial defects. A report written by the British national committee elucidated the implications of such preferences, noting that 'the auroral forms which were photographed were in general selected as being the brightest, or steadiest, or most clean cut in the sky,' the easiest to capture in difficult conditions, and thus not representative of all auroral activity on a given night.[367] This selection bias in the photographic material would naturally shape the results gained from measurements and calculations carried out on the plates.

Analysing Auroral Photographs

The practice of photography in extreme environments required the negotiation of much more than just the release of the camera shutter. Establishing the credibility of images constructed in the field involved the careful consideration of the development process, transportation of the glass plates, measurement of the photographs, computations and the publishing of results.[368] The IPY auroral photographs were developed at the Arctic stations during the daytime several days after they had been taken. As Stephenson's journal reflects, the dry plates were vulnerable to tarnishing. On 28 January 1933 he recorded that 'we are getting a strange marking on [the plates] which in some cases is completely spoiling the exposure. The mark is exactly like the grain in a piece of wood.'[369] Suspecting the defect to be caused by oxidisation of the copper tank containing the photographic developer, Stephenson cleaned the tank thoroughly and developed some plates in a different container. Those developed in the old tank were still faintly marked whereas those in the separate dish were unstained and thus the tanks were cleaned more regularly, and the photographs continued to be checked for marks.

Overexposed, blemished and tarnished images underscore the materiality of the photographic process. As Peter Geimer argues, the disruption or damage to the photographic plate makes visible

---

[366] Ibid., 2.

[367] Ibid., 272.

[368] Sara Hillnhuetter, Stephanie Klamm, and Friedrich Tietjen, 'Introduction: Where does photography start? And where does it end? A Hyrbid introduction', in Sara Hillnhuetter, Stephanie Klamm, and Friedrich Tietjen (eds.), *Hybrid Photography: Intermedial Practices in Science and Humanities* (New York: Bloomsbury Academic, 2021): pp. 1-5, p. 1; Jennifer Tucker, 'Photography and the Making of Modern Science', in Gil Pasternak (ed.), *The Handbook of Photography Studies* (Abingdon: Routledge, 2020): pp. 235-255, p. 244.

[369] Stephenson, 'Journal 14 May 1932 - 04 October 1933', 103.

both the potential and limitations of the medium.[370] Owing to their fragile nature, the plates were stored carefully in boxes or crates, laid on their longest edge to reduce the pressure on any slightly odd sized negatives. The low temperatures of the Arctic risked the plates becoming brittle, further exacerbating the delicacy of the approach required. They were then transported to laboratories and observatories in the home countries of the IPY researchers to be evaluated. The vulnerability of the plates became conspicuous in 1929, demonstrated by a letter written by Størmer to Stagg, in which the former complained that the plates he had received had not been carefully packed and had therefore been damaged in transit.[371]

Interpreting the photographs was a skill embedded within the auroral visual subculture, learnt and stabilised through *The Atlas of Auroral Forms.* Reports written by Stagg, working at the Meteorological Office in Edinburgh after the Polar Year, and J. Patterson, director of the Meteorological Service of Canada, summarised the general patterns of auroral appearances at Fort Rae and Chesterfield. Published in 1935 and 1934 respectively, these accounts were based on examination of the photographic record directly after the IPY. Stagg discerned that auroral intensity was unusually low during the programme, with displays often characterised by a 'lack of robustness and definition.'[372] The most common form witnessed at Fort Rae was a diffuse arc extending across the horizon. No pulsating or flaming aurorae appeared whatsoever, although 72 coronas were observed in the early season. In midwinter the lights frequently appeared in the north sky, whereas during autumn and spring the aurora was more commonly positioned in the east or south, indicating either a migration of activity or diurnal variation in the position of the phenomenon. Comparing the locations of aurorae also implied that the zone of maximum frequency lay very close to the Fort Rae station, which Stagg claimed made assigning categories to parts of its structure more difficult. At Chesterfield, the typical display constituted faint bands and arcs in a transverse path from southeast to southwest. Generally, activity reached a maximum one hour after local midnight.[373]

The altitude of aurorae, its verticality, featured as both an important component of the phenomenon's visuality as well as the subject of scientific scrutiny during the IPY.[374] In the year

---

[370] Peter Geimer, *Inadvertent Images: A History of Photographic Apparitions* (Chicago: University of Chicago Press, 2018), p. 7.

[371] Carl Størmer to J.M. Stagg 23 December 1929, letter, *Oslo National Library*, MS folder 657 Ubehandlet 115: Carl Størmer: Brevarkiv.

[372] Stagg and The British National Committee for the Polar Year, *Some General Characteristics of Aurora at Fort Rae*, p. 3.

[373] J. Patterson, 'Preliminary Report on Auroral Magnetic, and Earth-Current Observations at Chesterfield, Northwest Territories, Canada', *Transactions of the American Geophysical Union* 15, no. 1 (1934): 166-167, 166.

[374] von Hardenberg and Mahony, 'Verticalities in the history of science', 596.

following the programme, there was much debate about how best to find the average and minimum heights of aurorae.[375] The atlas provided no advice, but Størmer, working at the Institute of Theoretical Physics at the University of Oslo, sent some initial suggestions to Stagg in a letter dated September 1934. He advised that, in selecting photographs to analyse from the thousands collected, 'it would be wise to drop… a great deal of those where the displacement is nearly parallel to the arc'.[376] On a practical note, he urged that an assistant for carrying out the calculations was necessary because each pair took between three and four hours to analyse. In what is a rare mention referring to the role of women within the highly gendered context of the Second IPY, Størmer stated he had 'never tried how a girl will do the work' but accepted Stagg's suggestion that they may be proficient at the computations.[377]

Using stereoscopic methods to find auroral heights was contemplated as revealed in the correspondence between Stagg, Chapman, Col. M. M. McLeod of the British War Office, George Clarke Simpson of the Meteorological Office and Dr French at the optical engineering firm Messrs. Barr & Stroud.[378] Chapman and McLeod carried out preliminary tests using stereoscopes used for aerial cartography on photographs of the lights. Then, on 2 November 1934, Stagg sent four pairs of plates Simpson, who forwarded them to French.[379] The plates ranged from excellent quality to the poorest photographs, which included significant development stains. Reporting back, French discerned that the photographs gave a definite stereoscopic effect but was doubtful whether the instruments at Barr & Stroud would be useful for carrying out height measurements. He suggested that the only technology which might fulfil the role was the stereo-goniometer belonging to the War Office. Using this instrument, however, would require significant computations, nullifying its advantages as a means of simplifying the calculation process.

It was decided that the Norwegian geometric method was the optimal approach. This method instructed that a pair of negative parallactic plates should be enlarged and projected one after the other onto a wall, on which paper was fastened. The negatives were used because they provided greater resolution than prints made subsequently from them.[380] Usually, three reference stars were selected,

---

375 'Discussions of errors in auroral measurements', *University of Aberdeen Archives*; 'Notes on auroral plate measurements, lists of photographs, classification of auroral forms' (Aberdeen Archives).

376 Størmer to Stagg, 28 September 1934.

377 Ibid., 3.

378 J. M. Stagg, Col. M.M. McLeod (War Office), Barr and Stroud Ltd *et al.*, 'Correspondence and notes on measurements of auroral plates', *Aberdeen Archives*, MS. 3152/25/1/1.

379 J. M. Stagg to G. C. Simpson, 'Correspondence and notes on measurements of auroral plates', *University of Aberdeen Archives*, MS. 3152/25/1/1.

380 Laurence E. Keefe and Dennis Inch, *The Life of a Photograph: Archival Processing, Matting, Framing and Storage* (Waltham: Focal Press, 1984), p. 269.

and the outline of the aurora sketched onto the paper.[381] The optical centre should be found by graphical methods and marked onto the sheets. Then the paper should be removed and the angles between the same stars calculated by means of underlying nets. Once the paper had been re-pinned, corresponding points of the aurora were either found visually or by the direction of the displacement given by the nets. The value of the parallax could then be found by placing the nets under the sketches and illuminating the sheets from below. From the parallax the distance from the head station to the aurora could be found by the slide rule, as Størmer elaborated in a 1952 publication.[382] Under Stagg's direction, British researchers altered this method, employing a twin projection apparatus so that the photographs could be positioned side-by-side on the wall and thus viewed simultaneously. This was found to be 'almost indispensable' because it allowed the contours of auroral density to be drawn more precisely.[383] This was particularly pertinent for Fort Rae researchers because the horizontal direction of the arcs and bands was often parallel to the displacement between the two sites of photography.

Fort Rae scientists endeavoured to measure 500 pairs of photographs before seeking to learn of the results gained by the international community to avoid being prejudiced in favour of certain heights.[384] However, by 1947 they had still not published any measurements.[385] Before the Second IPY, no photographs had been taken of the northern lights below 100km above the earth's surface. There were, however, occasional local reports of aurorae reaching much further into the atmosphere, even descending low enough to be walked through.[386] Generally, such testimonies were dismissed as fantastical but locating the minimum height of aurorae became a central issue during the Second IPY, not least because its resolution would reveal the penetrability of electric corpuscles from the sun.[387] In terms of the lowest aurorae witnessed during the IPY, two structures at 71 and 77km were recorded at the Chesterfield station.[388] On 16 April and 20 April 1933, Canadian scientists led by Alty in

---

[381] 'Azimuths and elevations of photographic reference stars', *University of Aberdeen Archives*.

[382] Carl Størmer, *Results of the Observations and Photographic Measurements of Aurora in Southern Norway and From Ships in the Atlantic During the International Polar Year* (Blindern, Oslo: The Institute of Theoretical Astrophysics, 1952), p. 8.

[383] Stagg 'Auroral photography, various notes, measurements, log of measured plates', 6.

[384] Ibid., 12.

[385] Currie, 'The Polar Aurora', 252.

[386] Chapman, 'The Audibility and Lowermost Altitude of the Aurora Polaris', 341; Frank T. Davies and Balfour W. Currie, 'Audibility of the Aurora and Low Aurora', *Nature* 32 (1933): 855-856, 856; Malcolm Rigby, 'Recent Research of the Aurora and the Work Planned for the Second International Polar Year', *Bulletin of the American Meteorological Society* 13 (1932): 195-200, 197.

[387] Størmer, *Results of the Observations and Photographic Measurements of Aurora*, p. 37.

[388] Patterson, 'Preliminary Report on Auroral Magnetic, and Earth-Current Observations', 167.

Saskatoon exceeded this measurement, recording aurorae as low as 60km above the ground.[389] Through the use of parallactic photography, the minimum position of aurorae was fixed at a considerably lower altitude than had been assumed before 1932.

Calculations from Chesterfield indicated that the mean height of aurorae was between 103 and 106km above the earth's surface, with a secondary maxima appearing between 114 and 122km.[390] The Polar Year height measurements were invoked by E. V. Appleton, R. Naismith and L. J. Ingram in their paper entitled, 'British Radio Observations During the Second International Polar Year,' to confirm that the E-region of the upper atmosphere has an electron density maximum at approximately 100km.[391] Moreover, British physicist, Thomas Eckersley, cited Størmer's height measurements in a later 1953 paper to assert that layers of ionisation exist in the upper atmosphere at approximately 1km apart.[392] As Currie suggested, knowledge of the altitude of the phenomenon also indicated that above 100km oxygen dissociates into atomic form, whereas nitrogen remains in a molecular structure, a theory later elaborated by Jean Cabannes and J. Gauzit, without direct mention of the IPY results although with reference to average auroral heights.[393]

Auroral photographs were seldom printed in scientific publications during the 1930s. Indeed, of the nineteen articles surveyed in this chapter produced in the decade following the IPY, only two included photographs despite discussions of photography appearing in all of them. McGregor's 1935 report on observations at Point Barrow contained five photographs of his Barnet superior ortho plates, aligning with the recommendation of Harang and Tønsberg, and E. W. Hewson's 1937 paper, entitled 'A Survey of the Facts and Theories of the Aurora,' displayed two.[394] Each of the prints were primarily illustrative. That the photographs remained unpublished is reminiscent of the lack of photographs included within Warren De la Rue's sunspot articles of the late 1860s and early 1870s, despite their importance to his project to produce a continuous account of the quantitative

[389] T. Alty and F. J. Wilson, 'Height of the Aurora in Canada', *Nature* 133 (1934): 687-688, 688.

[390] Patterson, 'Preliminary Report on Auroral Magnetic, and Earth-Current Observations', 167.

[391] Edward Victor Appleton, R. Naismith, and L. J. Ingram, 'British Radio Observations During the Second International Polar Year', *Philosophical Transactions of the Royal Society of London Series A – Mathematical and Physical Science* 764, no. 236 (1937): 191-259, 253.

[392] T. J. Eckersley, 'Recombination and Diffusion and Spread Echoes from the Ionosphere', *Proceedings of the Physical Society, Section B* (1953): 1025-1038, 1033.

[393] Jean Cabannes, 'The Light of the Night Sky', *Science Progress* 33, no. 131 (1939): 435-446, 445; Currie, 'The Polar Aurora', 262; J. Gauzit, 'The Composition of the Upper Atmosphere According to the Dissociation of Oxygen and Nitrogen Molecules', *Bulletin of the American Meteorological Society* 25 (1944): 245-250, 245.

[394] E. W. Hewson, 'A Survey of the Facts and the Theories of the Aurora', *Reviews of Modern Physics* 9 (1937): 403-431, 404 & 417; C. J. McGregor, 'Auroral Observations at Point Barrow, Alaska (During the International Polar Year)', *Transactions of the American Geophysical Union* 16, no. 1 (1935): 147-151, 149.

developments of the surface of the sun.[395] As Holly Rothermel contends, 'Photography in this instance became a silent, objective, scientific tool'. [396] The case of the aurora is less clear-cut, considering the accuracy of the photographs was not self-evident; they were legitimised through the calibration of human practices across vast distances. The lack of printed visual material more likely reflects the significance of photographic quantity instead of quality; it was the assimilation of many photographs rather than the reviewing of any individually which informed the IPY results.

The Photographic Record and Visuality of Retrospection

As Elizabeth Edwards notes, 'photographs are profoundly temporal things'. Within them, time is collapsed into a small material object, from which one can view a visual representation of a moment in the past.[397] Future uses and expectations are embedded within these photographs.[398] Yet, photographic records are not a passive resource; they are open to retelling, curated by the way they are stored with multitudes of other like photographs, recirculated and reconsidered in light of new research questions.

The photographic collection captured between 1932 and 1933 and visuality of retrospection allowed a novel form of the aurora to come to light years after the Second IPY programme had finished. In 1927, Størmer published an article in *Nature* detailing an unnamed but 'remarkable aurora' captured from his station in Bygdö, near Oslo.[399] As he documented, 'the arc appeared on the plates as a curtain of rays which were difficult to distinguish visually'.[400] The lights were grey-violet in colour and it was found by later calculations that they reached the immense height of 1000km above the earth's surface. Størmer hypothesised that the form was situated in the part of the

[395] Warren de la Rue, 'Researches on solar physics (I). Heliographical positions and areas of sun-spots observed with the Kew photoheliograph during the years 1862 and 1863', *Philosophical Transactions of the Royal Society of London Series A – Mathematical and Physical Science* 159 (1869): 1-110; Warren de la Rue, 'Researches on solar physics (II). The positions and areas of the spots observed at Kew during the years 1864, 1865, 1866, also spotted area the sun's visible disk from the commencement of 1832 up to May 1868', *Philosophical Transactions of the Royal Society of London Series A – Mathematical and Physical Science* 160 (1870): 389-496.

[396] Rothermel, 'Images of the Sun', 163.

[397] Elizabeth Edwards, 'Photography and the Business of Doing History', in Gil Pasternak (ed.), *The Handbook of Photography Studies* (Abingdon: Routledge, 2020): pp. 170-186, p. 179.

[398] Gregg Mitman and Kelley Wilder, 'Introduction', in Gregg Mitman and Kelley Wilder (ed.), *Documenting the World: Film, Photography and the Scientific Record* (Chicago: University of Chicago Press, 2016): pp. 1-23, p. 16.

[399] Carl Størmer, 'An Effect of Sunlight on the Altitude of Aurora Rays', *Nature* 120 (1927): 329-330, 329.

[400] Ibid.

atmosphere illuminated by the sun.[401] This 1927 paper went relatively unnoticed, cited by only one English language journal article by E. O. Hulbert in 1928 and one German paper in the same year.[402]

With the benefit of hindsight, Størmer re-examined the photographic records made between 1911 and 1922 to discern whether any aurorae of extreme altitudes were also visibly exposed to the sun's rays. Additionally, he revisited the logbooks kept from these years for any mention of violet or grey aurorae.[403] He found the unusual aurora had been accidentally captured on only two previous occasions, 22-23 March 1920 and 13-14 May 1921.[404] Størmer gave the extraordinary phenomenon a name, the *sunlit aurora* and used the photographs from March 1920 and May 1921 to plot the position of the rays on these nights in relation to the earth's shadow. From this exercise he surmised that the 'action of the sunlight seems to be a pressure on the upper atmosphere, driving it away tangentially to the earth, like a tail.' [405] In 1929, Størmer recorded his desire to capture more photographic evidence of this remarkable occurrence, setting the scene for the more thorough investigation of the phenomenon from multiple stations during the Second IPY.[406]

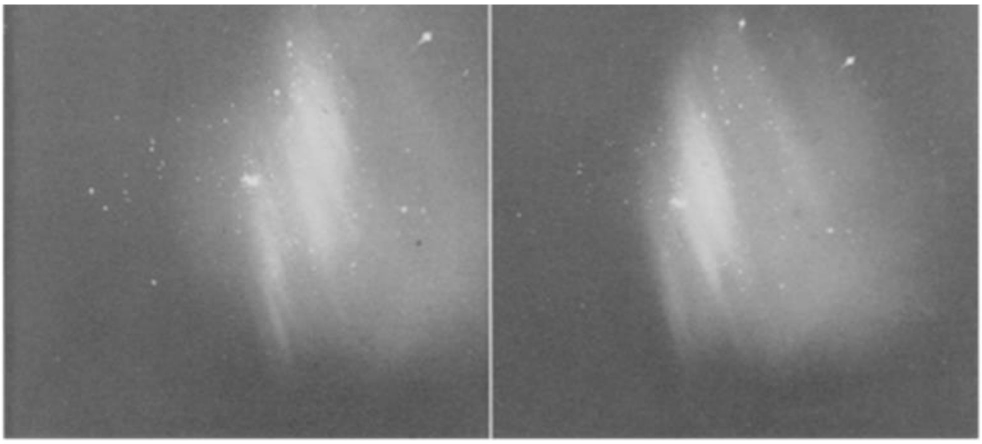


Fig. 45. Carl Størmer, 'Parallax Photographs 19-20 March 1933, 21h 08m 55s, showing sunlit invisible rays from two stations', in *Results of the Observations and Photographic Measurements of Aurora in Southern Norway and From Ships in the Atlantic During the International Polar Year* (Blindern, Oslo: The Institute of Theoretical Astrophysics, 1952), p. 117.

---

[401] Ibid.

[402] E. O. Hulbert, 'The Origin of the Aurora Borealis', *Physical Review* 31, no. 6 (1928): 1038-1039, 1039.

[403] Størmer, 'An Effect of Sunlight on the Altitude of Aurora Rays', 329.

[404] Carl Størmer, 'The Distribution in Space of the Sunlit Aurora Rays', *Nature* 123 (1929): 82-83, 82.

[405] Størmer, 'An Effect of Sunlight on the Altitude of Aurora Rays', 330.

[406] Størmer, 'The Distribution in Space of the Sunlit Aurora Rays', 82; Carl Størmer, 'The Spectrum of Sunlit Aurora Rays as Compared with the Spectrum of Lower Aurora in the Earth's Shadow', *Nature* 124 (1929): 263-264.

There is, however, no mention of the sunlit aurora in *The Atlas of Auroral Forms*. Presumably, this was because sufficient data about its morphology, patterns of appearance and situation was yet to be collected. Moreover, it was only in 1952, once again retroactively, that parallax photographs of the sunlit aurora from the Second IPY were published.[407] The sunlit aurora was hardly visible with the naked eye, as indicated by Størmer's description of the rays as 'invisible', alongside his photographs taken on 19-20 March 1933.[408] Therefore, only by looking into the past at photographs at a later date, rather than visualising the structure in the present, could the qualities of this obscure form be seen. As Chapman wrote in Størmer's obituary, 'he was quick to recognise new auroral features revealed by his photographic synthesis. The most outstanding of these was the remarkable sunlit aurora.'[409]

The Fort Rae photographs taken between 1932 and 1933 were useful to Chapman twenty years after the Second IPY too. In 1953 Chapman was researching not the aurora itself, but the sections of sky surrounding its forms. He noticed that the segment beneath aurorae was often darker than the sky above the structure. Chapman wrote to Stagg to ask if he had perceived a similar characteristic during his time at Fort Rae. In a letter dated 11 February 1953 to James Paton at the Department of Natural Philosophy at the University of Edinburgh, Stagg relayed the details of his reply. He wrote that he, 'told Prof. Chapman that the dark segment was frequently noticed, but we paid no particular attention to it as a separate phenomenon.'[410] Stagg and other members of the expedition had assumed that the apparent darkness was an artefact of their own vision, an illusion induced by contrast with the brightness of the lights. However, because Chapman considered 'the matter of some importance either to produce evidence for or against the phenomenon as a real one,' Stagg had begun re-examining the photographs taken during the Polar Year.[411] He contended that if the phenomenon were real, the dark segment should be imprinted on the photographic plate, revealing an interesting faith in the evidence of the camera as a tool for the veridical evocation of the past.

Photometric measurements did reveal a discrepancy between the region of sky above the aurora and that which was below on a small selection of photographs, demonstrating that the photographic archive was a valuable tool for the creation of knowledge twenty years after the IPY. Nevertheless, little in the way of conclusive results were gleaned from the exercise, and the dark

---

[407] Størmer, *Results of the Observations and Photographic Measurements of Aurora*, p. 117; Carl Størmer also presented a paper on 'sunlit aurorae' in 1954: Carl Størmer, 'Sunlit Aurorae', 1954, Ontario: 95-115.

[408] Størmer, *Results of the Observations and Photographic Measurements of Aurora*, p. 117.

[409] Sydney Chapman, 'Prof Carl Størmer, For Mem. R. S', *Nature* 180 (1957): 633-634, 633.

[410] J. M. Stagg to J. Paton (Department of Natural Philosophy Edinburgh University), 11 February 1953, letter, *University of Aberdeen Archives*, MS. 3152/1/11.

[411] Ibid.

segment beneath aurorae remained a puzzle for future auroral observers.[412] It is significant that, taken for granted at the time, it was again in retrospect, entangled with the memories of twenty years prior, that the objectivity of certain aspects of the phenomenon was seriously contemplated. The archaeology of the photographs shifted visual perception, allowing the aurora to be seen anew and thus carry additional knowledge.

Conclusion

In conclusion, *The Atlas of Auroral Forms,* produced by the IUGG, transformed 1930s auroral science into a standardised, synchronised and internationally integrated activity. It put photography at the forefront of auroral research, creating a visual foundation for the study of the northern lights. This was not a simple task, and it was not inevitable that it would succeed. Rather, the atlas and the auroral researchers of the IPY overcame the difficulties of calibrating the camera lens across continents, generating the most comprehensive study of the morphology and verticality of the northern lights ever created. Of all the varied work included as part of the Second International Polar Year, the auroral photographic investigation was one of the most co-ordinated. No other area of focus had such a reference text, able to standardise practices and the mode in which results were presented to such a degree.

Historians have generally presupposed that the programmes of the Second IPY were co-operative.[413] Yet, little research has directly addressed the accuracy of this assumption. Many projects were in fact separately managed. For example, French plans for an integrated expedition to the Antarctic were derailed, so their researchers occupied stations at Scoresby Sound in relative isolation. Austrian scientists used huts in Jan Mayen that had been maintained by the Danish government but experienced little scientific co-operation during the programme and the Cambridge and Oxford University expeditions were completely disconnected from other IPY activity.[414] Moreover, other endeavours related to the northern lights, such as that of auroral spectroscopy, were considerably less

[412] Francis Celoria, 'The Alleged Dark Segment in Aurora Borealis Displays', *British Astronomical Association* 78 (1968): 129-132, 129.

[413] Elzinga, 'Through the Lens of the Polar Years', 317; Roger D. Launius, James Rodger Fleming, and David H. DeVorkin, 'Rise of Global Scientific Inquiry in the International Polar and Geophysical Years', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International and Geophysical Years* (London: Palgrave Macmillan, 2010): pp. 1-9, p. 3; Marc Rothenberg, 'Making Science Global? Coordinated Enterprises in Nineteenth-century science', in Roger D. Launius, James Rodger Flemng, and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (London: Palgrave Macmillan, 2010): pp. 23-36, p. 33.

[414] G. C. Simpson, 'The Second Polar Year 1932-1933', *Polar Record* 1, no. 2 (1931): 64-67.

co-ordinated. Auroral photographic research was unusual in its high levels of integration and communication because *The Atlas of Auroral Forms*, produced directly before the beginning of the Polar Year, was successful in its standardisation project.

For the most part, researchers engaged in the programme made manifest the protocols and aims of the atlas, enacting its instructions in the challenging and freezing conditions of the polar regions and producing images imbued with the stylistic conventions that it displayed. The new visual language the atlas introduced and its emphasis on well-defined correctly exposed serial images shaped the way convincing evidence of the phenomenon appeared after 1930. The atlas trained the eye to visualise the lights in specific ways: encouraging the viewer to pay close attention to the phenomenon's morphology, register the most active parts of the display and observe the movement of the aurora on a static photographic plate. The uniformity of the photographs allowed for comparison between continents, parallax calculations and the distinguishing of structural patterns at a glance.

The team at Chesterfield Inlet calculated the first height measurements of aurorae in Canada. Those working in Norway captured an enormous quantity of parallactic images. The expedition to Fort Rae followed the atlas closely, producing both parallactic and single station photographs. Scientists at Lerwick and Point Barrow also took thousands of photographs linked to the atlas's taxonomic scheme. After decades of speculation, the height to which aurorae descend was determined and information about its antecedent conditions, structure and development deduced. Knowledge of auroral heights was widely significant, directly informing understandings of layers of ionisation within the atmosphere, electron densities within the E-region and the disassociation of oxygen molecules at altitudes over 100km. Furthermore, the retrospective gaze, inherent in observing photographs, facilitated contemplation of the subjectivity of the photographic medium and shed new light on the sunlit aurora and the dark segment beneath auroral displays.

That being said, alterations were also made to the methods outlined in the atlas. Fort Rae scientists diverged from the IBC scale and overcame the problem of tarnishing during the developing process without reference to the atlas, while the Dutch party drew from different aesthetic principles in the creation of their images and used non-standard equipment. Significantly, the atlas also provided no instructions for the measurement of the photographic plates, an intrinsic and important aspect of the practice of auroral photography in the 1930s. The case of IPY auroral research thus demonstrates Tucker's argument that there is a disparity between the idealised methods of science as offered by an atlas and the practices carried out at ground-level.[415] Even though *The Atlas of Auroral Forms* was primed to determine the practices of the Second IPY, and for the most part did succeed, there were still circumstances wherein the activities of researchers needed to react to the conditions of the space in which they operated and overcome unexpected challenges thrown into the mix by the unpredictable

[415] Tucker, 'Objectivity, Collective Sight and Scientific Personae', 654.

aurora.

I have explored the verticality of the aurora, as both part of the phenomenon's evasive intangibility and a subject of direct scientific scrutiny, lending weight to the view that considerations of the vertical axis were deeply embedded within atmospheric studies of the twentieth century. The verticality of the aurora shaped how the phenomenon was observed, examined and photographed in the era. Bodies and instruments were positioned to view the aurora overhead, researchers were encouraged to include foreground objects in their photographs and thus visually connect the aurora to the ground, and the phenomenon was consistently conceptualised as an object out of reach, unpredictable and intangible. Moreover, calculating the altitude of the phenomenon was a key motivation for the IPY programme, a project which took into consideration both the horizontal distance between various stations and substations but crucially also the vertical height of aurorae. The concept of verticality deserves greater recognition within histories of the atmospheric sciences of the twentieth century to further provide the spatial turn with 'some vitality, some graininess, some needed texture.'[416]

This chapter has drawn attention to the auroral programme of the Second IPY as a standardisation project, stabilised by an atlas created specifically for the purpose of directing its research practices. As an instrumental and visually focused history, it has shown how an endeavour to fix and categorise an unruly, fleeting and variable phenomenon overcame and reacted to the challenges of vertical atmospheric fieldwork in extreme conditions. The historiography of the Second IPY would benefit from greater exploration of the scientific practices which took place within specific programmes as well as a more profound recognition of the embodied reactions of observers and the importance of the concept of the verticality to meteorological and atmospheric investigations.

[416] Reidy, 'Verticality and Why Mountains Matter', 587.

The Spectral Life of the Aurora Borealis: Sensing Colour and Audibility During the Second International Polar Year, 1932-33.

'I am from Whalsay and remember on clear and frosty nights about thirty years ago the 'pretty dancers' (as we called them) coming in wide yellowish streaks in the N.E. sky. They would flit to and fro, making a noise as if two planks had met flat ways – not a sharp crack but a dull sound, loud enough for anyone to hear. We boys got so used to this that we never heeded the noise when the pretty dancers came out to clap their hands'.[417]

This extract from a letter written by Shetland Islander, Peter Hutchison, was published in The Shetland Times on 20 May 1933. Relating tales of audible aurorae from thirty years prior, it was submitted in response to heightened interest in the possibility of auroral sound during the Second International Polar Year. The mention of the phenomenon's 'yellowish' hue also speaks to frequent discussions regarding the equivocal nature of auroral colour during the IPY.

The chromatic and audible qualities of the aurora are dealt with here in tandem because both necessitated the use of the bodily senses as an instrument of scientific inquiry. Moreover, both characteristics were transient, difficult to elucidate and considered to be potentially illusive. Indeed, they were spectral in the sense that they were quantities with a measurable wavelength but also in the sense of Shane McCorristine's *Spectral Arctic*: eerie, otherworldly and liminal.[418] Although within western scientific discourse the light and sound of the aurora are considered to be entirely separate aspects, this is not the case for more northern cosmologies. Within Sámi culture, the aurora is known as 'guovsahas', which can be translated to 'the audible light'.[419] Outside of the western hierarchy of the senses, the embodied registration of the phenomenon is not automatically considered an entirely visual preserve, thus motivating a connected, integrated investigation of the entire sensory witnessing experience.

In this chapter I explore the interplay between the aurora as an experiential and instrumental phenomenon, as it was conceived of by the IPY scientists of the 1930s, examining the way its impressions were sensed and communicated. The balance between reliance on the corporeal senses

---

[417] Peter Hutchison, 'Hearing the Aurora', *Shetland News*, 20 May 1933, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

[418] McCorristine, *The Spectral Arctic*.

[419] Asgeir Brekke, 'Aurora Borealis: How the Northern Lights got their misnomer', in Asgeir Brekke and Jon Børre Ørbæk (eds.), *Arctic Lights: Our Natural and Cultural Heritage* (Tromsø: Tromsø University Museum, 2006), p. 21.

and reliance on technological registration, however, differed in significant ways between the visual and audible investigations of the aurora. What was at stake with these multiple ways of recording the phenomenon was the very way the aurora was defined in the period.

The most significant deficiency of the photographic method, explored in the previous chapter, was that the photographic plate was insensitive to the brilliant hues of the northern lights. Nevertheless, the vivid colours of the aurora, ranging from common green to rare crimson and violet, were observed visually across all IPY stations researching the phenomenon, with careful viewing practices employed to ensure ocular reports could be calibrated. In many ways the investigation of auroral colour was a process of grappling with articulating the human body as an instrument. The aurora's fleeting hues were also examined simultaneously by means of spectroscopy, with a sensitivity dissimilar to the human eye. The primary aims, as proclaimed by the supplementary *Atlas of Auroral Forms* (1932), were to explore the many visible lines of the auroral spectrum aside from the predominant green line, correlate these with the altitude of aurorae, discover the intensity of various bands and to tabulate all spectroscopic observations. The atlas stated that 'up to the present time the question of the spectrum of the aurora must be considered as unsolved.'[420]

If the perception of auroral colour was a practice on the boundary of embodied and instrumental registers, taking place, at least partly, in the outdoor realm, then the effort to learn more about the disputed sound of the aurora was even more so a corporeal and hinterland pursuit. Crucially, it involved the sensory registers and viewpoints of local people and amateur scientists. By including the knowledge of laypeople, I probe its often uneasy relationship with what has been termed 'cosmopolitan' knowledge, or the established view of the scientific community.[421] There was considerable concern amongst auroral researchers as to whether the aurora's apparent sound was illusory, imagined or objective. Within the anglophone IPY literature, discussions surrounding the issue played out in a local Shetland Island newspaper as well as the academic journal, *Nature*. The auroral sound debate had consequences for understandings of the altitude of aurorae and therefore knowledge of the composition of the upper atmosphere as well as the verification of folkloric stories, but it also captivated and intrigued on an aesthetic level.

In the early 2000s, sound studies, focusing on the 'production and consumption of music, sound, noise and silence', became a dynamic area of interdisciplinary research.[422] Much work in the domain of sound studies has concentrated on the technologies of sound production. Alexandra Hui explores the impact of recorded music on the types of listening which came into being in the twentieth

[420] The International Geodetic and Geophysical Association, *Supplements to The Photographic Atlas of Auroral Forms*, p. 18.

[421] Vetter, *Field Life*, p. 15.

[422] Trevor Pinch and Karin Bijsterveld, 'New keys to the world of sound', in Trevor Pinch and Karin Bijsterveld (eds.), *The Oxford Handbook of Sound Studies* (Oxford: Oxford University Press, 2012): pp. 1-36, p. 4.

century (2012).[423] Emily Thompson similarly charts behavioural changes in early twentieth century American society in response to the new 'soundscape of modernity'. *The Oxford Handbook of Sound Studies* (2012), edited by Trevor Punch and Karin Bijsterveld, is self-consciously ordered by different sites including the laboratory, clinic, home and field and interrogates how noise within these various spaces has been staged, reworked, edited and consumed.[424] Together, these works argue for the consideration and reconfiguring of the relationship between sound, body and space. This theme of the literature is one that I will take up, in relation to the aurora, a phenomenon experienced through the senses and intrinsically tied to the polar regions.[425] The visuality of the aurora has often been taken for granted in historical works and only three pieces of secondary research exist on the topic of auroral sound, two of which are primarily scientific themselves.[426] The other is Shane McCorristine's exploration of auroral sound accounts during the earlier British search for the Northwest Passage between 1818 and 1859, explaining the ways in which the aurora, and its apparent noise, enchanted and re-enchanted witnesses.[427]

Perceiving Auroral Colour

As Diane Young succinctly notes, 'colours animate things in a variety of ways, evoking space, emitting brilliance, endowing things with an aura of energy' and can be combined to 'create a medley of effective and sensual impressions'.[428] This was certainly true of the aurora, its colourful displays deeply affecting those who viewed it.[429] Compelling, thought-provoking, and brilliant, visual fascination with the aurora likely motivated scientists of the Second IPY to participate in the programme, with an affinity for its iconography acting as the 'binding glue' of the loosely connected

---

[423] Alexandra Hui, 'Sound objects and sound products: standardising a new culture of listening in the first half of the twentieth century', *Culture Unbound: Journal of Current Cultural Research* 4 (2012): 599-616, 600.

[424] Pinch and Bijsterveld, 'New keys to the world of sound', p. 4.

[425] Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America* (Cambridge: The MIT Press, 2004), p. 2.

[426] Colin S. L. Keay, 'C. A. Chant and the Mystery of Auroral Sounds', *The Journal of the Royal Astronomical Society of Canada* 84, no. 6 (1990); Shane McCorristine, '"Involuntarily we listen": Hearing the Aurora Borealis in Nineteenth-Century Arctic Exploration and Science', *Canadian Journal of History* 48 (2013): 29-61; S. M. Silverman and T. F. Taun, 'Auroral Audibility', in H. E. Landsberg and J. Van Mieghem (eds.), *Advances in Geophysics* (Amsterdam: Elsevier, 1973): pp. 155-266..

[427] McCorristine, '"Involuntarily we listen"'.

[428] Diane Young, 'The Colour of Things', in Christopher Tilley, Webb Keane, Susanne Küchler *et al.* (eds.), *Handbook of Material Culture* (New York: Sage Publications, 2006): pp. 173-185, p. 265.

[429] The aesthetic appeal of aurorae is discussed in: Gunnar Thór Jóhannesson and Katrín Anna Lund, 'Aurora Borealis: Choreographies of Darkness and Light', *Annals of Tourism Research* (2017): 183-190.

scientific community. So crucial was the embodied register to the endeavour to discover the elements responsible for the colours of the aurora that, at the British Fort Rae Polar Year station, positioned on the northwest tip of Great Slave Lake in northern Canada, 'the extensive notes forming the record of these observations are based solely on the evidence of the eye'.[430]

Recording auroral colour was a process of negotiating the reliability and efficacy of the human senses as an instrument in the pursuit of knowledge about the distant phenomenon. The challenging nature of documenting the northern lights outdoors at night in northern Canada necessitated highly regulated performances of viewing. During the early season, from August to September 1932 at Fort Rae, one observer would stand in the auroral camera shelter for the entirety of a display, dictating its details to an assistant inside the nearby meteorological hut. Exhibiting the very local entangling of indoor and outdoor practices these researchers would communicate via a telephone wire and earpiece. The assistant, unable to see the phenomenon but equipped with a chronometer, recorded all relayed information alongside precise time measurements. The data transcribed often corresponded to the most active parts of the night sky or those parts which were most easily describable, rather than reflecting a holistic portrait of the phenomenon on a given night. Later in winter, this method of observation became untenable because displays could last for fifteen hours. After 20 September 1932, the outdoor observer was substituted for another member of the party every four or five hours, the longest period it was considered an individual could practically remain outside in freezing conditions.[431]

It was preferable for one individual to observe for as long as possible so that the results collected were more consistent. This is because auroral brightness and colour are subjective in three predominant ways, and thus one individual's account is more consistent than that of multiple people. First, an observer's eyes needed to adjust to the darkness of the outdoor environment, which could take up to half an hour, before they could be relied upon to record the phenomenon accurately. Second, the amount of training an auroral witness received and their experience of viewing the lights influenced their ability to understand what was unusual and worth noting down. As Balfour Currie, leader of the Canadian Chesterfield IPY expedition, recollected in 1947, 'the estimated values vary greatly with the conditioning of the observer's eyes to darkness at the time of an observation and with his past experience at observing auroras with a large range of luminosities'.[432] Third, aurorae could appear to have yellow or orange tinges due to the psychological blending of the upper red parts of the

[430] Stagg and The British National Committee for the Polar Year, *Some General Characteristics of Aurora at Fort Rae*, p. 251.

[431] Ibid.

[432] Currie, 'The Polar Aurora', 251.

phenomenon and the lower green colour, a common arrangement of displays.[433] Not representing a genuine emission, it required a trained observer to see beyond this ocular illusion.

The polar regions were known to be visually treacherous spaces where mirages and other atmospheric illusions could deceive the eyes. Viewers of Mount Erebus have experienced the colours of the mountain shifting increasingly towards the blue end of the chromatic spectrum as the evening light scatters, foreshortening the mountain from an observer's perspective due to the unusually dry atmospheric conditions of the Antarctic.[434] Moreover, in the 1840s, the Antarctic explorer Charles Wilkes was accused of 'immoral mapping', claiming to have discovered a vast Antarctic continent, having seen a superior mirage.[435] In Kathryn Yusoff's words, 'Antarctica presents a visual disturbance in the production of geographic knowledge.'[436] Vision alone could not guarantee accuracy but trained vision, that which was employed at the Canadian Polar Year stations, could be relied upon, at least in theory, to mitigate the collection of spurious data, providing the most standardised observational information possible.

There is a clear resemblance between the tandem practice of observing the fleeting light of the aurora and the procedure that was used at the Cavendish Laboratory in Cambridge to count scintillations in the early 1920s under the direction of Ernest Rutherford.[437] The scintillation counter was an instrument consisting of a glass plate covered with zinc sulphide which would flash when hit by a charged particle. Used to quantify alpha, beta and gamma radiation emitted from a radioactive source, it was hoped this method would reveal the constituents of the atom. During the experiment, one individual would sit in a darkened room with the radioactive source, watching for flashes on the scintillation screen through a microscope. A period of two minutes would be timed before the observer relayed the number of flashes to another experimenter sitting in the next room, who recorded the information and reset the apparatus while the first observer was blindfolded so that their eyes could stay accustomed to the darkness.[438] Much like in the polemical Cambridge-Vienna controversy

---

[433] Joseph W. Chamberlain, *Physics of the Aurora and Airglow: International Geophysics Series*, vol. 2 (Cambridge: Academic Press, 1961), p. 125.

[434] Fox, 'Walking in Circles', p. 28.

[435] Kathryn Yusoff, 'Climates of Sight: Mistaken Visibilities, Mirages and 'Seeing Beyond' in Antarctica', in Denis Cosgrove and Veronica della Dora (eds.), *High Places: Cultural Geography of Mountains, Ice and Science* (2008): pp. 48-64, p. 49.

[436] Ibid., 53.

[437] Maria Rentetzi, *Trafficking Materials and Gendered Experimental Practices: Radium Research in Early Twentieth Century Vienna* (New York: Columbia Press, 2008), p. 141.

[438] C. G. Darwin, 'The Discovery of Atomic Number', *New Zealand Science Review* 14 (1956): 102-108, 102; Jeffrey Alan Hughes, 'The Radioactivists: Community, Controversy and the Rise of Nuclear Physics', unpublished thesis (1993), *University of Cambridge*.

of the 1920s, the standardisation and calibration of results was of the utmost importance to researchers of the IPY. The situation in the Arctic differed, however, in that no results were queried by other research groups. In fact, imperfect results were anticipated from the chaotic auroral phenomenon, and no individual piece of data was deemed significant enough to be challenged.

The expectation of imperfect results explains why auroral observations were documented relatively imprecisely within the IPY logbooks. The aurora was rendered as it was seen, even if it eluded neat categorisation. At Fort Rae, terms including 'purple-ish red colour' and 'probably much highly coloured band activity' were recorded.[439] The researchers at College, Alaska employed an initial system, wherein common green aurorae were represented by the letters 'GR' and red and purple aurorae appeared as 'RD' and PR' respectively.[440] Usually exceedingly bright, the auroral green line was surprisingly described as 'very pale' at Sheridan, Wyoming on 31 May 1933.[441] Observers at Columbus Ohio logged an unusual white and pale yellow aurora, 'brighter than the brightest of lunar halos' on 20 October 1932.[442] 'Bands of brilliant pink and green, curtains and pulsating surfaces' were catalogued at the Lerwick Observatory on 4 April 1932. Similarly, 'brilliant green and red colours' were seen from a number of places in Scotland on 3 April 1932.[443] Although it was deemed necessary to report auroral colours, drawing attention to unusual hues, there was no systematic taxonomic scheme underwriting the geographically disparate IPY records. Plausible, persuasive accounts of auroral colour based on honest visual observation were valued over precise but shallow records.

The difficulty with which experiential auroral colour observations were calibrated compelled IPY researchers to turn to an alternative means of determining the phenomenon's hues. Rather like the problem of discussing coloured stars in the nineteenth century, a standardised methodology was required. In 1825 William Henry Smyth began observing deep-sky objects from his private observatory in Bedford, UK, which was fitted with a 5.9-inch refractor telescope. Significantly, Smyth published a chromatic scale for the classification of double stars using optical astronomy in

---

[439] Fort Rae Expedition Members, 'Auroral Observations made at Fort Rae'; Fort Rae Expedition Members, 'Auroral Log Record, Polar Year 1932-1933', *Aberdeen Archives*, MS. 3152/26/3.

[440] US Department of Agriculture: Weather Bureau, '1933 Visual Observation Aurora College Alaska Class 2', *Auroral Data Obtained during the Second International Polar Year, August 1932-August 1933* (1938), Second International Polar Year Records, *Department of Terrestrial Magnetism*, *Washington*, Image 9408, Series 1, Subseries C: Aurora Binder, October 1932-September 1933, Box 3a, folder 3.

[441] Ibid., 189.

[442] Ibid., 190.

[443] Air Ministry Meteorological Office, *The Observatories' Year Book 1932*, pp. 45-47.

1864, entitled, ‘Sidereal Chromatics, or the Colours of Multiple Stars’.[444] Furthermore, Horace Benedict de Saussure, a Genevan geologist and explorer, created the cyanometer in 1789, an instrument consisting of sheets of 52 shades of blue paper, used to compare the colour of the sky at different altitudes. Both systems for classifying colour aimed to make communicable visual aspects of their scientific subjects. The spectroscope was heralded as the instrument which could not only establish the wavelengths of auroral colours precisely but also give an indication as to their mechanism. It was discussed as an instrument providing ‘objective registration of the aurora borealis’ by Harang, the director of the Tromsø Observatory.[445]

Instrumental Sensing of Auroral Colour

During the winter of 1867-1868 Anders Jonas Ångström, Professor of physics at Uppsala University, carried out the first spectroscopic observation of the aurora using a theodolite and transmission grating.[446] The light he observed was almost monochromatic but did not correspond with any known simple gases.[447] A multitude of theories were put forward relating the causes of Ångström’s spectroscopic line, later identified as having a wavelength of 5577 Å. At the end of the nineteenth century Norman Lockyer theorised that it could be a result of meteoritic manganese whereas Carl Runge and Arthur Schuster favoured Krypton.[448] John McLennan was awarded the Royal Society Gold Medal for discovering the cause of the green light of the aurora and presented his finding at the Bakerian Lecture in London in 1928.[449] He asserted that green aurorae at altitudes lower than 250km resulted from a ‘forbidden’ transition between two metastable states of atomic oxygen, $^1D_2$ and $^1S_0$.

444 William Henry Smyth, *Sidereal chromatics; being a re-print, with additions, from the “Bedford cycle of celestial objects,” and its “Hartwell continuation,” on the colours of multiple stars* (London: John Bowyer Nichols and Sons, 1864).

445 Leiv Harang, 'An Apparatus for Registration of the Aurora Borealis', *Magnetism and Atmospheric Electricity* 37 (1932): 167-168, 167.

446 Simón Reif-Acherman, 'Anders Jonas Ångström and the Foundation of Spectroscopy – Commemorative Article on the Second Centenary of His Birth', *Spectrochimica Acta Part B: Atomic Spectroscopy* 102, no. 1 (2014): 12-23, 21.

447 Helge Kragh, 'Auroral Chemistry: The Riddle of the Green Line', *Bull. Hist. Chem.* 35, no. 2 (2010): 97-104, 99.

448 Norman Lockyer, 'On the Wave-length of the Chief Fluting Seeing in the Spectrum Manganese', *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 46 (1889): 35; C. Runge, 'The Origin of the Aurora Spectrum', *Nature* 59 (1898): 29; Arthur Schuster, 'The Origin of the Aurora Spectrum', *Nature* 58 (1898): 151.

449 J. C. McLennan, 'Bakerian Lecture – The Aurora and its Spectrum', *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 120 (1928): 327-357, 341.

Atomic oxygen is excited by electrons dissipated from nitrogen molecules, which have been ionised by the sun's radiation, and in dropping back down to its original energy level, a photon of 550nm is produced.

It was within this context, four years later, that the IPY continued the project of auroral spectroscopy, focusing on the elements which cause crimson and violet aurorae. Helge Kragh's research on the auroral green line debate, spanning from the 1860s until 1928, deals with the interplay between theory and experiment. I explore 1930s auroral spectroscopy from a novel perspective, scrutinising situated practices of Arctic IPY research.[450] Much like the discipline of astrophysics in the late nineteenth century, examined by Charlotte Bigg, auroral spectroscopy occupied a space on the permeable boundary of the laboratory, field and observatory, often moving between them.[451]

The spectroscopic view of the aurora, while produced by an instrumental device, was not antithetical to the aesthetic experience of witnessing auroral colour. Joseph Kaplan, an eminent American geophysicist and later the first director of the University of California's Institute of Geophysics and chairman of the US national committee for the International Geophysical Year, was drawn to the aurora for its 'fickleness, since no two aurorae have exactly the same spectrum'.[452] He marvelled at the 'strange combination of lines and bands' auroral colours produced in spectrographs.[453] Explicitly referring to the iconographic power of spectroscopic imagery, Kaplan's personal fascination reveals the possibility of an aesthetic response to the more ordered, rigid, labelled lines of a spectrograph, compared to a wild, flowing auroral display.[454] Nor was astrophysical spectroscopy considered to be a purely mechanical pursuit. As Charlotte Bigg has argued, 'astrophysical spectroscopists developed skills for making spectroscopy reliable, making it a practice of experts, whose bodies and minds became finely tuned to the conditions necessary for its successful performance.'[455]

---

[450] Kragh, 'The Spectrum of the Aurora Borealis'; Helge Kragh, 'The Green Line: A Chapter in the History of Auroral Physics', *Astronomy and Geophysics* 50, no. 5 (2009): 525-528; Kragh, 'Auroral Chemistry'.

[451] Charlotte Bigg, 'Staging the Heavens: Astrophysics and Popular Astronomy in the Late Nineteenth Century', in David Aubin, Charlotte Bigg, and H. Otto Sibum (eds.), *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture* (Duke Uni. Press, 2010): pp. 305–324.

[452] Joseph Kaplan, 'The Production of the Auroral Spectrum in the Laboratory', *Transactions of the American Geophysical Union* 15, no. 1 (1934): 162-165, 162.

[453] Ibid.

[454] This visual appreciation of spectra has been noted by Klaus Hentschel as being 'abound in the spectroscopic literature', although more common in the nineteenth century than the twentieth century: Klaus Hentschel, *Mapping the Spectrum: Techniques of Visual Representation in Research and Teaching* (Oxford: Oxford University Press, 2002), p. 457.

[455] Bigg, 'Spectroscopic Meteorologies', 776.

Guidelines were put in place to standardise the instrumental practice of auroral spectroscopy for the Polar Year, as recounted by Currie and his colleague, H. W. Edwards, in 1936.[456] A helium spectrum was taken before and after each night of spectrographic work to ensure that the apparatus was calibrated correctly. The instrument was to be pointed at the brightest region of the display if the phenomenon was present and at an altitude approximately 60 degrees above the southern region if not. The spectroscope should be exposed for a period between half an hour and two hours. In contrast to the photographic work there was no standard spectroscopic instrument employed by all participating research groups. Presumably this was because the spectrographic results were calibrated by comparisons with known wavelengths and thus did not need to rely on the same model of instrument for legitimacy.

Significantly*, The Atlas of Auroral Forms* advised that a pocket spectroscope be used during the IPY to decipher whether an atmospheric luminosity was an aurora or just an illuminated cloud.[457] Researchers were instructed to rely on this instrumental definition, dependent on whether the green line at 5577 Å was present, as a diagnostic tool. The auroral spectrum was decomposed to a single element, despite each aurora producing unique sets of spectroscopic bands. What had been understood as a symptom of the aurora since the 1860s was moulded into a criterion. The reality, however, was less clear-cut. During the IPY the green line definition of aurorae was challenged, and most researchers understood and recorded the aurora as existing only if they could see it, while

Fig. 46. 'Spectroscope encased in a white box on the concrete roof of the Tromsø Auroral Observatory, 1930', from the *collections of the Perspektivet Museum.*

[456] Currie and Edwards, 'On the Auroral Spectrograms Taken at Chesterfield', 265.

[457] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*, p. 20.

conceptualising the aurora as a transient and unruly phenomenon.

The majority of spectroscopic images generated during the IPY depict the relative intensities of auroral bands, represented by the thicknesses of the lines, in a horizontal or vertical scheme. The images were generally qualitative, only featuring labels of lines discussed in the accompanying text and the line at 5577 Å. Spectra taken at different times or of different elements could be compared at a glance. *The Henry Draper Catalogue,* providing spectroscopic classifications of 225,300 stars, published in several editions between 1918 and 1924, also encouraged this way of viewing spectra.[458] Similarly, as Daston and Galison argue, the Morgan, Wilson, Keenan and Kellman *Atlas of Stellar Spectra* (1943) relied on its readers making visual judgements in flashes of recognition.[459] That being said, in many cases a comparator was also used to determine the wavelengths of auroral light after the spectroscopic images had been projected onto a screen.[460] This method seemed 'wiser than the more quantitative micro-chronometer methods', according to Currie and Edwards, because it allowed for the varying lengths of auroral exposures on separate plates.[461] Strong auroral radiations were also identified by comparison with the known spectrum of helium.[462]

When the Tromsø Auroral Observatory was established in 1928, two spectroscopes of high dispersion and light gathering power were assembled on the roof of the building, housed inside wooden containers fitted with temperature controls.[463] Vegard, in charge of the Norwegian spectroscopic exploration of the aurora, spent much time at Tromsø during the IPY. As he stated in a synoptic overview of his activity in 1933, 'up to the present 83 lines and bands have been observed [in the auroral spectrum], which means that 33 new lines and bands have been detected through the work at the new auroral observatory'.[464] The four spectrograms shown in fig. 47 were captured by Vegard with the large glass spectroscope at Tromsø between February and March 1933 and published in 1935. Taken with the same slit aperture on different nights, they all represent the violet band at 4278 Å.[465] These simple, almost identical representations visually reinforce the presence of a consistent

[458] A. Jump Cannon and E. C. Pickering, 'The Henry Draper Catalogue' (1918), *Cambridge: The Observatory*.

[459] Morgan, William Wilson, Philip Childs Keenan *et al.*, *An Atlas of Stellar Spectra with an Outline of Spectral Classification* (Chicago: University of Chicago Press, 1943), p. 335.

[460] Currie and Edwards, 'On the Auroral Spectrograms Taken at Chesterfield', 266.

[461] Ibid.

[462] Ibid., 268.

[463] Alv Egeland and William J. Burke, 'Auroral Research at the Tromsø Northern Lights Observatory: The Harang Directorship, 1928-1946', *History of Geo and Space Sciences* 7 (2016): 53-61, 55.

[464] Lars Vegard, 'The Auroral Spectrum and the Upper Atmosphere', *Nature* 132 (1933): 682, 682.

[465] Vegard also spent much time investigating the spectroscopic lines responsible for red aurorae in: Lars Vegard, 'The Interpretation of the Northern Lights and the Structure of the Ionosphere', *Results of the Exact*

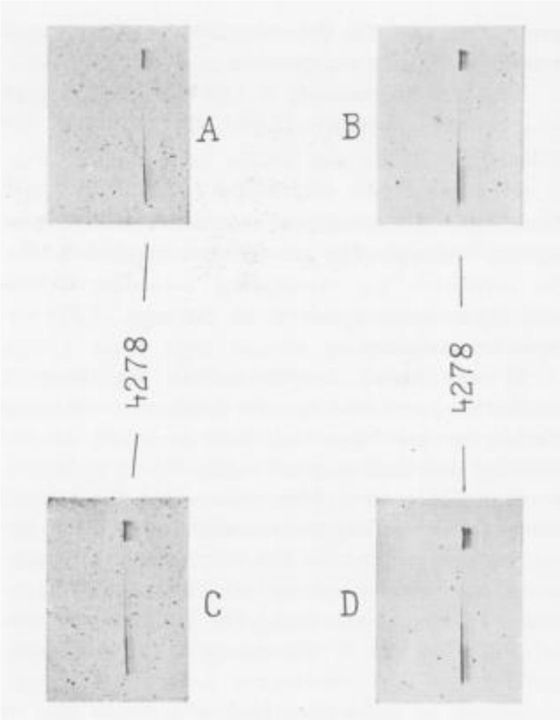


Fig. 47. Four Spectrograms captured by L. Vegard and E. Tønsberg in February-March 1933 in L. Vegard and E. Tønsberg, 'Continued Investigations on the Temperature of the Upper Atmosphere Determined by Means of Bands Appearing in the Auroral Spectrum', *Geof. Publ.* XI, no. 2 (1935), 6.

Fig. 48. Professor Lars Vegard, photographed by Narve Sharp, *Nasjonalbiblioteket*, Norway, Prof. Vegard File Number: 475.

characteristic of all aurorae (though not the auroral green line), and thus a spectroscopic base line for the detection of aurorae.

Identifying this violet emission within the auroral spectrum was achievement enough but Vegard wished to use the measurements of the band at 4278 Å to estimate the temperature of the atmosphere at the altitude at which aurorae occur.[466] To do so, he and E. Tønsberg measured the intensity of the bands by placing a Zeiss Stufenfilter intensity scale in front of the spectrograph slit and then compared this distribution with 'a theoretical expression corresponding to a Maxwellian

---

Natural Sciences (1938): 229-281; Lars Vegard and E. Tonsberg, 'Enhancement of Red Lines and Bands in the Auroral Spectrum from a Sunlit Atmosphere', *Nature* 137 (1936): 778-779.

[466] Lars Vegard and E. Tønsberg, 'The Temperature of the Auroral Region Determined from Band Spectra', *Geof. Publ.* 3 (1938): 3-7; Lars Vegard and E. Tønsberg, 'Investigations on the Auroral and Twilight Luminescence including Temperature Measurements in the Ionosphere', *Geof. Publ.* 13, no. 1 (1940): 3-22.

distribution of rotational energy'.[467] If the observations obeyed the theoretical law, the energy within the band system could be found and from this the maximum temperature of the element positioned in the atmosphere could be derived. Vegard and Tønsberg calculated the temperature to be approximately -48 degrees Celsius.[468] This result, though not corroborated by further reports, represented a contribution to understandings of the rarity and conditions of the thermosphere in the 1930s.

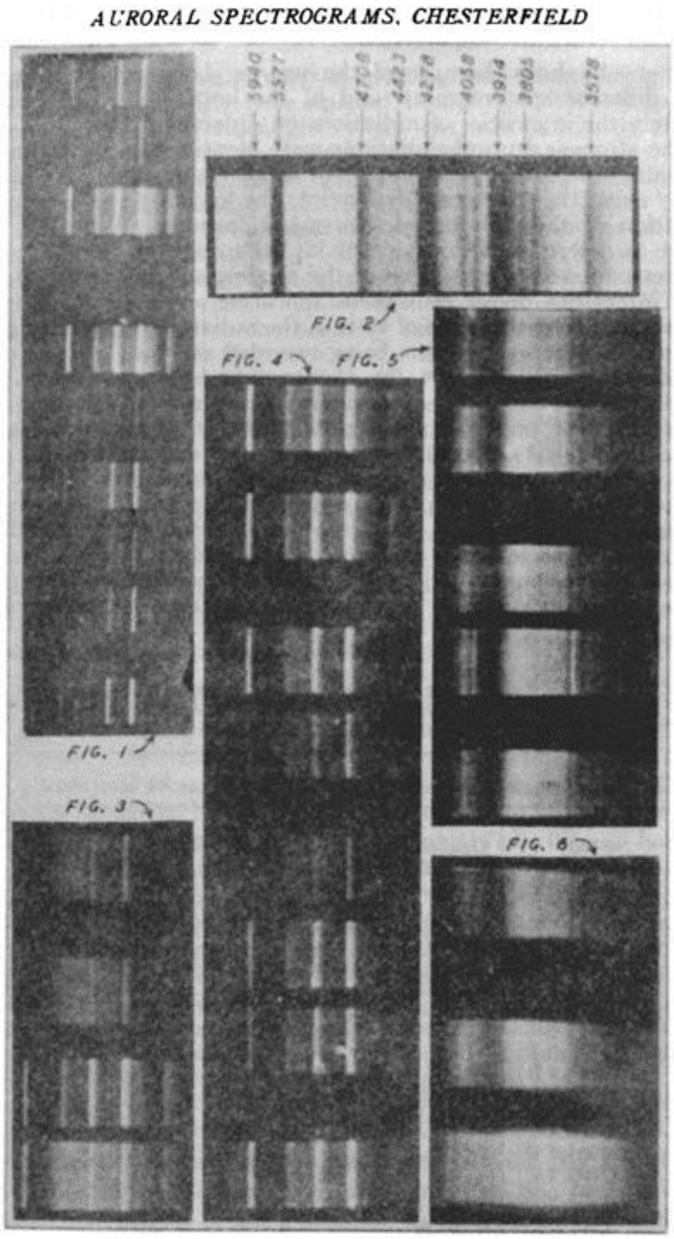


Fig. 49. 1-6 Typical Spectrograms taken at Chesterfield, Canada in Currie, B. W. and H. W. Edwards, 'On the Auroral Spectrograms Taken at Chesterfield, Canada, During 1932-1933', *Terrestrial Magnetism and Atmospheric Electricity* 41, no. 1 (1936), 265.

[467] Lars Vegard and E. Tønsberg, 'Continued Investigations on the Temperature of the Upper Atmosphere Determined by Means of Bands Appearing in the Auroral Spectrum', *Geof. Publ.* 11, no. 2 (1935): 3-14, 4.

[468] Ibid., 13.

At the Chesterfield station in Canada, Currie and Edwards employed the same spectroscope used by McLennan in the 1920s in their study of the 5577 Å line.[469] In 1936 they published a study of 693 auroral spectrograms taken during the IPY.[470] Crowded onto one page and shown in fig. 49, Currie and Edwards presented six 'typical' spectrograms as an overview of their results.[471] The second spectrograph displayed is a synoptic image, depicting the most common wavelengths appearing at Chesterfield, with prominent bands at 5577, 4278 and 3914 Å. Their third spectrograph portrays negative band systems without the auroral green line. Taken on 2 January 1933, the fourth plate relates the greater intensity of red radiations during twilight periods. With these results Currie and Edwards concluded that the Vegard-Kaplan band system, a nitrogen band system discovered by Vegard and Kaplan during the Polar Year, was commonly visible in the aurora and red radiations increased in intensity during twilight and moonlit periods.[472]

Surprisingly, their visual and spectrographic records did not correspond well, which Currie and Edwards attributed to the varying exposure times of the spectrographic plates and the fact that bright aurorae were observed between periods when the spectroscope was used. This implied that embodied visual observations could not be halted because they yielded diverse, and sometimes contradictory, information and could be carried out in the time it took to set up the spectroscopic apparatus. Similarly, there was a low correlation-coefficient between intense spectrographic activity and records of magnetic and electrical activity. This, Currie and Edwards accounted for by arguing that bright aurorae may be displaced from the location of the fluctuating earth currents.

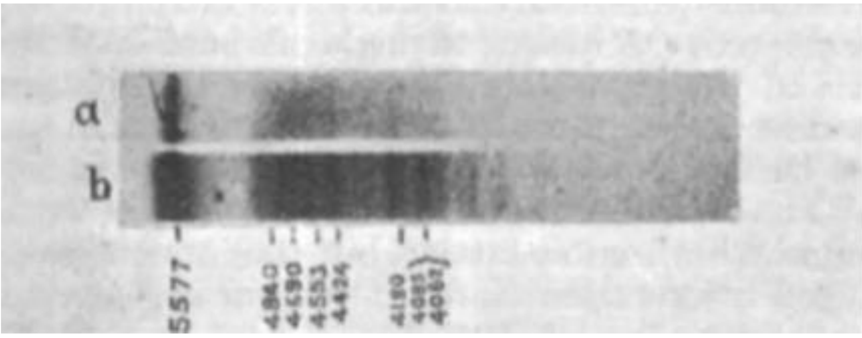


Fig. 50. Spectrum (a) Zodiacal Light and the Night Sky; (b) Night Sky taken 12-29 April 1933, in K. R. Ramanathan, and J. V. Karandikar, 'Spectrum of the Night Sky and of the Zodiacal Light', Nature, 132 (1933), 749.

[469] Currie and Edwards, 'On the Auroral Spectrograms Taken at Chesterfield', 266; J. C. McLennan and J. J. C. Ireton, 'Spectroscopy of the Light from the Night Sky', *Canadian Journal of Physics* 2 (1930): 279-290.

[470] Currie and Edwards, 'On the Auroral Spectrograms Taken at Chesterfield', 265.

[471] Ibid.

[472] Currie and Edwards, 'On the Auroral Spectrograms Taken at Chesterfield', 271; Joseph Kaplan, 'New Band System in Nitrogen', *Physical Review* 44, no. 11 (1933): 947, 947.

The problem of whether the auroral green line was present in the night sky spectrum as well as the auroral spectrum was researched by several groups during the IPY. Currie and Edwards argued that because the line at 5577 Å did not appear in several of their spectrographs, 'the green-line luminescence is not a permanent characteristic of the night-sky light at Chesterfield as it is at lower latitudes', thus making it a unique auroral characteristic which could be used for identification purposes.[473] K. R. Ramanathan and J. V. Karandikar, carrying out investigations at the Meteorological Office at Poona, India, contradicted the Chesterfield results. They asserted that the green line was a general characteristic of the night sky spectrum at all latitudes.[474] The persuasive image Ramanathan and Karandikar published is a stark representation of their claim, with the line at 5577 Å bold against a white background in both their night sky and zodiacal light spectrographs. The major difference between the two experiments was that the spectroscope used in India was exposed for 27 and 75 hours respectively between 12 and 29 April 1933, whereas the Canadian research group used a maximum of two-hour exposures. The Indian team purposefully used unusually long exposures because they expected to find the line at 5577 Å after Jean Dufay had found the emission within the night sky spectrum in France. The instrumental practice of allowing much greater time to elapse made visible a feature on the fringes of the spectroscope's sensitivity.

Confident that their low latitude position would ensure no interference from the aurora, Ramanathan and Karandikar explicitly aimed to settle a 'non-agreement of views between different investigators' on whether the night-sky and auroral spectra were identical.[475] The Indian researchers justified their universality argument by referring to Dufay's results as well as to those of Vesto Melvin Slipher working in the US.[476] They agreed that the spectrum of the aurora differed from that of the night-sky because the aurora contained negative nitrogen bands which could not be detected in the night sky spectrum but insisted that the 'auroral green line' existed in both. Chapman, one of Britain's leading geophysicists, emphasised the significance of this debate for questions about the composition of the upper atmosphere.[477] The difference between the night-sky spectrum and that of the aurora, according to Chapman, was that the atmospheric particles experienced much stronger excitation during auroral displays and thus the auroral green line was simpler to detect. These findings and the

---

[473] Currie and Edwards, 'On the Auroral Spectrograms Taken at Chesterfield', 271.

[474] K. R. Ramanathan and J. V. Karandikar, 'Spectrum of the Night Sky and of the Zodiacal Light', *Nature* 132 (1933): 749, 749.

[475] K. R. Ramanathan, 'A Note on the General Spectrum of the Night Sky as observed in India', *Nature* (1932): 406-410.

[476] J. V. Karadikar, 'Lines or Bands in the Spectrum of the Night Sky', *Indian Association for the Cultivation of Science* (1934): 245-250, 245.

[477] Sydney Chapman, 'On the Production of Auroral and Night-Sky Light', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 66 (1937): 657-665, 663.

subsequent discussion cast doubt on the instrumental definition of the aurora as a phenomenon which contained the green spectroscopic line at 5577 Å.

Vegard also brought into question the green line definition of aurorae while investigating auroral colour beyond the visible spectrum and thus beyond the realm of experientiality. In preparation for the Polar Year, he made inquiries as to which plates would best capture the infrared light of the aurora. Dr. Brucke and Dr. Lacmann, working in Berlin, advised that the Agfa infrared plate 810 would be most suitable.[478] Five months before the Polar Year, Vegard tested these plates with the Tromsø spectroscope, finding two clear auroral absorption lines within the infrared region of the electromagnetic spectrum. He asserted, 'they have very much the appearance of band sequences belonging to the first positive group of nitrogen'.[479] Throwing into question McLennan's 1928 announcement, Vegard argued that if 'the auroral line 5577 Å is to be identified with the oxygen line observed by McLennan, we should expect a number of oxygen lines to appear in the infra-red… None of these oxygen lines can be identified with the two infrared auroral lines.'[480] Indeed, in 1939 in a paper published with B. Rypdal, he concluded that 'the typical auroral spectrum does not correspond to one definite condition of excitation, but to a range of conditions varying within wide limits.'[481] Spectroscopic investigations revealed the elements responsible for violet aurorae, brought to light common auroral wavelengths, and expanded the investigative gaze beyond the visible spectrum. Yet, significantly, spectroscopic analysis also challenged the instrumental definition of the aurora as a line at 5577 Å within the polar year programme.

Auroral Audibility

Although sight has long occupied the premier position in western conceptions of the senses, auditory perception has nonetheless been valued highly.[482] Sound and hearing were subject to scientific scrutiny in the nineteenth century. For example, Parisian physiologist, François Magendie, studied the degeneration of aural perception with age and the pain associated with listening to high-pitched noises. In 1860 Ernst Mach began his investigation of the sense of passing time using modified metronomes. In 1863 Herman von Helmholtz published *Sensations of Tone,* a foundational work on acoustics and auditory perception. William Wundt, the German physiologist generally considered the

[478] Lars Vegard, 'Spectrographic Observations of Infra-red Lines in the Auroral Spectrum', *Nature* 129 (1932): 468, 468.

[479] Ibid.

[480] Ibid.

[481] B. Rypdal and L. Vegard, 'The Excitation Functions of Nitrogen Bands and their Bearing on Auroral Problems', *Geof. Publ.* 12, no. 12 (1939): 3-20, 3.

[482] Howes and Classen, 'Introduction: Ways and Meaning', p. 9.

founding father of experimental psychology, published a treatise related to the mind's differentiation of various tones in 1891.[483] Richard Staley's recent research shows the strong connection between the physical sciences, sensation and psychological research in the nineteenth century.[484] Furthermore, only two years before the beginning of the First IPY the phonograph cylinder, an early device for the recording and reproducing of sound, was patented by Thomas Edison. It became commercially available, as did disc records, in the 1880s. Sound recording devices such as the phonograph introduced new modes of listening, most significantly for the purpose of this article: hearing noises recorded in the past.

Indeed, even auroral sound had been discussed within western scientific discourse since the middle of the nineteenth century. J. R. Capron published descriptions of the strange noises accompanying the northern lights from a number of observers in 1879, despite disbelieving them himself.[485] One year before the First Polar Year, George Burder asked in *Nature* whether apparent auroral sound could be a physiological phenomenon akin to the hissing the brain conjures when a meteor is witnessed.[486] Major Dawson, in charge of the British Polar Year Expedition to Fort Rae of 1882-3, claimed to have heard the aurora himself, likening the sound to the 'sharp squall of wind in the rigging on a ship'.[487] In more northern cultures the concept of auroral audibility was far more deeply entrenched. In the Sámi language the aurora is known as 'guovsahas', which can be translated to 'the audible light'.[488] The two senses were linguistically connected, elevating the sound of the aurora to a defining feature of the phenomenon, in stark contrast to the western hierarchy of the senses which privileged vision.

In his outline of the work scheduled to take place during the Second IPY published in 1932, Malcolm Rigby wrote for the *Bulletin of the American Meteorological Society* that auroral sound was 'one of the most disputed points not only among scientists but among laymen as well'.[489] Chapman considered the Second IPY a unique opportunity to research the connection between auroral sound and unusually low aurorae. He asserted that 'with the better organisation of auroral observation which

[483] Wilhelm Wundt, *Ueber Vergleichungen von Tondistanzen* (Leipzig: Druck von Breitkopf & Härtel, 1891).

[484] Richard Staley, 'Sensory studies, or when physics was psychophysics: Ernst Mach and physics between physiology and psychology, 1860-71', *History of Science* 59, no. 1 (2018): 93-118, 96.

[485] C. S. Beals, 'The Audibility of the Aurora and its Appearance at Low Atmospheric Levels', *Journal of the Royal Astronomical Society of Canada* 27 (1932): 184-200, 184.

[486] George E. Burder, 'Sound of the Aurora', *Nature* 23 (1881): 529; E. Hubbard also argued for the psychological expectation of the sounds producing them in the mind in 1881 in: E. Hubbard, 'Sound of the Aurora', *Nature* 24 (1881): 5.

[487] Henry P. Dawson, 'The British Circumpolar Expedition', *Nature* (1882): 484-485, 484.

[488] Brekke, 'How the Northern Lights got their misnomer', p. 21.

[489] Rigby, 'Recent Research of the Aurora', 197.

it is hoped will be achieved during the proposed new Polar Year, there is more chance that opportunities for critical examination of these appearances will occur.'[490] The incidence of loud aurorae was understood to be rare; it was estimated among observers who believed in the sounds that only 5% of violent aurorae produced them.[491] The criteria for sifting through data shifts when a phenomenon is known to be extremely uncommon: individual accounts or single pieces of information become more significant pieces of evidence. It was hoped that the thirteen-month IPY programme would provide answers to the auroral sound problem. As Raviv Ganchrow, an artist and researcher of sound, argues, 'listening *takes* place. Acts of listening emplace subjectivity and situate eventfulness'.[492] Environmental listening is an activity which is intrinsically situated.

At the Chesterfield site, Currie and Frank Davies conducted an extensive survey, asking the local inhabitants of the west coast of Hudson Bay, including traders, policemen and missionaries, whether they had ever heard sound accompanying the northern lights. Setting up an overt dichotomy in the description of their results, Currie and Davies detailed the answers of the indigenous population and 'white people' separately.[493] They demoted the significance of indigenous testimony, arguing that it 'may be faulty and have induced a greater susceptibility to a subjective effect'.[494] Just as the indigenous accounts of auroral sound were partially discounted, so too have indigenous knowledges been continually subject to considerable doubt in histories of polar exploration, demonstrating the ingrained colonial mindset which dictated which bodies and whose senses could be relied upon for veridical perception. The implication that not all bodies are treated as equally reliable or trustworthy instruments for knowledge creation is explored in Nanna Kaaland's research on the construction of authority in Arctic travel narratives of the nineteenth century.[495] In particular, the uneasy position of indigenous voices, such as Suersaq, an Inuk and cultural intermediary hired by the Second Grinnell expedition of 1853-1855 in search of the lost Franklin expedition, is addressed. His knowledge,

---

[490] Chapman, 'The Audibility and Lowermost Altitude of the Aurora Polaris'; Other strange sounds were also reported from the IPY stations during the winter of 1932-3. For example, French physicist, A. Dauvillier, reported unusual sounds emanating from Inland ice in Greenland: A. Dauvillier, 'Strange Sounds from Inland Ice, Greenland', *Nature* 133 (1934): 836.

[491] Beals, 'The Audibility of the Aurora and its Appearance at Low Atmospheric Levels', 198.

[492] Raviv Ganchrow, 'Fray', in Arie Altena (ed.), *The Dark Universe* (Amsterdam: Sonic Acts Press, 2013): pp. 118-131, p. 126.

[493] Davies and Currie, 'Audibility of the Aurora and Low Aurora', 856.

[494] Ibid.

[495] Nanna Kaalund, *Explorations in the Icy North: How Travel Narratives Shapes Arctic Science in the Nineteenth Century* (Pittsburgh: University of Pittsburgh Press, 2021).

Kaalund argues, 'did not fit comfortably into the established perception of the Arctic explorer' in a period during which the identity of a legitimate Arctic explorer was in the process of being defined.[496]

Particularly frequent accounts originated from Burrel on Hudson Straits, Harrison on the east coast of Hudson Bay and in the region between Chesterfield Inlet and the Churchill River, albeit very few had heard the sounds at Baker Lake and none could recall the sounds from Southampton Island. In the testimonies Currie and Davies received there was little correlation between unusually low aurorae and the sounds, but an almost universal association between the noises and violent, rapidly moving aurorae positioned directly overhead. Despite the distinction made by Currie and Davies, members of all ethnographic groups interviewed claimed to have heard the aurora. Crucially though, no one involved in the survey had heard the aurora in the winter of 1932-3, leading Currie and Davies to conclude that they resided in the region in a particularly 'quiet' year.[497] Currie also kept a diary of unusual optical and acoustical phenomena throughout the Chesterfield expedition. Clearly hoping to hear the aurora himself, he included second-hand accounts of 'whistling' or 'rustling' accompanying some displays and retold a story of the aurora descending so low that it killed a small number of people, which he noted could have been due to the destructive effects of lightning.[498] Here, Currie displayed his own paternalistic disbelief in accounts which could not be reconciled with received scientific discourse, offering his own secondary version of a more 'realistic' scenario.

The exception to the 'quiet year' was the account of John Rae, an assistant observer on the Canadian Chesterfield expedition, who claimed to have heard auroral sounds on 20 March 1933, asynchronous with the phenomenon's movement.[499] Both Currie and Davies were engaged in parallactic photography at the time and listened unsuccessfully for the sounds, although they witnessed the 'brilliant greenish-white flashes' darting overhead.[500] Introducing another subjective factor into the debate, they noted that they may have been unable to perceive the sounds 'due to less sensitive hearing', compared to the 23-year-old Rae.[501] They put forward the argument that the bodies of younger people could be more assuredly relied upon to register the sounds. The height determinations calculated from the photographs showed no unusual displacement of the phenomenon.

---

[496] Ibid., 172.

[497] Reginald Ruggles Gates reported hearing a 'low hissing or swishing' at Fort Smith on Slave River in the Canadian North West on 10 August 1928 in: Ruggles Gates, 'The Audibility and Lowermost Altitude of the Aurora Polaris', *Nature* (1931): 486.

[498] Balfour W. Currie, 'Record of Optical, Acoustical and Unusual Phenomena', notebook 1932-1933, an edited transcript of the diary appeared in the #35, Spring 1987 issue of The Musk-Ox (1987), *Department of Geological Sciences at the University of Saskatchewan*, p. 53.

[499] Davies and Currie, 'Audibility of the Aurora and Low Aurora', 856.

[500] Ibid.

[501] Davies, 'The Canadian Second Polar Year Expedition to Chesterfield Inlet', 2-3.

No further comment was addressed to Rae's record, presumably because the Chesterfield team were awaiting supporting evidence from other research groups involved in the IPY. At the British Fort Rae station in Canada, there were no records of auroral sound to corroborate Rae's report.[502]

Lending some credibility to the theory of auroral sound, Størmer published two letters he received from his colleagues who claimed to have heard the sounds in 1926 and 1938 respectively. On 15 October 1926, Hans S. Jelstrup was observing Polar stars atop Voxenaasen hill near Oslo. In his breaks, he witnessed one of the 'most splendid aurora' he had ever seen. Hans Jelstrup and his assistant, G. Jelstrup, went outside to watch the yellow-green fans of the light display at 19h 15m GMT and both noticed a 'very curious faint whistling sound distinctly undulatory, which seemed to

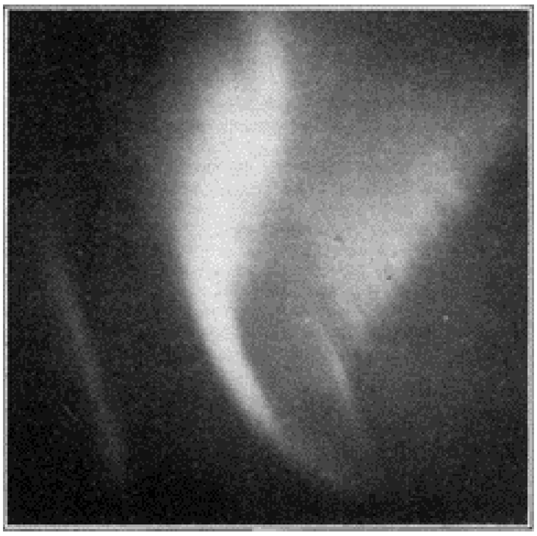


Fig. 51. 'Auroral Curtains photographed on 15 Oct 1926', in Carl Størmer, 'The Aurora of October 15, 1926, in Norway and Sounds Associated with it', *Nature* 119, 45 (1927), 45.

follow exactly the vibrations of the aurora'.[503] Returning after they had finished their astronomical work, the sounds had ceased and they noticed 'that the atmosphere was as if swept clean from statics and disturbances'.[504] Published in 1927, this narrative may have motivated interest in the phenomenon and emboldened IPY scientists to more readily believe aural reports, given that Størmer endorsed the

[502] Stagg and The British National Committee for the Polar Year, *Some General Characteristics of Aurora at Fort Rae*, p. 6.

[503] Carl Størmer, 'The Aurora of October 15, 1926, in Norway and Sounds Associated with it', *Nature* 119 (1927): 45-46, 45.

[504] Ibid.

account and was an authority within the community. Størmer also published an article in *Nature* in 1938 detailing the experience of his assistant, Mr. Tjönn, hearing the lights at the Njuke Mountain station in Tuddal, Norway. In a letter, Tjönn wrote that he perceived a sound like 'burning grass or spray' for approximately 10 minutes following the movement of the aurora.[505] This second account, approved by Størmer, likely also reinforced belief in the possibility of auroral sound in the latter half of the 1930s.

Størmer's retelling of Tjönn's experience was invoked by Clement Williamson in the auroral sound debate which played out in *The Shetland News*. Williamson was a well-connected Shetland Island photographer, writer and amateur astronomer, residing in Scalloway. He corresponded with astronomers at the Mount Wilson observatory as well as H. G. Wells on the subject of time travel and was awarded the Swedish gold medal of the Royal Order of the Polar Star for his assistance to Swedish fisherman who visited Scalloway in the early twentieth century. Williamson was also a proficient musician, having learnt to play Scottish folk songs on the fiddle, piano, xylophone and recorder.[506] His musical interest speaks to his fascination with auroral sound. As one of the only amateurs directly involved in the auroral sound debate, Williamson's contribution was taken surprisingly seriously by some of the leading scientists of the era.

Fig. 52: Clement J. Williamson, 1904-1994. 'Scalloway's People', *Scalloway Museum.*

Having received a letter from Størmer in 1938, Williamson recounted Tjönn's description in a letter to the editor, revealing that it was deeply 'gratifying' to relay the report in support of his own

[505] Carl Størmer, 'Photographic Measurement of the Great Aurora of January 25-26, 1938', *Nature* 141, no. 3578 (1938): 955-957, 956.

[506] Clement the Polymath, Museum Panel, *Scalloway Museum*.

belief in objective auroral sound.[507] Williamson had previously written a letter to *The Shetland News*, following an appeal by the editor in 1933 to receive accounts of the noises from the region and beyond at the height of interest in the phenomenon during the IPY. Recalling a still night in October 1926, he had asserted that he heard ‘the sound a cane makes when drawn swiftly through the air, just a low murmuring swish, drumming and continuous’.[508] Unusually, Williamson did not claim to perceive the sound simultaneously with the flashes of light.

Williamson’s account was published in *The Shetland News*, among a multitude of others in 1933. Reverend H. A. Edwards wrote in about his experience living in Canada for 25 years, stating that ‘on three or four occasions’, ‘when the rippling waves of light passed along the light-spears there was a distinct sound as of crackling – occasionally as loud as the crack of a whip’.[509] Similarly, Edward Dixon likened the noise to ‘rustling silk’, having heard it on the island of Orkney in 1917.[510] The extract from a letter by Peter Hutchinson with which this chapter opened, published on 20 May 1933, spoke of the sound ‘as if two planks had met flat ways – not a sharp crack but a dull sound, loud enough for anyone to hear’.[511] In 1933, the Dominion Astrophysical Observatory in British Columbia, Canada similarly collected 141 letters, reinforcing the auroral sound narrative. These vivid and personal recollections, written in the experiential idiom and all somewhat congruent, constituted a substantial piece of evidence in favour of auroral sound during, and in the years surrounding, the Polar Year. It is significant that experiences from previous decades were still relevant in the 1930s. Much like the sunlit aurora of the previous chapter, the rarity and liminality of the aural phenomenon meant its nature could only be uncovered over a number of years.

As well as a space for exchanging auroral sound reports, *The Shetland News* acted as a forum for the more detailed discussion of the possible mechanism of auroral sound through Williamson’s

---

[507] C. J. Williamson, 'The Aurora', *Shetland News*, Letter to the Editor, 1938, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

[508] C. J. Williamson, 'Hearing the Aurora', *Shetland News*, Letter to the Editor, 1933, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

[509] H. A. Edwards, Reverend, 'Hearing the Aurora', *Shetland News*, c. 1930, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

[510] Edward Dixon, 'The Aurora', *Shetland News*, Letter to the Editor, *Shetland Museum and Archives* D1/591/2a/2,3,6a; Other examples from the Shetland News include: M. Ashford, Officer in charge of the Observatory at Lerwick, 'Is the Aurora Heard?', *Shetland News*, Letter to the Editor, 1939, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a; J. F., 'The Aurora', *Shetland News*, Letter to the Editor, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a; H. V. Rabgliati, 'The Aurora at Flooden', *Shetland News*, c. 1930, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a; Anonymous, 'The Aurora', *Shetland News*, Letter to the Editor, 1938, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a; Alan E. Slater, 'Hearing the Aurora', *Shetland News*, 1938, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

[511] Hutchison, 'Hearing the Aurora'.

correspondence. Williamson forwarded a copy of the observations taken from the Lerwick observatory and accounts of Shetland Islanders to eminent radio physicist, Sir Oliver J. Lodge, in 1933. Lodge commented that although not impossible for the sound to be objective, ‘it is difficult to be certain whether it is a suggestion due to the vividness of the appearance’ of the aurora.[512] Here Lodge pinpointed the first of two dominant themes of the sound debate: whether the noises heard were illusory, imagined or objective, revealing an interesting trust in vision but not in the body’s capacity for veridical hearing. It was noted by Williamson, however, that if the brain produced a psychological sound because it expected there to be one, this should be the case with every aurora, not just with the most violent displays.[513]

Lodge clearly took Williamson’s collection of notes seriously because he deemed it worth forwarding to Simpson, at the time working as the director of the Meteorological Office in London. As published in *The Shetland News,* Simpson replied stating that ‘whether or not aurora is accompanied by sounds is a problem which has been very much discussed by men of science and even yet no generally accepted conclusion has been reached.’[514] Because all research so far indicated that the aurora occurred at approximately 100 km above the earth’s surface, Simpson concluded that ‘it would be physically impossible for sounds to be generated which could be heard on the earth’s surface’.[515] As such, Simpson elucidated the second major sticking point of the debate: the impracticality of auroral sound reaching earth, especially travelling fast enough to be heard simultaneously with the movement of the lights.

A discussion focused on low aurorae took place between Simpson, Chapman and Axel Corlin, a Swedish physicist working on cosmic radiation at Lund Observatory, in *Nature* between April 1931 and November 1932, just before the Polar Year. Corlin began by detailing an aurora he witnessed on 16 November 1929 at Abisko, Sweden, which he claimed appeared ‘below the clouds… only a few thousand meters above the ground’.[516] Although he heard no noise, Corlin put forward the example to provide a potential explanation for auroral sound. Published one month later, Simpson’s paper attributed Corlin’s narrative to an ocular illusion, citing his own experience witnessing aurorae at Karasjok, Norway between October 1903 and September 1904.[517] Corlin replied with another article, his claim now bolstered by a second account of a low altitude aurora in Norwood, Canada on the same

[512] Lodge's statement was printed in the article: Williamson, 'Hearing the Aurora'.

[513] Ibid.

[514] Ibid.

[515] Simpson's answer printed in Williamson's article: ibid.

[516] Axel Corlin, 'Observations of a Low Altitude Aurora and Simultaneous Phenomena', *Nature* 127 (1931): 553-554, 533.

[517] G. C. Simpson, 'Low Altitude Aurora', *Nature* 127, no. 3209 (1931): 663, 663.

day as his own.[518] Chapman, praising Simpson as a 'first-rate observer', referenced three more incidences wherein the meteorologist had demystified cases of low aurorae while accompanying Robert Scott's Terra Nova Expedition of 1910.[519] This, Chapman argued, did not 'dispose of the possibility' of low aurorae but 'emphasised the need for caution in accepting reports even from the most trustworthy and convinced observers'.[520] Trained, disciplined hearing in the western scientific mode was valued in verifying the objectivity of low aurorae, and thus the possibility of auroral sound.

Ultimately, the auroral sound debate was neither settled within the Second IPY programme nor the rest of the twentieth century. Today, there remains no clear-cut explanation for the phenomenon. That being said, the answer which has garnered the most support was first tentatively suggested in 1923 by Clarence Chant, a well-known Canadian astronomer who took part in Sir Arthur Eddington's 1919 solar eclipse expedition and presided over the Royal Astronomical Society of Canada from 1904 to 1907. At the end of his 1923 article, 'The Audibility of the Aurora', which was primarily dedicated to publicising previously overlooked accounts of auroral sound, Chant proposed that the noises could be produced by a mechanism similar to that of a brush discharge.[521] The motion of the lights alters the earth's magnetic field and induces changes in the electrification of the atmosphere, even at a significant distance. This electrification produces a crackling sound much closer to the earth's surface, with transduction occurring in the observer's clothes or spectacles or possibly in surrounding objects including fir trees or the cladding of nearby buildings. Within this hypothesis, auroral sound is intrinsically an embodied experience; the very act of an individual being in the Arctic, wearing clothing through which the electrical discharge could travel, brought auroral sound into existence. Such a personal, proximal, and almost tangible experience of the Artic noises vindicated the corporeal approach of IPY investigations. Chant's theory correlated well with many accounts of auroral sound and vindicates the proximal, personal approach of the IPY observers. This theory is also supported by occasional reports of the smell of ozone accompanying the aurora.[522]

Without referencing Chant's work, Størmer tentatively put forward a similar theory in 1927, asserting that electrostatic discharges in the surroundings, including trees and antennae, could be responsible for the sounds.[523] Nevertheless, despite the fact that surveys and crowdsourcing formed a

---

518 Axel Corlin, 'The Low Altitude Aurora of Nov. 16, 1929', *Nature* 127 (1931): 928, 928.

519 Chapman, 'The Audibility and Lowermost Altitude of the Aurora Polaris'; G. C. Simpson, 'Auroral Observations in the Antarctic', *Nature* 102 (1918): 24-25.

520 Chapman, 'The Audibility and Lowermost Altitude of the Aurora Polaris'; Sydney Chapman, 'Low Altitude Aurorae', *Nature* 130, no. 3290 (1932): 764-765, 341.

521 C. A. Chant, 'The Audibility of the Aurora', *Journal of the Royal Astronomical Society of Canada* 7 (1923): 273-284, 284.

522 Silverman and Taun, 'Auroral Audibility', p. 193.

523 Størmer, 'The Aurora of October 15, 1926', 45.

crucial part of the exploration of the phenomenon, Chant's 1923 paper in the well-respected *Journal of the Royal Society of Canada* was entirely overlooked in the literature of the Second IPY; no mention of brush discharges was made within IPY publications whatsoever. Nor did Chant's obituary, written after his death in 1956 by John Heard, include any mention of his auroral sound hypothesis, indicating that it was a peripheral aspect of his scientific career.[524] The audibility of the northern lights was confronted purely from a corporeal rather than instrumental perspective during the IPY and has been perceived through this embodied lens in subsequent, more recent, decades.

Conclusion

The Second International Polar Year marked a period wherein the aurora was in the process of being delineated, bounded and configured with reference to the corporeal senses and the instrument of the spectroscope. The process of determining the aurora's ontology was channelled by discussions relating to the subjectivity of individual observational experiences and hampered by uncertainty over its quintessential aspects. The difficulty of capturing the aurora borealis, intrinsically connected to the spatiality of the Arctic, prompted both embodied and technological ways of sensing its spectral life. Crucially, both the chromatic and audible qualities of the aurora necessitated sensory registration, though the balance between reliance on experiential and instrumental epistemologies worked differently in each case.

The body became an instrument, a credible source of knowledge creation during the IPY despite, or perhaps because of, the place of the Arctic as a realm of uncertainty in the western imaginary. The fundamental otherworldliness of polar phenomena meant that the senses were intrinsically implicated in their construction because occurrences such as the aurora could not be captured meaningfully without the affective emotions and bodily sensations with which it was experienced. Auroral hues were witnessed visually by members of all expeditions participating in the Second IPY programme, the fleeting colours of the phenomenon holding an aesthetic appeal while also challenging observers to calibrate their estimations of its hues across various research stations. Systematic performances of viewing provided the most rigorous observational procedures. Supplementing this ocular analysis was the process of technologically sensing the aurora via spectroscopy. This chapter makes the case for instrumental recording to be considered a type of 'sensing', in an idiom related to, but with a different sensitivity from, bodily sensation.

In contrast to Kragh's work on the relationship between the theory of the auroral green line and experimental setups, this chapter has explored 1930s auroral spectroscopy from a perspective which pays heed to both the practices of capturing spectroscopic images and the complex and

[524] J. F. Heard, 'Clarence Augustus Chant', *Journal of the Royal Astronomical Society of Canada* 51 (1957): 1-4.

sometimes contradictory information that was gained from this very visual form of instrumental sensing. Spectroscopic investigations aimed to identify the wavelengths of visible and non-visible light emitted from the aurora and trace these to the elements which produced them. Violet aurorae, the variation in emissions at different times of the night, the temperature of the thermosphere and universal characteristics of the night sky were also key categories of evaluation during the Second IPY. Yet, even when focusing on the auroral spectrum, IPY researchers considered the aurora to be more than the sum of its spectroscopic lines, a phenomenon with wider historical and scientific significance, wild, contingent on atmospheric conditions and part of a visual and aural experience. Crucially, the aurora was not defined as a line on a spectrograph and even the common assumption that the aurora could be identified by the presence of the green spectroscopic line at 5577 Å was called into question during the Polar Year.

The auroral sound debate was central to discussions taking place within the scientific community of auroral researchers in the 1930s, involving the leading geophysicists and meteorologists of the time. The aural phenomenon took on a special significance in 1932 and 1933, in tune with a heightened focus on the northern lights as one of four key topics of investigation during the IPY. Although left open-ended, this key episode in the history of auroral science deserves greater historical consideration. This chapter has drawn attention to what was a real possibility during the 1930s, a subject to which much time and effort was afforded and one which has been very little discussed in the secondary literature of the IPY or more broadly. An interesting avenue for further research would be the longer history of auroral sound within mythology and folklore.

Interestingly, IPY research on the aural phenomenon was approached from a purely experiential rather than instrumental perspective, relying entirely on the senses of those who claimed to have heard the sounds. No specific instruments were transported to the Arctic with the purpose of analysing the sounds, despite the development of acoustic technologies and the dominance within the physical sciences of epistemologies based on mechanical instruments. This could be said to reflect the secondary importance of the auroral sound debate, given that the western hierarchy of the senses privileged vision. Moreover, the chromatic qualities of the aurora could be documented, measured and analysed accurately whereas its aural capacities were a source of confusion, at the limits of registration techniques and discussed sceptically as a potential illusion. Visual evidence of elusive phenomena was deemed firstly, to be more significant and secondly, more easily quantifiable.

In the case of auroral sound, local perspectives were sought through surveys and newspaper campaigns. Yet, it was the knowledge produced from IPY expeditions and auroral observatories which was trusted with verifying the accuracy of local testimony. Interestingly though, both the more local journal, *Shetland News,* and the academic journal, *Nature,* acted as forums in which these ideas were discussed. Williamson, an amateur observer, drove the conversation in the Shetland Islands, corresponded with some of the leading physicists of the time and was taken seriously within the scientific establishment. The auroral sound debate was more open to amateur participation, both in terms of Williamson's contribution and crowdsourcing practices, than ocular investigations of the aurora, once again, potentially because of its peripheral status.

Ultimately, the practices of investigating the aurora borealis during the Second IPY relied, to a large degree, on the embodied senses – perhaps a surprising finding for a physical science with access to precision technologies. The knowledge of the aurora gained from the IPY was predominantly situated, corporeal and experiential. Lacking from the historical literature of the IPY is a thorough exploration of the embodied sensory capacity of expedition members, intertwined as their corporeal perception was with the subjects of their scientific scrutiny and the environments in which they found themselves. This chapter has bridged the gap between sensory registers and IPY research, following the lead of historians, cultural geographers and anthropologists self-consciously engaging with the 'sensory turn'. Much room, however, is left for work to be done approaching other areas of the Second IPY programme from a sensory perspective. This perspective may also afford a recognition that technological and embodied practices were not antithetical within the physical and geophysical sciences of the early twentieth century; indeed, they often complemented one another.

Light Displays and Radio Blackouts: Studying Auroral Echoes During the International Geophysical Year, 1957-58.

From the outset, the International Geophysical Year of 1957-8 was aimed at more than just scientific objectives; it was organised to connect nations and break down conceptual barriers to sharing information in a time of distinct global tension. While the geophysical sciences had long been connected to military pursuits, the relationship between the two became closer with the advent of nuclear weapons and the launching of Sputnik 1, the earth's first artificial satellite, in October 1957.[525] Nevertheless, the IGY was conceptualised as a peaceful, co-operative event which could assuage global tensions. In the words of Sir Edward Appleton, the British pioneer of radio physics, the 'International Geophysical Year can and will become a great instrument for fashioning the peace of the world.'[526]

The programme was instigated by James Van Allen, Chapman and Lloyd Berkner, who formulated the idea at an after-dinner conversation on 5 April 1950. It was then organised by the Special Committee for the International Geophysical Year (CSAGI). The first meeting of the special committee was held at the Palais des Academies in Brussels in July 1953, followed by a meeting in Rome in October 1954 and a subsequent conference held in the original venue in September 1955.[527] The scope of the programme had greatly increased since the 1932-3 Second International Polar Year, with approximately 60,000 scientists, engineers and technicians taking part as well as a large number of volunteer observers.[528] So too was the duration of the 'year' extended to encompass the ambitious range of observations set to take place; the IGY lasted for eighteen months.

Aurora and airglow formed one of twelve categories of investigation, with 270 stations carrying out auroral work.[529] The project to learn more about the phenomenon's disruption of radio communications fitted harmoniously into the overarching internationalist ethos of the IGY as it aimed

---

[525] Elena Aronova, 'Geophysical Datascapes of the Cold War: Politics and Practices of the World Data Centres in the 1950s and 1960s', *Osiris* 32, no. 1 (2017): 307-327, 309.

[526] Edward Victor Appleton, 'The International Geophysical Year 1957-58', Ryland Lecture (22 May 1958), *Churchill College Archives, University of Cambridge*; James Paton, 'Sir Edward Appleton's Speech', *Section IV: Aurora and Airglow in The British National Committee for the International Geophysical Year Report*, *Cambridge University Library*, NGY/22a(55), p. 8.

[527] 'Report from the General Secretary of the CSAGI' (03 January 1956), *University of Cambridge Library*, GBR/0180/RGO 64/76.

[528] D. C. Martin, 'Some Achievements of the International Geophysical Year', *Journal of the Royal Society of Arts* (1959): 406-422, 407.

[529] D. C. Martin, 'The International Geophysical Year', *The Geographical Journal* 124, no. 1 (1958): 18-29, 21.

to remove barriers to transnational exchange. The eminent atmospheric physicist and chairman of the US National Committee for the IGY, Joseph Kaplan, wrote in 1965 that, 'modern civilisation, being highly dependent on reliable transportation and communication, requires as complete as possible a knowledge of natural events that might cause interference.'[530] He continued, speaking simultaneously in the personal and global idiom: 'even today, a man standing on his back porch in Seattle, watching the play of the aurora borealis, enjoys the spectacle and scarcely realises that a pilot flying across the north Atlantic may be in serious trouble because of the aurora's interference with the functioning of his radio set.'[531]

Embedded in the cultural environment of the Cold War, aurorae in their most extreme form and the accompanying radio blackouts mirrored the onset of nuclear attack.[532] Interference with radio signals, the disruption caused to radar and the masking of potential incoming missiles resonated with heightened fears of nuclear detonation, granting an immediacy to the problems of magnetic storms connected to the brilliant lights of the aurora.[533] One auroral researcher was asked to verify that lights photographed over Siberia were of auroral origin and not the result of a 'mysterious secret experiment' at the Air Force Geophysical Laboratory in Boston in the early 1960s, highlighting the confusion that could be caused by the phenomenon.[534] Aurorae in their weaker forms could cut off northern territories from vital communications networks, particularly pertinent when attempting to relay messages related to weather or illness.

Attention to the varying strengths of auroral appearances leads us to an analysis of the sensitivities of methods of registration, modulated by radio echo transmission powers and the spatial situation of detecting stations. This perspective illuminates, in particular, the different scales on which radio scientists of the IGY were operating and the challenges which the aurora posed to communication. Following Edward Jones-Imhotep's work on natural orders which interfered with

---

[530] Joseph Kaplan, 'The International Geophysical Year', *Publications of the Astronomical Society of the Pacific* 68, no. 404 (1956): 381-404, 386.

[531] Ibid.

[532] Czeslaw Centkiewicz, *Die Insel der Nebel und Stürme: die erste polnische Expedition im Zweiten Internationalen Polarforschungsjahr 1932-33* (Leipzig: Brockhaus Verlag, 1956), p. 81; Victor H. Lawn, 'Aurora Borealis Blacks out Radio', *New York Times*, 1958, 62; Edward Manley, 'Wireless Man in the Arctic Keeps in Touch with New York', *New York Times*, 18 September 1927; Hanns Tollner, Rudolf Kanitscheider, and Fritz Kopf, *Vierzehn Monate in der Arktis: die österreichische Polarjahrexpeditions 1932/33 nach Jan Mayen, veranstaltet von der Akademie der Wissenschaften in Wien* (Wien: Tyrolia, 1932), p. 52.

[533] E. Jones-Imhotep, *The Unreliable Nation: Hostile Nature and Technological Failure in the Cold War* (Cambridge: MIT Press, 2017).

[534] Syun-ichi Akasofu, 'Space Physics in the earliest days, as I experienced', *Perspectives of Earth and Space Scientists* (2020): 1-10, 7.

strategically sensitive radio communications in Northern Canada during the Cold War, this chapter evaluates the way the aurora seriously disrupted the information exchange and therefore bestowed a continued significance on the experiential knowledge of lay participants.[535]

The aurora australis had not previously been recorded systematically from Antarctica, leaving a significant gap in contemporary understandings of the phenomenon. The main priorities of auroral research during the 1950s were, therefore, to investigate the geographical distribution of aurorae in the northern and southern hemispheres, assess the connection between visual and radio echo reports and evaluate the east-west drift of displays.[536] This chapter focuses on the social and physical communication networks established to examine the aurora by means of radio echoes, taking the Jodrell Bank Observatory and the Halley Bay Antarctic station as central nodes. The concentration of this chapter on the British perspective is motivated by the current overwhelming focus of the historiographical landscape on the activities of the US and USSR during the IGY.[537] Jodrell Bank held a unique position with regards to Cold War tensions, interacting with scientists from both sides of the iron curtain, while also engaging in activities which could be described as surveillance of the upper atmosphere. Moreover, although well documented from a geopolitical and institutional perspective, the IGY itself has received little historiographical scrutiny in terms of its scientific programmes, with the exception of the space race.[538]

As we learn from Jim Secord, it is 'in tracing the patterns of circulation… that we can create a history that goes beyond particularly instances.'[539] Successful networks are heterogenous in their component parts but work in unison through formalised procedures and hierarchies.[540] These

[535] Jones-Imhotep, *The Unreliable Nation*.

[536] Chamberlain, *Physics of the Aurora and Airglow*, p. 136; Carl R. Eklund, *Antarctica: Polar Research and Discovery During the International Geophysical Year* (New York: Holt, Rinehart and Winstron, 1963), p. 120; James Paton, 'Report on Observation of Aurora', report, *British National Committee for the International Geophysical Year, Aurora Subcommittee, Jodrell Bank Archive, University of Manchester*.

[537] Bullis, *The Political Legacy of the International Geophysical Year*; Christy Collis and Klaus Dodds, 'Assault on the Unknown: historical and political geographies of the International Geophysical Year (1957-8)', *Journal of Historical Geography* 34 (2008): 555-573; Divine, *The Sputnik Challenge*; Elzinga, 'Through the Lens of the Polar Years', 313; Roger D. Launius, 'The IGY and the satellite race: a reconsideration of a cold war crisis that never should have been', *American Geophysical Union* fall meeting (2006); Allan A. Needell, *Science, Cold War and the American State* (Abingdon: Taylor & Francis, 2013); Sullivan, *Assault on the Unknown*.

[538] Dian Olson Belanger, 'The International Geophysical Year in Antarctica: A Triumph of "Apolitical" Science, Politics, and Peace', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan, 2010): pp. 265-278; Collis and Dodds, 'Assault on the Unknown'.

[539] James A. Secord, 'Knowledge in Transit', *Isis* 95, no. 4 (2004): 654-672, 665.

[540] Jonathan Murdoch, 'The spaces of actor-network theory', *Critical Review* 29, no. 4 (1998): 357-372, 363.

networks 'juxtapose spaces and times in line with the translating impulses of centrally placed actors'.[541] The term 'network' first referred to material transportation systems in the nineteenth century, before taking on conceptual connotations as a group of social communicators in the twentieth century.[542] Incidentally, the notion of a 'network' was also beginning to gain traction in the 1950s in the context of artificial intelligence.[543]

Crucially, the networks of the IGY auroral radio programme can be characterised by the themes of both interaction and interference. The theme of interference arises on multiple intersecting scales, from the individual reading spurious results within auroral echoes to the havoc the aurora could wreak in both hemispheres by disrupting communications. The general public was also perceived as interfering with the work of Jodrell Bank Observatory in the 1950s. Their presence, it was imagined, would destroy the productive laboratory environment in which serious radio work could be carried out.[544] This, however, was strongly contrasted with the relationship between amateur observers and the Edinburgh Observatory, which encouraged members of the public to participate in the practice of observing aurorae. The shifting dichotomy between free exchange and blocked, restricted or misunderstood communication mirrored the larger patterns of Cold War co-operation and obstruction during the period. With a sensitivity to exchanges of atmospheric knowledge in a time of extreme geopolitical tension, this chapter speaks to the project set out by John R. McNeill and Corinna R. Unger to combine the historiographies of the Cold War and environmental sciences.[545]

Social Network

The period allowed for IGY preparation was significantly longer than for either the First or the Second IPYs and the participating research teams were undoubtedly better connected through the use of novel technologies, including radio transmission. The challenge of the IGY, however, was to implement a co-ordinated and useful programme of research across a much larger range of stations, all carrying out their own slightly different echo experiments. Each base studying auroral echoes was given a copy of *The International Geophysical Year Instruction Manual* (1956).[546] The Falkland

---

[541] Ibid.

[542] Armand Mattelart, *Invention of Communication* (Minneapolis: University of Minnesota Press, 1996), p. 21.

[543] Maad M. Mijwel, 'History of Artificial Intelligence', *Computer Science* (2015): 3-4.

[544] Agar, *Science and Spectacle*, p. xix; P.N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (MIT Press, 2010), p. 3.

[545] J.R. McNeil, C.R. Unger, and German Historical Institute, *Environmental Histories of the Cold War* (Cambridge: Cambridge University Press, 2010), p. 4.

[546] Committee of CSAGI, 'The International Geophysical Year Instruction Manual', vol. 4 Aurora and Airglow (London: Publication Committee of CSAGI, 1956), AS7/Z/2/15 BAS.

Island Dependencies Survey (FIDS) stations used the same observation sheets and instruction manual distributed to observers in the northern hemisphere.[547] To some extent, just as the *Atlas of Auroral Forms* (1930) had organised the photographic programme of the Second IPY, the instruction manual and documentation sheets created a standard format for 1950s auroral observation.[548] Yet, the IGY instruction manual was rarely mentioned in the literature or relied upon to the same degree as the *Atlas of Auroral Forms*. For one thing, terms and conventions from the 1930s atlas were still employed, meaning there was no need for an all-encompassing overhaul of the linguistic or practical guidelines set out. Secondly, there existed a less clear hierarchy in the 1950s auroral community; instructions flowed less certainly from a centre to a periphery.

In 1945 Patrick Blackett, an eminent British physicist, and Bernard Lovell, the first director of Jodrell Bank Observatory, had discovered that they could record echoes from the trails of meteors using radio equipment. Lovell pursued this line of enquiry, attempting to detect the Perseid meteor shower by radar in July and August of 1946. It was Størmer of the Theoretical Physics Department at the University of Oslo who first suggested that the researchers at Jodrell Bank should become involved in auroral echo work.[549] At first, in 1949, there seemed to be a lack of correlation between auroral echoes recorded in Norway and those obtained from Jodrell Bank.[550] Lovell and Størmer decided they may have been hampered by the slightly different directions in which each of their radio telescope aerials were pointing and ensured that this was corrected for the IGY.[551] Størmer also co-ordinated his methodology with the US auroral programme, writing frequently to Professor Donald Berkey at Colgate University, New York and C. W. Gartlein at Cornell University in the years leading up to the IGY.[552]

The Jodrell Bank radio apparatus consisted of twin Yagis aerials, a transmitter which sent a pair of pulses 150 times each second, a receiver, a video amplifier, the output of which was displayed on one of two cathode ray tubes and a camera, which was triggered automatically when aurorae were

[547] James Paton to Otto Schneider, Instituto Antarctico Argentino (Buenos Aires), 28 July 1959, letter, *Royal Society Archives EXP/11/1/1/181*.

[548] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*.

[549] Carl Størmer to Bernard Lovell, 22 April 1950, letter, *Jodrell Bank Archive University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

[550] Bernard A. C. Lovell to Carl Størmer, 21 October 1949, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956; Bernard A. C. Lovell to Carl Størmer, 16 November 1949, letter, *Jodrell Bank Archive*, *University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

[551] Lovell to Størmer, 21 October 1949.

[552] Carl Størmer to Donald Berkey, 03 October 1954, letter, *National Library of Oslo*.

detected.[553] The peak transmitting power was 10kW and the receiver sensitivity 2.1W. The Royal Society provided £5,000 for staff costs and £1,800 for equipment costs for the duration of the IGY at Jodrell Bank.[554] Just as networks involving industrial firms and consulting engineers made the acquisition of instruments possible, so too did relationships with funding agencies, politicians and civil servants need to be cultivated to make the work of an observatory possible.[555]

This is not to say that communication between radio physicists always ran smoothly. The miscommunication between Alan H. Jarrett and Lovell regarding the operating power of their radio telescopes demonstrates the difficulties embedded in communications between individuals, let alone the remote aurora.[556] Jarrett was a graduate student at the time of the IGY, working at the University of St Andrews, later becoming the Director of the Boyden Observatory near Bloemfontein in South Africa. Jarrett wrote a letter to Lovell dated 7 December 1955 to relay that he envisaged using a power of 100kW in an attempt to obtain echoes from the sunlit aurora, continuing Størmer's Second IPY investigations.[557] Jarrett subsequently applied to the Royal Society for a grant of £980 in addition to the £500 he had previously been awarded for his radio work.[558] The question as to whether his application was sound was referred from P. B. Moon, the Chairman of the Royal Society Government Grant board, to Lovell in June 1956. Lovell stated that he could not support Jarrett's experiments because he had specifically warned against using a high-power transmitter because there was no clear evidence indicating that it would allow for reflections from sunlit aurorae and the apparatus was unnecessarily expensive and likely to give a 'good deal of technical trouble'.[559]

Jarrett's plans, costly and not proven to work, were not only disruptive to the British IGY radio effort but were also interfering in the process of discipline making. The IGY took place at a time of rigidifying professional boundaries within the physical sciences, wherein the conditions of radio astronomy were not set, and the field was considered to be on the periphery of what counted as

---

553 'The Auroral Echo Equipment at Jodrell Bank', International Geophysical Year 1953, *Jodrell Bank Archive, University of Manchester*.

554 'The Royal Society: International Geophysical Year July 1957 - Dec 1958', Correspondence on International Geophysical Year, *University of Cambridge Library*, GBR/0180/RGO 9/565.

555 Agar, *Science and Spectacle*, p. xiv.

556 Alan H. Batten, 'The Beginnings of Modern Astronomy at the University of St Andrews', *Journal of Astronomical History and Heritage* 17, no. 1 (2014): 39-44, 43.

557 A. H. Jarrett to Bernard Lovell, 07 December 1955, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

558 Ibid.

559 Bernard A. C. Lovell to P. B. Moon, 20 June 1956, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

astronomy.[560] Indeed, in the 1950s optical astronomers 'were often critical of radio observations and continually exhorted radio astronomers to raise the levels of precision of their results'.[561] Lovell's position and the status of radio astronomy were themselves at stake and thus Jarrett's maverick methods were threatening the position being carved out for the discipline.

In January 1957, concerns were growing that Jarrett's proposal was not only untenable but would also obstruct the whole of the British radio effort. Lovell wrote to Moon in January 1957 urging that Jarrett's new attempts to use a 300kW transmitter 'might have very serious effects on our own work, because of back scatter'.[562] Additionally, he complained to Professor N. Feather at the University of Edinburgh in the same month that Jarrett's project 'might well jeopardise the important series of systematic observations which can be carried out with power in the 10K range.'[563] It transpired that Jarrett's apparatus did not become operational in time for the IGY, which Lovell blamed directly on Jarrett's unwillingness to accept the advice from Jodrell Bank.[564] The breakdown in communication between the primary British radio echo station and a researcher on the periphery exemplifies an obstruction in the transmission of information on an interpersonal level. Indeed, the auroral radio echo work was not an integrated affair but was rather fraught with these small-scale communication challenges between colleagues.

Several different approaches to auroral radio echo work meant that the results were difficult to manage. Researchers in Saskatoon, Canada transmitted radio wavelengths of 3-5m, those working in Sweden used a wavelength of 8m while the Jodrell Bank Observatory made use of wavelengths between 4 and 8m.[565] Rather than being standardised via a reference text, the radio programme was co-ordinated through the more haphazard method of exchange and correspondence. Norwegian geophysicists stayed in frequent contact with their British and American colleagues, often comparing their techniques and results. Harang, a Professor at the University of Oslo working in Tromsø corresponded with Professor F. J. M. Stratton, the Director of the Solar Physics Observatory at Cambridge, regarding sunspot activity; with Chapman on the topic of auroral spectroscopy; with

[560] David O. Edge and Michael Joseph Mulkay, *Astronomy Transformed: The Emergence of Radio Astronomy in Britain* (New Jersey: Wiley, 1976), p. 271.

[561] Ibid.

[562] Bernard A. C. Lovell to P. B. Moon, 02 January 1957, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

[563] Bernard A. C. Lovell to N. Feather, 28 January 1957, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

[564] Bernard A. C. Lovell to D. C. Martin, 19 March 1958, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

[565] Bernard A. C. Lovell and British National Committee for the International Geophysical Year Aurora Subcommittee, 'Radio Observations of aurorae', *Jodrell Bank Archive, University of Manchester*.

Appleton regarding radio methods and the destruction of the Tromsø radio equipment during the Second World War; and with Fleming of the Carnegie Institute of Washington about potential collaboration.[566] Indeed, Harang agreed to copy the designs of the British radio echo telescopes for the upcoming Geophysical Year, once they had been fully tested,.[567]

Interference between various members of the radio network manifested as social, metaphorical and literal disturbances as in the miscommunication and disagreement between Jarrett and Lovell and the differing approaches of British, Scandinavian and Canadian observatories. While the observatories studying the aurora were connected to one another via radio and telegraph technologies, the difficulties in co-ordinating such an expansive observational programme were starkly apparent and potentially threatening to the auroral investigation.

Amateur Observation

Another important component of the IGY endeavour was visual aurorae observations carried out by a large social network of amateurs. The human experience of the aurora was varied, affective, difficult to understand and remained valuable to researchers in the 1950s, despite instrumental advancements including the advent of radio echo technology. Individual accounts brought a personal element to the study of a phenomenon which could span nations, helpful for showing that the IGY was a democratic endeavour, operating at the intersection of local and international scales. Most observers contributed on a volunteer basis and watched the skies for as long as they could when convenient to them.

The auroral project was by no means the only instance of harnessing the power of amateur observation in the IGY. The Moonwatch programme, instigated by Fred Whipple to aid in the observation of satellites, is perhaps the most well-known and successful example of amateur participation, lasting for a further two decades after the completion of the Geophysical Year.[568] Moonwatchers and other amateur radio operators spotted Sputnik I when its batteries and radio transmissions failed, were the first outside organisation to observe the US satellite, Explorer I, and watched Sputnik II re-enter the atmosphere in April 1958. In a lecture presented at the Dedication of Lindheimer Astronomical Research Centre at Northwestern University, Whipple extolled the virtues

[566] Leiv Harang, correspondence, Kopiboker 1928-1971, *Tromsø State Archives*.

[567] Leiv Harang to Edward Victor Appleton, 17 December 1952, correspondence, Observatoriet på Haldde and Nordlysobservatoriet Kopiboker 1928-1971, *Tromsø State Archives*, 22/07/1932-21/12/1933.

[568] W. Patrick McCray, *Keep Watching the Skies: The Story of Operation Moonwatch and the Dawn of the Space Age* (Princeton: Princeton University Press, 2008), p. 144; McCray, 'Amateur Scientists', 636.

of embodied sensing, remarking that, ‘even with the naked eye we can see back 2 million years in time’.[569]

The majority of US visual observations of the aurora were made by a network of volunteers under the guidance of C. W. Gartlein at Cornell University.[570] In the UK, James Paton, working at the Edinburgh Observatory, distributed forms designed for the capturing of simple auroral data to members of the Aurora and Zodiacal Light Section of the British Astronomical Association (BAA). The BAA consisted mainly of professional or retired meteorologists, ships’ officers at sea, members of other astronomical societies and individuals interested in the night sky.[571] Many of the volunteer observers were recruited by appeals in semi-popular scientific journals and magazines as well as radio talks in the Schools Broadcasting Services.[572] The distributed forms contained a map of the British Isles, over which the rough shape and position of an aurora could be drawn.

The Royal Society also provided guidance, suggesting that it could be useful if an assistant were available to stand near a door or window and relay the details of a display to a scribe.[573] If an observer were working alone a torch would be necessary for taking notes, although it should have a subdued red light if possible.[574] It was even possible for an observer to view aurorae partially obscured by cloud with the use of purpose built filters which could be placed in front of an observer’s eyes.[575] If more than one filter was used, interesting additional information regarding the relative intensities of the spectral components of an auroral display could be yielded, according to Chapman.[576] This provided the eye with an unusual sensitivity to auroral colour and brightness, which Chapman argued would ‘make possible the recording of auroras that would escape observation by the unaided eye, or even with a pocket spectroscope’.[577] The number of filters made available and used, however, was dependent on observers buying their own.

[569] F.L. Whipple, 'The call of space', Conference Presentation, *Dedication of the Lindheimer Astronomical Research Center*, 04 May 1967, Northwestern University.

[570] Stanley Ruttenberg, USNC-IGY program office, National Academy of Sciences, *IGY General Report, United States Program for the International Geophysical Year, 1957-8*, vol. 5 (Chicago: University of Chicago, 1959), p. 20.

[571] 'Note to Colonel Robert Arthur Smith, R. A. M. C., The Royal Society', *Jodrell Bank Archive, University of Manchester*.

[572] Sydney Chapman, 'Visual Aurora Observation', *Annals of the Geophysical Year*, vol. 4-5 (London: Pergamon Press, 1958), p. 49.

[573] 'The Processing and Duplication of International Geophysical Year Observations' (08 February 1956), The Royal Society, *University of Cambridge Library*, NGY/1(56).

[574] Ibid.

[575] Chapman, 'Visual Aurora Observation', p. 47.

[576] Ibid.

[577] Ibid.

Once completed, the documentary forms were returned to Paton.[578] In some cases, notes and drawings of the aurora were written on scraps of paper or postcards instead of the designated forms. For example, fig. 53 shows a postcard sent by amateur observer, G. E. Thrussell, describing an aurora he witnessed over Pirton Herts near Hitchin from 10:05 to 10:20 on 21 January 1957.[579] The illustration depicts the various colours of the phenomenon across the horizontal axis as well as the direction of the bands in the lower portion of the aurora. Purple shades, a reddish zone and a bright yellowish light could apparently be seen on this particular night. Just as sketches of the aurora had been an important piece of evidence in the Second, and particularly the First IPY, they continued to provide a human perspective on the phenomenon in the 1950s.

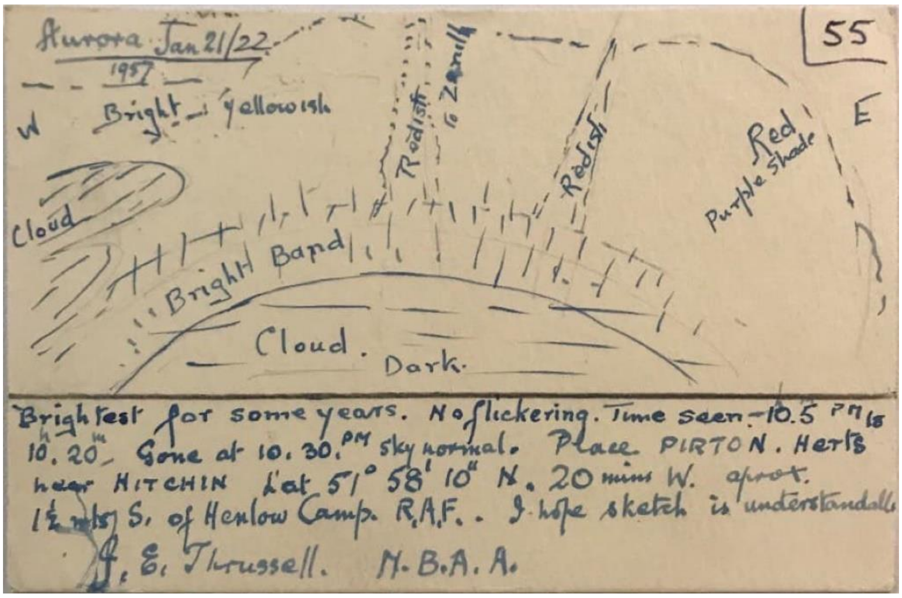


Fig. 53. G. E. Thrussell, Aurora on January 21/22, 1957, Auroral Observation Data 1957, *Aberdeen Archives,* MS: 3151/5/1-11.

It was precisely because the network of amateur observers had received little training for auroral observation that they were useful to Paton and Lovell. The scientific establishment were interested in what observers had witnessed with their eyes and not their interpretation of events. There has been a long history of the close connection between crowdsourcing and objectivity, but this case demonstrates that the information is more useful the less the individual knows about the subject of study. In this way, the ill-informed amateur can calibrate the expert. This line of reasoning resonates with E. Walter Maunder's Greenwich schoolboy experiment of 1903, to verify 'the actuality of the

[578] 'Ship: Weather Recorder, 'Aurora Survey', Marine Observer's form', Auroral Observation data 1957, *Aberdeen Archives,* MS: 3151/5/1-11.

[579] G. E. Thrussell, 'Aurora' (21-22 January), Auroral Observation Data 1957, *Aberdeen Archives*, MS: 3151/5/1-11.

"Canals" observed on Mars'.[580] Maunder used schoolboys who were 'wholly and entirely ignorant of the appearance of Mars in the telescope' to demonstrate that an untrained observer possessed a strong tendency to draw a network of fine straight lines when positioned at a certain distance from an image that they were instructed to copy, even when those lines did not appear on the original image.[581] It was exactly because the schoolboys were uninformed that they were useful in demonstrating the eye's tendency to resolve indistinct detail into straight lines.

One of the main outputs from the collection of visual auroral data was to ascertain the relationship between visual observations and radio echoes. The echoes were classified according to four criteria: duration, range, sharpness, and strength.[582] Longer echoes, those which lasted between 10 minutes and an hour, seemed to have the best correlation with visual observations.[583] After having left Jodrell Bank Observatory as a research assistant in 1957, Edward Doylerush sent his notes on visual observations of aurora to both Paton and C. D. Watkins. Watkins found his records had a strong correlation with the activity recorded on auroral echoes, especially concerning the aurora witnessed on 10 February 1958.[584] This correlation was deemed to be significant and was forwarded to Paton for his information.[585] C. W. Gartlein, G. Sprague and R. C. Waag put forward two possible explanations in 1960 for cases where the visual and radio data did not match. They argued that the part of the aurora which reflects radio waves was not always at the front of the visual display.[586] In fact, the leading edge of the aurora was rarely found to be a smooth surface and thus radio echoes could be reflected from many parts of the display. Additionally, the absence of auroral echoes may have been due to the aspect sensitivity of the radar receiver.[587] One significant discrepancy was that radar technology enabled observers to detect *daytime* aurora that would be impossible to observe visually, providing a much larger volume of data than was previously possible.

---

580 J. E. Evans and E. W. Maunder, 'Experiments as to the actuality of the 'Canals' observed on Mars', *Monthly Notices of the Royal Astronomical Society*, vol. 63 (1903), pp. 488-499; Josh Nall, *News from Mars: Mass Media and the Forging of a New Astronomy 1860-1910* (Pittsburgh: University of Pittsburgh Press, 2019), p. 153.

581 Evans and Maunder, 'Experiments as to the actuality of the 'Canals' observed on Mars', 489.

582 Kaplan, 'The International Geophysical Year', 390.

583 Ibid.

584 Doylerush to Bernard Lovell, 12 March 1958, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

585 Ibid.

586 C. W. Gartlein, G. Sprague, and R. C. Waag, '41Mc/s IGY Auroral Radar at Ithaca, New York', *Journal of Geophysical Research* (1960): 2255-2259.

587 Ibid.

The professional expertise of radar researchers stood in stark contrast to the amateur observational practices of auroral eyewitnesses positioned around Britain. The radio operators used trained judgement whereas the amateur observers did not have a role in manipulating the data that they sent to observatories.[588] Ways of coping with interference differed considerably between these two groups. Indeed, physical disturbances such as cloud cover and the necessity of sleep and other routine activities provided challenges to comprehensive observation among amateur participants rather than the noise and interference of communication technologies which plagued the professional registering of aurorae, as shall be shown in the following sections.

Physical Network

As well as a social network, made tangible via letters and radio exchanges, the IGY also involved a physical network of stations set up to make congruent measurements over a large area of the globe. In terms of the material components of this physical network, at Jodrell Bank Observatory an aerial mounted on a tower 20 ft above ground level transmitted a 15-microsecond pulse of 10kW peak power every 300 micro-seconds during the auroral observation phase. The aerial was used for both transmission and reception and therefore the scattering of the signal in directions other than directly backwards was not detected. This arrangement allowed for discrimination between auroral activity and the presence of meteors, both of which cause ionisation at approximately 100km above the earth's surface.[589] The camera attached to the radio apparatus was loaded with spools of recording film, which was used at a rate of three or four days per spool. A researcher was employed to check the film at 24-hour intervals to make sure the equipment was operating correctly.

While a principal part of this planetary network, Jodrell Bank was also an important node in the geopolitics of the Cold War, positioned geographically between the US and USSR. The 250-ft antenna at Jodrell Bank was the only instrument which could track the passage of the Sputnik I carrier rocket outside of the USSR in late 1957.[590] The detection of the Sputnik I and II rocket bodies demonstrated that the telescope had the ability to detect Interim Ballistic Missiles (IBMs). Later, in the early 1960s, Jodrell Bank became part of NASA's Deep-Space Network, while the USSR also relied on the observatory to verify that their lunar probe, Luna 2, had reached the moon in September 1959. Yet, there existed an undercurrent of secrecy in relation to the observation of the northern

---

588 Daston and Galison, *Objectivity*, p. 321.

589 David P. Harrison, 'Radio Echo Aurora and Meteor Equipment', *Jodrell Bank Archive, University of Manchester*, NGY/29, BAS Archives.

590 Sven Grahn, 'Jodrell Bank's role in early space tracking activities (Part 1)' (1999), *University of Manchester Library*, GB 133 JBA/CS12/21; P. Moore, *The Sky at Night* (New York: Springer, 2010), p. 108.

atmosphere in this period. Indeed, the monitoring of aurorae from Manchester could have been interpreted along the lines of surveillance work.

The Halley Bay station in Antarctica, a hut with a pitched roof established by the Royal Society on 6 January 1956, was another important node in the British physical network of IGY stations and has remained in use in various forms up to the present day. The equipment used to capture radio echoes at Halley Bay was explicitly labelled as 'identical' to that employed at Jodrell Bank.[591] The same radio frequencies were also used at both sites. The Halley Bay station was set up as a southern mirror, providing a useful and commensurable copy, complementing the Manchester observatory in the planetary network. According to the American geographer Carl R. Eklund, writing in 1953, the Antarctic provided an 'ideal laboratory, a region unspoiled by the clutter of civilisation and the complications of trees, plants, life forms' for the study of the physical sciences, and especially the phenomena of the upper atmosphere.[592] This was a common theme in the literature of the twentieth century, equating the vast expanses of both the Arctic and Antarctic as well as high altitude places, with a form of sterility, spotlessness and exclusivity usually associated with the controlled conditions of the laboratory.[593] Eklund pointed out that there were many unanswered questions relating to the aurora australis: 'Were the two auroras closely related? Did they always occur at the same time? Were they caused by the sun's radiation? How much did they differ? And why?', for which Antarctica, and particularly Halley Bay, would prove a useful experimental site.[594]

The new Antarctic data did not drastically alter geographical understandings of auroral distribution but did provide a much larger set of data points showing the frequency of the aurora australis from various southerly positions. From Halley Bay, aurorae were only observed in a single belt in a southerly direction. During the IGY the aurora australis was detected at Halley Bay on 134 nights out of a possible 164, which was explicitly compared to the appearance of the aurora borealis on 13 nights within the same time period at Jodrell Bank Observatory.[595] In a 1965 paper, Harrison reiterated the significance of the simultaneity of auroral displays at Jodrell Bank and the most active and intense aurorae at Halley Bay.[596] Indeed, to Harrison the direct comparison between the two sites made sense on a personal level, given that he graduated from the University of Manchester in 1955 and worked at Jodrell Bank for two more years on the construction of radio equipment before

---

[591] David P. Harrison, 'A Radio - Echo Study of the Aurora Australis', unpublished thesis (1965), *Victoria University of Manchester*, 43.

[592] Eklund, *Antarctica*, p. 14.

[593] Heggie, 'Extreme Acts', p. 219; Bigg, Aubin, and Felsch, 'The Laboratory of Nature', 315.

[594] Eklund, *Antarctica*, p. 15.

[595] David P. Harrison and C. D. Watkins, 'A Comparison of Radio Echoes from the Aurora Australis and Aurora Borealis', *Nature*, vol. 182 (1958), pp. 43-44, p. 43.

[596] Harrison, 'A Radio - Echo Study of the Aurora Australis', 1.

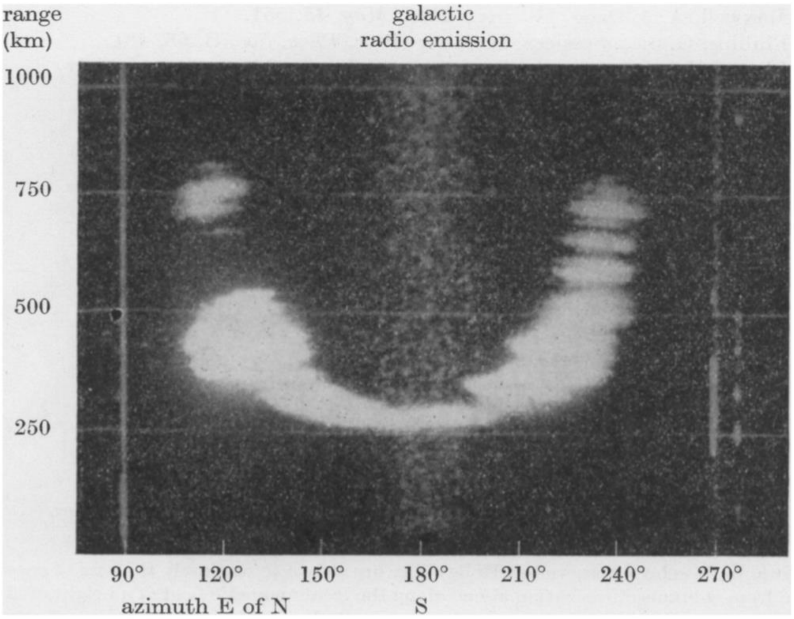


Fig. 54. David P. Harrison, ‘A Radio – Echo Study of the Aurora Australis’, *Doctoral Thesis submitted to the Victoria University of Manchester* (1965), p. 230.

participating in the IGY Halley Bay expedition himself. The visibility of hemispheric auroral synchronism seen in fig. 55 was produced by the uneven relationship between the two sites. Akin to amateur observers, who may have been less attuned to the finer details of auroral displays, the insensitivity of the geographical position of Jodrell Bank was useful for the very reason that it represented *only* extreme magnetic activity.

Interestingly, simultaneous aurora in the northern and southern hemispheres were not always of the same type, which Eklund suggested was due to the downward drift in homogenous ribbons and an upward drift in rayed forms, from his study of the radio echoes.[597] Researchers at Yerkes Observatory in Wisconsin found that the aurora’s ribbon phase was caused by the bombardment of atmospheric gases by protons, whereas the rayed forms were created when they were excited by electrons. This discrepancy, Lovell declared in a 1956 letter to Paton, was ‘precisely the kind of data which one hoped to pick up during the IGY’.[598] These insights into the nature of the aurora came about through the harnessing of the aurora’s ability to reflect radio waves as well as the distinction between northern and southern aurorae arising from the planetary network. The aurora’s ‘interference’ was a useful and productive quality for IGY researchers but was also a challenging and potentially dangerous characteristic for those who relied on reliable radio communications at extreme latitudes.

[597] Eklund, *Antarctica*, p. 123.

[598] James Paton to Bernard Lovell, 15 November 1956, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

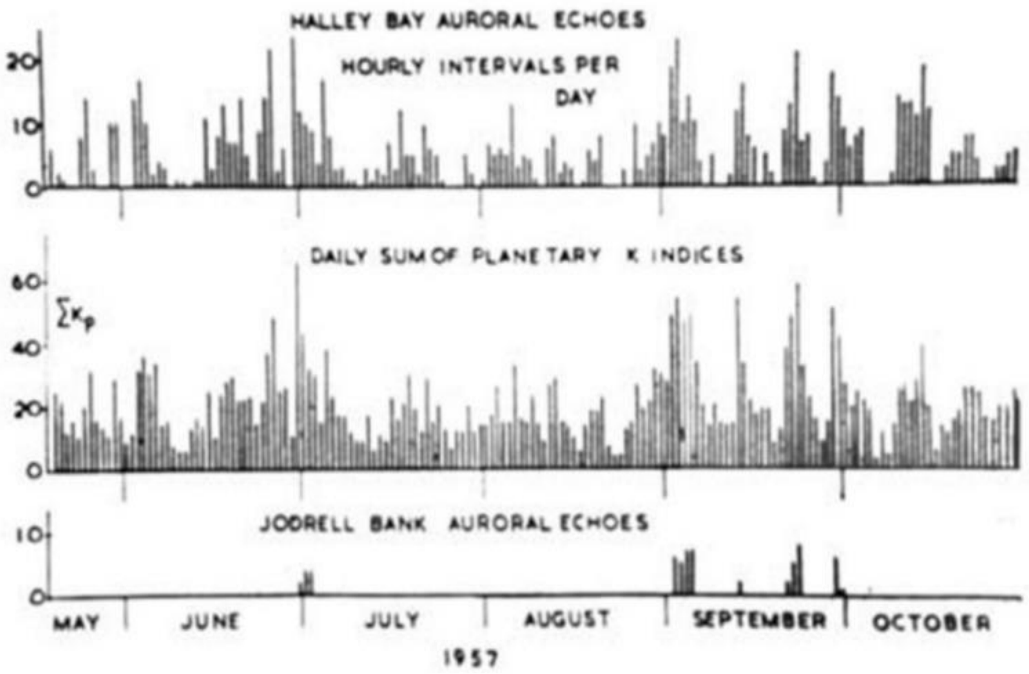


Fig. 55. 'Number of hourly intervals a day of auroral radio echoes detected at Halley Bay and Jodrell Bank compared with the daily sum of the planetary K index, Kp', in D. P. Harrison and C. D. Watkins, 'A Comparison of Radio Echoes from the Aurora Australis and Aurora Borealis,' *Nature* 182 (1958): 43-44, 43.

Interference

Interference was a serious consideration at Jodrell Bank, both in terms of spurious radio signals and in the context of disturbances caused by visitors to the observatory. Jon Agar argues these two elements were discussed using the same terms; 'both were 'intrusive', 'threatening' and discursively located at the boundaries of Jodrell Bank'.[599] It certainly became part of the culture at the observatory to exclude visitors, particularly in the years surrounding the Geophysical Year. Hundreds of letters requesting to see the radio telescope in the 1950s were politely refused. The only visitor who was accepted *during* the Geophysical Year was Dr. Gautier, visiting from the Cavendish Laboratory in Cambridge, in order to co-ordinate auroral radio observations.[600] Mr Kaare Longlo, visiting from Oslo, was also accepted as a visitor in the previous decade at the behest of Harang to further the cooperative methods implemented by the Norwegian and British research groups.[601]

---

[599] Agar, *Science and Spectacle*, p. 116.

[600] Cavendish Laboratory to Bernard Lovell, 30 November 1957, Visitors to Jodrell Bank, *Jodrell Bank Archive, University of Manchester*, GB 133 JBA/VIS/2/2.

[601] Leiv Harang to Edward Victor Appleton, 20 August 1945, letter, Kopinoker 1928-1971, *Tromsø State Archives*.

Before leaving Britain for the Antarctic Halley Bay station, concern over radio interference 'loomed large, as one of the major problems confronting the expedition'.[602] As the FIDS General IGY Report of 1956 stated, the primary concern was 'the interference caused by the communications transmitter to the ionospheric, radio-sonde, radio-echo and scintillation equipment.'[603] The radio echo hut was located 100 yards to the east of the main hut and 200 yards to the north-east of the communication aerials.[604] Henry Dyer, the daytime radio operator, worked to separate the times of radio transmissions from the periods when the radio equipment was being used for atmospheric observation.[605] Through trial and error, he identified the frequencies which caused the most interference, subsequently discarding them. Disruption still arose when 'the human factor' resulted in the overlapping of transmissions with ionospheric time, especially when relaying long messages or when a delay in making contact with another operator occurred. Nevertheless, 'most of the smaller interference problems were adjusted by direct negotiation between the individuals concerned', demonstrating the ways in which interpersonal communication could overcome radio disruption.[606]

While the radio transmissions occasionally interfered with the reception of echoes and signals from the ionosphere, so too did the atmospheric conditions disrupt radio communications between Halley Bay and London. Almost every day in the base diaries of the expedition, it was noted whether reception of the programme 'Calling Antarctica' on BBC radio was possible. The signals were rarely heard during the summer and midwinter but on days such as 30 September 1957, 'Calling Antarctica was heard well'.[607] On this particular occasion it was noted in the base diary that it 'was the last of the present series and was extended by 15 minutes. We enjoyed the longer programme and Gwynne received a personal message'.[608] Calling Antarctica was also an opportunity for the researchers stationed at Halley Bay to receive information about the IGY findings at other bases and hear from individuals such as Lovell and HRH Prince Philip.[609]

Researchers at Halley Bay also experienced difficulties with earthing the radio equipment, and challenges relating to the suppression of background noise, produced largely from the station's

[602] Falkland Island Dependencies Survey, 'General IGY report 1956', *British Antarctic Survey*, AD6/2HB/1956/A.

[603] Ibid.

[604] Harrison, 'Radio Echo Aurora and Meteor Equipment'.

[605] Falkland Island Dependencies Survey, 'General IGY report 1956'.

[606] The Falkland Island Dependencies Survey is now known as the British Antarctic Survey (BAS): Ibid.

[607] 'Halley Bay Base diary 1957' (27 October 1957), Halley Bay Collection, *BAS Archives*.

[608] Ibid.

[609] Ibid.

generators.[610] By the end of 1956 a humidifier was installed in the generator shed to mediate this latter problem.[611] Snow static, although less disruptive than initially expected, also created fine spikes on the radio echoes, very similar to those produced by auroral corona discharges and thus confusing to the radio operators. 'In severe cases these spikes saturate the receiver' so that no other signals can be detected, we are told in the equipment log for the expedition,.[612] Moreover, the Halley Bay Annual General Report of 1958 remarked that the detection of spurious signals and radio noise required constant vigilance throughout the IGY.[613]

Additionally, physical obstruction caused by the meteorological conditions at Halley Bay impeded the radio echo work during the IGY. An entry written in the Halley Bay base diary on 27 October 1957 noted that Dyer had significant difficulty in getting to and from the radio echo hut due to deep snow and his ignorance of the guide rope pattern.[614] In February 1958, the radio echo hut became completely buried in snow. The door to the south of the building had been used as an entrance previously but two periods of drifting snow from unusual directions caused the door to become completely blocked.[615] This obstacle, however, was overcome by using a hatch at the other end of the hut, leading to a wooden shaft through which any member of the expedition could climb.[616] The physical and noise-related disruptions to the work at Halley Bay represents the everyday experience of dealing with interference during the IGY programme. Be it caused by meteorological conditions or the overlapping of signals, the sensitivity of the radio equipment meant that neither messages from Britain nor the echoes received from the aurora were necessarily clear-cut or legible.

Auroral Echoes

Three radio methods were used to investigate the aurora during the IGY, harnessing the phenomenon's tendency to 'interfere'. First, short-wave radio beams were bounced off auroral forms back to the original station to detect and place aurorae independent of cloud cover. This produced radio echoes, where the intensity of the echoe was given by the blackening of the film. Second, measurements of the scintillation and absorption of the radiation received from radio stars passing

[610] 'Copy of cable forwarded to Lieutenant-Commander Dalgliesh' (16 October 1956), *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

[611] Falkland Island Dependencies Survey, 'General IGY report 1956'.

[612] Harrison, 'Radio Echo Aurora and Meteor Equipment'.

[613] 'Annual General report 1958', Halley Bay Collection, *BAS Archives*, A/1958/2.

[614] 'Halley Bay Base diary 1957'.

[615] 'Royal Society Radio Echo Report' (1959), *BAS Archives*, NGY/49 (59).

[616] Ibid.

through the auroral region provided insights into ionospheric turbulence and drift. Third, radio waves emitted from the aurora itself were registered.

It has been argued that discrete echoes, rather than their diffuse counterparts, provide a 'good replica' of the pulse bounced off the aurora. Discrete echoes are reflected from a thin sheet of auroral ionisation that is aligned with the earth's magnetic field lines. Homogenous arcs often appear as discrete echoes.[617] They are also produced primarily during the dark hours, whereas diffuse echoes often occur during the times when the sun illuminates the reflecting region. Fig. 56 represents a portion of the radio echo film record taken on the night of 27 April 1956, before the beginning of the Geophysical Year. It depicts an aurora of approximately 500km in range detected from Jodrell Bank Observatory. The slow and fast film speeds, noted on the top of the echo, reveal the different perspectives that these film speeds facilitated; the latter is more useful in this instance, providing a view of the aurora's rough shape over time, whereas the slower speed only allowed for a simple strip of light repeated in series. The echoes themselves were difficult to read and required considerable training in order to differentiate between frequencies reflected by the aurora and sporadic radio signals.

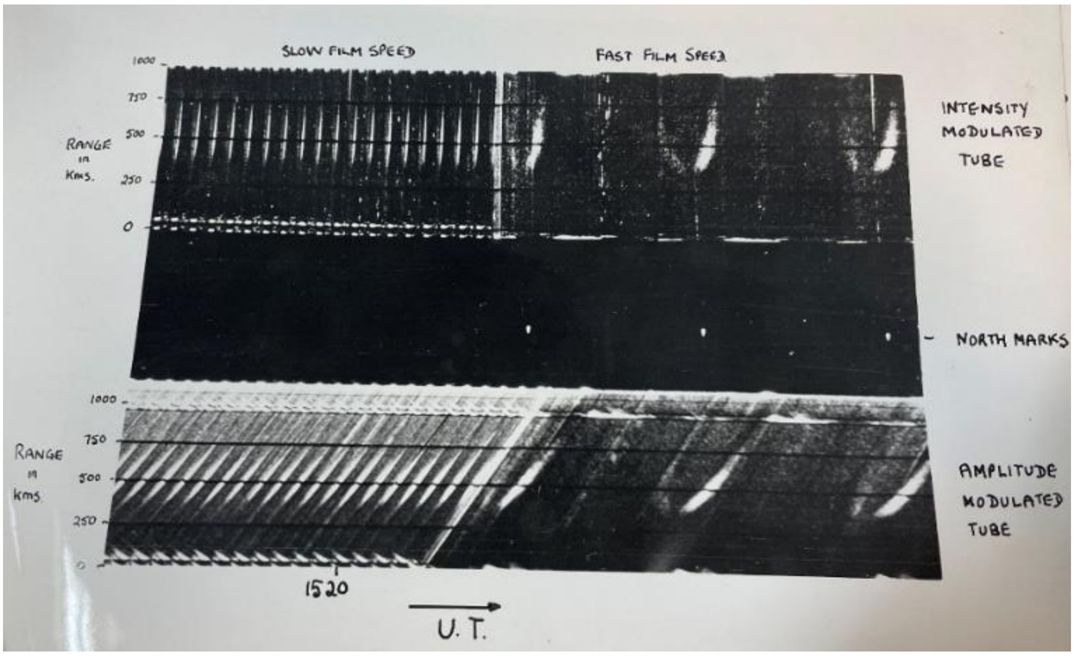


Fig. 56. 'Portion of Film Record for 27 April 1956 showing changes in film speed', International Geophysical Year 1953-1957, *University of Manchester Archives.*

[617] Ray L. Leadabrand, 'Radio studies of the aurora', *Journal of the Physical Society of Japan: International Conference on Cosmic Rays and the Earth Storm* 17 (1962): 218-222, 219.

One of the primary questions posed by groups of radio physicists before the Geophysical Year was whether a horizontal east-west drift in aurorae could be detected by means of radio echoes in the frequency range of 40Mc/s to 100Mc/s. As Lyon and Kavadas described in their 1958 paper, a previous investigation carried out by Aspinall and Hawkins at Jodrell Bank in 1950 had revealed that motions could be detected from individual auroral echoes, thus inspiring this focus.[618] In line with the recommendations set out by the International Union of Radio Science and the International Astronomical Union, a certain number of days in each month were selected for carrying out auroral drift measurements during the IGY. At the Tromsø and Kjeller stations in Norway the programme was extended to record drift observations two days each week.[619]

Several methods of assessing the east-west drift of aurorae were used by various research groups. It was found that the simplest method was to use a pencil-beam aerial directed at low elevation, sweeping continuously across the azimuth of an aurora, which would be connected to a pixel per inch screen.[620] K. Bullough and T. R. Kaiser, working at Jodrell Bank, introduced a method for more convenient *continuous* observation. In their setup, a narrow beam was directed towards the NW or NE and if the drift of auroral ionisation detected crossed the geomagnetic lines of latitude, either a receding or approaching velocity could be identified.[621] From an understanding of this motion, the east-west drift could then be calculated. Harang and Tröim were very familiar with the methods of Jodrell Bank from numerous correspondence and were therefore able to narrate the practices employed at the observatory accurately in their 1961 paper.[622]

In this paper, Harang and Tröim compared their auroral echoes directly to the Jodrell Bank drift results.[623] They concluded that their observations at Kjeller were far more regular and similar to the Jodrell Bank echoes than those collected at Tromsø. In a second paper, it was noted that the Kjeller results also resembled those obtained from Cambridge.[624] The Kjeller echoes showed prevailing westerly drift of areas of auroral ionisation from 17:00 to 24:00 hrs, and an easterly drift from 24:00 to 05:00 hrs, in agreement with the sequence of motions found at Jodrell Bank by

[618] G. F. Lyon and A. Kavadas, 'Horizontal Motions in Radar Echoes from Aurora', *Canadian Journal of Physics* 36, no. 12 (1958): 1661-1671.

[619] Leiv Harang and K. Maljord, 'Drift Measurements of the E-Layer at Kjeller and Tromsø During the International Geophysical Year', *Geofysiske Publiskasjoner: Geophysica Norvegica* 22, no. 1 (1960): 1-25, 2.

[620] Leiv Harang and J. Tröim, 'Studies of Auroral Echoes (I)', *Planetary and Space Science* 5 (1961): 33-36, 33.

[621] Ibid.

[622] Ibid.

[623] Ibid.

[624] Harang and Maljord, 'Drift Measurements of the E-Layer', 2.

Bullough and Kaiser in 1955.[625] It was suggested by Pamela Rothwell and Carl E. McIlwain in 1960 that the diurnal variation of aurorae may be connected to free protons in the Van Allen Belt, a zone of energetic charged particles in the planet's magnetosphere and one of the major discoveries of the IGY.[626]

The echoes observed in Canada, however, did not follow this pattern. As J. S. Kim and Balfour Currie noted in 1958, 'there is no definite indication of a reversal of the east-west motions close to midnight'.[627] Kim and Currie took pains to differentiate between imagined or illusory horizontal motion and that which could be detected on radio equipment, indicating a more quantifiable drift sequence. Having seen the aurora countless times themselves, they explained that the motion of auroral ionisation can be perceived by the human eye in two ways. First, the body of a display can appear to shift rapidly between forms. Second, the entire display can be displaced. The first type, according to Kim and Currie, is 'more apparent than real', an artefact of an observer's eyes created by the rapid appearing and disappearing of auroral rays, which can give the impression of waves across a curtain.[628] 'Detection' of the second type, they contend, 'depends on the presence of persistent convolutions and structures that cannot be confused with the more transient features that characterise the first type of movement'.[629] Speaking once again to the problem of subjective uncertainty, Kim and Currie remarked that lateral movement can also create an illusion of slow rotation. They wrote: 'these [movements] again may be more apparent than real, variations in the lateral direction of an arc as it moves eastward or westward being interpreted as rotations'.[630] Observers, they urged, must be on guard for such ways that their vision might be fooled and thus, Kim and Currie argued, radio echoes were a more reliable way of perceiving auroral drift.

As Kim and Currie's paper shows, the phenomenon's capacity to delude also applied to experts in the field of auroral studies. Having trained to observe the phenomenon and watched countless displays, a researcher within the scientific establishment still needed to exert energy and effort to 'see through' the phenomenon's deceptive tendencies. Furthermore, illusions and confusion arising from the perception of auroral movement constituted another form of interference in the proper understanding of the phenomenon. That being said, the interference of the aurora, while

---

[625] K. Bullough and T. R. Kaiser, 'Radio Reflections from Aurorae (II)', *Journal of Atmospheric and Terrestrial Physics* (1955): 201-214.

[626] Pamela Rothwell and Carl E. McIlwain, 'Magnetic Storms and the Van Allen Radiation Belts', *Journal of Geophysical Research* 65, no. 3 (1960): 799-806, 799.

[627] J. S. Kim and Balfour W. Currie, 'Horizontal Movements of Aurora', *Canadian Journal of Physics* (1958): 160-170, 160.

[628] Ibid.

[629] Ibid.

[630] Ibid.

problematic for communications networks, the accurate perception of the phenomenon and work carried out by radio astronomers, was harnessed during the IGY to reveal new information about the nature of the aurora and its east-west drift.

Conclusion

The pattern of communication within the IGY radio auroral programme was one of both interaction *and* interference. The aurora of the 1950s disrupted transnational exchanges and yet, it was through the use of radio, that critical and far-reaching communication technology, that knowledge of the high atmosphere and the connection between light phenomena in the Arctic and Antarctic could be gained.[631] IGY scientists stationed around the poles experienced both light displays and extreme latitude radio blackouts and spent the eighteen-month programme reconciling the two. On multiple scales the social and physical hemispheric networks of the IGY laid the foundations for the radio investigation of the aurora. The north met the south, with mirroring stations and an emphasis on simultaneous observations of the aurora australis and aurora borealis, and the east met the west, in the sense that Jodrell Bank Observatory was set between Cold War pressures but also a desire for internationalism.

Radio was both a means of transferring knowledge *about* the aurora as well as a method by which researchers of the IGY could reach and 'communicate' with the phenomenon itself. Transmission between the atmosphere and the earth's surface, as well as between individuals, was modulated, throughout the IGY, by the differing sensitivities of advanced radio technologies. We are talking here of aurorae that are sometimes invisible to the human eye, and which can be confused with the detonation of ballistic missiles. We are also talking of sensitivity contingent on position, latitude more specifically, as was made abundantly clear with the direct comparisons of the frequency and intensity of aurorae detected at Jodrell Bank and Halley Bay. The attempt to detect the ionisation of sunlit aurorae depended on the use of greater transmission powers so that the elusive form might be detected by the St Andrews receivers, to the detriment of the British radio effort and its part in the process of discipline-making. Moreover, the sensitivity of the radio aerials employed during the IGY was such that both auroral ionisation and random noise were pictured on the resultant echo, just as snow static threatened to mask appearances of the aurora and weak communications signals between polar and mid-latitude stations were sometimes lost among radio noise.

[631] American Geophysical Union (eds.), *Antarctica in the International Geophysical Year: Based on a Symposium on the Antarctic* (Washington: National Committee for the International Geophysical Year, 1956), p. 2.

The discourse of disruption was applied to visitors to Jodrell Bank in the 1950s, indicating that anyone not directly involved in the radio work was seen to be intruding on laboratory space, given the complexity and scale of the instruments housed there and the potential secrecy of the methods used during the Cold War. It remained true, however, that imaging techniques could not entirely replace the visual experience of the aurora outside the walls of Jodrell Bank. Amateur observers, interacting with the Edinburgh observatory, were crucial to the auroral programme and not considered to be a hindrance or disruptive factor when it came to recording the visual data of the aurora, just as the Moonwatch programme was significant for the monitoring of satellites.[632] A primary concern of the IGY was documenting the phenomenon from an embodied perspective and in fact the correlation between experiential and instrumental reckonings became a subject of serious scrutiny during the period. Perhaps unexpectedly in an era of big science and high-precision technology, the sensory register continued to play a large role in developing understandings of the light displays of the aurora in the late 1950s.

The social production of the specialist community of auroral researchers was based on communication networks as opposed to a reference text, as had been the case for the Second IPY. The organisational burden of the IGY was left to individuals, who corresponded and exchanged instruments and techniques with their colleagues in various research stations and observatories in mid-latitude and polar regions. The vast expanse of the IGY project and the sheer number of individuals involved meant that miscommunication and misunderstandings were inevitable. Nevertheless, Jodrell Bank became a ‘standard station’ in this physical and social network, a site from which other results could be contrasted and compared, in the eyes of researchers including Harang, Lyon and Kavadas.

This chapter has bridged a gap between histories of Cold War geopolitics and the environmental sciences in response to a call from John R. McNeill and Corinna R. Unger.[633] There is still significant work to be done in analysing the communications networks of the IGY, from researchers to funding bodies and from a local perspective to an international scale. Moreover, with the exception of Lehman’s evaluation of the IGY oceanic investigation, the scientific programmes of the IGY deserve considerably more scholarly attention.[634] This chapter has illuminated a portion of the less often told history of British scientific work and communications during the Cold War, demonstrating the significance of the lens of networks in understanding the workings of such a vast international project. Finally, it has explored the congruent presence of both interaction and interference on the personal and planetary scales involved in historical attempts to communicate *with* nature and *about* such natural phenomena as the aurora.

[632] McCray, *Keep Watching the Skies*, p. 144.

[633] McNeil, Unger, and German Historical Institute, *Environmental Histories of the Cold War*, p. 4.

[634] Jessica Lehman, 'Making an Anthropocene Ocean: Synoptic Geographies of the International Geophysical Year (1957–1958)', *Annals of the American Association of Geographers* 110, no. 3 (2020): 606-622.

Synopticism and the All-Sky Camera During the International Geophysical Year, 1957-58

Fig. 57. 'IGY Optical Station as it appeared in 1959 at the Ballaine Lake Observatory in the woods north of the UAF Buildings', the all-sky camera is within the third dome from the viewer and was originally housed atop the tower-like structure behind it, *Photograph reproduced with permission of Charles Deehr.*

'The chemist or the physicist can perform experiments in his laboratory, establishing the conditions of these experiments. The natural laboratory of the geophysicist is the earth itself, and the experiments are performed by nature.'[635]

As Joseph Kaplan, the eminent atmospheric physicist and chairman of the US National Committee for the IGY, made clear in 1956, the planet in its entirety was the stage set for the International Geophysical Year of 1957-8. The IGY was established as a rugged observational pursuit with its objects of study found in the vast unstable outdoor realm. The programme aimed at a 'synoptic',

[635] Kaplan, 'The International Geophysical Year', 383.

comprehensive view of the planet, encompassing a wide range of geophysical methods probing the land, ocean and atmosphere. Unlike its First and Second International Polar Year predecessors, it incorporated *all* latitudes, hence the change of name.[636] The aspiration to gain a panoptic outlook was in tune with the cultural moment of the 1950s, wherein the post-war one-world movement, Cold War politics, cybernetics research and the powerful ideology of scientific internationalism underwrote the propensity to see 'local forces as elements of a planetary order'.[637]

The concept of 'synopticism' became a touchstone for the IGY endeavour. Hugh Odish, the Executive Director of the US National Committee for the IGY explicated the importance and meaning of the word at a speech before the US National Press club in 1959. He stated that, 'the fundamental purpose of the IGY was the acquisition of synoptic data – data taken simultaneously on and about the earth in order to get a planetary view of weather, geomagnetism, the ionosphere, the aurora and the like.'[638] Here, Odish's aspirations for the programme moved beyond the scale of the international to the planetary, encompassing a shift from a type of view which gained legitimacy through the locality of particular field sites to the privileging of the 'view from nowhere'.[639] This begs the question, how could planetary knowledge be constructed from the intersecting scales of the individual, national and the hemispheric?[640] More broadly, as Simon Naylor asks, 'how have particular spaces and spatialities impacted upon the formulation of scientific theories?'[641]

Jessica Lehman has shown how a synoptic portrait of the world's oceans and their planetary-scale dynamics developed during the IGY through the analytic of 'synoptic geographies'.[642] Synoptic geographies, as Lehman puts it, 'operate inductively, linking distant places through careful coordination to produce coherent and quantifiable understandings of the earth as a planet.'[643] The resultant data from remote sensing technologies are 'scaled-up' and combined to form maps, charts and visual aids which can be overlaid upon two dimensional representations of the earth, providing a totalising perspective. Lehman argues that while planetary knowledge is inevitably built from multiple

---

636 David R. Bates, *The Earth and its Atmosphere* (New York: Science Editions, 1957), p. 21; Ruttenberg, *IGY General Report*, p. 2.

637 Edwards, *A Vast Machine*, p. 3.

638 Hugh Odishaw, 'The Meaning of the International Geophysical Year', speech, 1959, 1959-1961, Box 6, A83-10, Dwight D. Eisenhower Library, Abilene, Kansas.

639 Shapin, 'Placing the View from Nowhere'.

640 Deborah Coen frames the problem of climate change as a problem of scale: Deborah Coen, *Climate in Motion: Science, Empire, and the Problem of Scale* (Chicago: University of Chicago Press, 2018).

641 Simon Naylor, 'Introduction: Historical Geographies of Science: Places, Contexts, Cartographies', *The British Journal for the History of Science* 38, no. 1 (2005): 1-12, 9.

642 Lehman, 'Making an Anthropocene Ocean'.

643 Ibid., 607.

local sites, attention to the global scale exposes the larger dynamics of imperialism and geopolitics which inflect its construction.[644]

Paul Edwards describes how weather data was 'made global' in the 1940s and 1950s through the use of computer systems, standardised observations and improved communications networks, all contributing to his concept of a 'global knowledge infrastructure'.[645] Although, conspicuously, the IGY was one of the 'last global weather data networks whose foundations were not shaped fundamentally by computer modelling and computerised data processing'.[646] Adding to these accounts, the 'synoptic' is presented here as a concept largely built through publication and display. In contrast to much of the existing historiography of the IGY, this chapter takes the synopticism of the scientific *media* rather than the organisation of the programme as the lens through which to understand the construction of 'planetary knowledge'.[647]

The emergence of an aerial view, or 'Apollo's eye' to borrow the titular phrase from Denis Cosgrove's 2001 work, has been studied extensively.[648] Cosgrove argues that the modern era saw the 'closure' of the complete pictorial imagination of the globe by bringing the east and west together and through 'axial advance along the meridian to the polar ends of the earth'.[649] The 1950s and 1960s saw a very visual process of global meaning-making with the advent of the satellite view.[650] Although the view from above had long been associated with military mapping, the satellite era brought a renewed strength to aerial surveillance.[651] Gemma Cirac-Claveras takes a different perspective, demonstrating

[644] Ibid., 610.

[645] Edwards, *A Vast Machine*, p. 187.

[646] Ibid., 207.

[647] Elzinga, 'Through the Lens of the Polar Years'; Gregory A. Good, 'Sydney Chapman: Dynamo behind the International Geophysical Year', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan US, 2010): pp. 177-203; Adrian Howkins, 'Science, Environment, and Sovereignty: The International Geophysical Year in the Antarctic Peninsula Region', in Roger D. Launius, James Rodger Fleming, and David H. DeVorkin (eds.), *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan US, 2010): pp. 245-264.

[648] Peter Adey, *Aerial Life: Spaces, Mobilities, Affects* (New York: John Wiley & Sons, 2010); Denis Cosgrove, *Apollo's eye: a cartographic genealogy of the earth in the western imagination* (Baltimore: The John Hopkins University Press, 2001).

[649] Cosgrove, *Apollo's eye*, p. 207.

[650] As Denis Cosgrove argues, 'the idea of seeing the globe seems also to induce desires of ordering and controlling the object of vision' in: Ibid., 5.

[651] Cosgrove, *Apollo's eye*, p. 239; Klaus Dodds, 'Aerial Surveying, Geopolitical Competition and the Falkland Islands and Dependencies Aerial Survey Expedition (FIDASE 1955-7)', in Peter Adey, Mark Whitehead, and Alison Williams (eds.), *From Above: War, Violence and Verticality* (Oxford: Oxford University Press, 2014):

the ways in which French satellite imagery was embedded within longer traditions of the practices of natural history and aerial photography in the field in the 1960s and 1970s.[652] All in all, the remote sensing capabilities of the satellite and the sociotechnical imaginary that it engendered provided a unique and unprecedented view of the earth as a whole.

Panoptic vision, by contrast, was sought within the auroral programme of the IGY in two significant ways. First, temporally: the two previous Polar Years were discussed extensively by those geophysicists who participated, placing the programme within a clear temporal and intellectual lineage. The endeavour was viewed as the climax of the 1882-3 and 1932-3 IPY events, set to succeed where they had fallen short. Second, synopticism was constructed through the all-sky camera photographs as media. A chain of 114 automatic all-sky cameras were set up in strategic positions, creating a chain of visibility in the northern and southern hemispheres to detect the geographical extent of aurorae on a global scale and the formation and degeneration of auroral forms from start to finish.[653] It is crucial to remember that this 'synopticism' was the result of painstaking labour-intensive reconstruction of extreme volumes of data. These perspectives provided a reply (though not necessarily an answer) to the problem of the fragment illuminated in the First Polar Year. The ineffable aurora which could only be reproduced partially at the end of the nineteenth century was now subject, at least in theory, to complete planetary observation, albeit at a low resolution and subject to a host of organised individuals willing to merge vast volumes of data. The inevitable gaps in the data functioned to unsettle the picture of 'completeness' bestowed on the all-sky images but also highlighted the 'comprehensive' qualities of the sequence.

To date, the history of the auroral programme of the IGY has primarily been written by those who participated in it themselves. Syun-Ichi Akasofu, who was the first recipient of the Sydney Chapman Chair professorship at University of Alaska Fairbanks (UAF) in 1985 and founded the International Arctic Research Centre of UAF in 1998, provided the most detailed and complete account of the period.[654] Akasofu had written to Chapman as a graduate of Tohoku University, Japan

---

pp. 71-94; Caren Kaplan, 'The Balloon Prospect: Aerostatic Observation and the Emergence of Militarised Aeromobility', in Peter Adey, Mark Whitehead, and Alison Williams (eds.), *From Above: War, Violence and Verticality* (Oxford: Oxford University Press, 2014): pp. 19-40; Elizabeth DeLoughrey, 'Satellite Planetarity and the Ends of the Earth', *Public Culture* 26, no. 2 (2014): 257-280.

[652] Gemma Cirac-Claveras, 'Re-imagining the Space Age: Early Satellite Development from Earthly Fieldwork Practice', *Science as Culture* 31, no. 2 (2022): 163-186.

[653] Hugh Odishaw, 'International Geophysical Year: A Report on the United States Programme', *Science* 128, no. 3339 (1958): 115-125, 116.

[654] C. T. Elvey, 'Auroral morphology', *Planetary and Space Science* 12, no. 8 (1964): 783-797; Syun-ichi Akasofu, 'Dynamic Morphology of Auroras', *Space Science Reviews* 4, no. 1 (1964): 498-540; Akasofu, 'Space Physics in the earliest days'.

and was invited to study under him at Fairbanks in 1958, completing his PhD there in 1961. He played a central role in aggregating the auroral Polar Year data after the programme had finished, analysing the all-sky camera photographs to find the significant result that one aurora extended 10,000km across the earth's surface and elucidating the patterns of what he termed, 'the auroral substorm'.[655] Also working at the Fairbanks station during the IGY were such scientists as Charles Deehr and Neil Davis. This chapter will follow the many and multiple sites of all-sky imagery creation and evaluation, with significant insights drawn from the Fairbanks Alaska station, which became a World Data Centre for the magnetic and all-sky camera data collected during the IGY.

This is a story of the different scales, dimensions and modalities of synopticism at play. I will address how 'synopticism' was interpreted at the level of the IGY research station and as a vast objective of hemispheric night sky observation, and how these two differing scales were folded into the publication space through all-sky imagery. Researchers of the IGY moved beyond the international paradigm to the planetary perspective. They staged previous attempts at understanding the aurora as incomplete to emphasise the exhaustive practices of the IGY. The temporal dimensions of the 'synoptic view', be it over one single night or the whole of the eighteen-month programme, became constitutive of the perspective. Furthermore, I argue that the homogenising perspective (the word *synoptic* being derived from *synopsis*) moves towards the realm of remote sensing but does not entirely do away entirely with the personal, experiential knowledge which has been so central to the auroral project of the nineteenth and early twentieth centuries.

The Synoptic *Historical* Perspective of the IGY

The synoptic perspective that the IGY facilitated was both *planetary* and *temporal*. From the standpoint of the late 1950s, auroral researchers could scrutinise not only a large portion of the polar atmosphere at night and the development of auroral forms in minute detail, but they could survey the trajectory of their own field over the past century. Their position was one of a privileged broad outlook, with all the dead ends and triumphs of auroral science up to that point in view. From the vantage point of the late 1950s, IGY reports suggested that encyclopaedic knowledge of the phenomenon could be achieved, with the subtextual implication that auroral science was coming to its conclusion. As Kaplan remarked in the year before the programme's commencement, research in the geophysical sciences would be brought 'to an unprecedented climax' during the Geophysical Year.[656]

[655] Syun-ichi Akasofu, 'The dynamical morphology of the aurora polaris', *Journal of Geophysical Research (1896-1977)* 68, no. 6 (1963): 1667-1673, 500.

[656] Kaplan, 'The International Geophysical Year'.

Marking the culmination of the 'auroral sciences' was the realisation of the aim of monitoring the aurora australis, which was achieved with fifty stations in operation across the Antarctic.[657]

Much of the auroral literature of the IGY followed a framework which first included accounts of past efforts to understand the phenomenon before presenting new research. In detailing and magnifying past investigations, those who participated in the IGY situated themselves and their work in the context of centuries of fascination with the northern lights. In his 1958 survey of the work carried out during the IGY, D. C. Martin, working at the Royal Society, began in the seventeenth century with the naming of the aurora borealis by French philosopher and astronomer, Pierre Gassendi, in 1621.[658] He provided a short compendium of historical interactions with the aurora including Seneca's reference to the phenomenon in 'Questiones Naturales' and Edmond Halley's famous report of the 1716 great aurora.[659] Additionally, Eklund discussed Kristian Birkeland's terrella experiments to set the scene for his forthcoming description of Antarctic auroral investigations in his longer synopsis of geophysical research of the IGY.[660] Even the 'International Geophysical Year Instruction Manual, no. IV Aurora and Airglow' recounted Captain James Cook's sighting of an aurora in 1773 and the creation of Hermann Fritz's isochasm map before providing guidance for auroral observers.[661]

Most often, the IGY was consciously viewed within a temporal scheme connected to the First and Second IPYs. F. R. Park, a member of the Radio and Electrical Engineering Division of the National Research Council in Ottawa, Ontario, included a short discussion of the limitations of the First IPY in his publication on all-sky cameras in 1961. He lamented that 'observations were fraught with many difficulties and did not provide consistent results'.[662] In the same vein Akasofu commented in 1963 that the observations of the 1882-3 and 1932-3 programmes, 'were limited… to detailed studies of auroral displays at individual observatories,' neatly emphasising the necessity of the more revealing synoptic method of the IGY.[663] James Stagg, leader of the Second IPY expedition to Fort Rae, similarly noted the shortcomings of the First IPY in comparison to the 1932-3 endeavour. He wrote that, 'in 1882-3 none of the expeditions, so far as I know, carried out any upper air work'. Moreover, he asserted that, with advancements in understandings of the earth's magnetic field 'one observatory can no longer be considered representative of a large area of the earth around it', as it was

[657] Martin, 'The International Geophysical Year', 23.

[658] Ibid., 18.

[659] Ibid.

[660] Eklund, *Antarctica*, p. 119.

[661] Committee of CSAGI, 'The International Geophysical Year Instruction Manual'.

[662] F. R. Park, 'An All-Sky Camera for Auroral Photography', *Journal of the Royal Astronomical Society of Canada* 55 (1961): 203-210, 203.

[663] Akasofu, 'The dynamical morphology of the aurora polaris', 498.

in the First IPY.[664] From Stagg's viewpoint, one station could not represent the complex region in which it was situated, which is interesting considering the shift towards the creation of a hemispheric perspective built from images from individual stations in the IGY.

James Paton sought to learn directly from his experience of the Second IPY, writing in a letter to D. C. Martin in June 1958 and repeating the sentiment in a message transmitted to MacDowell at Halley Bay, that it would be best to circulate a concise synopsis of the geographical distribution of aurorae found at the station to other Antarctic bases while the IGY was still ongoing.[665] The reason for this was that during the Second IPY, 'by the time each nation published its data separately, the initial enthusiasm had waned and the whole purpose of simultaneous observations never achieved.'[666] This exercise, it was thought, might extend the enthusiasm of participants so that a more detailed analysis could be carried out after all the information had been gathered.[667] In this way, the personal experience of the Second IPY directly influenced the methods employed during the IGY; with the benefit of hindsight the failures of the previous programme were thrown into sharp relief.

The incomplete and little analysed data of the previous IPYs motivated the centrality of synopticism in the IGY. Constructing an apparently complete and all-encompassing overview of the auroral phenomenon was undertaken to transcend the fragmentary nature of past efforts to capture it. The word 'synoptic' had entered the lexicon of the IGY itself as a descriptor which furnished the observational data with value and significance. Indeed, it became the gold standard by which visual logs of the aurora were judged. The objective of the auroral programme, Kaplan wrote in his 1956 article setting out his hopes for the IGY, is the 'creation of synoptic maps showing auroral distribution at small intervals'.[668] Airline pilots commissioned to document any aurorae they witnessed on their scheduled flights above the clouds were considered 'a vital factor in filling in bad weather gaps in our synoptic picture' by Peter Millman, an astronomer and the head of the Upper Atmosphere Research Section.[669] 'Filling the gaps' was another oft-repeated turn of phrase, also appearing in Kaplan's 1956 article, which further justified the project and resonated with metaphors of charting new territory and bearing new knowledge.[670] The all-sky camera, with its almost constant watch, automated operation

---

[664] J. M. Stagg, 'The British Polar Year Expedition to Fort Rae, N.W. Canada, 1932-1933', Conference Presentation, *The G. J. Symons' Memorial Lecture of the Royal Meteorological Society*, 21 March 1934, 253.

[665] Paton to Schneider, 28 July 1959; James Paton, G. M. Thomas, and S. Evans to Halley Bay via G. H. Whitefield MacDowall, 19 June 1958, letter, *Royal Society Archives*, EXP/11/1/1/181.

[666] Paton to Schneider, 28 July 1959.

[667] Stan Evans to D. C. Martin, 16 June 1958, letter, *Royal Society Archives*, EXP/11/1/1/181.

[668] Kaplan, 'The International Geophysical Year', 386.

[669] Peter Millman, 'A visual auroral programme for the IGY', *Journal of the Royal Astronomical Society of Canada* 51 (1957): 186-188, 186.

[670] Kaplan, 'The International Geophysical Year', 386.

and vast perspective was heralded as an instrument which would fill in the gaps and correct the mistakes of previous efforts to learn about the aurora's ontology. It would provide a complete view, and thus reinforce the notion that individually, researchers of the IPY were positioned at the climax of auroral science.

The All-Sky Camera

The all-sky camera was first introduced to auroral studies in 1947 by Gartlein at Cornell University. Gartlein's 'direct' all-sky camera system involved a cine camera placed directly above a convex mirror. In the early 1950s Willy Stoffregen, a German instrument maker working at Uppsala University, produced an updated 'folded' all-sky system. Light hitting the folded system underwent two reflections, first in the convex mirror and then in a plane mirror before entering the lens of the camera.[671] The advantages of the folded system include greater mechanical rigidity and compactness.[672] The Stoffregen design was adopted by the US and Russia and the majority of all-sky cameras employed during the IGY were of the Stoffregen design.[673]

The all-sky camera apparatus consists of a camera situated below a spherical mirror, with a secondary mirror placed at the top of the mechanism to direct light into the photographic lens.[674] A small hole is cut in the spherical mirror so that the lens can receive light. The central position of the photographic lens explains the blind spot in the resulting image. With a hole standing in for the retina, the all-sky camera loosely resembles the anatomy of the human eye and yet, interestingly, all-sky images are further from the way we perceive the aurora visually than conventional photographic technologies. The camera is usually placed within an insulated box with thermostatically controlled heaters, timing gear and overhead wires or metal supports which provide grid references on the developed photographs. Each photographic apparatus has a 500km view from horizon to horizon. An image of the camera at the Tromsø Geophysical Observatory is displayed in figure 58, while a photograph of the camera within its shelter at Fairbanks, Alaska, can be seen in figure 59. Prior to the Polar Year, all-sky cameras (sometimes referred to as *whole-sky cameras*) had been employed in the field of cloud studies. An instrument involving a revolving camera, designed by Fred. W. Mueller,

[671] K. Schlegel and H. Lühr, 'Willy Stoffregen - An early pioneer of advanced ionospheric and auroral research', *Hist. Geo Space. Sci.* 5 (2014): 149-154, 149.

[672] A. G. McNamara, 'Elementary considerations in the optical design of an all-sky camera for aurora photography', *National Research Council Canada* (1957): 14, 2.

[673] Park, 'An All-Sky Camera for Auroral Photography', 203.

[674] C. T. Elvey, 'How to build, operate, organise, and interpret photographic data: The Alaskan All-Sky Camera', *Annals of the Geophysical Year*, vol. V (London: Permagon, 1958): pp. 133-151.

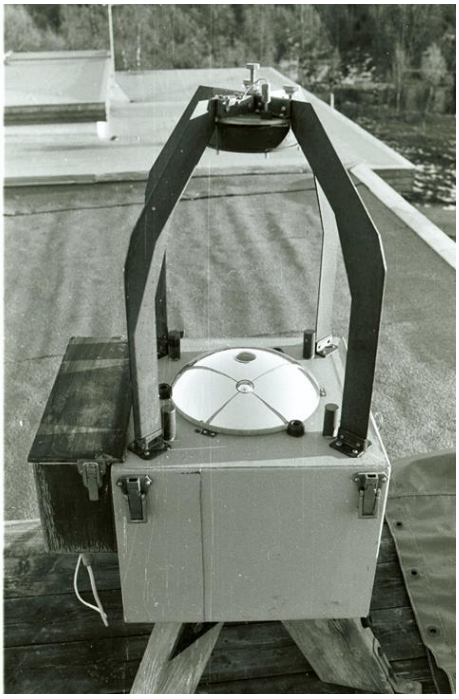


Fig. 58. A Willy Stoffregen All-Sky Camera housed at the Tromsø Geophysical Observatory in Magnar G. Johnsen, 'All-Sky Camera', *Tromsø Geophysical Observatory (TGO) Norwegican Centre for Space Weather*, https://site.uit.no/spaceweather/2015/01/13/all-sky-camera/.

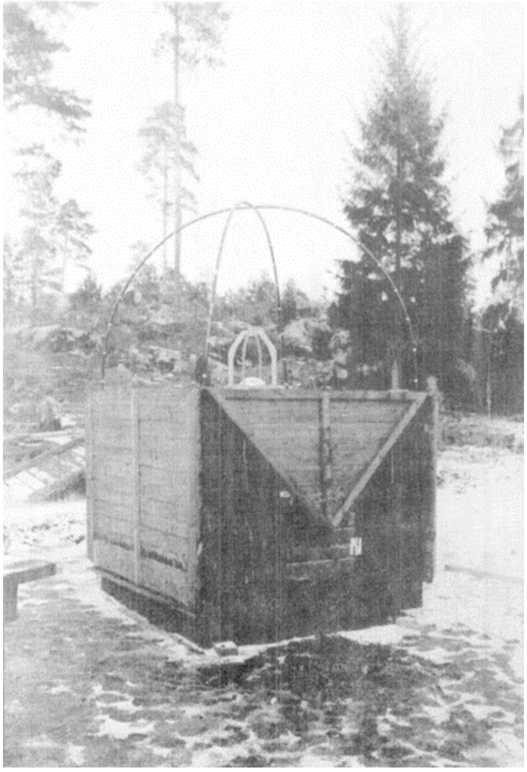


Fig. 59. A Stoffregen design all-sky camera within its housing at the College, Alaska IGY station in T.N. Davis and C.T. Elvey, 'Construction of an All-Sky Camera,' *Geophysical Institute at the University of Alaska* (1955), 40.

was used in the 1910s to produce photographs of cloud forms across a large portion of the sky.[675] Robin Hill, an amateur meteorologist and biochemist at the University of Cambridge, designed and constructed a wood-bodied all-sky camera consisting of a convex mirror positioned above a pinhole lens in the 1920s.[676] It was popular for a time but rarely used after 1935.[677]

The relative weakness of auroral light, which plagued early photographic studies of the phenomenon, also posed a problem to the scientists of the IGY. In order to capture the aurora with an

675 Oliver L. Fassig, 'A revolving cloud camera', *Monthly Weather Review* 43, no. 6 (1915): 274-275, 274; K. McGuffie and A. Henderson-Sellers, 'Almost a Century of "Imaging" Clouds Over the Whole-Sky Dome', *Bulletin of the American Meteorological Society* 70, no. 10 (1989): 1243-1253, 1243.

676 Robin Hill, 'A lens for whole sky photographs', *Quarterly Journal of the Royal Meteorological Society* 50, no. 211 (1924): 227-235.

677 Henry Schmidt, 'Robin Hill's Cloud Camera: Meteorological Communication, Cloud Classification', in J. Nall, L. Taub, and F. Wilmoth (eds.), *The Whipple Museum of the History of Science, Objects and Investigations* (Cambridge: Cambridge University Press, 2019): pp. 257-274, p. 1.

all-sky camera, exposures of between 5 and 15 seconds taken at 1-minute intervals were used with a lens aperture of f1.4. These longer shutter speeds tended to blur the motion of the aurora. This, however, was of little consequence given that the all-sky records were primarily used for the positional data that they provided. The fastest films available, such as Ilford HP3 film, were employed and subsequently processed using a high contrast developer.[678] Generally, the developed photographs showed the aurora in much greater contrast than would have been seen by the naked eye for ease of comparison and analysis. The series of auroral photographs in figure 60, taken from the Saskatoon station on 13 March 1957, furnish us with an example.[679] The negative prints depict stark black swirls, with some delineation between fainter shades of grey. Moreover, the series demonstrates that the shape and forms of aurorae can change considerably over the course of just a few minutes.

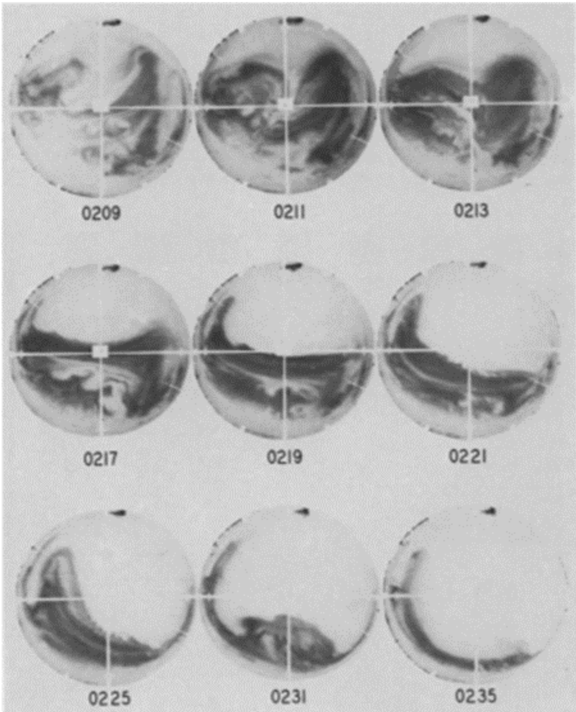


Fig. 60. 'Series of all-sky photographs (in negative) showing fine details of the torch-like structure; Saskatoon, 13 March 1957', printed in S.-I. Akasofu, 'A Study of Auroral Displays Photographed from the DMSP-2 satellite and from the Alaska Meridian chain of Stations', *Space Science Reviews* (1974): 617-725, 665.

[678] G. M. Thomas and James. Paton, 'Auroral Results from Halley Bay During The International Geophysical Year', *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 256, no. 1285 (1960): 241-244, 57.

[679] Syun-Ichi Akasofu, 'A Study of Auroral Displays Photographed from the DMSP-2 satellite and from the Alaska Meridian chain of Stations', *Space Science Reviews* (1974): 617-725, 665.

In the 1950s the all-sky camera was directly compared to the use of visual observers, the primary method of documenting the aurora during the First IPY prior to the advent of auroral photography. Perhaps unexpectedly, G. M. Thomas, working at the Department of Natural Philosophy at the University of Edinburgh, contended that ‘as regards purely positional data the all-sky camera holds little advantage, if any, over the visual observer’.[680] It was noted that extremely short-lived auroral forms may appear in the one-minute intervals between the exposures taken by the camera, which a human observer could witness and record if they were watching.[681] Although the opposite point could also be made; as Thomas pointed out, ‘where the all-sky camera scores is in the timing of sudden changes; these may occur when the visual observer is making a note in his log or is otherwise distracted’.[682] An outdoor observer might have a greater sensitivity to the intricate details of an auroral display but their accuracy was limited by the act of having to write down a complete description which would be recorded automatically on the all-sky photographic film. According to Davis, Deehr and Leinbach, working in Alaska, the all-sky camera was slightly less able than the visual observer to detect very weak aurorae.[683] They also argued, however, that the photographic apparatus often revealed that faint diffuse forms were more complex segments of arcs or bands when viewed on the all-sky film.[684]

The major benefits of the all-sky camera system were twofold. First, the apparatus allowed for the use of far fewer man hours. As was made clear in the literature of the First IPY, a single researcher could not be employed throughout the entire night without pause and could not always be alert to the changes in the aurora or be able to communicate the nuances of its appearance. The all-sky cameras, by contrast, only needed a couple of minutes attention each day. The apparatus would also capture the aurora in a uniform manner across different stations.[685] Second, as mentioned by Deehr, Leinbach and Davis, ‘the all-sky camera is much superior to the visual observer in accurately locating and recording the shape of most auroral forms,’ two important data points collected during IGY.[686] A visual observer, by contrast, would sometimes report aurorae at much higher angles than they were

[680] G. M. Thomas, 'Auroral Photography Using All Sky Cameras', *The Journal of Photographic Science* (1959): 55-57, 57; Thomas and Paton, 'Auroral Results from Halley Bay'.

[681] Neil Davis, Charles S. Deehr, and H. Leinbach, *An Evaluation of Auroral All-sky Camera Observations* (Fairbanks: University of Alaska, 1960), p. 9.

[682] Thomas, 'Auroral Photography Using All Sky Cameras', 57.

[683] Davis, Deehr, and Leinbach, *An Evaluation of Auroral All-sky Camera Observations*, p. 8.

[684] Ibid., 9.

[685] Neil Davis and Donald S. Kimball, *Incidence of Auroras and their north-south motions in the northern auroral zone* (Fairbanks: Geophysical Insitute of the University of Alaska, 1960), p. 1.

[686] Davis, Deehr, and Leinbach, *An Evaluation of Auroral All-sky Camera Observations*, p. 8.

really positioned. Indeed, Stoffregen argued that 'the accuracy of the visual observer by only looking at the sky is not great enough'.[687]

The all-sky camera certainly held some key advantages over the visual observer in the period and its use was rationalised with reference to the argument that it obviated the need for constant human observation. Although there were some research questions, including the detection of auroral drift movements, which necessitated the use of the all-sky camera (as well as radio echoes), the photographic equipment largely stood in as a less labour-intensive version of a visual observer with a much wider field of view. In certain instances, visual observations supported the work of the all-sky camera and the two were used in combination to provide insights into the nature of the aurora. Interestingly, the resolution of the all-sky camera was not good enough to capture the path of Sputnik I after its launch on 4 October 1957. It was by both radio signals and visual observation that the path of the Soviet satellite was detected in the western hemisphere. The Geophysical Institute at Fairbanks, Alaska, detected the satellite in the early hours of the morning on 6 October 1957 but it was a local man, Dexter Stegemeyer, according to Davis' account, who first spotted Sputnik I in the region.[688]

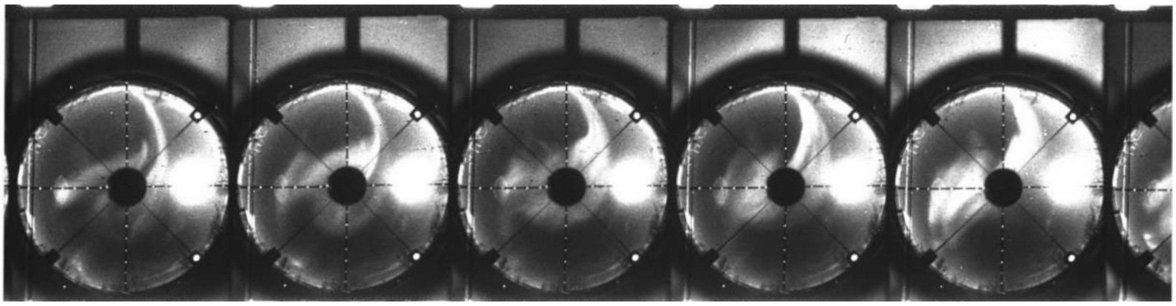


Fig. 61. 'Aurora at Abisko, Sweden 01/02/1958', taken at 1-minute intervals, *Polar Environment Data Science Centre and the National Institute of Polar Research (NIPR) archives, Japan.*

Multiple Sites: Chains of Cameras

The impulse to construct a standardised planetary network for the purposes of weather forecasting and data exchange can be traced to the 1873 International Meteorological Congress in Vienna, with the International Meteorological Organisation coming into being in 1879. A telegraphically connected weather system was expanded in the first half of the nineteenth century. Later, weather forecasters became early adopters of computer modelling technologies, introducing such techniques in 1954.[689] The World Meteorological Organisation (WMO), founded in 1950 from the IMO, continued to hold

---

[687] Willy Stoffregen, 'All-Sky Camera Auroral Research during the Third Geophysical Year 1957-58', *Tellus* 7, no. 4 (1955): 509-517, 511.

[688] Neil Davis, *Alaska Science Nuggets* (Fairbanks: Geophysical Institute, University of Alaska, 1982), p. 31.

[689] Edwards, *A Vast Machine*, p. 14.

the torch as a forum for the exchange of weather data and research. Linking local and global weather information requires an individual to develop an understanding of atmospheric phenomena on intersecting scales. The same can be said of IGY auroral observation, which began in earnest on 1 July 1957. Likening the project to international weather forecasting, Millman contended that he 'hoped to plot maps, similar to synoptic weather maps, showing the location of the aurora at each hour of the night'.[690]

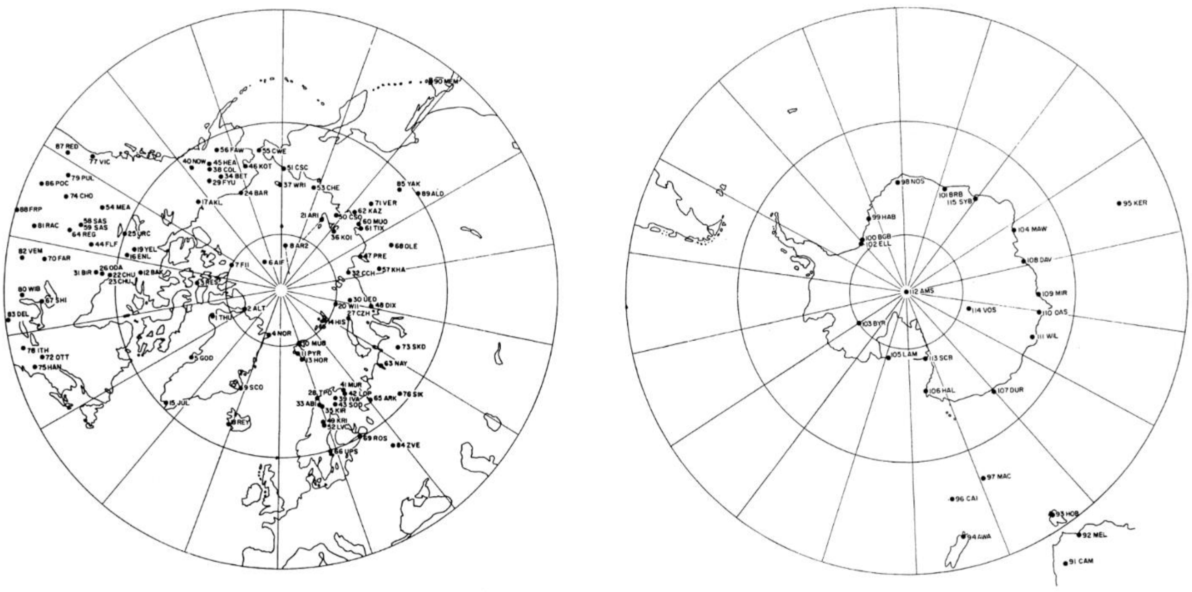


Fig. 62. The positions of the IGY all-sky cameras in the northern and southern hemispheres, printed in Willy Stoffregen, *I. G. Y. Ascaplots: Annals of the International Geophysical Year*, vol. 20 (Amsterdam: Elsevier Science, 2013).

A chain of nine all-sky Model DA-3 cameras were designed and built by the Canadian Radio and Electrical Engineering Division of the National Research Council and operated at the Canadian IGY stations.[691] The all-sky unit included a timing and control mechanism situated within the cast aluminium base as well as altitude marker lights located on each of the camera's supporting legs. Rolls of 35mm film, 100ft in length, were inserted into the camera and used at a rate of one roll per 24 hours. During the IGY 1,454 rolls of film were developed in total from the nine Canadian stations.[692] Out of a total 2800 hours of film recorded at the Fairbanks station in Alaska, approximately 800 hours captured some form of aurora.[693] Of these 800 hours, a quarter recorded aurorae which were of at least

[690] Millman, 'A visual auroral programme for the IGY', 186.

[691] Park, 'An All-Sky Camera for Auroral Photography', 206.

[692] Ibid., 209.

[693] Helen M. Tyron, *Auroral Index for College, Alaska derived from all-sky camera photographs, September 1957 - December 1958* (Fairabanks: Geophysical Institute of the University of Alaska, 1959), p. 4.

moderate intensity on clear nights uninterrupted by clouds, moonlight or failures of the equipment. As was often the case, the aurorae in fig. 60, captured at Saskatoon on 13 March 1957, were presented in series when published to show how rapidly a single auroral form could change.

At many stations, a stopwatch was placed on the mirror in view of the lens so that the time of exposure could be captured on the photograph. At Fairbanks, plastic numbers would rotate, driven by a small electric motor. These numbers needed to be reset daily and the card bearing the date needed to be updated by hand too.[694] The exposures themselves were controlled by various forms of mechanical relays. As Charles Deehr recalls from his time working at the Fairbanks station during the IGY, 'an experienced operator could curl up in the box beneath the camera to listen to all of the mechanical harmonisation to determine how the camera was working over several sequences'.[695] As this demonstrates, the embodied reactions of the operator could intuitively calibrate the instrument through familiarity and an attunement with its sounds. The uncomfortable positioning of the body curled beneath the camera further points to a close-proximity, reciprocal relationship between the device and the body of the observer. Additionally, the Stoffregen all-sky camera at Fairbanks was initially equipped with an Arriflex 16mm camera. Davis, however, found that the model was 'altogether too precisely built' to operate with the timing mechanism and thus it was replaced with the Kodak K-100, which was 'sloppy enough to operate under the conditions in the field at the time.'[696] This indicates an intriguing trust not in precision instrumentation but in devices which could work well as part of a whole apparatus. It was not the scale of the camera that mattered, but the scale of the whole apparatus. Most significantly, it was the complexities and ruggedness of the field which necessitated a less precise model of camera.

The resulting all-sky photographs themselves were small in scale, square representations with sides measuring approximately one inch, so little detail on the plate could be discerned. For all the emphasis on 'synopticism', auroral researchers seemed uncharacteristically relaxed about gaps in their data, demonstrating that the power of the all-sky photographs was found in the sequencing of the series, rather than individual auroral events. Sometimes, six projectors were gathered so that photographs with the same timestamps from six different stations could be viewed simultaneously, providing an even wider vision of the geography of the aurora across the northern or southern hemispheres.[697] Davis found hand driven projectors for the 100ft rolls of film from the DeBry Technical Institute in Chicago to allow for the viewing of auroral film as if it were cine film at the

[694] Charles S. Deehr, Emeritus Professor at the University of Alaska and member of the Geophysical Institute Arctic Research Consortium of the Unites States, July & August 2022, correspondence by email.

[695] Ibid.

[696] Ibid.

[697] C. T. Elvey and Albert Belon, *Description of the all-sky camera, its methods of operation; an instrument (ascagraph) for measuring the film* (Fairbanks: Geophysical Institute at the University of Alaska, 1959), p. 27.

Fairbanks station.[698] The all-sky film could be viewed both forwards and backwards in time, which was considered a substantial aid in following the changes of auroral forms. The combination of data from different all-sky cameras, spanning almost an entire hemisphere, created what could be characterised as an 'all-night' perspective (rather than all-sky), if one were to emphasise the temporal dimension. The aurora, from these images, could be viewed simultaneously across the dark time-zones, creating a *temporally* synoptic perspective rather than a *spatial* vista.

Fig. 63. 'T. Neil Davis in All-sky Camera view at Kotzebue 1 January 1959', *Charles Deehr Photograph.*

The all-sky camera images recorded at Fairbanks, Alaska and Flin Flon, on the Saskatchewan Manitoba border, were explicitly discussed in relation to auroral echoes taken from the respective stations. As G. F. Lyon described, the camera could capture aurorae at a distance of 350-650km from the radar equipment.[699] There were only 33 nights during the period from 18 January to 18 April 1958 for which the sky was clear and aurorae could be witnessed at Flin Flon. It was found that on only 5% of occasions where quiet aurorae were detected on the all-sky film, was an echo also recorded. For 'curled' auroral structures, as shown in figure 64, echoes were recorded on 31% of occasions. For rayed structures the percentage fell to 14%.[700] The discrepancies in the data gained from these

[698] Deehr to, July & August 2022.

[699] G. F. Lyon, 'The association of visible auroral forms with radar echoes', *Canadian Journal of Physics* 38, no. 3 (1960): 385-389, 386.

[700] Ibid.

different modes of registering the aurora meant that each form of observation remained crucial because it yielded diverse information. Human monitoring was still needed to corroborate the data gained from these other instrumental sources. Furthermore, discussions regarding the reconciliation of the opposing data and the symptomatic definition of aurorae were still ongoing during the IGY.

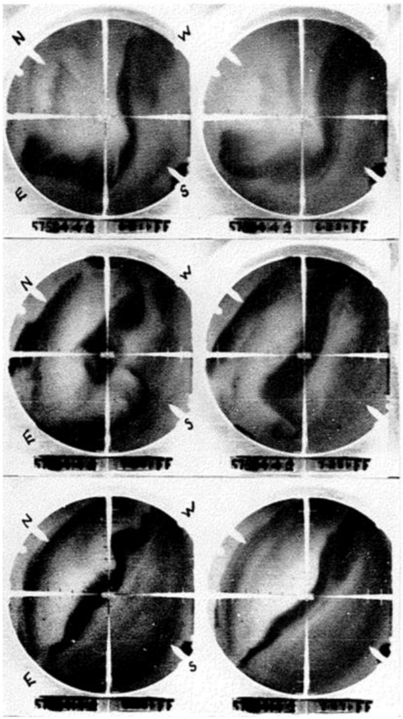


Fig. 64. Negative Flin Flon all-sky camera film, showing arcs with ‘curl structure’ for the night of March 18/19 1958, in G. F. Lyon, 'The association of visible auroral forms with radar echoes,' *Canadian Journal of Physics* 38, no. 3 (1960), p. 387.

Quantative measurements of the drift motions from the all-sky cameras were also used in conjunction with the radio echo evidence discussed in the previous chapter. As Thomas, Balfour Currie and J. S. Kim pointed out, assessing auroral drift was an almost impossible task for a human observer, who would often confuse the illusory changes in brightness as geographical displacement.[701] Instead, the film developed from the all-sky camera would be projected from a micro-viewer onto a grid marking the cardinal directions. It would only be a simple matter of comparing like images to observe the drift movement of the phenomenon on a given night. With the assumption that the aurora occurs at approximately 100km above the earth’s surface, the velocity of the auroral form could also be calculated.[702]

[701] Thomas, 'Auroral Photography Using All Sky Cameras', 57; Kim and Currie, 'Horizontal Movements of Aurora', 60.

[702] Thomas, 'Auroral Photography Using All Sky Cameras', 57.

The Japanese contribution to atmospheric studies during the IGY was directed from the Kokubunji station in Tokyo and primarily concerned with ionospheric absorption measurements, given the relative rarity of auroral events at such a latitude. An all-sky camera, however, was set up at the Memanbetsu Magnetic Observatory in northern Japan, with a reciprocal model installed at the Japanese Antarctic Base.[703] The most notable auroral event of the IGY was the 'great aurora' of 11

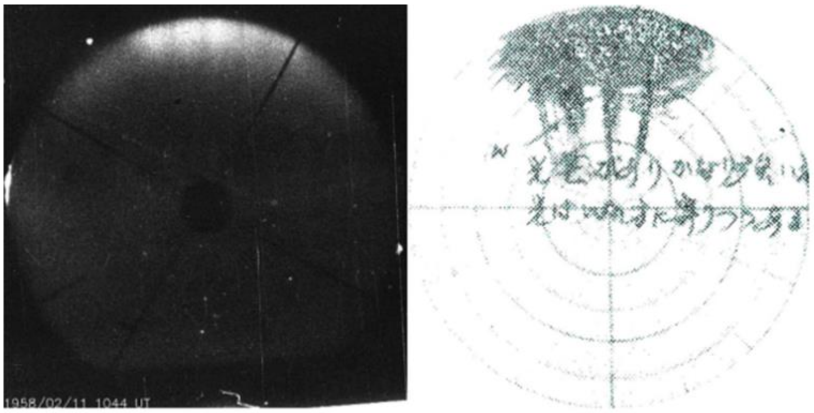


Fig. 65. All-sky photograph at 1044 UT on 11 February 1958 (left) and hand-made sketch at 1037 UT on 11 February 1958 (right), both observed at the Memanbetsu Magnetic Observatory in northern Japan, Ryuho Kataoka, Shiori Uchino, Yasunori Fujiwara, Shigeru Fujita, and Kazuaki Yamamoto, 'Fan-shaped aurora as seen from Japan during a great magnetic storm on February 11, 1958,' J. Space Weather Space Clim. 9 (2019), 2.

February 1958. An intense magnetic storm was recorded and IGY stations from around the globe reported witnessing white, red and green auroral colours. The aurora was situated in the north and was reported as taking the form of 'white pillars' from the Memanbetsu Magnetic Observatory.[704]

Figure 65 shows side by side an all-sky photograph next to a sketch drawn onto an all-sky perspective template, plotted from the radio echo data received at Memanbetsu Magnetic Observatory.[705] Indeed, echoes produced from the Abashiri Local Meteorological Office in Memanbetsu were also represented in the form of an all-sky grid, changing with time, as shown in figure 66.[706] The circular iconography of the all-sky perspective made for a convenient chart of auroral ionisation, which could be quickly and easily compared with the photographic data. The

[703] Science Council of Japan National Committee of the International Geophysical Year, *Japanese Contribution to the International Geophysical Year 1957/1958* (Tokyo: Ueno Park, 1958), p. 29.

[704] Elvey and Belon, *Description of the all-sky camera, its methods of operation*.

[705] Ryuho Kataoka, Shiori Uchino, Yasunori Fujiwara *et al.*, 'Fan-shaped aurora as seen from Japan during a great magnetic storm on February 11, 1958', *J. Space Weather Space Clim.* 9 (2019): 1-7, 2.

[706] Hisashi Hayakawa, 'A review of Japanese auroral records on the three extreme space weather events around the International Geophysical Year (1957-1958)', *Geoscience Data Journal* (2022): 1-16, 13.

combination of all-sky, radar and observational information together provided researchers with a view which tended even more so to a 'complete' view of the aurora of 11 February 1958. Indeed, the epistemic virtue of synopticism was derived from the use of multiple forms of registration during the IGY, so that the aurora could be said to be observed on 'all fronts', it was embedded within sequential series and manifested both temporally and spatially. One station could have a complete set of auroral photographs, albeit with the occasional insignificant gap in the data, but on a larger scale, tending towards the synoptic ideal, all-sky images from different stations could be combined and viewed together after the IGY programme, creating a regional, if not planetary, perspective.

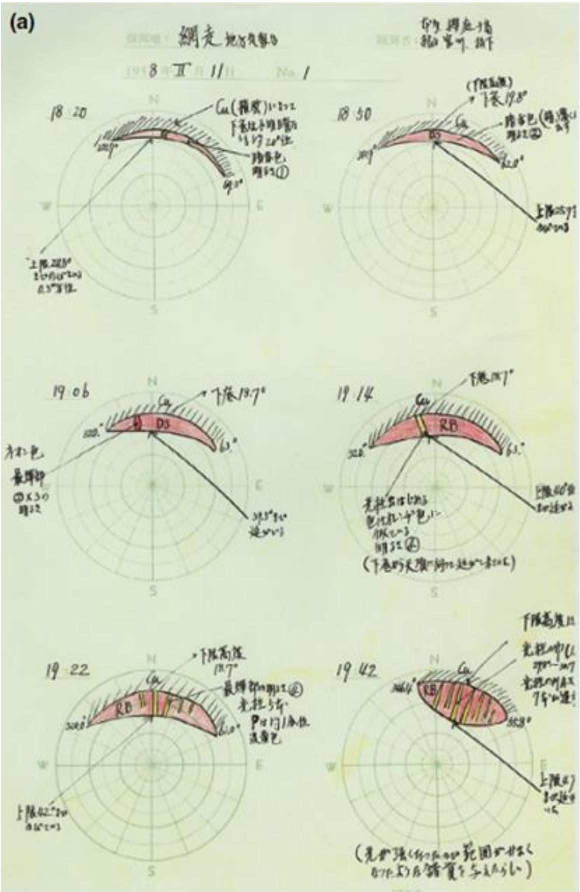


Fig. 66. Auroral radar charts drawn between 18:20 and 19:42 on 11 February 1958 at the Abashiri Local Meteorological Office.

The Auroral Oval

An all-sky perspective had been *imagined* for observation of aurorae significantly earlier than the IGY. Jean-Jaques d'Ortous de Mairan, a French geophysicist and astronomer, printed a proto-all-sky etching of an aurora which appeared on 19 October 1726 to the west of Paris in his *Traite Physique et*

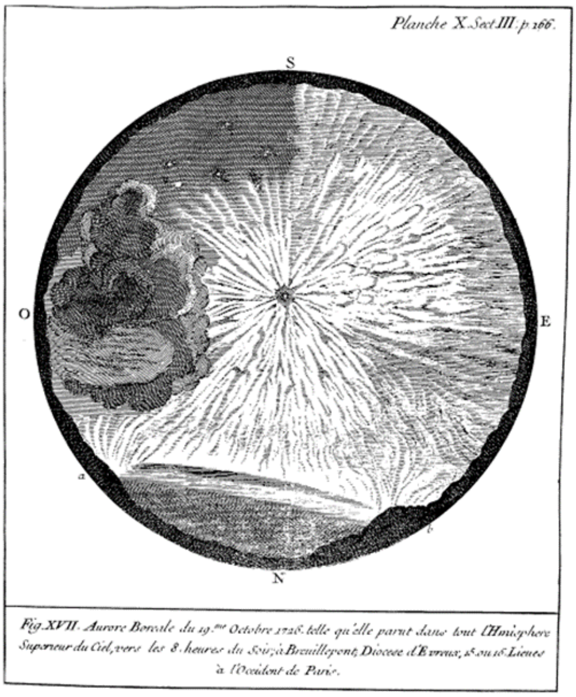


Fig. 67. Jean-Jacques d'Ortous de Mairan, *Traité physique et historique de l'aurore boréale, par M. de Mairan. Suite des Mémoires de l'Académie royale des sciences année* MDCCXXXI. Seconde edition (Paris, Impr. Royale, 1754), p. 177.

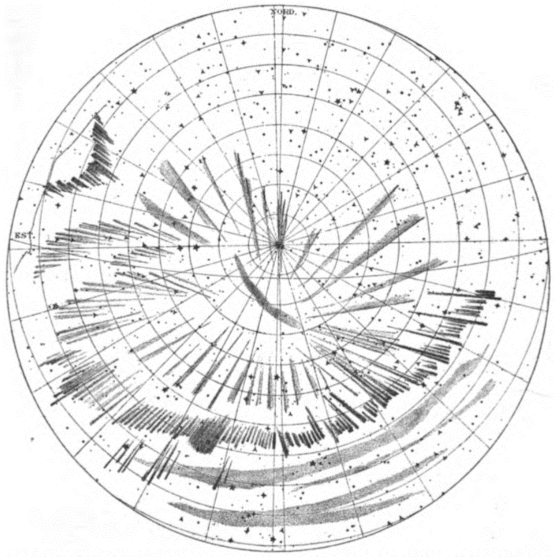


Fig. 68. 'The Aurora Borealis of 6 January 1883' in Vilhelm Carlheim-Gyllenskiöld, 'Aurora Borealis', *Observations faites au Cap Thorsden Spitzberg, par l'Expédition Suédoise* (Stockholm: P.A. Norstedt, 1886), p. 422.

Historique De l'Aurore Boreale (1754).[707] Shown in fig. 67, the centre of the image represents the zenith of the aurora, as if the viewer were lying on the ground looking directly to the sky. The observer is imagined as having panoptic vision, looking at each horizon at once. The auroral image also looks remarkably similar to the iris of an eye, an artistic choice which resonated with ideas of the body as a microcosm of the universe in the period. In the First Polar Year of 1882-3, a more transparent version of an all-sky projection was envisioned, with the aurora similarly plotted in a circular format against the constellations of the night sky, as can be seen in the sketch by Carlheim-Gyllenskiöld featured in figure 68.[708] The IGY was by no means the first occasion for which a holistic map of the aurora was attempted. Elias Loomis, an American mathematician, and Hermann Fritz, a German solar physicist, were among the first to plot auroral distribution on a global scale in 1860 and

[707] Jean-Jacques d'Ortous de Mairan, *Traité physique et historique de l'aurore boréale, Suite des Mémoires de l'Académie royale des sciences année 1731*, vol. 2 (Paris: Impr. Royale, 1754), p. 177.

[708] Carlheim-Gyllensköld, *Observations faites au Cap Thordsen*, p. 422.

1881 respectively.[709] Loomis noted that there exists an ‘auroral zone’ in which the frequency of auroral appearances is far greater than average, and Fritz created his renowned ‘isochasm’ map, charting the lines of equal frequency of auroral visibility. The aurora was thus conceptualised from a position above the earth rather than purely as a phenomenon gazed upon from the ground in the second half of the nineteenth century. The planetary perspective came into being before the implementation of the all-sky camera realised its potential in the late 1950s.

Loomis’s 1860 ‘chart showing the distribution of auroras in the northern hemisphere’ can be seen in figure 69.[710] In constructing the chart, Loomis collected observations from 128 locations. It shows that near the latitude of 40 degrees, only 10 aurorae occur annually, whereas near 42 degrees, the average number is 20, near 45 degrees north 40 aurorae appear and at the latitude of 50 80 aurorae appear.[711] Further north, Loomis’s treatise contends, aurorae diminish in their brilliancy and are rarely

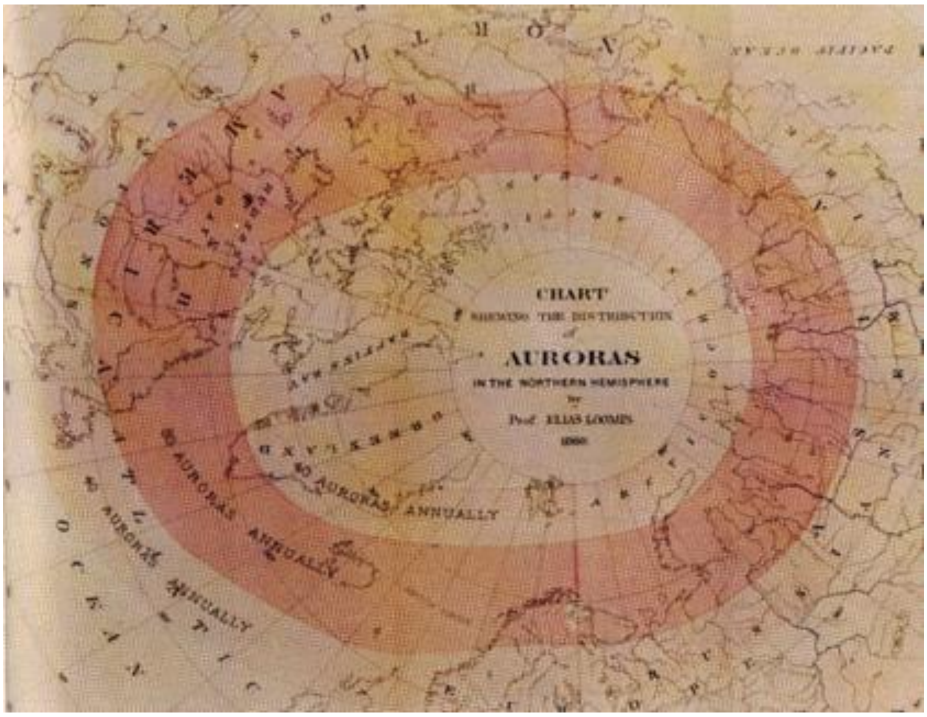


Fig. 69. Elias Loomis, ‘the Great Auroral Exhibition of Aug 28th to Sept 4th, 1859 and geographical distribution of auroras and thunder storms’, *American Journal of Science and Arts* (1860), 95.

[709] Hermann Fritz, *Das Polarlicht* (Leipzig: F. A. Brockhaus, 1881); Elias Loomis, 'The Great Auroral Exhibition of 28 August - 04 September 1859 and geographical distribution of auroras and thunder storms', *American Journal of Science and Arts* 5 (1860): 82-104.

[710] Loomis, 'The Great Auroral Exhibition of 28 August - 04 September 1859', 95.

[711] Ibid., 94.

seen further south. Loomis himself admitted that 'these observations are not as complete as could be desired'.[712] Without enough data points Loomis could not infer the pattern of auroral distribution for the southern hemisphere but surmised that it likely had a similar shape.[713]

Akasofu explicitly referenced the Loomis chart as part of his justification for studying global auroral frequency. Recalling his early research in 2020, Akasofu wrote that, according to the chart, aurorae 'should appear overhead in Fairbanks (geomagnetic latitude: 65 degrees) as soon as darkness sets in midwinter.'[714] This, he found, was not the case; auroral arcs appeared in the northern sky in the evening. It was this discrepancy which prompted Akasofu to investigate the shape of the zone of maximum auroral frequency during and directly after the IGY. Paton directly referenced Fritz's isochasm map (isochasm referring to the Aristotelian name for aurorae: *chasmata*) in his 1958 publication providing a summary of the aurorae present in the Geophysical Year.[715] Despite the 'inadequate data' available in 1873, Paton noted that Fritz's chart was broadly accurate for the number of aurorae occurring in Scotland and the Shetland Islands in the 1950s.[716] According to G. M. Thomas, however, the primary disadvantage of Fritz's methodology was that each data point represented an aurora which may have occurred 'roughly 1000km from the site' plotted, incidentally

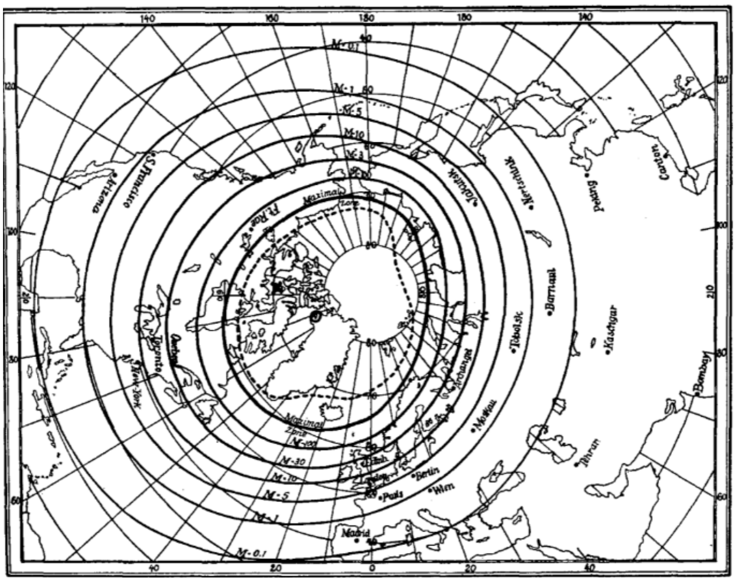


Fig. 70. Hermann Fritz, *Das Polarlicht* (Leipzig: F. A. Brockhaus, 1881).

[712] Elias Loomis, 'The Aurora Borealis, or polar light: its phenomena and laws', *American Journal of Science and Arts* 5 (1869): 208-248, 217.

[713] Ibid.

[714] Akasofu, 'Space Physics in the earliest days', 4.

[715] James Paton, 'Auroral Activity during 1957', *The Observatory* 78 (1958): 219-221, 219.

[716] Ibid.

on a scale not too dissimilar from the information gathered from the all-sky camera's 500km view.[717]

Despite Thomas's criticism, making use of the broad perspective facilitated by the cameras was one of the principal aims of the IGY. Akasofu wrote in 1963 that 'there was some pre-IGY evidence to suggest that arcs and bands might extend over at least 5000km.'[718] Only with the introduction of the all-sky cameras did it become possible to verify this claim. In his publication on the dynamics of auroral morphology, Akasofu asserted that the great aurora of 11 February 1958 may have contained bands which seemed to extend from Sakhalin, a Russian island north of Japan, to the south of Newfoundland in Canada, approximately 10,000km in length.[719] Resonating with the planetary nature of IGY investigations, he argued that 'we may regard such global auroral activity as a whole single event'.[720]

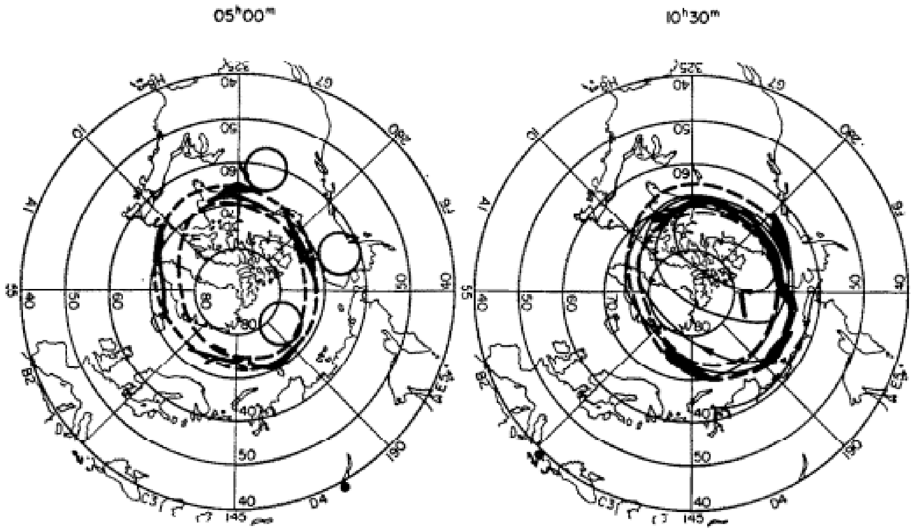


Fig. 71. The location of the auroral oval and data from the world-wide network of all-sky cameras on 19 December 1957 in Y. I. Feldstein and G. V. Starkov, 'Auroral oval in the IGY and IQSY period and a ring current in the magnetosphere,' *Planetary and Space Science* 16, no. 1 (1968), 130.

Returning to the shape of hemispheric auroral distribution, Russian scientists, Feldstein, Khorosheva and Lebedinsky, analysed the all-sky photographic observations after the IGY and presented the conclusion that aurorae were distributed in an oval shape around each magnetic pole in 1962.[721] The materials used for the investigation were 35 Soviet ascaplots, produced by a device

717 Thomas and Paton, 'Auroral Results from Halley Bay', 214.

718 Akasofu, 'The dynamical morphology of the aurora polaris', 500.

719 Ibid.

720 Ibid.

721 Neil Bone, *Aurora: Observing and Recording Nature's Spectacular Light Show* (Berlin: Springer Science & Business Media, 2007), p. 143; Ya I. Feldstein and G. V. Starkov, 'Auroral oval in the IGY and IQSY period

which automatically plotted 'synoptic auroral maps' from the all-sky photographs, as well as 79 other IGY ascaplots: 55 from the northern hemisphere and 24 from the south.[722] Aurorae, they showed, appear along an *oval* band at varying geomagnetic latitudes rather than along a circle around the magnetic pole at a latitude of approximately 67 degrees.[723] The dotted line in figure 71 represents the auroral oval alongside observational data of the aurora captured by the all-sky cameras on 19 December 1957. The centre of the auroral oval is displaced towards the dark portion of the earth and shifts diurnally. These results were shared at the International Conference on Cosmic Rays and the Earth Storm, held 5-15 September 1961 in Kyoto.[724] C. T. Elvey and Davis attended the conference, participating in the discussion of Lebedinsky, Feldstein and Khorosheva's paper, demonstrating the culture of east-west exchange that the IGY programme engendered.

Despite the fact that the visual and graphic technologies used to construct the Feldstein, Khorosheva and Lebedinsky auroral oval image in fig. 71 had advanced considerably since the nineteenth century, the depiction distinctly resembles the framing of both the Fritz and Loomis charts. The community that this new 1968 imagery was directed towards, however, did differ from that of the earlier depictions. Loomis' auroral oval was published in the *American Journal of Science and Arts* (1860), from which it can be inferred that it held a general interest among a wide section of the readership whereas the 1968 chart was directed towards a much more specific and focused audience, published in the journal of *Planetary and Space Science* (1968). Indeed, it was the way in which this 1968 image was displayed and shared which underpinned its formulation as evidence of a synoptic view of the aurora. In 1968, however, the question remained as to why the auroral oval had such a shape. It was only later, in the 1970s, that Akasofu proposed that the intersection of the Van Allen radiation belt with the ionosphere agreed with the shape of the auroral oval. He hypothesised that

---

and a ring current in the magnetosphere', *Planetary and Space Science* 16, no. 1 (1968): 129-133, 129; AI Lebedinsky, Ya I Feldstein, and OV Khorosheva, 'Investigations of Auroral Planetary Distribution', *Journal of the Physical Society of Japan Supplement* 17 (1962): 249, 249; USSR researchers studied auroral interference in radio communication thoroughly: Y. S. Lyubovtseva, A. D. Gvishiani, A. A. Soloviev *et al.*, 'Sixtieth anniversary of the International Geophysical Year (1957–2017) – contribution of the Soviet Union', *Hist. Geo Space. Sci.* 11 (2020): 157–171.

[722] Elvey and Belon, *Description of the all-sky camera, its methods of operation*, p. 28; Lebedinsky, Feldstein, and Khorosheva, 'Investigations of Auroral Planetary Distribution', 249.

[723] Ya I. Feldstein and GV Starkov, 'Dynamics of auroral belt and polar geomagnetic disturbances', *Planetary and Space Science* 15, no. 2 (1967): 209-229, 209; AI Lebedinsky, 'Synchronous auroral registration by all-sky camera C-180 and patrol spectrograph C-180-S', *Ann. Internat. Geophys. Year* 11 (1961): 133-144; Lebedinsky, Feldstein, and Khorosheva, 'Investigations of Auroral Planetary Distribution', 254.

[724] Lebedinsky, Feldstein, and Khorosheva, 'Investigations of Auroral Planetary Distribution', 254.

'electrons stream into the ionosphere along the outer radiation belt to produce the aurora.'[725] With this explanation and the evidence put forward in 1962, the auroral oval came to be accepted within the field of auroral science.

Auroral Substorms

In an effort to gain greater knowledge of planetary atmospheric dynamics and increase the predictive power of weather forecasters in the nineteenth century, Loomis attempted to discern a 'law of storms' governing the formation, development and eventual dispersion of global storm events.[726] Before the IGY, there existed a long tradition of analysing the dynamics of magnetic storms, beginning with Alexander Von Humboldt in the early nineteenth century and taken up by Carl Friedrich Gauss and Wilhelm Weber in the 1830s.[727] In investigating 'auroral substorms', Akasofu's objective in the early 1960s was much the same as these pursuits. By his account, he hoped to delineate 'the sequence of auroral events in the entire polar region during the passage from auroral quiet through the various active phases to subsequent calm'.[728] This is how Akasofu defined 'the auroral substorm', a phrase suggested by Chapman to capture the fact that several substorms lasting between one and three hours may occur during one geomagnetic storm on a given night.[729] The phrase also harked back to Kristian Birkeland's 'polar elementary storms', the name he gave to magnetic storms in the polar regions in 1908.[730]

Research by Professor Veryl Fuller, working at the University of Alaska, Fairbanks during the 1930s, suggested that the aurora was statistically quiet in the evening, active at midnight and patchy in the early morning. Scientists of the 1950s stationed at Fairbanks self-consciously understood their own project as a continuation of Fuller's work after his death in 1935.[731] Akasofu sought to revise the knowledge inherited from the Second IPY after scanning 'miles of all-sky film' from Fairbanks taken

---

[725] Akasofu, 'Space Physics in the earliest days', 5.

[726] Fleming and Seitchek, 'Advancing Polar Research and Communicating its Wonders', p. 3.

[727] S. R. C. Malin and D. R. Barraclough, 'Humboldt and the Earth's Magnetic Field', *Quarterly Journal of the Royal Astronomical Society* 32, no. 3 (1991): 279-293, 282.

[728] Akasofu, 'The dynamical morphology of the aurora polaris', 503.

[729] Akasofu, 'Space Physics in the earliest days', 5.

[730] Kristian Birkeland, *The Norwegian Aurora Polaris Expedition, 1902-1903: On the cause of magnetic storms and the origin of terrestrial magnetism* (Christiania: H. Aschelhoug, 1908), p. 84.

[731] Veryl Fuller and Ervin Bramhall, *Auroral research at the University of Alaska, 1930-1934* (College, Alaska: Miscellaneous Publications of the University of Alaska and chapters 1-3 are reprinted in Terrestrial Magnetism and Atmospheric Electricity (1931), (1932), (1933) and (1935), 1937); Neil Davis, *The College Hill Chronicles: How the University of Alaska Came of Age* (University of Alaska Foundation, 1992), p. 144.

during the IGY.[732] As hinted by this expression, the volume of data obtained during the IGY was itself on a different scale from that produced in the previous programmes. By his own account, the first thing Akasofu noticed was that the aurora appeared repeatedly in the northern horizon in the evening and shifted southwards as the night progressed, before moving back towards the north after midnight.[733] Relatively few researchers in the field of auroral studies had a chance to survey many of the all-sky films in the years following the IGY. Thus, as Akasofu pointed out, many of his colleagues found it difficult to accept his theory of auroral substorms because 'no one can remain at the midnight hour for six hours to witness the development of auroral substorms twice.'[734] This reveals an interesting tendency, also prominent in the First and Second Polar Years, to trust knowledge gained from experience, either in the field or through viewing the photographic evidence oneself. Akasofu had built up a different experience from his colleagues in having access to a wide variety of the all-sky images and therefore was able to gain novel insights into the phenomenon's nightly patterns.

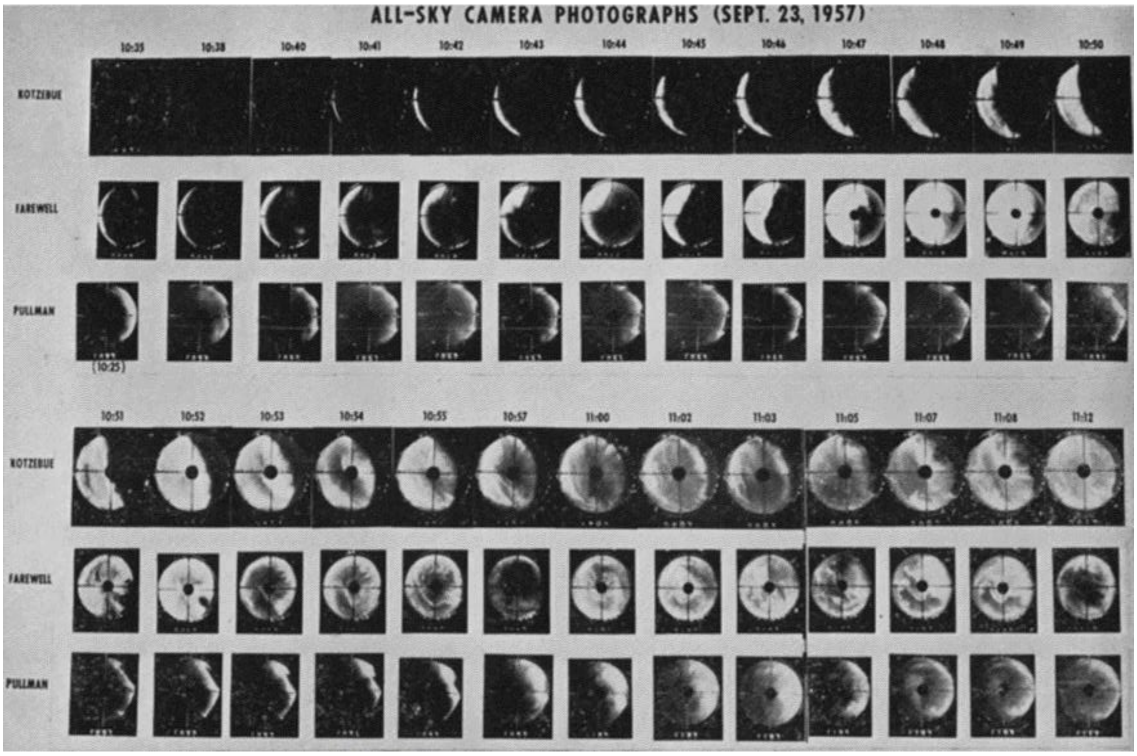


Fig. 72. 'All-sky camera photographs (Sept 23 1957)', from Kotzebue, Alaska, Farewell, Alaska and Pullman, Washington in Syun-ichi Akasofu and Sydney Chapman, *A study of magnetic storms and auroras*, (Geophysical Institute of the University of Alaska, 1961), p. 182.

[732] Syun-ichi Akasofu, 'Proceedings of the Second International Conference on Substorms', 07-11 March 1994, Fairbanks, Alaska, 5.

[733] Akasofu, 'Space Physics in the earliest days'.

[734] Ibid., 6.

Akasofu then broadened the scale of his study of the all-sky data from a single station view to a hemispheric perspective. He chose to view all-sky film from Alaska, Canada and Siberia simultaneously because it would reveal the auroral formations in the midnight sector, the morning sector and the evening sector respectively. This process of reviewing film from three locations at once was 'confusing and frustrating' because 'all-sky images are very distorted' and 'aurorae change greatly even in one minute'.[735] Other uncertainties which had to be taken into account included the shifting of the northern position marker due to the movement of Arctic ice flows, which could be overcome by using the polestar for calculations.[736] Additionally, some crucial film stills were missing because the presence of polar bears meant the camera operator could not approach the all-sky camera to replace the film. Ultimately, though it took two years to analyse the all-sky films, the process was fruitful because each station seemed to show the same auroral substorm sequence.

After Akasofu's discovery of the three hourly lifespan of an auroral substorm, the phases of the substorm could be evaluated. The initial formation phase came to be known as the 'growth phase', with a sudden brightening of one of the quiet arcs in the midnight meridian being the first indication that an auroral substorm was about to begin. Then the aurora would undergo a transformation from a homogenous arc to many forms within the 'substorm onset'. The 'break-up' phase of the aurora involved rapidly moving forms and, finally, the 'recovery phase' could be characterised by pulsating

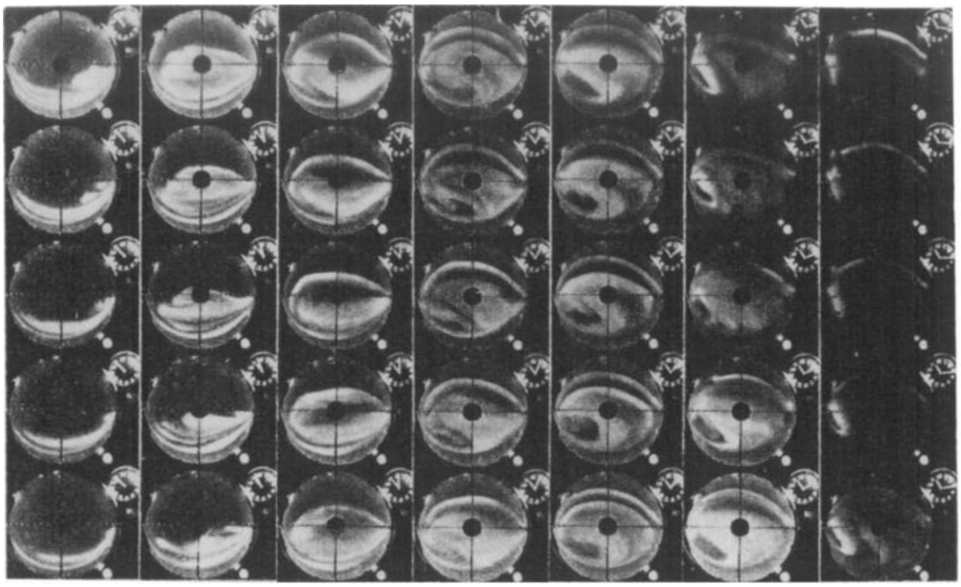


Fig. 73. Point Barrow all-sky camera images, 19 February 1958, showing the formation of a group of loops in the breakup phase of the auroral lifespan, in Syun-ichi Akasofu, D. S. Kimball, and Ching- I. Meng, 'The dynamics of the aurora—III westward drifting loops,' Journal of Atmospheric and Terrestrial Physics 27, no. 2 (1965/02/01/ 1965), 190.

[735] Ibid., 5.

[736] Ibid.

patchy auroral forms.[737] Crucially, a single observer could not witness the entirety of an auroral substorm because their field of view is limited to only aurorae in the near vicinity. The delineation of the constitutive parts of an auroral substorm demonstrated 'synoptic' temporal knowledge of the phases of auroral appearances.

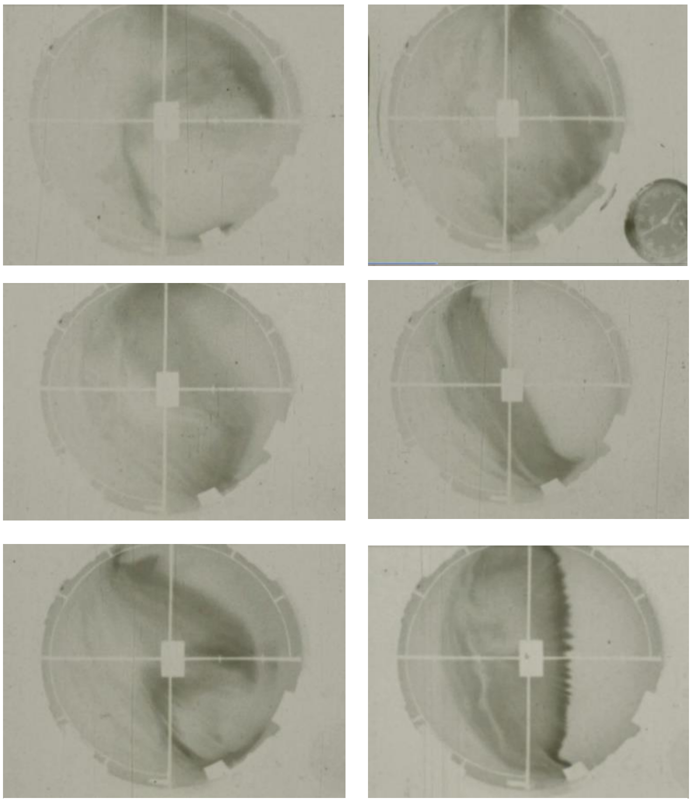


Fig. 74. Auroral all-sky images taken from Halley Bay, 5-6 June 1957 0125-0800, Films of Auroras at Halley Bay, *Royal Society Archive*: AV/3/15/2.

The purpose of the IGY all-sky photographs taken at Halley Bay was subtly different to those obtained elsewhere. The function of the camera was not to provide a permanent record but rather to investigate 'detailed behaviour in larger displays'.[738] Therefore, the camera was only operated when the aurora could be witnessed visually and the frequency with which photographs were taken was increased to four times per minute rather than the once per minute routine adopted at the majority of other research stations.[739] Before embarking on the journey to Halley Bay, those in charge of auroral observations would spend a short time in Edinburgh to be shown the instructions and observing sheets. Then, while in Antarctica, they would learn from their predecessors. As Paton noted in a letter

[737] Ibid.

[738] Thomas and Paton, 'Auroral Results from Halley Bay', 241.

[739] Stan Evans, 'Research Note' (1958), *Royal Society Archives*, NGY/127(58); Stan Evans, 'Systematic movements of aurorae at Halley Bay', *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* (1960): 234-240.

to Otto Schenider in 1959, 'experience had been embodied in the auroral log and in this way has been handed on from one observer to his successor'.[740] The human operator of the all-sky camera remained a key part of the observational and documentary process, with tacit knowledge of the apparatus being handed down and learnt through specific training.

Stan Evans oversaw the all-sky camera at Halley Bay during the IGY and changed his daily routine to match the operation of the photographic instrument.[741] Capturing auroral forms was nevertheless far from a smooth process. All of the photographs taken at Halley Bay in 1957 were 'marred by the unsightly screens required to intercept the direct rays from various lamps around the base'.[742] This was rectified in 1958, when the all-sky apparatus was moved to a position on top of a tower built fifteen feet above the snow and therefore also above the station's base lights. Even so, as Evans noted, photographic observations were also more liable than visual observations to be 'confused by cloud of moonlight'.[743] A portion of the film record taken on 5-6 June 1957 is depicted in figure 74; it shows the rapid changes the aurora underwent in a matter of minutes. Aurorae such as this were often viewed as a time-lapse film. For an auroral feature to be recorded, Thomas and Evans adopted the criterion that the form must be readily visible on at least four consecutive exposures. In this way, the definition of aurorae was predicated on a scaled quantity; only if an auroral form lasted for at least one minute was it considered an aurora at all.

Conclusion

The 'field' was reconfigured within the auroral programme of the IGY as the earth in its entirety. The distinct spatiality of multiple research stations situated around the northern and southern hemispheres influenced the way in which synopticism was constructed from individual accounts, photographs with a 500km view and about a planetary phenomenon. These intersecting scales of knowledge creation ultimately shaped the way the aurora was visualised and understood in the 1950s as a phenomenon not just gazed at from below but also as a vast manifestation of planetary-scale dynamics, in two uneven ovals around the poles. The all-sky view had been imagined prior to 1957. Yet, it was only with the IGY programme that the perspective was fully integrated and its potential for auroral science realised. The synopticism of the IGY stood in stark contrast to the perceived ineffability of the aurora repeatedly expressed during the First IPY. Indeed, the all-sky camera seemed to solve the problem of the fragment by presenting the holistic 'view from nowhere'.[744] Moreover, the all-sky photographs

[740] Paton to Schneider, 28 July 1959.

[741] Stan Evans, 'BAS General IGY Report 1956' (1956), *BAS archives*, AD6/2HB/1956/A.

[742] G. M. Thomas, 'FIDS report on auroral and airglow observations', *BAS archives - NGY/27(58)* (1958).

[743] Evans, 'BAS General IGY Report 1956'.

[744] Shapin, 'Placing the View from Nowhere'.

were analysed in conjunction with radio echo data, visual observations and spectroscopic results, compiling the fragments of the aurora's nature into a meaningful whole.

The synoptic power of the IGY was two-fold: it was both *planetary* and *historical* and the differing scales of synopticism at play in the programme were folded into the publication space. The auroral work was consistently and consciously historically embedded by its participants; the all-sky photographic collection was viewed as the climax of the IPY events and the culmination of auroral science. The word 'synoptic' itself had entered the lexicon of the IGY and became the measure by which visual and schematic data was deemed valuable. Crucially, it was the very visual power of photographic images, and the plotted charts derived from them, as opposed to taxonomic strategies, which held sway in presenting a holistic view of the aurora in the 1950s. The presentation of all-sky photographs in series and the plotting of auroral distribution data onto hemispheric charts informed and underpinned claims of an exhaustive and all-encompassing perspective. The auroral photographs were also viewed as if they were part of a moving picture film, one after the other in quick succession, pre-empting the later use of cine camera to capture auroral movements. Sometimes the 'film' was played backwards so as to provide a new perspective on the transformation of auroral forms and occasionally six films from different stations were projected onto a screen simultaneously.

Aurorae of 10,000 km in length were captured and recorded, moving the IGY from an international perspective towards a planetary view and revealing the full geographical extent of the phenomenon's displays. Problems and gaps in the data at individual stations were noted but did not significantly influence the outcome of research projects considering it was the collation of vast quantities of auroral data which was the primary objective of the programme. The two most significant outcomes of the IGY all-sky programme were the discovery of auroral substorms, which provided an overview of the life of an aurora from formation to its 'breaking up', and a greater understanding of the global pattern of aurorae in the maximum frequency zone and beyond. Both of these results speak to the synoptic aims of the IGY endeavour, presenting the aurora as a *temporally* and *geographically* 'complete' phenomenon.

As an automatic instrument for capturing the northern lights at intervals of one minute throughout the eighteen-month Geophysical Year the all-sky camera achieved what no person could endure. The human observer was limited by their embodied reaction to the outdoor elements, meaning that they could only remain outside for a finite period, and the difficulty of reporting what they saw, a problem consciously debated since the First IPY of 1882-3. Further from the way the eye perceives the phenomenon, the distorted and confusing 'fish-eye' perspective of the all-sky camera presented some difficulties for IGY researchers. Importantly though, the camera did not obviate the necessity of auroral researchers on the ground. Indeed, they were required to monitor and maintain the device, replacing the film and checking the mechanisms daily, observers were still enlisted to record weak aurorae and auroral changes at a greater sensitivity of once per minute and of course, they were needed to analyse the photographs, after the Geophysical Year had ended.

This chapter has situated the auroral work of the IGY within the wider cultural moment of the 1950s, wherein a distinct global planetary awareness had emerged, and large volumes of ‘complete’, holistic data sets were valued and prioritised. The individual practices of observation and evaluation at the Arctic and Antarctic research stations occupied during the IGY have been traced against the global, panoptic perspective that the all-sky camera facilitated. In this way and with a sensitivity to the ‘scaling up’ project of ‘synoptic geographies’, this case study has demonstrated the ways in which the particular spatiality of many stations situated around the poles underpinned the construction of planetary knowledge of the aurora. Future research would benefit from further attention to the intersecting scales of the planetary and the local in discussing multi-sited research projects, especially those inquiring into the nature of the atmosphere, weather and the climate, in future research.

Conclusion

Images and Perspectives

As the research presented in this thesis has shown, specific situated practices of knowledge creation were required for the experience of the remote and inspiring aurora to be coupled with the epistemic cosmology of modern western science. The aurora is different from other distinctly visual atmospheric and geophysical phenomena, such as lightning and cosmic rays where questions of instability and distance also arise, because of its position surrounding the poles. It matters that the aurora is a polar phenomenon because, crucially, it was inaccessible in two dimensions. The aurora, situated in the liminal space of the ionosphere, was intangible in the vertical plane. Moreover, its extreme latitude location meant it could only be observed by a limited number of people either living in the polar regions or able to mobilise resources to travel to these areas. From this study we therefore learn much about how nineteenth and twentieth century geophysical researchers dealt with an elusive intangible phenomenon not easily reached along two axes.

While the aurora needed to be communicated to those who would never witness the phenomenon, it posed considerable challenges to horizontal 'virtual witnessing' endeavours. What has been repeatedly shown throughout this thesis is that the aurora resisted simple representation, its intangibility, unpredictability, and fleeting nature challenging the registration techniques of observers and observational instruments. Weyprecht, the Austro-Hungarian polar explorer who inspired the First IPY programme and galvanised scientific evaluation of the polar regions, revealed his underlying belief in the ineffability of the aurora when he stated that 'no pencil can draw it, no colours can paint it and no words can describe it'.[745] The problem of capturing the aurora, its essence, colours, formations, movement, development and its witnessing experience, was tackled in a variety of ways from 1880 to 1960.

Most significantly, the different aspects of the phenomenon were separated, fragmented into various features which could be investigated by individual visual means, especially during the First and Second IPYs. Images were fundamental to the project of understanding the aurora's ontology in the nineteenth and twentieth centuries; the ways in which the phenomenon was represented were the very means by which knowledge of the aurora was constructed. Research questions, put forward in the Polar Years of 1882-3, 1932-3 and 1957-8, were answered in the mode of the visual, pictorial and

---

[745] Karl Weyprecht, 'Fundamental Principles of Scientific Arctic Investigation', Conference Presentation, *Academy of Sciences*, January 1875, Vienna; Weyprecht quoted in: Payer, *New Lands Within the Arctic Circle*, p. 209.

graphical *because* the aurora could not be meaningfully brought down to the surface of the earth and communicated across latitudes.

Scientific images should be understood as having their own aesthetic lineages, which can be traced, as James Elkins has argued.[746] It should also be noted, however, in contrast to Elkins' assertions, that scientific images form part of a much broader tradition of representation, which encompasses artistic movements, the popular imagination and technological developments. Images created of the aurora were subject to aesthetic judgements and operations were applied to them in order to prepare the depictions for publication or presentation to colleagues. Often, they were carefully constructed to put forward visual arguments, as was the case for Paulsen's aurora of 15 November 1882, making contact with the hills to the south-west of Godthaab, or Lemström's watercolour paintings, which professed to show that his apparatus produced an artificial aurora above the mountains of Luossavaara and Orantunturi in 1871 and 1882 respectively. I argue that scientific images can carry meaning particularly persuasively, especially with regard to elusive phenomena, with researchers preferring to put forward their assertions in the form of visual insinuation, calibrated against earlier pictorial conventions.

Fig. 16. Adam Paulsen, 'Aurora (multiple rayed-bands) observed to South-West from Godthaab on 15 November 1882 at 00h 30m', drawing in *Observations Internationales Polaires, 1882-83, Expédition Danoise: Observations Faites A Godthaab* (Copenhagen: Chez G. E. C. Gad, Libraire de L'université, 1893), p. 3.

[746] Elkins, 'Art History and Images That Are Not Art'.

The value of the auroral images in stabilising the phenomenon, as well as their perceived accuracy, was closely linked to the methods by which they were produced. Painstaking, arduous and heroic masculine observation as well as a shift towards naturalism imbued the auroral hand-drawings with legitimacy. The organising power of the *Atlas of Auroral Forms* (1930) co-ordinated auroral photography during the Second IPY, while the trust in both the spectroscope and the embodied senses formed the basis of reliable representation of the colours of the aurora. Collaboration and different ways of dealing with interference played a central role in the construction of auroral radio echo data in the IGY and the stitching together of all-sky camera images was the process by which a coherent picture of planetary auroral activity was created in the 1950s.

The specific language used to refer to the aurora remained a crucial indicator of the state of auroral science throughout the period. The word 'synopticism' entered the lexicon of auroral research by the time of the IGY and was used as a touchstone for the investigative project. The aurora's apparent ineffability contrasted starkly with the synoptic vision that the all-sky camera was heralded as facilitating. No longer discussed as only partially recorded, as it had been in the 1880s and 1930s, a perspective which tended towards a holistic, all-encompassing outlook emerged and came to dominate the discourse of auroral science. Indeed, conceptually, the all-sky camera was envisioned to solve the problem of the fragment. It allowed for a significantly more extensive temporal and geographical view of the aurora than had previously been possible and brought together data on the separate aspects of the phenomenon. It exposed an aurora of 10,000km in length and revealed the appearance of the three-hourly auroral substorm, repeating several times on a given night.

In the First and Second IPYs, collaboration and co-ordination across horizontal distances were fundamental to constructing atmospheric knowledge. Collaboration privileges location: the positioning of research stations in the zone of maximum auroral frequency (as well as other practical and scientific considerations) qualified the work carried out therein with utility and authority. The objective of synopticism, however, is to create a 'view from nowhere'. Indeed, the location of the observational site should not matter because the entire planet would be monitored and thus a particular place disappears from the all-encompassing view. In this way, the synoptic perspective represents a kind of objectivity which strives to get rid of individual position, whereas the collaborative view marks a more subjective, contingent viewpoint.

The enormous ambition of the IGY programme and the complete planetary perspective envisaged as emerging from the scale of work undertaken is demonstrated by the posters created by Herbert Danska for the US National Academy of Sciences outreach booklet. The posters 'Poles' and 'Sun & Earth' feature the aurora as a key emblem representing the sheer magnitude of the project and the serious attention paid to the phenomenon's connection with the solar wind was studied. As a direct manifestation of this resolute self-assurance, at the bottom of 'Sun & Earth', a question from the Book of Job is posed: 'knowest thou the ordinances of heaven? Canst thou set the dominion thereof in the earth?'[747] The posters lay bare an intertwined fascination with the vast, unstable and sometimes unpredictable mechanisms of planet earth as well as the instruments which reveal these operations. Printed in 1958, the posters evoke a sense of the sublime mystery of geophysical phenomena and interplanetary forces, which they suggest were just at this moment coming to be known.

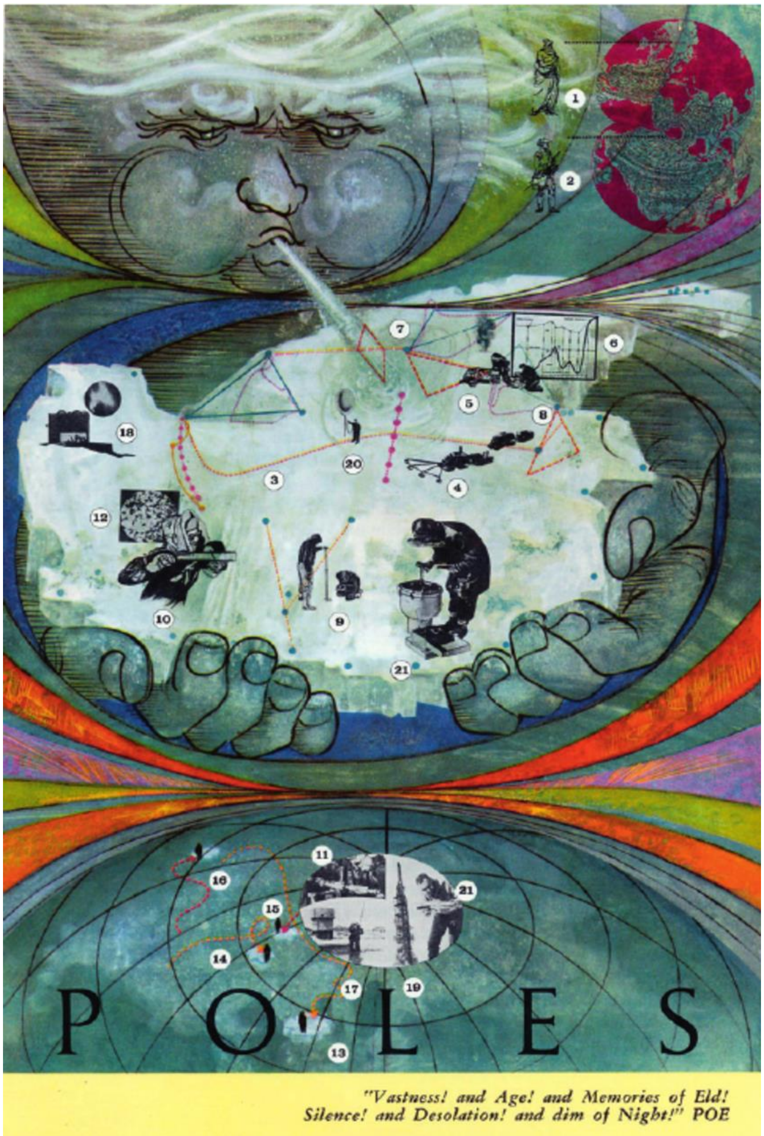


Fig. 75. Herbert Danska 'Poles', one of the six posters produced by the National Academy of Sciences' IGY Committee, the numbers on the poster represent points discussed in the educational outreach booklet, *Planet Earth* (National Academy of Sciences, 1958).

[747] Herbert Danska, 'Sun & Earth', one of the six posters produced, the numbers on the poster represent points discussed in the educational outreach booklet, *Planet Earth* (IGY Committee, 1958), *National Academy of Sciences*.

Fig. 76. Herbert Danska 'Sun & Earth', one of the six posters produced by the National Academy of Sciences' IGY Committee. The numbers on the poster represent points discussed in the educational outreach booklet, *Planet Earth* (National Academy of Sciences, 1958).

Nevertheless, the synoptic perspective of the IGY and the subsequent exhaustive understanding of the aurora was largely more an ideal than a reality. First, significant gaps existed in the all-sky record of the aurora caused by cloud cover and faulty apparatus. Second, the chain of all-sky stations allowed for an 'all-day' view of aurorae in the northern hemisphere but the data gathered from Antarctica was less geographically comprehensive. Third, questions as to the synchronicity of northern and southern aurorae as well as the relationship between auroral forms and the Van Allen radiation belt remained. Moreover, a synoptic view needed to be painstakingly constructed after the Polar Year by willing researchers, running the film through multiple projectors and comparing the photographs with individual observations and the radio echo data. It is easy for the labour involved after the photographs were taken to be masked by the grandiose claims of complete planetary observation.

Experiential and Instrumental Sensing

This thesis has taken as its primary focus the shifting balance between the experiential and instrumental registration of the aurora throughout the International Polar and Geophysical Years and the periods surrounding these events. In the late nineteenth century, the aurora was primarily recorded using the corporeal senses: an observer's eyes would become accustomed to the darkness, and the individual would note down or sketch the aurora's formations. The entire embodied experience, however, involved far more than just vision. An observer would patiently watch and listen, huddled in the cold or peering through a window into the night, tensed and ready, feeling moved or awestruck when a particularly vibrant light display appeared but also tired and possibly bored from the countless hours spent on routine observational shifts. The experience of witnessing an auroral display was considered paramount to constructing knowledge of the phenomenon. As Tromholt wrote in his 1885 treatise, if one has very rarely or never seen an auroral display, 'one might just as well form a theory of glaciers from seeing an icicle or construct the grammar of a language from the knowledge of a dozen words.'[748] The significance of the corporeal register to auroral science lends credence to the argument that the body mattered to the late nineteenth and early twentieth century geophysical sciences —a notion more commonly 'restricted to the history of medicine and the science of life and human difference.'[749]

Rooted within the view that first-hand observation was a necessity for researchers working in the field was the understanding that the aurora was too deeply affective to be communicated with any kind of verisimilitude. At the limits of documentation techniques, the language of occlusion was

[748] Tromholt, *Under the Rays of the Aurora Borealis (1)*, p. 195.

[749] Mahony and Randalls, 'Introduction', p. 8.

ushered in, giving a sense of the epistemological conundrum of recording the phenomenon while also underscoring the indescribable, inaccessible part of its nature. Although the characterisation of the aurora as an ineffable and sublime atmospheric object is most markedly present within the literature of the First IPY, this does not mean that it became 'an object of analysis rather than wonder and marvel' after 1883, as Spring has contended.[750] Spring's argument relies on the assumption that if an individual experiences the sublime they are not able to be analytical but, crucially, analysis is not the opposite of wonder. Indeed, the very reason many chose to study the aurora and did so successfully was aesthetic fascination. Even during the IGY, seventy years after the First Polar Year, the excitement of witnessing an extraordinary auroral display was tangible. A particularly whimsical and representative example comes from the British Antarctic Survey Base Diary of 1956. The entry on 25 August describes 'a magnificent display of aurora, many bands all over the sky and even some red ones', which prompted several of the Halley Bay expedition members to go outside 'and see it in our shirt sleeves and slippers at -40 Fahrenheit!'.[751] The language deployed in the published material may have become more sober but the aesthetic embodied reaction to the phenomenon certainly had not diminished by the 1950s.

It was not only the senses of those who had received observational training that could contribute to records of the aurora's activity throughout the Polar Years. Indeed, broad amateur participation was actively sought and encouraged throughout the period from 1880 to 1960, in contrast to much other work carried out under the umbrella of the physical sciences, which, by the middle of the twentieth century, had primarily restricted access and the ability to practice to experts. In some cases, the less amateur observers were able to interpret the aurora, the more useful they became, since their accounts of their sensory observations were to the point and ripe for collation and comparison by trained professionals.

Tromholt, a teacher by training, can be understood as an amateur participant in the First International Polar Year - this was certainly how he was perceived by his Danish colleagues, including Paulsen, despite his integral role in documenting the aurora during the programme. Furthermore, crowdsourcing practices were crucial to the auroral sound debate of the 1930s. Counterintuitively, the extreme location of the aurora *widened* participation to some degree because lived experience, over the course of decades, became important for the registration of very rare events. Amateur scientists also participated in the IGY, sending reports of aurorae to James Paton at Edinburgh Observatory to be collated and mapped throughout the eighteen-month programme. Crucially though, despite the attention paid to the perspectives of lay people, it was the temporary inhabitants of the Artic and Antarctic speaking and writing in the mould of western scientific

---

[750] Spring, 'Between Spectacle and Science', 207.

[751] 'Halley Bay Base diary 1956' (25 August 1956), Halley Bay Collection, *BAS Archives*, p. 19.

discourse who were trusted with verifying local testimony and ultimately constructing knowledge of the aurora throughout the period. Indigenous perspectives, while sought, were often demoted in significance unless they could be corroborated by an individual within the scientific establishment.

The aurora's ability to deceive the senses was a cause of concern for researchers working to standardise and systematise knowledge of the phenomenon. Observers were trained to see past the aurora's visual illusions in the First IPY, with an understanding that yellow aurorae were invariably seen due to the psychological merging of pink and green segments and that the rapid flow of aurorae may have resulted in an increase in the perceived brightness of a display. During the IGY the motion of auroral ionisation could be identified on radio echoes but would often confuse the human eye because the displacement of the phenomenon caused an observer to perceive a slow rotation of the lights. Moreover, much discussion of the sounds of the aurora hinged on whether the crackling noises heard in Scandinavia, the Shetland Islands and northern Canada alike were the result of an aural illusion, perhaps conjured by the mind as a result of the vividness of a display. The concern as to the fallibility of the senses in registering aurorae was tied to the broader perception of the untrustworthiness of the polar landscape, spaces where superior mirages and unusual lighting could readily fool an onlooker.

Discussions surrounding the issue of objectivity were at the forefront of IPY discourses precisely because the aurora had the capacity to delude the senses. The First International Polar Year took place in a period at the height of popularity of the maxim: 'mechanical objectivity'.[752] Yet, the early practices of capturing the aurora were predominantly non-instrumental. Standing in for the 'mechanical' element in the system were the rigorous procedures established to guide the practice of drawing the aurora, including sketching its forms on paper placed on top of a light box, which would in turn homogenise the format in which images were presented. In this way, the body *became* and instrument. The standardisation of techniques was taken further in the Second International Polar Year wherein the *Atlas of Auroral Forms* (1930) set the conventions and protocols for the practice of auroral photography. In this case it was not the photographic technology which ensured the images would be commensurable – as Daston and Galison argue, 'objectivity did not imply photography; photography did not imply objectivity' – but rather the often-simultaneous practices employed to create the photographs, directed by the atlas.[753] While the atlas's conventions were implemented to a certain extent, ultimately the research presented in this thesis demonstrates that the atlas could not entirely pre-empt and account for all the complexities of research in the field.

Across the period, from 1880 to 1960, the experiential, situated mode of knowledge creation remained important to the endeavour to understand aurora, despite the emergence of new

---

[752] Daston and Galison, *Objectivity*, p. 124.

[753] Ibid., 161.

technological means of recording its properties. Nevertheless, with the introduction of photography, spectroscopy and radio imaging, the balance of registration techniques shifted towards instrumental modes of reproduction as devices facilitated new perspectives on the aurora, beyond that which could be sensed by the human eye. Significantly, the aurora itself came to be defined by the senses and instruments which were employed to capture it in each of the periods. The word 'aurora' did not refer to one and the same object over the course of the nineteenth and twentieth centuries. The structure of this thesis is distinctly chronological as well as strongly thematised to highlight the instability of the phenomenon from 1880 to 1960 and draw out the ways in which the meaning of the aurora was transformed.

In the First IPY, the aurora was deemed to be present in the sky only if it was visible to the human eye, however faint or short lived the display may have been. Aurorae present on a cloudy night could not be seen and thus could not be detected. In drawing the phenomenon, researchers of the 1880s were charting the unknown, plotting the forms that they witnessed in an almost mimetic act of imitation. This does not mean to say that the ocular interpretation of the aurora is the only or most fundamental way of understanding the phenomenon. In the Sámi language the most commonly used word for the aurora is 'guovsahas', which can be translated to 'the audible light'.[754] The phenomenon is defined by the combination of two sensory registers: sound and light.

By the time of the Second IPY, the definition of aurora in the orthodox scientific idiom had changed. What counted as an aurora was that which could be captured on a photographic plate, with a potential exposure time of several minutes. The sunlit aurora, for example, could not be observed by sight but would show up on a developed plate if taken under the correct conditions. Non-symptomatic aurorae that were invisible to the human eye thus changed the very meaning of the phenomenon. Moreover, there was significant debate as to whether the auroral green line at 5577 Å constituted a fundamental characteristic of auroral displays and could thus be used for identification purposes. Within the *Atlas of Auroral Forms* (1930) it was argued that an aurora could be differentiated from, say, an illuminated cloud, if the green line could be detected with a spectroscope.[755]

Similarly, violet emissions were suggested as a possible characteristic for determining the presence of an auroral display. The auroral spectrum shown in fig. 77 was taken on Agfa Isochrome plates by Harang at the Tromsø auroral observatory on the night of 25 November 1930. It depicts not just the auroral green line but two strong emissions of shorter wavelengths at the violet end of the spectrum and was used to discuss the relationship between violent aurorae, which give the strongest spectroscopic readings, and the sun's activity.[756] This, and Vegard's research, indicated that violet

[754] Brekke, 'How the Northern Lights got their misnomer', p. 21.

[755] The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms*, p. 20.

[756] Harang, 'An Apparatus for Registration of the Aurora Borealis'.

emissions could potentially replace the ‘auroral green line’ within the definition of aurorae if only the sensitivity of the apparatus was great enough. Moreover, the presence of the ‘auroral green line’ within the night sky spectrum threw doubt on the criterion as a definitive factor, as did Vegard’s experiments searching for oxygen lines within the infrared light of the aurora. Spectroscopic lines were an obviously limited mode of representation, displaying no information about the position or shape of aurorae, certainly not representative of the whole witnessing experience. It was in this contentious period though, with these debates, that the aurora was coming to be defined by the instruments which could register certain aspects of the phenomenon’s ontology instead of embodied observation.

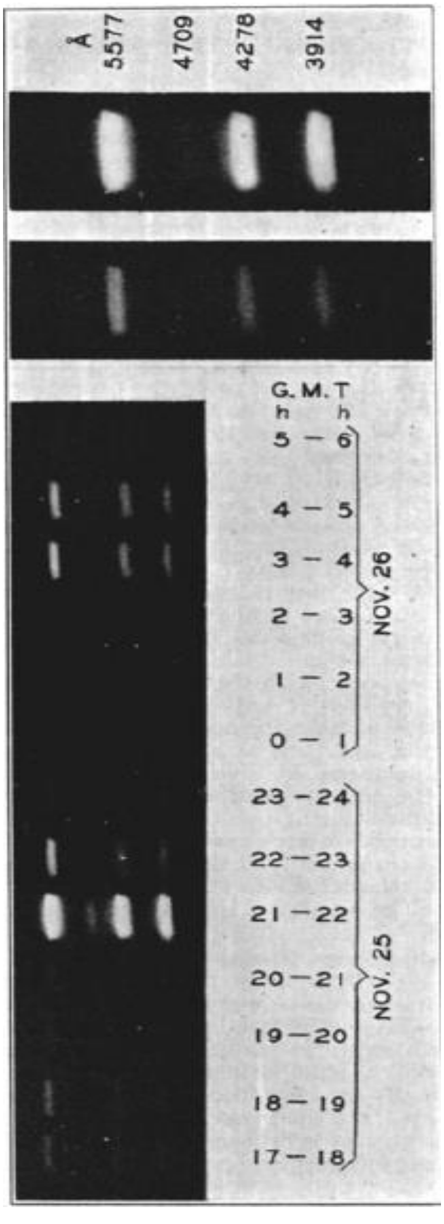


Fig. 77. Aurora of 25-26 November 1930, as observed from the Tromsø Auroral Observatory in Leiv Harang, ‘An Apparatus for Registration of the Auroral Borealis’, *Magnetism and Atmospheric Electricity* 37 (1932): 167-168, 168.

Once again, by the time of the IGY, the definition of the aurora had shifted with the emergence of new technologies for capturing the phenomenon. An aurora could be deemed to be present in the sky if a radio echo device detected an auroral ionisation pattern. The phenomenon came to be defined as the charged particles produced as a result of the interaction between the solar wind and the constituents of the ionosphere. This meant that daytime aurorae could be identified systematically for the first time, broadening the definition of aurorae far beyond what was visible to the human eye. The all-sky camera also altered understandings of the aurora’s ontology by shifting the perspective from the ground, looking upwards, to an outlook from above the earth. By facilitating a view of the geographical extent of aurorae across continents, the instrument emphasised the aurora as a planetary phenomenon rather than a smaller-scale individual object in the night sky.

In sum, what was at stake with the negotiation of experiential and instrumental sensing of the aurora was the construction of the phenomenon itself through the ways in which it was captured and reproduced, contingent on technologies and observational practices. As the definition of the aurora changed from a phenomenon which was present only when it was witnessed to an atmospheric object which was deemed to exist by photographic, spectroscopic and radio recordings, despite being invisible to the naked eye, knowledge of its relationship with the earth's magnetic field and the solar wind came to the fore. The larger picture of the phenomenon's patterns and dynamics could be visualised, including the synchronism of the aurora borealis and aurora australis as the technologies of imaging the aurora developed. While first-hand embodied sensing seemed to give access to some elusive part of the phenomenon, it was these instruments used for auroral registration which transformed the very definition of the aurora.

Temporality

The temporality of auroral research is a theme which arises in the context of the retrospection involved in the IPY programmes, which were consciously understood in relation to their earlier counterparts. The auroral work of the IGY was viewed by many of its participants as the culmination of the science as it had developed over the last century. The Second IPY was positioned explicitly as an answer to some of the problems of the First IPY, including the lack of conclusive scientific results and deficiency in analysis of the auroral images. The auroral work of the First IPY was set in a lineage of large-scale transnational endeavours which included the Magnetic Crusade and the formation of the International Meteorological Organisation IMO.

Furthermore, embedded within the images produced during the various IPY programmes are specific visual temporalities. They encompass different stages of image making: preparation before the event, including the transportation and readying of plates and instruments, the moment of recording, be it either by pencil or the click of a camera shutter, and then the preservation of the images and subsequent analysis. Researchers of the First IPY implemented rigorous practices and

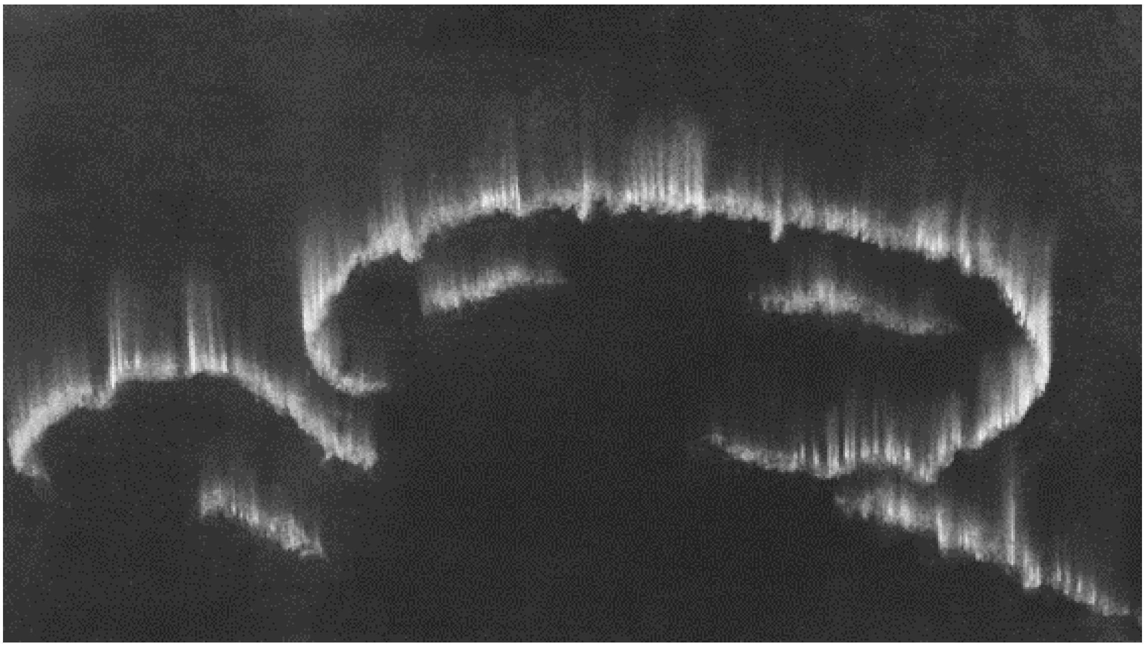


Fig. 15. Sophus Tromholt, 'Northern Lights in Kautokeino 6 Oct 1882, 7h 3m', photograph of a drawing, Sophus Tromholt Collection, *University of Bergen Library*, ubb-trom-249.

furnished their hand-drawings with precise timestamps, so that the variables of time and individual style could be controlled and the resultant images compared against one another. As Tromholt's hand-drawing depicting an aurora which appeared at 7h 3m on 6 October 1882 at his Kautokeino base demonstrates, the researchers aimed to capture the aurora in the specific rather than the general register.

The camera, to a greater extent, was viewed as a means of freezing the aurora at one point in time during the Second IPY. The photographs depicted in fig. 78 represent a changing aurora as captured at Lerwick observatory in the Shetland Islands on 23 November 1930 shifting across several minutes with timestamps consciously written on the plate. Although the auroral images were presented as a single moment, often they depicted a longer stretch of time, be it the movement of the aurora on a photographic plate exposed for several minutes, an individual drawing auroral patterns which would shift every time they looked up from their sketch or the characteristic words used to describe the impression of the aurora from a year of observation. Crystallising time in a two-dimensional image may have been an ambition of the IPY programmes but it was not realised. In fact, auroral researchers of each period were more interested in the longer perspectives afforded by the collection of large volumes of data over the course of a year or the eighteen months allocated for the IGY than they were in individual representations.

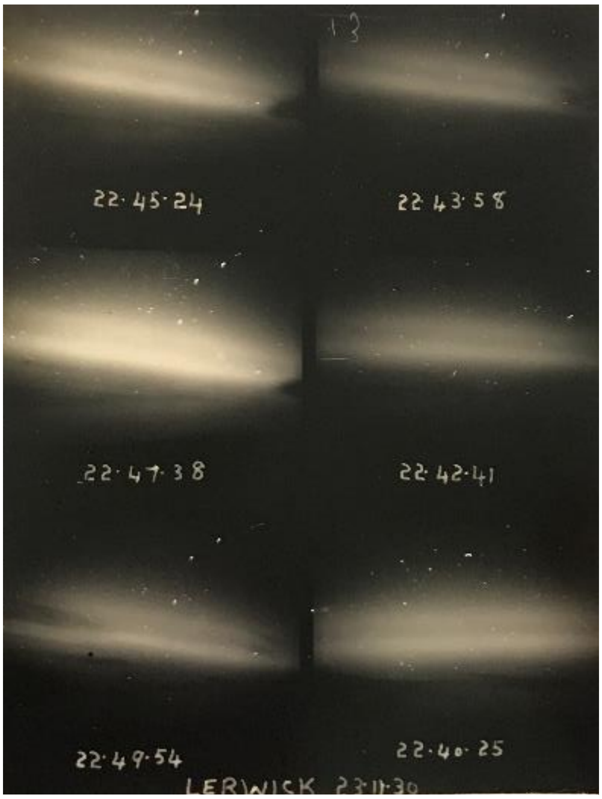


Fig. 78. Lerwick Auroral Photograph, 23/11/1930, Krogness Auroral Photographs, *University of Aberdeen Archives*, MS. 3152/26/3.

The auroral images produced across the three IPY programmes were often shown in series, conferring on the portrayals a sense of passing time and the progress of the phenomenon over a particular night. The Krogness photographs were positioned in a pattern of six so that the development of a single aurora could be seen, spectrographs from different portions of the evening were compared and the all-sky images were consciously shown as if they were stills in a film to give a sense of progression. By placing the all-sky photographs in a scheme next to each other, or projecting them side by side on a screen, not only was an 'all-sky' perspective achieved but so too could an 'all-day' perspective be visualised. The sequentiality of auroral appearances was a serious subject of scrutiny, making the time at which certain formations appeared a crucial metric culminating in the discovery of the auroral substorm in the early 1960s.

The retrospective gaze involved in reviewing the photographic record in search for sunlit aurorae is one particularly pertinent example of an unusual temporal perspective providing new insight into the phenomenon, reminding us that photographs are open to reinterpretation and can bear new knowledge with the benefit of hindsight. First, in 1927 Størmer returned to the auroral photographs he had taken between 1911 and 1922 to check whether he had previously captured the newly designated form, the sunlit aurora, accidentally. He found the high-altitude violet-grey phenomenon had been previously photographed on two occasions on 22-23 March 1920 and 13-14 May 1921. Second, Størmer returned to the volume of photographs taken during the Second IPY in 1957, once again retroactively, to search for parallax photographs of the sunlit aurora. The sunlit aurora could not be seen with the naked eye and therefore it was only through secondary analysis of the photographic plates, after the fact, that the formation could be detected. It was Størmer's photographic synthesis, the archaeology of the photographic collection with temporal distance from the original display, which brought this new type of aurora to light.

That being said, the passing of time did not always yield vastly different perspectives on the phenomenon. The chart of auroral distribution published by Elias Loomis in 1860, produced from observations from 128 locations across the northern hemisphere, did not differ significantly from the images of the auroral oval constructed from the all-sky camera data in 1957. Both depicted an elongated oval over high latitude areas – only the 1957 images allowed for the shifting of the oval in distinct seasons and throughout a 24-hour cycle. The same pictorial conventions were still employed in the 1960s. The images from the two eras demonstrate that although developments in the technologies of sensing the aurora had developed, understandings of the distribution of the phenomena had not greatly advanced in the century between their publication dates. This thesis is not a history of inevitable progress, but rather an analysis of the ways in which images supported the various methods of atmospheric knowledge creation from the beginning of the period, when Loomis's chart was produced, to the end, when the IGY plots of auroral distribution were constructed. Perhaps unexpectedly, we see much continuity across the period in terms of pictorial conventions and ways of representing the aurora.

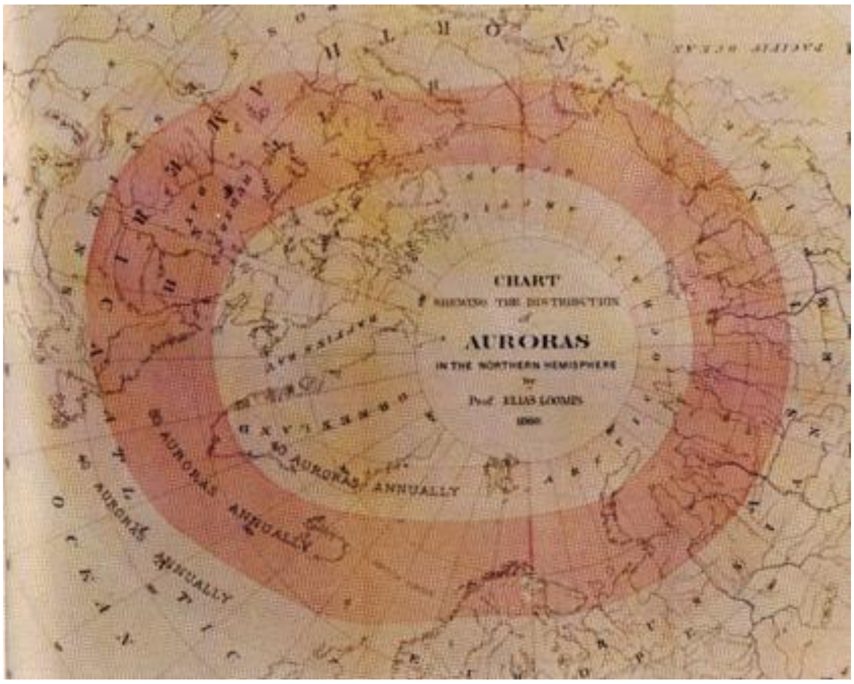


Fig. 68. Elias Loomis, Elias Loomis, 'the Great Auroral Exhibition of Aug 28th to Sept 4th, 1859 and geographical distribution of auroras and thunder storms', *American Journal of Science and Arts* (1860), 95.

Spaces of observation

Much of the auroral work of the International Polar Years took place outside, on cold nights at isolated research stations in the far north and south. Observing the aurora has always been, inherently, a situated practice due to the rarity of the phenomenon at mid-latitudes, almost like the practices of the natural historian viewing flora and fauna in situ. Before the advent of radio technologies, the aurora was necessarily documented in the dark: at night in spring and autumn or throughout the polar night in winter. While radio and all-sky research shifted practices toward remote sensing, the IGY nevertheless still required an embodied presence at the chain of stations surrounding both the northern and southern hemispheres.

The physical landscape of the polar regions was an important component of the auroral viewing experience. As John Wylie argues, 'landscape names the materialities and sensibilities with and according to which we see'.[757] Immersed within the polar regions, viewer and landscape were actualised as 'mobile and morphing ensembles of topographies, bodies and precepts'.[758] The scientific images and results produced during the IPYs were environmentally contingent. The aurora was

[757] John Wylie, 'Depths and Folds: On Landscape and the Gazing Subject', *Environment and Planning D: Society and Space* 24 (2006): 519-535, 520.

[758] Ibid., 533.

codified in the logbooks and images produced during the Polar Years as an object in its natural habitat, influenced by preconceptions of the spectral Arctic and Antarctic landscapes, with its choreography of light, darkness and colour engendering awe and evoking metaphors of virtue and enlightenment. The aurora generally appeared above a clear, white surface of snow, a feature of the terrain which influenced the sounds and visuals of the phenomenon, as well as the reception of transmitted radio signals. It is significant that the aurora was a polar phenomenon, different from other atmospheric objects including lightning and cloud formations, because of its position at extreme latitudes. The places where the aurora occurred were remarkably difficult to access and thus the number of individuals who witnessed the phenomenon first-hand was severely limited. Even so, local experts were marginalised with respect to the scientific metropole.

It must not be forgotten that the research stations of the IPY have operated as both physical *and* political spaces. The 1882-3 IPY Swedish station on Spitsbergen, for example, featured in a number of debates at the turn of the twentieth century regarding Swedish Sovereignty over the Svalbard archipelago.[759] Moreover, implicit within the spaces of observation used for the early IPYs were colonial overtones as buildings or huts were temporarily inhabited by mid-latitude visitors, with relatively little contact with local peoples other than as the subjects of ethnographic studies or contributors to the infrastructure of the research sites. As Urban Wråkberg argues, ‘the ring-shaped Arctic network of IPY stations during the early polar years formed a colonial frontier encircling untamed nature with stations that were outposts or forts.’[760]

What is interesting about the spatiality of the IPY events is that work was conducted at multiple isolated small-scale research sites, which spanned continents. This spatiality produced particular ways of seeing and standardising the aurora. In the First IPY, the sites constituted singular spaces where local knowledge could be produced. In contrast, the more extensive chain of stations operating during the IGY meant that data from each could be collated to form a hemispheric perspective on the aurora, underpinning the construction of knowledge on a planetary scale in the 1950s. The patterns of communication between the network of polar stations is another insight which can be gained from this type of multi-sited history. All three endeavours relied on the exchange of information to come to conclusions about the nature of the aurora.

---

[759] Urban Wråkberg, 'IPY Field Stations: Functions and Meanings', in Jessica Shadian and Monica Tennberg (eds.), *Legacies and Change in Polar Sciences: Historical, Legal and Political Reflections on the Polar Year* (2009): pp. 73-100, p. 74; Nils Gustaf Ekholm, 'Swedish Expedition to Spitzbergen 1882-83', *Proceedings of the Royal Geographical Society* (1884), *Scott Polar Research Institute*, 3339.

[760] Wråkberg, 'IPY Field Stations', p. 76.

A social network of radio physicists and a physical network of radio echo equipment underpinned the radio investigation of the phenomenon during the IGY. I have argued that the themes of communication and interference characterised the programme because stations were in frequent contact with one another but aurorae disrupted radio communications. One avenue of research within the auroral radio programme compared aurorae in the northern hemisphere with aurora in the south, taking Jodrell Bank as the exemplary northern site and comparing its echoes with those collected from Halley Bay. The difference in sensitivities of these two localities to the phenomenon meant that only violent aurorae could be registered at Jodrell Bank corresponding with only the most active auroral displays at Halley Bay. A type of hemispheric synchronism could thus be identified, albeit showing an uneven relationship produced by the displacement of the radio detectors from the zone of maximum auroral frequency.

Following from Cameron Brinitzer's work on the use of electromagnetic fields in the Social Mind and Body (SOMBY) Lab at the Central European University, it is clear that the dichotomy between the laboratory and the field requires reconsideration, given that that the two categories are no longer understood as being materially or theoretically distinct and that 'field sites' are variably generated.[761] It is hoped that this thesis has brought into relief the complexity and multiplicity of the term, 'the field'. While the rhetoric signifying the importance of first-hand witnessing was deeply rooted in a discourse which exalted the heroism and hardship of 'fieldwork', the practice of auroral science in the nineteenth and twentieth centuries was at least a dual endeavour, appealing to both the perceived virtues of field and laboratory approaches, as delineated by Kohler with regard to the biological sciences.[762]

Precision instruments, including spectroscopes, specially designed cameras and radio echo equipment were transported to the Arctic and Antarctic. The field sites were chosen because they were remote with restricted access, reminiscent of classic values attached to laboratory space. Certain practices, such as observations made with one participant outdoors relaying information to their indoor counterpart, extended across both realms. Situated concerns relating to features of the landscape, such as light pollution and cloud cover needed to be taken into account, while much analysis of the resulting images from the Polar Years occurred within observatories at lower latitudes, far from any routine auroral activity. As these concerns demonstrate, the distinct categories of laboratory and field lose their meaning when applied to the auroral work of the first three IPYs and thus the spaces of research can be better conceptualised based on practices, the significance of situated knowledge and permeability, both horizontal and vertical.

---

[761] Brinitzer, 'Generating Fields', 150.

[762] Kohler, *Landscapes and Labscapes*, p. 6.

With these alternative lenses outlined, the research presented in this thesis therefore offers a way of moving away from the dichotomy between the laboratory and the field within histories of the physical and geophysical sciences. What we see throughout the period surveyed is that investigations of the aurora continued to be done in the unpredictable outdoor realm, spaces which were also inhabited and contributed to livelihoods, even with the advent of more advanced technologies for capturing the phenomenon. The intervention that this history of the aurora makes to spatial methodologies is to emphasise the fine-grained practices of polar research, the interplay between remote sensing and human sensing in situ and the labour carried out from further afield as well as the constitution of the field as a vertical and sometimes intangible space.

Contemporary Perspectives

The Fourth international Polar Year, which took place from 1 March 2007 to 1 March 2009, fifty years after the IGY, has been the most recent of the international IPY programmes.[763] A proposal for the latest Polar Year was first suggested at the Scientific Committee on Antarctic Research (SCAR) meeting in Shanghai in July 2002 and was subsequently sponsored and organised by the International Council for Science (ICSU) and the World Meteorological Organisation, with 32 national committees also participating in the planning of the event. Auroral science was not a central concern of the Fourth IPY and little in the way of specific funding for auroral studies was contributed.[764] Ground-based auroral observations were instead included within the programme of the International Heliophysical Year, a UN sponsored scientific programme which took place in tandem and co-operated closely with the Fourth IPY. Nevertheless, there were no significant breakthroughs in the field of auroral science during this period.

Understandings of the nature of the aurora have, for the most part, changed little since the end of the IGY. Many of the ideas and language of the IPY programmes remains in use today. For example, the auroral substorm is still deemed to be a helpful term, describing the three-hourly cycle of auroral displays. All-sky cameras are still maintained and employed to capture the aurora on a year-round basis in specific locations, although they now capture the aurora in colour and the images are

[763] Mélanie Baroni and Guillemette Ménot, 'End of the fourth International Polar Year', Conference Presentation, *Collège de France and the French parliamentary committee for the evaluation of scientific and technological choices, Senate and National Assembly (OPECST)*, 14-15 May 2009.

[764] J. Provencher, J. Baeseman, D. Carlson *et al.*, *Polar Research Education, Outreach and Communication during the fourth IPY: How the 2007–2008 International Polar Year has contributed to the future of education, outreach and communication* (Paris: International Council for Science (ICSU), 2011).

generally made into timelapse film footage. The Tromsø auroral observatory is still in operation, now named the Tromsø Geophysical Observatory (TGO) as part of the UiT Arctic University of Norway. The Norwegian Centre for Space Weather (NOSWE) was established as a department at TGO and the work carried out there includes the operation of a chain of 19 magnetometers across mainland Norway, 6 all-sky cameras within Norway and geomagnetic and ionospheric research. The US satellites Isis II and Defence Meteorological Satellite Programme (DMSP) were among the first to photograph the aurora from space in the late 1960s and early 1970s.[765] While this technological method of visualising the aurora has brought a new vertical perspective from above the earth's ionosphere, citizen science also remains an integral part of the project to monitor aurorae. In 2018, amateur auroral observers reported and captured a new type of aurora consisting of a purple ribbon above a series of vertical green rays. The phenomenon came to be known as Strong Thermal Emission Velocity Enhancement (STEVE), and its nature is still actively being discussed among contemporary auroral researchers.

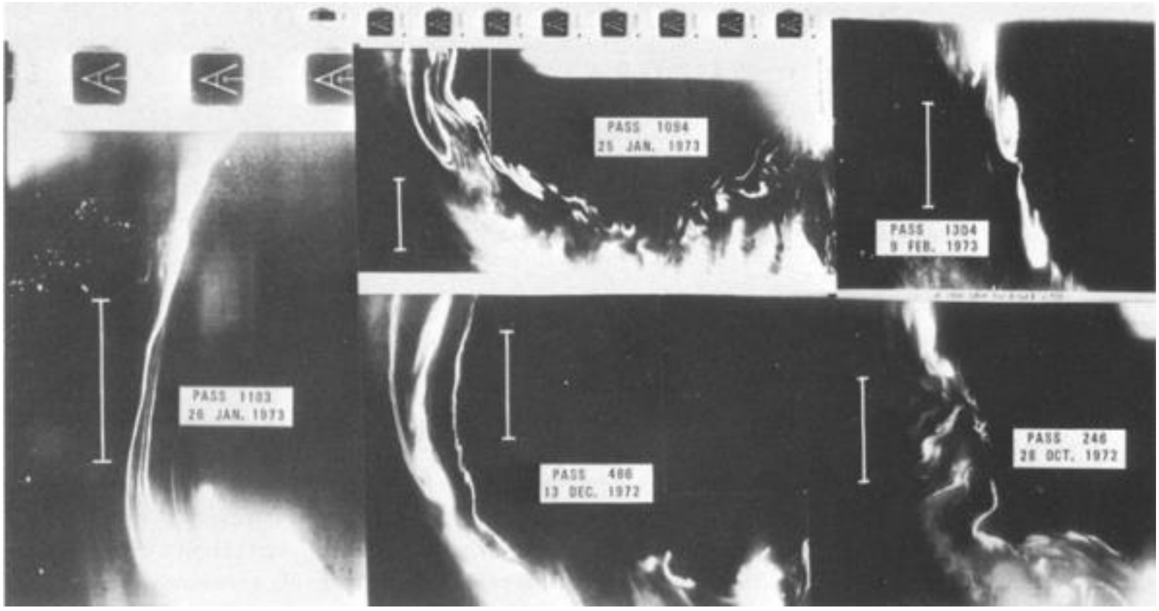


Fig. 79. 'Portions of DMSP images of discrete auroras in the northern hemisphere. White bars indicate a distance of ~1000km. Images from pass numbers 486, 1094 and 1103 show auroral arcs of great length. Images 246 and 1304 show spirals in discrete aurora; Image 1094 shows discrete aurora poleward of diffuse aurora extending from evening to morning', in T. Neil Davis, 'Observed Characteristics of Auroral Forms', *Space Science Reviews* 22 (1978): 77-113, 78.

[765] Akasofu, 'A Study of Auroral Displays Photographed from the DMSP-2 satellite'; Syun-ichi Akasofu, 'A study of auroral displays photographed from the DMSP-2 and ISIS-2 satellites', in Bengt Hultqvist and Lennart Stenflo (eds.), *Physics of the Hot Plasma in the Magnetosphere* (New York: Plenum Press, 1975): pp. 113-136.

Since the Second IPY, interest in the sound of the aurora has ebbed and flowed. In more recent years, a group at Aalto University in Helsinki, Finland, led by Unto K. Laine has taken up the mantle of investigating the 'eerie sounds' of the aurora.[766] In 2000 they set up sensitive outdoor sound recording devices and a parabolic reflector to increase the vertical scope of the apparatus at Sodankylä, a small village in northern Finland used by the Finnish research group during the First IPY. The Finnish group found that, surprisingly, that sounds associated with the aurora seemed to originate 70m above ground level. To account for this result, Laine has hypothesized that the sounds are created by discharges, similar to brush discharges, within an inversion layer of the atmosphere, a region wherein the temperature increases rather than decreases with greater distance from the earth's surface.[767] Nevertheless, Laine states that his hypothesis may be one among a plurality of possible causes for the ethereal sounds, and questions remain, including how the discharging mechanism is triggered.

On a different tack, the sound of the aurora has also been explored for its aesthetic value in the twenty-first century, inspiring musical compositions. Ēriks Ešenvalds, the Latvian composer, included journal extracts from nineteenth century accounts of the aurora written by American explorer, Charles F. Hall, and Norwegian explorer and statesman, Fridtjof Nansen, in his composition, *Northern Lights*.[768] The words of the reports are interwoven with the only known Latvian folksong recording the aural phenomenon, sung by a tenor solo. The composition makes use of tone chimes and tuned glasses filled with water to create an eerie ringing sound reverberating throughout the piece, making manifest the imagined sensations and emotions of experiencing an acoustic aurora.

Final Considerations

The research presented in this thesis has contributed to the historical literature of the atmospheric physical sciences by providing a visual, practice-based study of the experiential and instrumental ways in which the aurora was sensed in the years surrounding the International Polar and Geophysical Years. While most histories of the Polar Years focus on the organisation and funding of the

[766] Unto Kalervo Laine, 'Auroral Acoustic Project–a progress report with a new hypothesis', Conference Presentation, *Baltic–Nordic Acoustic Meeting (BNAM)*, 2016: 1–8, 1.

[767] Unto Kalervo Laine, 'Auroral crackling sounds and Schumann resonances', *Proc. Int. Cong. Sound and Vibration (ICSV)* (2019): 1–8.

[768] Ēriks Ešenvalds, 'Northern Lights' (Bienen School of Music Northwestern University, 19 January 2014), https://www.youtube.com/watch?v=jh09QDoJMMg; Dina Lenstner, 'Due North: Ēriks Ešenvalds and Aurora Borealis as a Claimed Artistic Space', *GESJ: Musicology and Cultural Science* 1 (2019): 11-17, 13.

programmes and most histories of the aurora are either written by the participants themselves or form a small part of much broader national histories, I have foregrounded the epistemologies underpinning the construction of auroral knowledge from the late nineteenth century through to the twentieth century. In sum, the auroral work of the three programmes operated at three main intersections: at the boundary between indoor and outdoor practices, amongst both amateur and professional voices, and within a shifting balance between embodied and technological sensing.

There is much room within the historiography for a more extensive exploration of the specific scientific programmes of the IPYs and their outcomes. For example, research undertaken in the fields of geomagnetism, ionospheric studies, geology, zoology and glaciology would benefit from more thorough historiographical scrutiny. Additionally, the intersection of planetary and local scales in discussions of the atmospheric sciences and multi-sited projects could be further evaluated. In terms of the aurora, the historiographical landscape would benefit from a deep analysis of the folkloric traditions of auroral mythology within indigenous high latitude cultures.

Finally, the construction of late nineteenth century auroral analogues deserves greater scholarly attention. Further research into Lemstrøm's artificial aurora experiments would reveal much about the way the aurora was defined in the period and the importance of the very visual replication of natural phenomena, connected to the issue of naturalism in art history. There exists a long tradition of mimetic experiments, which downscale sublime phenomena in the laboratory.[769] Lemström's artificial aurora defies this convention as his enormous electrical instrument was constructed outdoors atop three Finnish mountains.[770] Studying the construction of atmospheric analogues is important for gaining an appreciation of competing models of atmospheric electricity, has wider relevance for understanding the methods of grappling with elusive and potentially illusory objects and tells us much about the place of analogues in replicating the natural world at the end of the nineteenth century.

[769] Galison, *Image and Logic*, p. 19.

[770] Lemström, 'The Aurora Borealis', 60.

Bibliography

Abashiri Local Meteorological Office

'Auroral radar charts drawn on 11 February 1958 18:20-19:42', *Abashiri Local Meteorological Office*.

British Antarctic Survey Archives

'Halley Bay Base diary 1956' (25 August 1956), Halley Bay Collection, *BAS Archives*.

'Halley Bay Base diary 1957' (27 October 1957), Halley Bay Collection, *BAS Archives*.

'Annual General report 1958' (1958), Halley Bay Collection, *BAS Archives*, A/1958/2.

'Royal Society Radio Echo Report' (1959), *BAS Archives*, NGY/49 (59).

Committee of CSAGI, 'The International Geophysical Year Instruction Manual', vol. 4 Aurora and Airglow (London: Publication Committee of CSAGI, 1956), AS7/Z/2/15 BAS.

Evans, Stan, 'BAS General IGY Report 1956' (1956), *BAS archives*, AD6/2HB/1956/A.

Falkland Island Dependencies Survey, 'General IGY report 1956' (1956), *British Antarctic Survey*, AD6/2HB/1956/A.

Thomas, G. M., 'FIDS report on auroral and airglow observations', *BAS archives - NGY/27(58)* (1958).

Carnegie Institution of Washington Department of Terrestrial Magnetism Archives

US Weather Bureau, *Photographic Report of Aurora at Point Barrow, Alaska 1932-1933* vol. 7 (Washington: Carnegie Institution of Washington Department of Terrestrial Magnetism Archives, 1931-1936).

Charles Deehr Correspondence

Deehr, Charles S., 'Neil Davis in All-sky Camera view at Kotzebue on 01 January 1959', *photograph*.

Deehr, Charles S., 'IGY Optical Station as it appeared in 1959 at the Ballaine Lake Observatory in the woods north of the UAF Buildings', *the all-sky camera is within the third dome from the viewer and was originally housed atop the tower-like structure behind it, photograph reproduced with permission of Charles Deehr*.

Danish Meteorological Institute Archive

Moltke, Harald, 'Aurora toward the northwest', *Oil painting (60x60) (in the foreground is a spectrometer on a pillar)* (Akureyri, Iceland, 11th November 1899), *Danish Meteorological Institute (DMI)*.

Moltke, Harald, 'Aurora over Akureyri at 17:45', *painting* (01 September 1899), *Danish Meteorological Institute (DMI)*.

Moltke, Harald, 'Auroral Corona over Akureyri', *painting* (01 January 1900), *Danish Meteorological Institute (DMI)*.

Dwight D. Eisenhower Library, Abilene, Kansas

Odishaw, Hugh, 'The Meaning of the International Geophysical Year', *speech*, 1959, 1959-1961, Box 6, A83-10, Dwight D. Eisenhower Library, Abilene, Kansas.

Finnish Heritage Agency

Lemström, Karl Selim, 'Aurora atop Kommattivaara, Sodankylä', *watercolour* (12 November 1883), *Finnish Heritage Agency*, inventory ID: HK19501007:575.

Franklin Institute

Jennings, William N., 'Photograph of lightning' (02 September 1882), *Franklin Institute*.

Gerstein Science Information Centre, University of Toronto

Dall, William Healey, Asa Gray, John Murdoch, *et al.*, 'Report of the International Polar Expedition to Point Barrow, Alaska: In Response to the Resolution of the House of Representatives of 11 December 1884' (Washington: G.P.O, 1885), *Gerstein Science Information Centre, University of Toronto*.

Hazen, W. B. Brigadier, Brevet Major-General and Chief Signal Officer US army, 'detailed instructions concerning observations, instruments, at time, by the International Polar Conference, Hamburg 1-5 October 1879', *letter in Report of the International Polar Expedition to Point Barrow, Alaska in Response to The Resolution of the House of Representatives of 11 December 1884*, vol. 23 (Washington: Government Printing Office, 1885), *Gerstein Science Information Centre, University of Toronto*, 2298, pp. 7-17.

International Polar Year Expedition Members 1882-1883, 'Die österreichische Polarstation Jan Mayen, ausgerüstet durch Graf Hanns Wilczek, geleitet vom Emil Edlen von Wohlgemuth. Beobachtungs-Ergebnisse, hrsg. von der Kaiserlichen Akademie der Wissenschaften', vol. 2 (Wien: In Commission bei K. Gerold's Sohn, 1886), *Gerstein Science Information Centre, University of Toronto (scanned December 2008)*, Plate VIII.

Jodrell Bank Archive, University of Manchester

'The Auroral Echo Equipment at Jodrell Bank' (1953), International Geophysical Year 1953, *Jodrell Bank Archive, University of Manchester*.

'Copy of cable forwarded to Lieutenant-Commander Dalgliesh' (16 October 1956), *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

'Portion of Film Record showing changes in film speed' (27 April 1956), International Geophysical Year 1953-1957, *University of Manchester Archives*.

Cavendish Laboratory to Lovell, Bernard, 30 November 1957, Visitors to Jodrell Bank, *Jodrell Bank Archive, University of Manchester*, GB 133 JBA/VIS/2/2.

Doylerush to Lovell, Bernard, 12 March 1958, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Grahn, Sven, 'Jodrell Bank's role in early space tracking activities (Part 1)' (1999), *University of Manchester Library*, GB 133 JBA/CS12/21.

Harrison, David P., 'Radio Echo Aurora and Meteor Equipment', *Jodrell Bank Archive, University of Manchester*, NGY/29, BAS Archives.

Harrison, David P., 'A Radio - Echo Study of the Aurora Australis', unpublished thesis (1965), *Victoria University of Manchester*.

Jarrett, A. H. to Lovell, Bernard, 07 December 1955, letter, *Jodrell Bank Archive, University of Manchester,* correspondence series 7, International Geophysical Year 1955-1956.

Lovell, Bernard A. C. to Størmer, Carl, 21 October 1949, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Lovell, Bernard A. C. to Moon, P. B., 20 June 1956, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Lovell, Bernard A. C. to Moon, P. B., 02 January 1957, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Lovell, Bernard A. C. to Martin, D. C., 19 March 1958, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Lovell, Bernard A. C. and British National Committee for the International Geophysical Year Aurora Subcommittee, 'Radio Observations of aurorae', *Jodrell Bank Archive, University of Manchester*.

Paton, James, 'Report on Observation of Aurora', *report*, *British National Committee for the International Geophysical Year, Aurora Subcommittee*, *Jodrell Bank Archive, University of Manchester*.

Paton, James to Lovell, Bernard, 15 November 1956, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Størmer, Carl to Lovell, Bernard, 22 April 1950, letter, *Jodrell Bank Archive University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

New York Newspaper Archive

Lawn, Victor H., 'Aurora Borealis Blacks out Radio', *New York Times*, 1958.

Manley, Edward, 'Wireless Man in the Arctic Keeps in Touch with New York', *New York Times*, 18 September 1927.

Norwegian National Library, Oslo

'Kristian Birkeland experiments with the northern lights in a vacuum vessel' (1912), *Nasjonalbiblioteket*, https://urn.nb.no/URN:NBN:no-nb_digifoto_20160304_00236_bldsa_fPORTRETT_0034.

Boyle, Dr. to Størmer, Carl, 24 October 1930, letter, *Oslo National Library*, Carl Størmer Letter Archive, p. 115.

Fleming, John Adam to Mr Stokes, 10 November 1930, Letter, *Oslo National Library*, Carl Størmer letter archive, p. 115.

Fleming, John Adam to Størmer, Carl, 'International Polar Year', 04 October 1932, 1932–3 correspondence, *Oslo National Library*.

Fleming, John Adam to Fuller, Prof., (Alaska College School of Mines), 'Correspondence on the International Polar Year', 20 August 1932, letter, *Oslo National Library*.

International Geodetic and Geophysical Union Section of Terrestrial Magnetism to Edinburgh Observatory, 'International Polar Year', October 1930, 1932–3 correspondence, *Oslo National Library*.

Sharp, Narve, 'Professor Lars Vegard', *photograph*, *Nasjonalbiblioteket*, Prof. Vegard file number: 475.

Størmer, Carl, 'The Northern Lights', *photograph at home in the garden at Huk Aveny, Bygdøy, Nasjonalbiblioteket*.

Størmer, Carl to father, his, 19 March 1909, letter written while on a boat returning from Bossekop.

Størmer, Carl to Stagg , J.M., 23 December 1929, letter, *Oslo National Library*, MS folder 657 Ubehandlet 115: Carl Størmer: Brevarkiv.

Størmer, Carl to Berkey, Donald, 03 October 1954, letter, *National Library of Oslo*.

Perspektivet Museum

'Spectroscope encased in a white box on the concrete roof of the Tromsø Auroral Observatory' (1930), *Perspektivet Museum*.

Polar Environment Data Science CentreInstitute of Polar Research (NIPR)

'Aurora at Abisko, Sweden', *photographs taken at 1-minute intervals* (01 February 1958), *Polar Environment Data Science Centre and the National Institute of Polar Research (NIPR) archives*.

Rijkmseum voor Volkenkunde

Schouwenberg, van, 'East Greenland', *Photograph* (1934), Jaap van Zuylen Collection, *Rijkmseum voor Volkenkunde*, RV-A304-2-1-4.

van Zuylen, Jaap, 'East Greenland', *photograph* (17 March 1934), Jaap van Zuylen Collection, *Rijkmseum voor Volkenkunde*, RV-6222-265.

van Zuylen, Jaap, 'East Greenland', *photograph* (17 March 1934), Jaap van Zuylen Collection, *Rijksmuseum voor Volkenkunde*, RV-6222-264.

Royal Society Archive

'Note to Colonel Robert Arthur Smith, R. A. M. C., The Royal Society', *Jodrell Bank Archive, University of Manchester*.

'The Royal Society: International Geophysical Year July 1957 - Dec 1958', Correspondence on International Geophysical Year, *University of Cambridge Library*, GBR/0180/RGO 9/565.

'Auroral all-sky images taken from Halley Bay on 05-06 June 1957 01:25-08:00', Films of Auroras at Halley Bay, *Royal Society Archive*, AV/3/15/2.

'The Processing and Duplication of International Geophysical Year Observations' (08 February 1956), The Royal Society, *University of Cambridge Library*, NGY/1(56).

Evans, Stan, 'Research Note' (1958), *Royal Society Archives*, NGY/127(58).

Evans, Stan to Martin, D. C., 16 June 1958, letter, *Royal Society Archives*, EXP/11/1/1/181.

Paton, James to Schneider, Otto, Instituto Antarctico Argentino (Buenos Aires), 28 July 1959, letter, *Royal Society Archives EXP/11/1/1/181*.

Paton, James, G. M. Thomas and S. Evans to MacDowall, Halley Bay via G. H. Whitefield, 19 June 1958, letter, *Royal Society Archives*, EXP/11/1/1/181.

Scalloway Museum Archives

'Clement J. Williamson (1904-1994)', Scalloway's People, *Scalloway Museum*.

Scott Polar Research Institute

Fort Rae Expedition Members, 'Plate of Six Auroral Photographs', Fort Rae Picture Library Collection, *Scott Polar Research Institute*, P82/28/09.

Fort Rae Expedition Members, 'Expedition Member Equipped for a Cold Spell of Auroral Photography', Fort Rae Picture Library Collection, *Scott Polar Research Institute*, P82/28/08.

Fort Rae Expedition Members, 'One of the Krogness cameras that accompanied the British Fort Rae Expedition', *rear View* (1932-33), Fort Rae Picture Library Collection, *Scott Polar Research Institute*, P82/28/06.

Stephenson, Alfred, 'Journal 14 May 1932 - 04 October 1933', vol. 1 Expedition Materials, Alfred Stephenson Collection, *Scott Polar Research Institute*, GB 15.

Shetland Museum Archives

Anonymous, 'The Aurora', *Shetland News*, *Letter to the Editor*, 1938, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Ashford, M., Officer in charge of the Observatory at Lerwick, 'Is the Aurora Heard?', *Shetland News, Letter to the Editor,* 1939, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Dixon, Edward, 'The Aurora', *Shetland News*, *Letter to the Editor*, *Shetland Museum and Archives* D1/591/2a/2,3,6a.

Edwards, H. A., Reverend, 'Hearing the Aurora', *Shetland News*, c. 1930, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

F., J., 'The Aurora', *Shetland News*, *Letter to the Editor*, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Hutchison, Peter, 'Hearing the Aurora', *Shetland News*, 20 May 1933, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Rabgliati, H. V., 'The Aurora at Flooden', *Shetland News*, c. 1930, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Slater, Alan E., 'Hearing the Aurora', *Shetland News*, 1938, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Williamson, C. J., 'Hearing the Aurora', *Shetland News*, *Letter to the Editor*, 1933, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Williamson, C. J., 'The Aurora', *Shetland News*, *Letter to the Editor*, 1938, *Shetland Museum and Archives* D1/591/2a/2, 3, 6a.

Tromsø Geophysical Observatory

'Birkeland's terrella experiments', Ole Andreas Krogness papers, Observatoriet på Haldde and Nordlysobservatoriet 1912-1973, *Tromsø State Archives*.

Harang, Leiv, *correspondence*, Kopiboker 1928-1971, *Tromsø State Archives*.

Harang, Leiv to Appleton, Edward Victor, 20 August 1945, letter, Kopinoker 1928-1971, *Tromsø State Archives*.

Harang, Leiv to Appleton, Edward Victor, 17 December 1952, correspondence, Observatoriet på Haldde and Nordlysobservatoriet Kopiboker 1928-1971, *Tromsø State Archives*, 22/07/1932-21/12/1933.

Johnsen, Magnar G., 'A Willy Stoffregen All-Sky Camera housed at the Tromsø Geophysical Observatory', *All-Sky Camera, Tromsø Geophysical Observatory (TGO), Norwegican Centre for Space Weather (NOSWE)*, https://site.uit.no/spaceweather/2015/01/13/all-sky-camera/.

University of Aberdeen Archives

'Azimuths and elevations of photographic reference stars', *University of Aberdeen Archives*.

'Notes on auroral plate measurements, lists of photographs, classification of auroral forms' (Aberdeen Archives).

'Discussions of errors in auroral measurements', *University of Aberdeen Archives*.

'Lerwick Auroral Photograph', *photograph* (23 November 1930), Krogness Auroral Photographs Collection, *University of Aberdeen Archives*, MS. 3152/26/3.

'Ship: Weather Recorder, 'Aurora Survey', Marine Observer's form' (1957), Auroral Observation data 1957, *Aberdeen Archives*, MS: 3151/5/1-11.

Fort Rae Expedition Members, 'Auroral Log Record, Polar Year 1932-1933', *Aberdeen Archives*, MS. 3152/26/3.

Fort Rae Expedition Members, 'Auroral Observations made at Fort Rae, Canada, Aug 1932 – Aug 1933', vol. 2-5, *Aberdeen Archives*, MS 3152/29/2-5.

Fort Rae Expedition Members, 'Exposure Test Photograph' (1931-32), Krogness Auroral Photographs Collection, *University of Aberdeen Archives*, MS. 3152/26/3.

Fort Rae Expedition Members, 'Fort Rae Auroral Photograph' (1931-32), Krogness Auroral Photographs Collection, *University of Aberdeen Archive*, MS. 3152/26/3.

Fort Rae Expedition Members, 'Staff and equipment', *photographs* (1932), *University of Aberdeen Archives*, MS. 3152/26/4.

Fort Rae Expedition Members, 'Photograph of Camera used for Auroral Photography During the British Polar Year Expedition to Fort Rae' (1932-1933), *University of Aberdeen Archives*, MS:3152.

Fort Rae Expedition Members, 'Parallax Auroral Photographs from the Fort and the main base' (1932-1933), *University of Aberdeen Archives*.

Stagg, J. M. to Simpson, G. C., 'Correspondence and notes on measurements of auroral plates', *University of Aberdeen Archives*, MS. 3152/25/1/1.

Stagg, J. M., 'The British Polar Year Expedition to Fort Rae, N.W. Canada, 1932-1933', Conference Presentation, *The G. J. Symons' Memorial Lecture of the Royal Meteorological Society*, 21 March 1934.

Stagg, J. M. to J. Paton (Department of Natural Philosophy Edinburgh University), 11 February 1953, letter, *University of Aberdeen Archives*, MS. 3152/1/11.

Stagg, J. M., Col. M.M. McLeod (War Office), Barr and Stroud Ltd, *et al.*, 'Correspondence and notes on measurements of auroral plates', *Aberdeen Archives*, MS. 3152/25/1/1.

Stagg , J.M., 'Auroral photography, various notes, measurements, log of measured plates', *typescript*, Introduction to Auroral Photography, *University of Aberdeen Archives*, MS. 3152/1/3.

Størmer, Carl to Stagg, J. M., 28 September 1934, correspondence and notes on measurements of auroral plates, *University of Aberdeen Archives*, MS. 3152/25/1/1.

Thrussell, G. E., 'Aurora' (21-22 January 1957), Auroral Observation Data 1957, *Aberdeen Archives*, MS: 3151/5/1-11.

University of Bergen Library

'Sophus Tromholt in Sami costume standing among the instruments in his outdoor observatory at Kautokeino' (1882–83), Sophus Tromholt Collection, *University of Bergen Library*, ubb-trom-038.

Tromholt, Sophus, 'Northern Lights in Kautokeino at 07:03', *photograph of a drawing* (06 October 1882), Sophus Tromholt Collection, *University of Bergen Library*, ubb-trom-249.

University of Cambridge Library

'Report from the General Secretary of the CSAGI' (03 January 1956), *University of Cambridge Library*, GBR/0180/RGO 64/76.

Paton, James, 'Sir Edward Appleton's Speech', *Section IV: Aurora and Airglow in The British National Committee for the International Geophysical Year Report*, *Cambridge University Library*, NGY/22a(55), p. 8.

Wesley, William Henry, 'Eclipse', *lithograph sent to the Astronomer Royal George Airy* (1871), *Cambridge University Library*, RGO 6/135 f204r.

University of Saskatchewan Archives & Special Collections

Currie, Balfour W., 'Record of Optical, Acoustical and Unusual Phenomena', *notebook 1932-1933, an edited transcript of the diary appeared in the #35, Spring 1987 issue of The Musk-Ox* (1987), *Department of Geological Sciences at the University of Saskatchewan*.

Davies, Frank T., 'The Canadian Second Polar Year Expedition to Chesterfield Inlet, 1932-33', *University of Saskatchewan Archives & Special Collections,* J. E. Kennedy fonds, MG 102 additionals box 10.

Davies, Frank T., 'Parallactic Photographic Plates', *The Canadian Second Polar Year Expedition to Chesterfield Inlet* (1932–33), Currie-Davies Chesterfield Inlet Parallactic Plates, University Archives and Special Collections, *Department of Physics fonds*, *University of Saskatchewan*, RG 2043, 1111-267: Box 4: Plate 58 & 58S.

US Department of Agriculture: Weather Bureau, '1933 Visual Observation Aurora College Alaska Class 2', *Auroral Data Obtained during the Second International Polar Year, August 1932-August 1933* (1938), Second International Polar Year Records, *Department of Terrestrial Magnetism, Washington*, Image 9408, Series 1, Subseries C: Aurora Binder, October 1932-September 1933, Box 3a, folder 3.

Primary

'Aurora on 25-26 November 1930, as observed from the Tromsø Auroral Observatory in Leiv Harang', *An Apparatus for Registration of the Auroral Borealis*, *Magnetism and Atmospheric Electricity*, vol. 37 (1932), p. 168.

Air Ministry Meteorological Office, *The Observatories' Year Book 1932: Comprising the Meteorological and Geophysical Results Obtained from Autographic Records and Eye Observations at the Observatories at Lerwick, Aberdeen, Eskdalemiur, Cahirciveen (Valentina Observatory), and Richmond (Kew Observatory) and the Results of Soundings of the Upper Atmosphere by Means of Registering Balloons* (London: His Majesty's Stationery Office, 1934).

Akasofu, Syun-ichi, 'The dynamical morphology of the aurora polaris', *Journal of Geophysical Research (1896-1977)* 68, no. 6 (1963): 1667-1673.

Akasofu, Syun-ichi, 'Dynamic Morphology of Auroras', *Space Science Reviews* 4, no. 1 (1964): 498-540.

Akasofu, Syun-Ichi, 'A Study of Auroral Displays Photographed from the DMSP-2 satellite and from the Alaska Meridian chain of Stations', *Space Science Reviews* (1974): 617-725.

Akasofu, Syun-ichi, 'Series of all-sky photographs (in negative) showing fine details of the torch-like structure in Saskatoon on 13 March 1957', *A Study of Auroral Displays Photographed from the DMSP-2 satellite and from the Alaska Meridian chain of Stations*, *Space Science Reviews* (1974), p. 665.

Akasofu, Syun-ichi, 'A study of auroral displays photographed from the DMSP-2 and ISIS-2 satellites', in Hultqvist, Bengt and Lennart Stenflo (eds.), *Physics of the Hot Plasma in the Magnetosphere* (New York: Plenum Press, 1975): pp. 113-136.

Akasofu, Syun-ichi, 'Proceedings of the Second International Conference on Substorms', 07-11 March 1994, Fairbanks, Alaska.

Akasofu, Syun-ichi and Sydney Chapman, 'All-sky camera photographs at Kotzebue (Alaska), Farewell (Alaska) and Pullman (Washington) on 23 September 1957', *A study of magnetic storms and auroras* (Geophysical Institute of the University of Alaska, 1961), p. 182.

Akasofu, Syun-ichi, D. S. Kimball and Ching- I. Meng, 'Point Barrow all-sky camera images on 19 February 1958, showing the formation of a group of loops in the breakup phase of the auroral lifespan', *The dynamics of the aurora—III westward drifting loops*, *Journal of Atmospheric and Terrestrial Physics*, vol. 27, no.2 (1965), p. 190.

Alty, T. and F. J. Wilson, 'Height of the Aurora in Canada', *Nature* 133 (1934): 687-688.

American Geophysical Union (eds.), *Antarctica in the International Geophysical Year: Based on a Symposium on the Antarctic* (Washington: National Committee for the International Geophysical Year, 1956).

Appleton, Edward Victor, 'The International Geophysical Year 1957-58', *Ryland Lecture* (22 May 1958), *Churchill College Archives, University of Cambridge*.

Appleton, Edward Victor, R. Naismith and L. J. Ingram, 'British Radio Observations During the Second International Polar Year', *Philosophical Transactions of the Royal Society of London Series A – Mathematical and Physical Science* 764, no. 236 (1937): 191-259.

Baschin, O., 'Die ersten nordlichtphotographien, Aufgenommen in Bossekop (Lappland)', *Meteorol* Z, no. 17 (1900): 278-280.

Bates, David R., *The Earth and its Atmosphere* (New York: Science Editions, 1957).

Beals, C. S., 'The Audibility of the Aurora and its Appearance at Low Atmospheric Levels', *Journal of the Royal Astronomical Society of Canada* 27 (1932): 184-200.

Becquerel, Antoine Henri, *Recherches sur une propriété nouvelle de la matière: activité radiante spontanée ou radioactivité de la matière, Mémoires de l'Académie des Sciences de l'Institute de France* (Paris: Firmin-Didot, 1903).

Birkeland, Kristian, *The Norwegian Aurora Polaris Expedition, 1902-1903: On the cause of magnetic storms and the origin of terrestrial magnetism* (Christiania: H. Aschelhoug, 1908).

Bradford, William, *The Arctic Regions, illustrated with photographs taken on an expedition Greenland* (London: Sampson Low, Marston, Low & Searle, 1873).

British International Polar Year Expedition, 'Observations of the International Polar Year Expeditions, 1882-83: Fort Rae' (London: Tribuner & Co., 1886), *MBLWHOLI Library*.

Brown, Robert, 'Double-Arched Aurora with Streamers', *Our Earth and its Story: A Popular Treatise on Physical Geography* (1887), *The British Library*, catalogue number:014806127, digital store:10006. ff.6., p. 300.

Brown, Robert, *Our Earth and its Story: A Popular Treatise on Physical Geography* (1887).

Bullough, K. and T. R. Kaiser, 'Radio Reflections from Aurorae (II)', *Journal of Atmospheric and Terrestrial Physics* (1955): 201-214.

Burder, George E., 'Sound of the Aurora', *Nature* 23 (1881): 529.

Burke, Edmund, *A Philosophical Enquiry into the Origin of our Ideas of the Sublime and Beautiful* (London: J. Dodsley, 1764).

Cabannes, Jean, 'The Light of the Night Sky', *Science Progress* 33, no. 131 (1939): 435-446.

Cannon, A. Jump and E. C. Pickering, 'The Henry Draper Catalogue' (1918), *Cambridge: The Observatory*.

Capron, John Rand, 'The Aurora Borealis', *Nature* 3 (1870): 28.

Capron, John Rand, 'Aurora at Guildford on 24 October 1870', *lithograph from water colour, Aurorae: Their Characters and Spectra* (London: E. & F. N. Spon, 1879), plate 3, p. 19.

Capron, John Rand, *Aurorae: Their Characters and Spectra* (London: E. & F. N. Spon, 1879).

Capron, John Rand, 'To the Editor of the Meteorological Magazine', *Symons's Monthly Meteorological Magazine* XVII (1883): 55.

Capron, John Rand, 'Professor Lemström's Auroral Experiments in Lapland', *The Observatory* 6 (1883): 259-266.

Capron, John Rand, 'XLVII The Auroral Beam of November 17, 1882', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 15, no. 95 (1883): 318-339.

Carlheim-Gyllenskiöld, Vilhelm, 'The Aurora Borealis on 06 January 1883', *Observations faites au Cap Thordsen, Spitzberg, par L'Expédition Suédoise: Observations Astronomiques, Géodésiques et Marégraphiques, Exploration Internationale des Régions Polaires 1882-1883*, vol. 2: Aurora Boréales (Stockholm: L'Académie Royale des Sciences de Suéde, 1886), p. 422.

Carlheim-Gyllensköld, Vilhelm, *Observations faites au Cap Thordsen, Spitzberg, par L'Expédition Suédoise: Observations Astronomiques, Géodésiques et Marégraphiques, Exploration Internationale des Régions Polaires 1882-1883* vol. 2: Aurora Borealis (Stockholm: L'Académie Royale des Sciences de Suéde, 1886).

Carlheim-Gyllensköld, Vilhelm, 'Polar projection of the celestial sphere representing the aurora borealis on 25 December at 00:30', *Observations faites au Cap Thordsen, Spitzberg, par*

L'Expédition Suédoise: Observations Astronomiques, Géodésiques et Marégraphiques, Exploration Internationale des Régions Polaires 1882-1883, vol. 2: Aurora Boréales (Stockholm: L'Académie Royale des Sciences de Suéde, 1886), Plate XII.

Carlheim-Gyllensköld, Vilhelm, *Expédition Polaire Suedoise 1882-83* vol. 2 (Stockholm: L'Académie Royale des Sciences de Suède, 1887).

Cawood, J., 'The Magnetic Crusade: Science and Politics in Victorian England', *Isis* 70 (1979): 493-518.

Celoria, Francis, 'The Alleged Dark Segment in Aurora Borealis Displays', *British Astronomical Association* 78 (1968): 129-132.

Centkiewicz, Czeslaw, *Die Insel der Nebel und Stürme: die erste polnische Expedition im Zweiten Internationalen Polarforschungsjahr 1932-33* (Leipzig: Brockhaus Verlag, 1956).

Chamberlain, Joseph W., *Physics of the Aurora and Airglow: International Geophysics Series* vol. 2 (Cambridge: Academic Press, 1961).

Chambers, George, 'New reproduction of Rosse's M51 'nebula' image', *A Handbook of Descriptive and Practical Astronomy* (1861).

Chant, C. A., 'The Audibility of the Aurora', *Journal of the Royal Astronomical Society of Canada* 7 (1923): 273-284.

Chapman, Sydney, 'The Audibility and Lowermost Altitude of the Aurora Polaris', *Nature* 127, no. 3201 (1931): 341-342.

Chapman, Sydney, 'Low Altitude Aurorae', *Nature* 130, no. 3290 (1932): 764-765.

Chapman, Sydney, 'On the Production of Auroral and Night-Sky Light', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 66 (1937): 657-665.

Chapman, Sydney, 'Prof Carl Størmer, For Mem. R. S', *Nature* 180 (1957): 633-634.

Chapman, Sydney, 'Visual Aurora Observation', *Annals of the Geophysical Year*, vol. 4-5 (London: Pergamon Press, 1958).

Christie, W. H. M., 'The Magnetic Storm and Aurora', *Nature* 27 (1882): 82-87.

Church, Frederic Edwin, 'Aurora Borealis' (1865), *Smithsonian American Art Museum*.

Clement the Polymath, *Museum Panel*, *Scalloway Museum*.

Cole, J. Francis, 'The Aurora', *Nature* 27 (1882): 141.

Corlin, Axel, 'Observations of a Low Altitude Aurora and Simultaneous Phenomena', *Nature* 127 (1931): 553-554.

Corlin, Axel, 'The Low Altitude Aurora of Nov. 16, 1929', *Nature* 127 (1931): 928.

Currie, Balfour W., 'The Polar Aurora', *The Journal of the Royal Astronomical Society of Canada* 7 (1947): 249-264.

Currie, Balfour W. and H. W. Edwards, 'On the Auroral Spectrograms Taken at Chesterfield, Canada, During 1932-1933', *Terrestrial Magnetism and Atmospheric Electricity* 41, no. 1 (1936): 256-278.

Currie, Balfour W. and H. W. Edwards, '1-6 Typical Spectrograms taken at Chesterfield, Canada', *On the Auroral Spectrograms Taken at Chesterfield, Canada, During 1932-1933, Terrestrial Magnetism and Atmospheric Electricity*, vol. 41, no. 1 (1936), p. 265.

Danska, Herbert, 'Poles', *one of the six posters produced, the numbers on the poster represent points discussed in the educational outreach booklet, Planet Earth* (IGY Committee, 1958), *National Academy of Sciences*.

Danska, Herbert, 'Sun & Earth', *one of the six posters produced, the numbers on the poster represent points discussed in the educational outreach booklet, Planet Earth* (IGY Committee, 1958), *National Academy of Sciences*.

Darwin, C. G., 'The Discovery of Atomic Number', *New Zealand Science Review* 14 (1956): 102-108.

Dauvillier, A., 'Strange Sounds from Inland Ice, Greenland', *Nature* 133 (1934): 836.

Davies, Frank T. and Balfour W. Currie, 'Audibility of the Aurora and Low Aurora', *Nature* 32 (1933): 855-856.

Davis, Neil, 'Portions of DMSP images of discrete auroras in the northern hemisphere. White bars indicate a distance of ~1000km. Images from pass numbers 486, 1094 and 1103 show auroral arcs of great length; Images 246 and 1304 show spirals in discrete aurora; Image 1094 shows discrete aurora poleward of diffuse aurora extending from evening to morning', *Observed characteristics of auroral forms, Space Science Reviews*, vol. 22, no.1 (1978), p. 78.

Davis, Neil, *Alaska Science Nuggets* (Fairbanks: Geophysical Institute, University of Alaska, 1982).

Davis, Neil, *The College Hill Chronicles: How the University of Alaska Came of Age* (University of Alaska Foundation, 1992).

Davis, Neil and C. T. Elvey, 'A Willy Stoffregen All-Sky Camera within its housing at the College, Alaska IGY station', *Construction of an All-Sky Camera, Geophysical Institute at the University of Alaska* (1955), p. 40.

Davis, Neil and Donald S. Kimball, *Incidence of Auroras and their north-south motions in the northern auroral zone* (Fairbanks: Geophysical Insitute of the University of Alaska, 1960).

Davis, Neil, Charles S. Deehr and H. Leinbach, *An Evaluation of Auroral All-sky Camera Observations* (Fairbanks: University of Alaska, 1960).

Dawson, Henry P., 'The British Circumpolar Expedition', *Nature* (1882): 484-485.

Dawson, Henry P., 'Winter Life at Fort Rae', *Nature* 28 (1883): 371.

de la Rue, Warren, 'Researches on solar physics (II). The positions and areas of the spots observed at Kew during the years 1864, 1865, 1866, also spotted area the sun’s visible disk from the commencement of 1832 up to May 1868', *Philosophical Transactions of the Royal Society of London Series A – Mathematical and Physical Science* 160 (1870): 389-496.

de la Rue, Warren 'Researches on solar physics (I). Heliographical positions and areas of sun-spots observed with the Kew photoheliograph during the years 1862 and 1863', *Philosophical*

Transactions of the Royal Society of London Series A – Mathematical and Physical Science 159 (1869): 1-110.

de Mairan, Jean-Jacques d'Ortous, *Traité physique et historique de l'aurore boréale, Suite des Mémoires de l'Académie royale des sciences année 1731*, vol. 2 (Paris: Impr. Royale, 1754), p. 177.

de Mairan, Jean-Jacques d'Ortous, *Traité physique et historique de l'aurore boréale, Suite des Mémoires de l'Académie royale des sciences année 1731* vol. 2 (Paris: Impr. Royale, 1754).

Dickinson, Emily, 'Of Bronze and Blaze', *Emily Dickinson Museum*, 319.

Eckersley, T. J., 'Recombination and Diffusion and Spread Echoes from the Ionosphere', *Proceedings of the Physical Society, Section B* (1953): 1025-1038.

Ekholm, Nils Gustaf, 'Swedish Expedition to Spitzbergen 1882-83', *Proceedings of the Royal Geographical Society* (1884), *Scott Polar Research Institute*, 3339.

Eklund, Carl R., *Antarctica: Polar Research and Discovery During the International Geophysical Year* (New York: Holt, Rinehart and Winstron, 1963).

Elvey, C. T., 'How to build, operate, organise, and interpret photographic data: The Alaskan All-Sky Camera', *Annals of the Geophysical Year*, vol. V (London: Permagon, 1958): pp. 133-151.

Elvey, C. T., 'Auroral morphology', *Planetary and Space Science* 12, no. 8 (1964): 783-797.

Elvey, C. T. and Albert Belon, *Description of the all-sky camera, its methods of operation; an instrument (ascagraph) for measuring the film* (Fairbanks: Geophysical Institute at the University of Alaska, 1959).

Ešenvalds, Ēriks, 'Northern Lights' (Bienen School of Music Northwestern University, 19 January 2014), https://www.youtube.com/watch?v=jh09QDoJMMg.

Evans, J. E. and E. W. Maunder, 'Experiments as to the actuality of the 'Canals' observed on Mars', *Monthly Notices of the Royal Astronomical Society*, vol. 63 (1903), pp. 488-499.

Evans, Stan, 'Systematic movements of aurorae at Halley Bay', *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* (1960): 234-240.

Fassig, Oliver L., 'A revolving cloud camera', *Monthly Weather Review* 43, no. 6 (1915): 274-275.

Feldstein, Ya I. and GV Starkov, 'Dynamics of auroral belt and polar geomagnetic disturbances', *Planetary and Space Science* 15, no. 2 (1967): 209-229.

Feldstein, Ya I. and G. V. Starkov, 'Auroral oval in the IGY and IQSY period and a ring current in the magnetosphere', *Planetary and Space Science* 16, no. 1 (1968): 129-133.

Feldstein, Ya I. and G. V. Starkov, 'The location of the auroral oval and data from the world-wide network of all-sky cameras on 19 December 1957', *Auroral oval in the IGY and IQSY period and a ring current in the magnetosphere, Planetary and Space Science*, vol. 16, no.1 (1968), p. 130.

Fritz, Hermann, *Das Polarlicht* (Leipzig: F. A. Brockhaus, 1881).

Fuller, Veryl and Ervin Bramhall, *Auroral research at the University of Alaska, 1930-1934* (College, Alaska: Miscellaneous Publications of the University of Alaska and chapters 1-3 are reprinted in Terrestrial Magnetism and Atmospheric Electricity (1931), (1932), (1933) and (1935), 1937).

Gartlein, C. W., G. Sprague and R. C. Waag, '41Mc/s IGY Auroral Radar at Ithaca, New York', *Journal of Geophysical Research* (1960): 2255-2259.

Gates, Ruggles, 'The Audibility and Lowermost Altitude of the Aurora Polaris', *Nature* (1931): 486.

Gauzit, J., 'The Composition of the Upper Atmosphere According to the Dissociation of Oxygen and Nitrogen Molecules', *Bulletin of the American Meteorological Society* 25 (1944): 245-250.

Gogh, Van, 'The Starry Night', *oil on canvas* (1889), *The Museum of Modern Art (MoMA)*.

Goldstein, Eugen, 'On the Electric Discharge in Rarefied Gases', *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* xxvii (1880): 173-190.

Greely, Adolphus Washington, 'The United States Arctic Expedition to Lady Franklin Bay', *Proceedings of the Royal Geographical Society and Monthly Record of Geography* 4 (1882): 171-175.

Greely, Adolphus Washington, 'The Work of the Greely Expedition', *Science* 5 (1885): 168-170.

Greely, Adolphus Washington, 'The Magnetic and Tidal Work of the Greely Arctic Expedition', *Science* 9 (1887): 215-217.

Greely, Adolphus Washington, *Three Years of Arctic Service: An Account of the Lady Franklin Bay Expedition of 1881-84, and the Attainment of the Farthest North* (New York: C. Scribner's sons, 1894).

Halley, Edmund, 'An account of the late surprising appearance of the lights seen in the air, on the sixth of March last; with an attempt to explain the principal phenomena thereof'', *Philosophical Transactions* xxix (1716): 406-428.

Harang, Leiv, 'An Apparatus for Registration of the Aurora Borealis', *Magnetism and Atmospheric Electricity* 37 (1932): 167-168.

Harang, Leiv and Einar Tønsberg, *Investigations of the Aurora Borealis at Nordlys Observatoriet Tromsø 1929-1930* (Bergen: A. S. John Griegs Boktrykkeri, 1931).

Harang, Leiv and K. Maljord, 'Drift Measurements of the E-Layer at Kjeller and Tromsø During the International Geophysical Year', *Geofysiske Publiskasjoner: Geophysica Norvegica* 22, no. 1 (1960): 1-25.

Harang, Leiv and J. Tröim, 'Studies of Auroral Echoes (I)', *Planetary and Space Science* 5 (1961): 33-36.

Harrison, D. P. and C. D. Watkins, 'Number of hourly intervals a day of auroral radio echoes detected at Halley Bay and Jodrell Bank compared with the daily sum of the planetary K index, Kp', *A Comparison of Radio Echoes from the Aurora Australis and Aurora Borealis, Nature* vol. 182 (1958), p. 43.

Harrison, David P. and C. D. Watkins, 'A Comparison of Radio Echoes from the Aurora Australis and Aurora Borealis', *Nature*, vol. 182 (1958), pp. 43-44.

Hayes, Isaac Israel, *The Open Polar Sea: A Narrative of a Voyage of Discovery Towards the North Pole* (London: Sampson Low & Marston, 1867).

Heard, J. F., 'Clarence Augustus Chant', *Journal of the Royal Astronomical Society of Canada* 51 (1957): 1-4.

Hewson, E. W., 'A Survey of the Facts and the Theories of the Aurora', *Reviews of Modern Physics* 9 (1937): 403-431.

Hildebrandsson, Hugo Hildebrand, 'The Aurora in Spitzbergen', *Nature* 38 (1888): 84-85.

Hildebrandsson, Hugo Hildebrand, 'Studies of Clouds', *Nature* (1906): 416-417.

Hildebrandsson, Hugo Hildebrand, A. Riggenbach and L. Teisserenc de Bort, *International Cloud Atlas* (Paris: Gauthier-Villars et fils, 1896).

Hill, Robin, 'A lens for whole sky photographs', *Quarterly Journal of the Royal Meteorological Society* 50, no. 211 (1924): 227-235.

Hubbard, E., 'Sound of the Aurora', *Nature* 24 (1881): 5.

Huggins, William, 'On a Method of Photographing the Solar Corona without an Eclipse', *Proceedings of the Royal Society of London* 34 (1883): 409-414.

Hulbert, E. O., 'The Origin of the Aurora Borealis', *Physical Review* 31, no. 6 (1928): 1038-1039.

Humboldt, Alexander von, *Cosmos: Sketch of a Physical Description of the Universe* vol. 1 (London: Longman, Brown, Green and Longmans… and John Murray, 1849).

International Polar Year Expedition Members 1882-1883, 'Spiral Corona with Rays and Thread', *image*, *Die österreichische Polarstation Jan Mayen, ausgerüstet durch Graf Hanns Wilczek, geleitet vom Emil Edlen von Wohlgemuth. Beobachtungs-Ergebnisse, hrsg. von der Kaiserlichen Akademie der Wissenschaften*, vol. 2 (Wein: In Commission bei K. Gerold's Sohn, 1886), *Gerstein Science Information Centre, University of Toronto (scanned December 2008)*, Plate VIII.

International Polar Year Expedition Members 1882-1883, 'Corona-like Appearance', *image*, *Die österreichische Polarstation Jan Mayen, ausgerüstet durch Graf Hanns Wilczek, geleitet vom Emil Edlen von Wohlgemuth. Beobachtungs-Ergebnisse, hrsg. von der Kaiserlichen Akademie der Wissenschaften*, vol. 2 (Wien: In Commission bei K. Gerold's Sohn, 1886), *Gerstein Science Information Centre, University of Toronto (scanned December 2008)*.

James, William, *The Principles of Psychology* vol. 1 (Henry Holt and Co., 1890).

James, William, 'The Moral Philosopher and the Moral Life', *International Journal of Ethics* 1, no. 3 (1891): 330-345.

Jennings, William N., 'Lightning Photography', *Scientific American* 53, no. 10 (1885): 149.

Kant, Immanuel, *Critique of Judgement* (New York: Dover Publications, 2012).

Kaplan, Joseph, 'New Band System in Nitrogen', *Physical Review* 44, no. 11 (1933): 947.

Kaplan, Joseph, 'The Production of the Auroral Spectrum in the Laboratory', *Transactions of the American Geophysical Union* 15, no. 1 (1934): 162-165.

Kaplan, Joseph, 'The International Geophysical Year', *Publications of the Astronomical Society of the Pacific* 68, no. 404 (1956): 381-404.

Karadikar, J. V., 'Lines or Bands in the Spectrum of the Night Sky', *Indian Association for the Cultivation of Science* (1934): 245-250.

Kataoka, Ryuho, Shiori Uchino, Yasunori Fujiwara, *et al.*, 'All-sky photograph on 11 February 1958 at 10:44 (left) and hand-made sketch on 11 February 1958 at 10:37 (right), both observed at the Memanbetsu Magnetic Observatory in northern Japan', *Fan-shaped aurora as seen from Japan during a great magnetic storm on February 11, 1958, Journal of Space Weather and Space Climate*, vol. 9 (2019), p. 2.

Kataoka, Ryuho, Shiori Uchino, Yasunori Fujiwara, *et al.*, 'Fan-shaped aurora as seen from Japan during a great magnetic storm on February 11, 1958', *J. Space Weather Space Clim.* 9 (2019): 1-7.

Kim, J. S. and Balfour W. Currie, 'Horizontal Movements of Aurora', *Canadian Journal of Physics* (1958): 160-170.

Kimball, Herbert H., 'The Second International Polar Year, 1932-1933', *Transactions of the American Geophysical Union* 12, no. 1 (1931): 81-82.

Leadabrand, Ray L., 'Radio studies of the aurora', *Journal of the Physical Society of Japan: International Conference on Cosmic Rays and the Earth Storm* 17 (1962): 218-222.

Lebedinsky, AI, 'Synchronous auroral registration by all-sky camera C-180 and patrol spectrograph C-180-S', *Ann. Internat. Geophys. Year* 11 (1961): 133-144.

Lebedinsky, AI, Ya I Feldstein and OV Khorosheva, 'Investigations of Auroral Planetary Distribution', *Journal of the Physical Society of Japan Supplement* 17 (1962): 249.

Lemström, Karl Selim, 'The Aurora Borealis 2', *Nature* 28 (1883): 107-109.

Lemström, Karl Selim, 'The Aurora Borealis', *Nature* 28 (1883): 60-63.

Lemström, Karl Selim, 'The Results of the Scientific Expedition to Sodankylä', *Nature* 31 (1885): 372-376.

Lemström, Karl Selim, *L'aurore boréale. Étude générale des phénomènes produits par les courants électriques de l'atmosphère, with coloured plates* (Paris: Gauthier-Villars, 1886).

Lemström, Karl Selim, *Några resultat af den Finska Polarstationens arbeten i Sondankylä och Kultala åren 1882 - 84 berörande närmast Jordströmmarna och den elektriska strömmen från atmosferen och deras samband med Jordmagnetismen* (Helsingfors: J. C. Frenckell & Son, 1899).

Lemström, Karl Selim, *Electricity in Agriculture and Horticulture* (London: “The Electrician” Printing & Publishing Co. ltd, 1904).

Littleton, W., 'Dr. Tromholt’s Auroral Observatory at Kautokeino', *Nature* 28 (1883): 397-398.

Lockyer, Norman, 'On the Wave-length of the Chief Fluting Seeing in the Spectrum Manganese', *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 46 (1889): 35.

Loomis, Elias, 'The Great Auroral Exhibition of 28 August - 04 September 1859 and geographical distribution of auroras and thunder storms', *American Journal of Science and Arts* 5 (1860): 82-104.

Loomis, Elias, 'The Aurora Borealis, or polar light: its phenomena and laws', *American Journal of Science and Arts* 5 (1869): 208-248.

Lyon, G. F., 'Negative Flin Flon all-sky camera film, showing arcs with 'curl structure' on the night of 18-19 March 1958', *The association of visible auroral forms with radar echoes*, *Canadian Journal of Physics*, vol. 38, no. 3 (1960), p. 387.

Lyon, G. F., 'The association of visible auroral forms with radar echoes', *Canadian Journal of Physics* 38, no. 3 (1960): 385-389.

Lyon, G. F. and A. Kavadas, 'Horizontal Motions in Radar Echoes from Aurora', *Canadian Journal of Physics* 36, no. 12 (1958): 1661-1671.

Martin, D. C., 'The International Geophysical Year', *The Geographical Journal* 124, no. 1 (1958): 18-29.

Martin, D. C., 'Some Achievements of the International Geophysical Year', *Journal of the Royal Society of Arts* (1959): 406-422.

McAdie, Alexander, 'What is an Aurora?', *The Century Magazine* (1897): 874-878.

McAdie, Alexander, 'The first published photograph of the aurora taken by Brendel on 01 February 1892', *What is an Aurora?*, *The Century Magazine* (1897), p. 874.

McGregor, C. J., 'Auroral Observations at Point Barrow, Alaska (During the International Polar Year)', *Transactions of the American Geophysical Union* 16, no. 1 (1935): 147-151.

McLennan, J. C., 'Bakerian Lecture – The Aurora and its Spectrum', *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 120 (1928): 327-357.

McLennan, J. C. and J. J. C. Ireton, 'Spectroscopy of the Light from the Night Sky', *Canadian Journal of Physics* 2 (1930): 279-290.

McNamara, A. G., 'Elementary considerations in the optical design of an all-sky camera for aurora photography', *National Research Council Canada* (1957): 14.

Millman, Peter, 'A visual auroral programme for the IGY', *Journal of the Royal Astronomical Society of Canada* 51 (1957): 186-188.

Moltke, Harald, *Livsrjsen: Barndom - Ungdom - Rejser. Polarforskeren Knud Rasmussen, forfatteren Mylius Erichsen og maleren Harald Moltke's berømte Grønlandsekspedition 1902-04* (Copenhagen: Herov, O. J., 1965).

Morgan, William Wilson, Philip Childs Keenan, *et al.*, *An Atlas of Stellar Spectra with an Outline of Spectral Classification* (Chicago: University of Chicago Press, 1943).

National Committee of the International Geophysical Year, Science Council of Japan, *Japanese Contribution to the International Geophysical Year 1957/1958* (Tokyo: Ueno Park, 1958).

Odishaw, Hugh, 'International Geophysical Year: A Report on the United States Programme', *Science* 128, no. 3339 (1958): 115-125.

Park, F. R., 'An All-Sky Camera for Auroral Photography', *Journal of the Royal Astronomical Society of Canada* 55 (1961): 203-210.

Paton, James, 'Auroral Activity during 1957', *The Observatory* 78 (1958): 219-221.

Patterson, J., 'Preliminary Report on Auroral Magnetic, and Earth-Current Observations at Chesterfield, Northwest Territories, Canada', *Transactions of the American Geophysical Union* 15, no. 1 (1934): 166-167.

Paulsen, Adam, 'On the Height of the Aurora Borealis', *Nature* 29 (1884): 337-338.

Paulsen, Adam, *Observations Internationales Polaires, 1882-83, Expédition Danoise: Observations Faites A Godthaab* (Copenhagen: Chez G. E. C. Gad, Libraire de L'université, 1893).

Paulsen, Adam, 'Aurora (multiple rayed-bands) seen in the South-West from Godthaab on 15 November 1882 at 00:30', *drawing*, *Observations Internationales Polaires, 1882-83, Expédition Danoise: Observations Faites A Godthaab* (Copenhagen: Chez G. E. C. Gad, Libraire de L'université, 1893).

Payer, Julius, *New Lands Within the Arctic Circle: Narrative of the Discoveries of the Austrian Ship 'Tegetthoff' in the Years 1872-1874* vol. 1 (New York: D. Appleton and Co., 1877).

Payer, Julius, 'An Artistic expedition to the North Pole', *Geographical Journal* 5, no. 2 (1895): 106-112.

Proctor, H. R., 'Magnetic and Auroral Observations in High Latitudes', *Nature* 24 (1881): 241.

Ramanathan, K. R., 'A Note on the General Spectrum of the Night Sky as observed in India', *Nature* (1932): 406-410.

Ramanathan, K. R. and J. V. Karandikar, 'Spectrum of the Night Sky and of the Zodiacal Light', *Nature* 132 (1933): 749.

Ramanathan, K. R. and J. V. Karandikar, 'Spectrum (a) Zodiacal Light and the Night Sky; (b) Night Sky on 12-29 April 1933', *Spectrum of the Night Sky and of the Zodiacal Light*, *Nature*, vol. 132 (1933), p. 749.

Rigby, Malcolm, 'Recent Research of the Aurora and the Work Planned for the Second International Polar Year', *Bulletin of the American Meteorological Society* 13 (1932): 195-200.

Rindell, Arthur, 'Prof. Karl Selim Lemström', *Nature* 17 (1904): 129.

Rothwell, Pamela and Carl E. McIlwain, 'Magnetic Storms and the Van Allen Radiation Belts', *Journal of Geophysical Research* 65, no. 3 (1960): 799-806.

Runge, C., 'The Origin of the Aurora Spectrum', *Nature* 59 (1898): 29.

Rust, Frank, 'The Dutch Polar Expedition of 1882-3', *Journal of the American Geographical Society of New York* (1883): 375-380.

Ruttenberg, Stanley, USNC-IGY program office, National Academy of Sciences, *IGY General Report, United States Program for the International Geophysical Year, 1957-8* vol. 5 (Chicago: University of Chicago, 1959).

Rypdal, B. and L. Vegard, 'The Excitation Functions of Nitrogen Bands and their Bearing on Auroral Problems', *Geof. Publ.* 12, no. 12 (1939): 3-20.

Scheuchzer, Johann Jakob, 'Aurora Borealis', *copper engraving from Physica Sacra*, vol. 3 (Ausberg: Christian Ulrich Wagner, 1733), Tab. CXLIX, p. 160.

Scheuchzer, Johann Jakob, *Physica Sacra* vol. 3 (Ausberg: Christian Ulrich Wagner, 1733).

Schuster, Arthur, 'The Origin of the Aurora Spectrum', *Nature* 58 (1898): 151.

Simpson, G. C., 'Auroral Observations in the Antarctic', *Nature* 102 (1918): 24-25.

Simpson, G. C., 'Low Altitude Aurora', *Nature* 127, no. 3209 (1931): 663.

Simpson, G. C., 'The Second Polar Year 1932-1933', *Polar Record* 1, no. 2 (1931): 64-67.

Smyth, William Henry, *Sidereal chromatics; being a re-print, with additions, from the "Bedford cycle of celestial objects," and its "Hartwell continuation," on the colours of multiple stars* (London: John Bowyer Nichols and Sons, 1864).

Stagg, J. M. and The British National Committee for the Polar Year, *Some General Characteristics of Aurora at Fort Rae, N.W Canada, 1932-1933* (London: Percy Lund, Humphries & Co. Ltd, 1937).

Stoffregen, Willy, 'All-Sky Camera Auroral Research during the Third Geophysical Year 1957-58', *Tellus* 7, no. 4 (1955): 509-517.

Stoffregen, Willy, 'The positions of the IGY all-sky cameras in the northern and southern hemispheres', *I. G. Y. Ascaplots: Annals of the International Geophysical Year*, vol. 20 (Amsterdam: Elsevier Science, 2013).

Størmer, Carl, 'The Aurora of October 15, 1926, in Norway and Sounds Associated with it', *Nature* 119 (1927): 45-46.

Størmer, Carl, 'Auroral Curtains photographed on 15 October 1926', *The Aurora of October 15, 1926, in Norway and Sounds Associated with it, Nature*, vol. 119 (1927), p. 45.

Størmer, Carl, 'An Effect of Sunlight on the Altitude of Aurora Rays', *Nature* 120 (1927): 329-330.

Størmer, Carl, 'International Co-operation for Auroral Research', *The Journal of the Royal Astronomical Society of Canada* 23, no. 1 (1929): 1-7.

Størmer, Carl, 'The Distribution in Space of the Sunlit Aurora Rays', *Nature* 123 (1929): 82-83.

Størmer, Carl, 'The Spectrum of Sunlit Aurora Rays as Compared with the Spectrum of Lower Aurora in the Earth's Shadow', *Nature* 124 (1929): 263-264.

Størmer, Carl, 'Progress in the Photography of the Aurora Borealis', *Terrestrial Magnetism and Atmospheric Electricity* 37, no. 4 (1932): 475-477.

Størmer, Carl, 'Photographic Measurement of the Great Aurora of January 25-26, 1938', *Nature* 141, no. 3578 (1938): 955-957.

Størmer, Carl, *Results of the Observations and Photographic Measurements of Aurora in Southern Norway and From Ships in the Atlantic During the International Polar Year* (Blindern, Oslo: The Institute of Theoretical Astrophysics, 1952).

Størmer, Carl, 'Parallax Photographs on 19-20 March 1933 at 21:08:55', *showing sunlit invisible rays from two stations*, *Results of the Observations and Photographic Measurements of Aurora in Southern Norway and From Ships in the Atlantic During the International Polar Year* (Blindern, Oslo: The Institute of Theoretical Astrophysics, 1952), p. 117.

Størmer, Carl, 'Sunlit Aurorae', 1954, Ontario: 95-115.

Symons, G. J., 'Artificial Aurorae', *Symons's Monthly Meteorological Magazine* XVII (1883): 33-55.

Tacchini, P., 'The Aurora', *Nature* 27 (1882): 138.

The International Geodetic and Geophysical Association, *Supplements to The Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* vol. 1 (Oslo: Brøggers Boktrykkeri, 1932).

The International Geodetic and Geophysical Union, *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930).

The International Geodetic and Geophysical Union, 'Example of an HA type of aurora; a homogenous arc without ray structure, taken by Carl Størmer in Oslo on the night of 13 December 1927', *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930), p. 6.

The International Geodetic and Geophysical Union, 'Example of a G type of aurora; feeble glow, taken by Carl Størmer in Bossekop on the night of 14 March 1913', *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930), p. 10.

The International Geodetic and Geophysical Union, 'Example of a C type aurora; corona, taken by Carl Størmer in Bygdo on the night of 22 March 1920', *near the magnetic zenith*, *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930), p. 18.

The International Geodetic and Geophysical Union, 'Example of an RB type of aurora; bands with ray-structure, taken by Carl Størmer in Bossekop on the night of 03 March 1910', *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930), p. 12.

The International Geodetic and Geophysical Union, 'Format of auroral photographs within the atlas in a grid system of 6', *Photographic Atlas of Auroral Forms and Scheme for Visual Observations of Aurorae* (Oslo: A. W. Brøggers Boktrykkeri, 1930), p. 9.

Thomas, G. M., 'Auroral Photography Using All Sky Cameras', *The Journal of Photographic Science* (1959): 55-57.

Thomas, G. M. and James. Paton, 'Auroral Results from Halley Bay During The International Geophysical Year', *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences* 256, no. 1285 (1960): 241-244.

Thomson, J. J., 'On the Passage of Electricity through hot gases', *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* 29, no. 179 (1890): 358-366.

Tollner, Hanns, Rudolf Kanitscheider and Fritz Kopf, *Vierzehn Monate in der Arktis: die österreichische Polarjahrexpeditions 1932/33 nach Jan Mayen, veranstaltet von der Akademie der Wissenschaften in Wien* (Wien: Tyrolia, 1932).

Triewald, Samuel, 'Experimentum aurorae borealis artificialis', *Kungl. Vetenskapsakademiens Handlingar* (1744), plate 3.

Triewald, Samuel, 'Experimentum aurorae borealis artificialis', *Kungl. Vetenskapsakademiens Handlingar* (1744): 115-117.

Tromholt, Sophus, 'On the Aurora Borealis in Iceland', *Nature* 29 (1884): 537-538.

Tromholt, Sophus, 'Auroral Researches in Iceland', *Nature* (1884): 80-81.

Tromholt, Sophus, 'Measuring the Aurora Borealis', *Nature* 29 (1884): 409-412.

Tromholt, Sophus, 'A Note Relating to the History of the Aurora Borealis', *Nature* 32 (1885): 89-90.

Tromholt, Sophus, *Under the Rays of the Aurora Borealis: In the Land of the Lapps and Kvæns, vol 1* (Boston: Houghton Mifflin Harcourt, 1885).

Tromholt, Sophus, *Under the Rays of the Aurora Borealis: In the Land of the Lapps and Kvæns, vol 2* (London: Sampson Low, Maston, Searle, and Rivington, 1885) (trans. Siewers, Carl).

Trouvelot, Étienne Léopold, *Aurora Borealis, The Trouvelot Astronomical Drawings* (New York: C. Scribner’s Sons, 1881).

Trouvelot, Étienne Léopold, *The Trouvelot Astronomical Drawings Manual* (New York: Scribner’s sons, 1882).

Tyron, Helen M., *Auroral Index for College, Alaska derived from all-sky camera photographs, September 1957 - December 1958* (Fairabanks: Geophysical Institute of the University of Alaska, 1959).

Vegard, Lars, 'Spectrographic Observations of Infra-red Lines in the Auroral Spectrum', *Nature* 129 (1932): 468.

Vegard, Lars, 'The Auroral Spectrum and the Upper Atmosphere', *Nature* 132 (1933): 682.

Vegard, Lars, 'The Interpretation of the Northern Lights and the Structure of the Ionosphere', *Results of the Exact Natural Sciences* (1938): 229-281.

Vegard, Lars and E. Tønsberg, 'Continued Investigations on the Temperature of the Upper Atmosphere Determined by Means of Bands Appearing in the Auroral Spectrum', *Geof. Publ.* 11, no. 2 (1935): 3-14.

Vegard, Lars and E. Tønsberg, 'Four Spectrograms in February-March 1933', *Continued Investigations on the Temperature of the Upper Atmosphere Determined by Means of Bands Appearing in the Auroral Spectrum*, *Geof. Publ*, vol. 11, no. 2 (1935), p. 6.

Vegard, Lars and E. Tonsberg, 'Enhancement of Red Lines and Bands in the Auroral Spectrum from a Sunlit Atmosphere', *Nature* 137 (1936): 778-779.

Vegard, Lars and E. Tønsberg, 'The Temperature of the Auroral Region Determined from Band Spectra', *Geof. Publ.* 3 (1938): 3-7.

Vegard, Lars and E. Tønsberg, 'Investigations on the Auroral and Twilight Luminescence including Temperature Measurements in the Ionosphere', *Geof. Publ.* 13, no. 1 (1940): 3-22.

Warren, William Fairfield, 'Night Skies of Eden, an Actual Aurora Borealis', *Paradise Found: The Cradle of the Human Race at the North Pole* (1885), p. 67.

Warren, William Fairfield, *Paradise Found: The Cradle of the Human Race at the North Pole* (1885).

Weyprecht, Karl, 'Fundamental Principles of Scientific Arctic Investigation', Conference Presentation, *Academy of Sciences*, January 1875, Vienna.

Weyprecht, Karl, *Praktische Anleitung zr Beobacktung der Polarlichter und der magnetischen Erscheinungen in hohen Breiten* (Wien: Verlag von Moritz Perles, 1881).

Whipple, F.L., 'The call of space', Conference Presentation, *Dedication of the Lindheimer Astronomical Research Center*, 04 May 1967, Northwestern University.

Wilson, Edward Adrian, *Album of Photographs and Sketches with a Portfolio of Panoramic Views, British National Antarctic Expedition 1901-1904* (London: Royal Society, 1908).

Wilson, Edward Adrian, 'Auroral Curtain seen in the North on 05 July 1902 at 01:00-02:00', *Album of Photographs and Sketches with a Portfolio of Panoramic Views, British National Antarctic Expedition 1901-1904* (London: Royal Society, 1908), p. 290.

Wundt, Wilhelm, *Ueber Vergleichungen von Tondistanzen* (Leipzig: Druck von Breitkopf & Härtel, 1891).

Secondary

Adey, Peter, *Aerial Life: Spaces, Mobilities, Affects* (New York: John Wiley & Sons, 2010).

Agar, Jon, *Science and Spectacle: The Work of Jodrell Bank in Postwar British Culture* (Abingdon: Routledge, 1998).

Akasofu, Syun-ichi, 'Space Physics in the earliest days, as I experienced', *Perspectives of Earth and Space Scientists* (2020): 1-10.

Allen, Casey D., 'Why Fieldwork?', in Thornbush, Mary J., Casey D. Allen and Faith A. Fitzpatrick (eds.), *Developments in Earth Surface Processes* (Amsterdam: Elsevier, 2014): pp. 11-29.

Aronova, Elena, 'Geophysical Datascapes of the Cold War: Politics and Practices of the World Data Centres in the 1950s and 1960s', *Osiris* 32, no. 1 (2017): 307-327.

Baker, F. W. G., 'The First International Polar Year 1882-1883', *Polar Record* 21 (1982): 275-285.

Baroni, Mélanie and Guillemette Ménot, 'End of the fourth International Polar Year', Conference Presentation, *Collège de France and the French parliamentary committee for the evaluation of scientific and technological choices, Senate and National Assembly (OPECST)*, 14-15 May 2009.

Barr, Susan and Cornelia Lüdecke, *The History of the International Polar Years* (Berlin: Springer Science and Business Media, 2010).

Barr, William, 'Geographical Aspects of the First International Polar Year, 1932-1933', *Annals of the Association of American Geographers* (1983): 463-484.

Barr, William, *The Expeditions of the First International Polar Year, 1882-83* (Calgary: Arctic Institute of North America, 1985).

Batten, Alan H., 'The Beginnings of Modern Astronomy at the University of St Andrews', *Journal of Astronomical History and Heritage* 17, no. 1 (2014): 39-44.

Baxandall, Michael, *Painting and Experience in Fifteenth Century Italy: A Primer in the Social History of Pictorial Style* (Oxford: University of Oxford Press, 1988).

Belanger, Dian Olson, 'The International Geophysical Year in Antarctica: A Triumph of "Apolitical" Science, Politics, and Peace', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan, 2010): pp. 265-278.

Belanger, Noelle and Anna Westerstahl Stenport, 'The Politics of Colour in the Arctic Landscape: Blackness at the Centre of Frederic Edwin Church's Aurora Borealis and the Legacy of 19th Century Limits of Representation', *ARTMargins and the Massachusetts Institute of Technology* (2017): 6-26.

Benson, Etienne, 'The Post-Heroic Field', *Isis* 113, no. 1 (2022): 114-120.

Bigg, Charlotte, 'Spectroscopic Meteorologies', *Nuncius* 18 (2003): 765-777.

Bigg, Charlotte, 'Staging the Heavens: Astrophysics and Popular Astronomy in the Late Nineteenth Century', in Aubin, David, Charlotte Bigg and H. Otto Sibum (eds.), *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture* (Duke Uni. Press, 2010): pp. 305–324.

Bigg, Charlotte, David Aubin and Philipp Felsch, 'Introduction: The Laboratory of Nature – Science in the Mountains', *Science in Context* 22, no. 3 (2009): 311-321.

Böhme, Gernot, *The Aesthetics of Atmospheres* (Abingdon: Taylor & Francis, 2016).

Bone, Neil, *Aurora: Observing and Recording Nature's Spectacular Light Show* (Berlin: Springer Science & Business Media, 2007).

Bones, Stian, 'Norway and Past International Polar Years – A Historical Account', *Polar Research* 26 (2007): 195-203.

Bravo, Michael, 'Preface: Legacies of Polar Science', in Shadian, Jessica and Monica Tennberg (eds.), *Legacies and Change in Polar Sciences: Historical, Legal and Political Reflections on the Polar Year* (London: Routledge, 2009): pp. xiii-xvi.

Bravo, Michael, *North Pole: Nature and Culture* (London: Reaktion Books, 2019).

Brekke, Asgeir, 'Aurora Borealis: How the Northern Lights got their misnomer', in Brekke, Asgeir and Jon Børre Ørbæk (eds.), *Arctic Lights: Our Natural and Cultural Heritage* (Tromsø: Tromsø University Museum, 2006).

Brekke, Asgeir and A. Egeland, *The Northern Light: From Mythology to Space Research* (Oslo: Grondahl and Son Forlag, 1979).

Briggs, J. Morton, Jr., 'Aurora and Enlightenment: Eighteenth-Century Explanations of the Aurora of the Aurora Borealis', *Isis* 58, no. 4 (1967): 491-503.

Brinitzer, Cameron, 'Generating Fields', *Isis* 113, no. 1 (2022): 144-150.

Bullis, Harold, *The Political Legacy of the International Geophysical Year* (Washington D.C.: U.S. Government Printing Office, 1973).

Bynum, W.F. and Roy Porter, *Medicine and the Five Senses* (Cambridge: Cambridge University Press, 1993).

Canales, Jimena, 'Photogenic Venus: The “Cinematographic Turn” and its alternative in Nineteenth-Century France', *Isis* 93 (2002): 585-613.

Cetina, Karin Knorr, *Epistemic Cultures: How the Sciences Make Knowledge* (Cambridge: Harvard University Press, 1999).

Chetty, Suryakanthie, *Africa Forms the Key: Alex Du Toit and the History of Continental Drift* (Berlin: Springer Nature, 2021).

Cirac-Claveras, Gemma, 'Re-imagining the Space Age: Early Satellite Development from Earthly Fieldwork Practice', *Science as Culture* 31, no. 2 (2022): 163-186.

Coen, Deborah, *Climate in Motion: Science, Empire, and the Problem of Scale* (Chicago: University of Chicago Press, 2018).

Collis, Christy and Klaus Dodds, 'Assault on the Unknown: historical and political geographies of the International Geophysical Year (1957-8)', *Journal of Historical Geography* 34 (2008): 555-573.

Corbin, Alain, *Time, Desire and Horror: Towards a History of the Senses* (Oxford: Blackwell Publishers, 1995).

Corbin, Brenda G., 'Etienne Leopold Trouvelot: The Artist and Astronomer', Conference Presentation, *Library and Information Services in Astronomy V ASP Conference Series*, 18-21 June 2007, vol. 377, Cambridge, Massachusetts, USA: 352-360.

Cosgrove, Denis, *Apollo's eye: a cartographic genealogy of the earth in the western imagination* (Baltimore: The John Hopkins University Press, 2001).

Cosgrove, Denis, 'Introduction', in Cosgrove, Denis (ed.), *Geography and Vision: Seeing, Imagining and Representing the World* (London: I.B. Tauris, 2012): pp. 1-12.

Cosgrove, Denis and Veronica della Dora, 'Introduction', in Cosgrove, Denis and Veronica della Dora (eds.), *High Places* (New York: I.B. Tauris & Co, 2009): pp. 1-18.

Crary, Jonathan, 'Techniques of the Observer', *October* 45 (1988): 3-35.

Cronenwett, Philip N., 'Publishing Arctic Science in the Nineteenth Century: The Case of the First International Polar Year', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years*, vol. 2010 (New York: Palgrave Macmillan, 2010): pp. 27-46.

Daston, Lorraine, 'Cloud Physiognomy', *Representations* 135, no. 1 (2016): 45-71.

Daston, Lorraine and Peter Galison, *Objectivity* (Cambridge: Zone Books, 2007).

David, Robert, *The Arctic in the British Imagination 1818-1914* (Manchester: Manchester University Press, 2017).

Davidson, P., *The Idea of North* (London: Reaktion Books, 2005).

Deehr, Charles S., Emeritus Professor at the University of Alaska and member of the Geophysical Institute Arctic Research Consortium of the Unites States, July & August 2022, correspondence by email.

DeLoughrey, Elizabeth, 'Satellite Planetarity and the Ends of the Earth', *Public Culture* 26, no. 2 (2014): 257-280.

Diaconu, Mădălina, 'Longing for clouds – does beautiful weather have to be fine?', *Contemporary Aesthetics* 13, no. 16 (2015): 1-13.

Diaconu, Mădălina, 'Rescaling the Weather Experience: From an Object of Aesthetics to a Matter of Concern', *Environmental Values* 31, no. 1 (2022): 67-84.

Diamanti, Jeff, Lynn Badia and Marija Cetinić, 'Introduction', in Diamanti, Jeff, Lynn Badia and Marija Cetinić (eds.), *Climatic Realism: The Aesthetics of Weather and Atmosphere in the Anthropocene* (Abingdon: Taylor and Francis, 2020).

Divine, Robert A., *The Sputnik Challenge: Eisenhower's Response to the Soviet Satellite* (New York: Oxford Univ. Press, 1993).

Dixon, Deborah, 'Geographies of Touch/Touched by Geography', *Geography Compass* 4, no. 5 (2010): 449-459.

Dodds, Klaus, 'Aerial Surveying, Geopolitical Competition and the Falkland Islands and Dependencies Aerial Survey Expedition (FIDASE 1955-7)', in Adey, Peter, Mark Whitehead and Alison Williams (eds.), *From Above: War, Violence and Verticality* (Oxford: Oxford University Press, 2014): pp. 71-94.

Driver, Felix, 'Distance and Disturbance: Travel, Exploration and Knowledge in the Nineteenth Century', *Transactions of the Royal Historical Society* 14 (2004): 73-92.

Eather, Robert, *Majestic Lights: The Aurora in Science, History and the Arts* vol. 18 (Washington D. C.: American Geophysical Union: Special Publications Series, 1980).

Edge, David O. and Michael Joseph Mulkay, *Astronomy Transformed: The Emergence of Radio Astronomy in Britain* (New Jersey: Wiley, 1976).

Edwards, Elizabeth, 'Photography and the Business of Doing History', in Pasternak, Gil (ed.), *The Handbook of Photography Studies* (Abingdon: Routledge, 2020): pp. 170-186.

Edwards, P.N., *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (MIT Press, 2010).

Egeland, Alv and William J. Burke, *Kristian Birkeland: The First Space Scientist* (Heidelberg: Springer Netherlands, 2005).

Egeland, Alv and William J. Burke, *Carl Størmer: Auroral Pioneer* (Berlin: Springer Science and Business Media, 2010).

Egeland, Alv and William J. Burke, 'Auroral Research at the Tromsø Northern Lights Observatory: The Harang Directorship, 1928-1946', *History of Geo and Space Sciences* 7 (2016): 53-61.

Elkins, James, 'Art History and Images That Are Not Art', *The Art Bulletin* 77, no. 4 (1995): 553-571.

Elzinga, Aant, 'Through the Lens of the Polar Years: Changing Characteristics of Polar Research in Historical Perspective', *The Polar Record* 45, no. 245 (2009): 313-336.

Elzinga, Aant, *Achievements of the Second International Polar Year* (Berlin: Springer Science and Business Media, 2010).

Fara, Patricia, 'Northern Possession: Laying Claim to the Aurora Borealis', *History Workshop Journal* 42 (1996): 37-58.

Fara, Patricia, 'Lord Derwentwater's Lights: Prediction and the Aurora Polaris Astronomers', *Journal for the History of Astronomy* 1: Background (1996): 239-258.

Fleming, James Rodger, *Inventing Atmospheric Science: Bjerknes, Rossby, Wrexler, and the Foundations of Modern Meteorology* (Cambridge: MIT Press, 2016).

Fleming, James Rodger and Cara Seitchek, 'Advancing Polar Research and Communicating its Wonders: Quests, Questions and Capabilities of Weather and Climate Studies in International Polar Years', in Krupnik, Igor, Michael A. Lang and Scott E. Miller (eds.), *Smithsonian at the Poles: Contributions to International Polar Year Science* (Washington: Smithsonian Institution Scholarly Press, 2009): pp. 1-12.

Foster, Hal, *Vision and Visuality: Discussions in Contemporary Culture* (Seattle: Bay Press, 1988).

Fox, William, 'Walking in Circles: Cognition and Science in High Places', in Cosgrove, Denis and Veronica della Dora (eds.), *High Places* (New York: I.B. Tauris & Co., 2009): pp. 19-32.

Friedman, Robert Marc, 'Making the Aurora Norwegian: Science and Image in the Making of Tradition', *Interdisciplinary Science Reviews* 35, no. 1 (2010): 51-68.

Friedman, Robert Marc, 'Introduction: The Aurora in History', *Acta Borealia* 29, no. 2 (2012): 115-118.

Fuller, P., 'The Life and Times of John Rand Capron', *Antiquarian Astronomer* 8 (2014): 21-45.

Galison, Peter, *Image and Logic: A Material Culture of Microphysics* (Chicago: University of Chicago Press, 1997).

Galison, Peter and Alexi Assmus, 'Artificial Clouds, Real Particles', in Gooding, David, Trevor Pinch and Simon Schaffer (eds.), *The Uses of Experiment: Studies in Natural Sciences* (Cambridge: Cambridge University Press, 1989): pp. 225-274.

Ganchrow, Raviv, 'Fray', in Altena, Arie (ed.), *The Dark Universe* (Amsterdam: Sonic Acts Press, 2013): pp. 118-131.

Geimer, Peter, *Inadvertent Images: A History of Photographic Apparitions* (Chicago: University of Chicago Press, 2018).

Gieryn, T.F., *Truth-Spots: How Places Make People Believe* (University of Chicago Press, 2018).

Gieryn, Thomas F., 'City as Truth-Spot: Laboratories and Field-Sites in Urban Studies', *Social Studies of Science* 36, no. 1 (2006): 5-38.

Good, Gregory A., 'The Assembly of Geophysics: Scientific Disciplines as Frameworks of Consensus', *Studies in History and Philosophy Part B: Studies in History and Philosophy of Modern Physics* 31, no. 3 (2000): 259-292.

Good, Gregory A., 'Sydney Chapman: Dynamo behind the International Geophysical Year', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan US, 2010): pp. 177-203.

Good, Gregory A., 'Measuring the Inaccessible Earth: Geomagnetism, In situ Measurements, Remote Sensing, and Proxy Data', *Centaurus* 53, no. 2 (2011): 176-189.

Gooday, Graeme, 'Placing or Replacing the Laboratory in the History of Science?', *Isis* 99, no. 4 (2008): 783-795.

Griffero, Tonino, 'Is there such thing as an ‘atmospheric turn’? Instead of an introduction', in Tedeschini, Marco and Tonino Griffero (eds.), *Atmosphere and Aesthetics* (Berlin: Springer International Publishing, 2019): pp. 11-62.

Hamblyn, Richard, *Clouds: Nature and Culture* (London: Reaktion Books, 2017).

Hayakawa, Hisashi, 'A review of Japanese auroral records on the three extreme space weather events around the International Geophysical Year (1957-1958)', *Geoscience Data Journal* (2022): 1-16.

Heathcote, Niels H. de V. and Angus Armitage, 'The First International Polar Year', in Stuart, Sam (ed.), *The Histories of the International Polar Years and the Inception and Development of the International Geophysical Year: Annals of the International Geophysical Year*, vol. 1 (Oxford: Pergamon Press, 1959): pp. 7-100.

Heggie, Vanessa, *Higher and Colder: A History of Extreme Physiology and Exploration* (Chicago: University of Chicago Press, 2019).

Heggie, Vanessa, 'Extreme Acts: Narratives of Balance and Moderation at the Limits of Human Performance', in Jackson, M. and M. D. Moore (eds.), *Balancing the Self: Medicine, Politics and the Regulation of Health in the Twentieth Century* (Manchester: Manchester University Press, 2020): pp. 219-249.

Hentschel, Klaus, 'The Discovery of the Redshift of Solar Fraunhofer Lines by Rowland and Jewell in Baltimore around 1890', *HSPS* 23, no. 2 (1993): 219-277.

Hentschel, Klaus, *Mapping the Spectrum: Techniques of Visual Representation in Research and Teaching* (Oxford: Oxford University Press, 2002).

Hentschel, Klaus, *Visual Cultures in Science and Technology: A Comparative History* (Oxford: Oxford University Press, 2014).

Hepburn, Ronald W., 'The Aesthetics of Sky and Space', *Environmental Values* 19, no. 3 (2010): 273-288.

Hevly, Bruce, 'The Heroic Science of Glacier Motion', *Osiris* 11 (1996): 66-86.

Hillnhuetter, Sara, Stephanie Klamm and Friedrich Tietjen, 'Introduction: Where does photography start? And where does it end? A Hyrbid introduction', in Hillnhuetter, Sara, Stephanie Klamm and Friedrich Tietjen (eds.), *Hybrid Photography: Intermedial Practices in Science and Humanities* (New York: Bloomsbury Academic, 2021): pp. 1-5.

Hopwood, Nick, Simon Schaffer and Jim Secord, 'Seriality and Scientific Objects in the Nineteenth Century', *Hist Sci.* 48 (2010): 251-279.

Howes, David and Constance Classen, 'Introduction: Ways and Meaning', in Howes, David and Constance Classen (eds.), *Ways of Seeing: Understanding the Senses in Society* (Abingdon: Routledge, 2013): pp. 1-17.

Howkins, Adrian, 'Science, Environment, and Sovereignty: The International Geophysical Year in the Antarctic Peninsula Region', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalizing Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan US, 2010): pp. 245-264.

Hughes, Jeffrey Alan, 'The Radioactivists: Community, Controversy and the Rise of Nuclear Physics', unpublished thesis (1993), *University of Cambridge*.

Hui, Alexandra, 'Sound objects and sound products: standardising a new culture of listening in the first half of the twentieth century', *Culture Unbound: Journal of Current Cultural Research* 4 (2012): 599-616.

Jancović, Vladimir, 'Introduction', in Fleming, James Rodger, Deborah Coen and Vladimir Jancović (eds.), *Intimate Universality: Local and Global Themes in the History of Weather and Climate* (Sagamore Beach: Science Publications, 2006): pp. ix-xx.

Jay, Martin, 'The Senses in History', in Howes, David (ed.), *Senses and Sensation: Critical and Primary Sources Volume 2 History and Sociology* (London: Bloomsbury, 2018): pp. 63-70.

Jóhannesson, Gunnar Thór and Katrín Anna Lund, 'Aurora Borealis: Choreographies of Darkness and Light', *Annals of Tourism Research* (2017): 183-190.

Jones-Imhotep, E., *The Unreliable Nation: Hostile Nature and Technological Failure in the Cold War* (Cambridge: MIT Press, 2017).

Kaalund, Nanna, *Explorations in the Icy North: How Travel Narratives Shapes Arctic Science in the Nineteenth Century* (Pittsburgh: University of Pittsburgh Press, 2021).

Kaiser, D., *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (University of Chicago Press, 2009).

Kaplan, Caren, 'The Balloon Prospect: Aerostatic Observation and the Emergence of Militarised Aeromobility', in Adey, Peter, Mark Whitehead and Alison Williams (eds.), *From Above: War, Violence and Verticality* (Oxford: Oxford University Press, 2014): pp. 19-40.

Keay, Colin S. L., 'C. A. Chant and the Mystery of Auroral Sounds', *The Journal of the Royal Astronomical Society of Canada* 84, no. 6 (1990).

Keefe, Laurence E. and Dennis Inch, *The Life of a Photograph: Archival Processing, Matting, Framing and Storage* (Waltham: Focal Press, 1984).

Kessler, E.A., *Picturing the Cosmos: Hubble Space Telescope Images and the Astronomical Sublime* (University of Minnesota Press, 2012).

Klemun, Marianne and Ulrike Spring, 'Expeditions as Experiments: An Introduction', in Klemun, Marianne and Ulrike Spring (eds.), *Expeditions as Experiments: Practising Observation and Documentation* (New York: Springer Publishing, 2016): pp. 1-26.

Knudsen, Henrik, 'Battling the Aurora Borealis: The Transnational Coproduction of Ionospheric Research in Early Cold War Greenland', in Doel, Ronald E., Kristine C. Harper and Matthias Heymann (eds.), *Exploring Greenland: Cold War Science and Technology on Ice* (New York: Palgrave Macmillan US, 2016): pp. 143-165.

Kohler, Robert E., *Landscapes and Labscapes: Exploring the Lab-field Border in Biology* (Chicago: University of Chicago Press, 2002).

Kohler, Robert E., 'History of Field Science: Trends and Prospects', in Vetter, Jeremey (ed.), *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (New Jersey: Rutgers University Press, 2011): pp. 212-231.

Korff, Serge A., 'High Altitude Observatories for Cosmic Rays and Other Purposes', in Sekido, Yataro and Harry Elliot (eds.), *Early History of Cosmic Ray Studies: Personal Reminiscences with Old Photographs* (Berlin: Springer Science & Business Media, 2012): pp. 171-186.

Kragh, Helge, 'The Green Line: A Chapter in the History of Auroral Physics', *Astronomy and Geophysics* 50, no. 5 (2009): 525-528.

Kragh, Helge, 'The Spectrum of the Aurora Borealis: From Enigma to Laboratory Science', *Historical Studies in the Natural Sciences* 39, no. 4 (2009): 377-417.

Kragh, Helge, 'Auroral Chemistry: The Riddle of the Green Line', *Bull. Hist. Chem.* 35, no. 2 (2010): 97-104.

Krause, Reinhard A., 'Neumayer's Ambitions for Polar Research and his Role in the Establishment of the First International Polar Year 1882-3', *Transactions of the Royal Society of Victoria* 123, no. 95 (2011): 95-115.

Kuklick, Henrika, 'Personal equations: reflections on the history of fieldwork, with special reference to sociocultural anthropology', *Isis* 102, no. 1 (2011): 1-33.

Kuklick, Henrika and Robert E. Kohler, 'Introduction', *Science in the Field* 2, no. 11 (1996): 1-16.

Laine, Unto Kalervo, 'Auroral Acoustic Project–a progress report with a new hypothesis', Conference Presentation, *Baltic–Nordic Acoustic Meeting (BNAM)*, 2016: 1–8.

Laine, Unto Kalervo, 'Auroral crackling sounds and Schumann resonances', *Proc. Int. Cong. Sound and Vibration (ICSV)* (2019): 1–8.

Latour, Bruno, 'Visualization and Cognition: Thinking with Eyes and Hands', *Knowledge and Society* 6 (1986): 1-40.

Launius, Roger D., 'The IGY and the satellite race: a reconsideration of a cold war crisis that never should have been', *American Geophysical Union* fall meeting (2006).

Launius, Roger D., 'Toward the Poles: A Historiography of Scientific Exploration during the International Polar Years and the International Geophysical year', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (New York: Palgrave Macmillan, 2010): pp. 47-84.

Launius, Roger D., John M. Logsdon and Robert W. Smith, *Reconsidering Sputnik: Forty Years since the Soviet Satellite* (New York: Routledge, 2000).

Launius, Roger D., James Rodger Fleming and David H. DeVorkin, *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (London: Palgrave MacMillan, 2010).

Launius, Roger D., James Rodger Fleming and David H. DeVorkin, 'Rise of Global Scientific Inquiry in the International Polar and Geophysical Years', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International and Geophysical Years* (London: Palgrave Macmillan, 2010): pp. 1-9.

le Breton, David, 'Sensing the World in Cross-Cultural Perspective', in Howes, David (ed.), *Senses and Sensation: Critical and Primary Sources* (London: Bloomsbury Academic, 2018): pp. 43-53.

Lehman, Jessica, 'Making an Anthropocene Ocean: Synoptic Geographies of the International Geophysical Year (1957–1958)', *Annals of the American Association of Geographers* 110, no. 3 (2020): 606-622.

Lenstner, Dina, 'Due North: Ēriks Ešenvalds and Aurora Borealis as a Claimed Artistic Space', *GESJ: Musicology and Cultural Science* 1 (2019): 11-17.

Lewander, Lisbeth, 'Swedish Polar Policies from the First International Polar Year to the Present', in Launius, Roger D., James Rodger Fleming and David H. DeVorkin (eds.), *Globalising Polar Science: Reconsidering the International Polar and Geophysical Years* (London: Palgrave Macmillan, 2010): pp. 107-122.

Livingstone, David N., *Putting Science in its Place: Geographies of Scientific Knowledge* (Chicago: University of Chicago Press, 2003).

Lüdecke, Cornelia, 'The First International Polar Year (1882-83): A Big Science Experiment with Small Science Equipment', *Proceedings of the International Commission on History of Meteorology* (2004): 55-64.

Lynch, Michael, 'Discipline and the Material Form of Images: An Analysis of Scientific Visibility', *Social Studies of Science* (1985): 37-66.

Lyubovtseva, Y. S., A. D. Gvishiani, A. A. Soloviev, *et al.*, 'Sixtieth anniversary of the International Geophysical Year (1957–2017) – contribution of the Soviet Union', *Hist. Geo Space. Sci.* 11 (2020): 157–171.

Mahony, Martin and Samuel Randalls, 'Introduction', in Mahony, Martin and Samuel Randalls (eds.), *Weather, Climate, and the Geographical Imagination: Placing Atmospheric Knowledges* (Pittsburgh: University of Pittsburgh Press, 2020): pp. 3-21.

Malin, S. R. C. and D. R. Barraclough, 'Humboldt and the Earth's Magnetic Field', *Quarterly Journal of the Royal Astronomical Society* 32, no. 3 (1991): 279-293.

Marcel, Nicolet, 'The International Geophysical Year (1957-1958): Great Achievements and Minor Obstacles', *GeoJournal* 8 (1984): 303-320.

Mattelart, Armand, *Invention of Communication* (Minneapolis: University of Minnesota Press, 1996).

McCook, Stuart, 'It May be Truth but it is not Evidence: Paul Du Chaillu and the Legitimation of Evidence in the Field Sciences', *Osiris* 11 (1996): 177-197.

McCorristine, Shane, '"Involuntarily we listen": Hearing the Aurora Borealis in Nineteenth-Century Arctic Exploration and Science', *Canadian Journal of History* 48 (2013): 29-61.

McCorristine, Shane, *The Spectral Arctic: A History of Dreams and Ghosts in Polar Exploration* (London: UCL Press, 2018).

McCray, W. Patrick, 'Amateur Scientists, The International Geophysical Year, and the Ambitions of Fred Whipple', *Isis* 97, no. 4 (2006): 634-658.

McCray, W. Patrick, *Keep Watching the Skies: The Story of Operation Moonwatch and the Dawn of the Space Age* (Princeton: Princeton University Press, 2008).

McDougall, Walter A., *The Heavens and the Earth: A Political History of the Space Age* (Baltimore: Johns Hopkins Univ. Press, 1997).

McGuffie, K. and A. Henderson-Sellers, 'Almost a Century of "Imaging" Clouds Over the Whole-Sky Dome', *Bulletin of the American Meteorological Society* 70, no. 10 (1989): 1243-1253.

McNeil, J.R., C.R. Unger and German Historical Institute, *Environmental Histories of the Cold War* (Cambridge: Cambridge University Press, 2010).

Mijwel, Maad M., 'History of Artificial Intelligence', *Computer Science* (2015): 3-4.

Milam, Erika Lorraine, 'Making Place in the Field', *Isis* 113, no. 1 (2022): 121-127.

Minor, Adriana, 'Up-and-down journeys: The making of Latin American's uniqueness for the study of cosmic rays', *Centaurus* 62, no. 4 (2020): 698-719.

Mitchell, W. J. T., 'What Do Pictures Really Want?' 77 (1996): 71-82.

Mitman, Gregg and Kelley Wilder, 'Introduction', in Wilder, Gregg Mitman and Kelley (ed.), *Documenting the World: Film, Photography and the Scientific Record* (Chicago: University of Chicago Press, 2016): pp. 1-23.

Moore, P., *The Sky at Night* (New York: Springer, 2010).

Morus, Iwan Rhys, *When Physics Became King* (Chicago: University of Chicago Press, 2005).

Moss, K. and P. Stauning, 'Sophus Peter Tromholt: An Outstanding Pioneer in Auroral Research', *History of Geo and Space Sciences* (2012): 53-72.

Murdoch, Jonathan, 'The spaces of actor-network theory', *Critical Review* 29, no. 4 (1998): 357-372.

Nall, Josh, *News from Mars: Mass Media and the Forging of a New Astronomy 1860-1910* (Pittsburgh: University of Pittsburgh Press, 2019).

Nasim, Omar W., 'Observation, working images and procedure: the 'Great Spiral' in Lord Rosse's astronomical record books and beyond', *The British Journal for the History of Science* 43, no. 3 (2010): 353-389.

Nasim, Omar W., *Observing by Hand: Sketching the Nebulae in the Nineteenth Century* (Chicago: Chicago University Press, 2013).

Naylor, Simon, 'Introduction: Historical Geographies of Science: Places, Contexts, Cartographies', *The British Journal for the History of Science* 38, no. 1 (2005): 1-12.

Needell, Allan A., *Science, Cold War and the American State* (Abingdon: Taylor & Francis, 2013).

Otter, Chris, *The Victorian Eye: A Political History of Light and Vision in Britain, 1800-1910* (Chicago: University of Chicago Press, 2008).

Outram, Dorinda, 'New Spaces in Natural History', in Jardine, N., J.A. Secord and E.C. Spary (eds.), *Cultures of Natural History*, vol. 249–265 (Cambridge: Cambridge University Press, 1996).

Pallasmaa, Juhani, 'The Atmospheric Sense: Peripheral and the Experience of Space', in Tedeschini, Marco and Tonino Griffero (eds.), *Atmosphere and Aesthetics* (Berlin: Springer International Publishing, 2019): pp. 121-132.

Pang, Alex Soojung-Kim, 'Victorian Observing Practices, Printing Technology, and Representations of the Solar Corona (1): The 1860s and 1870s', *Journal for the History of Astronomy* (1994): 249-274.

Pang, Alex Soojung-Kim, 'Victorian Observing Practices, Printing Technology and Representations of the Solar Corona (2): The Age of Photomechanical Reproduction', *Journal for the History of Astronomy* 26, no. 1 (1995): 63-75.

Pang, Alex Soojung-Kim, *Empire and the Sun: Victorian Solar Eclipse Expeditions* (Redwood City: Stanford University Press, 2002).

Pinch, Trevor and Karin Bijsterveld, 'New keys to the world of sound', in Pinch, Trevor and Karin Bijsterveld (eds.), *The Oxford Handbook of Sound Studies* (Oxford: Oxford University Press, 2012): pp. 1-36.

Pluvinel, A. de la Baume and F. Baldet, 'Spectrum of Comet Morehouse', *The Astrophysical Journal: An International Review of Spectroscopy and Astronomical Physics* XXXIV, no. 2 (1911): 89-104.

Porter, Theodore M., 'The Objective Self', *review of Objectivity by Lorraine Daston and Peter Galison*, *Victorian Studies* 50, no. 4 (2008): 641-647.

Pouncey, Frances J., 'A History of Cloud Codes and Symbols', *Weather* (2003): 69-80.

Provencher, J., J. Baeseman, D. Carlson, *et al.*, *Polar Research Education, Outreach and Communication during the fourth IPY: How the 2007–2008 International Polar Year has contributed to the future of education, outreach and communication* (Paris: International Council for Science (ICSU), 2011).

Ramalingam, Chitra, 'Natural History in the Dark: Seriality and the Electric Discharge in Victorian Physics', *History of Science* 48 (2010): 371-398.

Ramos, Victor A., 'Hans Keidel and Alexander du Toit's relationship and its impact on Wegener's continental drift hypothesis', *Geological Society, London, Special Publications* 531, no. 1 (2023).

Reidy, Michael S., 'The Most Recent Orogeny: Verticality and Why Mountains Matter', *Historical Studies in the Natural Sciences* (2017): 578-587.

Reif-Acherman, Simón, 'Anders Jonas Ångström and the Foundation of Spectroscopy – Commemorative Article on the Second Centenary of His Birth', *Spectrochimica Acta Part B: Atomic Spectroscopy* 102, no. 1 (2014): 12-23.

Rentetzi, Maria, *Trafficking Materials and Gendered Experimental Practices: Radium Research in Early Twentieth Century Vienna* (New York: Columbia Press, 2008).

Rose, Gillian, 'The Question of Method: Practice, Reflexivity and Critique in Visual Culture Studies', in Heywood, Ian and Barry Sandwell (eds.), *The Handbook of Visual Culture* (London: Bloomsbury Publishing, 2017): pp. 542-558.

Roth, Lorna, 'Looking at Shirley, the Ultimate Norm: Colour Balance, Image Technologies, and Cognitive Equity', *Canadian Journal of Communication* 34, no. 1 (2009): 111-136.

Rothenberg, Marc, 'Making Science Global? Coordinated Enterprises in Nineteenth-century science', in Launius, Roger D., James Rodger Flemng and David H. DeVorkin (eds.), *Globalising*

Polar Science: Reconsidering the International Polar and Geophysical Years (London: Palgrave Macmillan, 2010): pp. 23-36.

Rothermel, Holly, 'Images of the Sun: Warren De la Rue, George Buddell Airy and Celestial Photography', *The British Journal for the History of Science* 26, no. 2 (1993): 137-169.

Roux, Mariëtte Le, 'Weird clouds may have inspired ‘The Scream’: scientists', *Agence France-Presse* (2017).

Rudwick, Martin 'The Emergence of a Visual Language for Geological Science 1760-1840', *History of Science* 14, no. 3 (1976): 149-195.

Ryan, James R., *Photography and Exploration* (London: Reaktion Books, 2013).

Salazard, Bruno, Christophe Desouches and Guy Magalon, 'Auguste and Louis Lumière, inventors at the service of the suffering', *European Journal of Plastic Surgery* 28 (2006): 441-447.

Schlegel, K. and H. Lühr, 'Willy Stoffregen - An early pioneer of advanced ionospheric and auroral research', *Hist. Geo Space. Sci.* 5 (2014): 149-154.

Schmidt, Henry, 'Robin Hill’s Cloud Camera: Meteorological Communication, Cloud Classification', in Nall, J., L. Taub and F. Wilmoth (eds.), *The Whipple Museum of the History of Science, Objects and Investigations* (Cambridge: Cambridge University Press, 2019): pp. 257-274.

Schöder, Wilfred, 'Otto Jesse and the Investigation of Noctilucent Clouds 115 Years Ago', *Bulletin of the American Meteorological Society* (2001): 2457-2468.

Schöder, Wilfred, 'One of the first noctilucent cloud photographs taken by Jesse on 02 July 1889', *Otto Jesse and the Investigation of Noctilucent Clouds 115 Years Ago, Bulletin of the American Meteorological Society* (2001), p. 2469.

Secord, James A., 'Knowledge in Transit', *Isis* 95, no. 4 (2004): 654-672.

Shapin, Steven, 'Placing the View from Nowhere: Historical and Sociological Problems in the Location of Science', *Transactions of the Institute of British Geographers* 23, no. 1 (1998): 5-12.

Shapin, Steven and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life* (Princeton: Princeton University Press, 2011).

Silverman, S. M. and T. F. Taun, 'Auroral Audibility', in Landsberg, H. E. and J. Van Mieghem (eds.), *Advances in Geophysics* (Amsterdam: Elsevier, 1973): pp. 155-266.

Smith, Robert W., 'Large-Scale Scientific Enterprise', in Kutler, Stanley (ed.), *Encyclopedia of the United States in the Twentieth Century*, vol. 2 (New York: Scribner’s, 1996): pp. 739–765.

Spear, Robert J., *The Great Gypsy Moth War: A History of the First Campaign in Massachusetts to Eradicate the Gypsy Moth, 1890-1901* (Amherst: University of Massachusetts Press, 2005).

Spring, Ulrike, 'Between Spectacle and Science: The Aurora in Central Europe, 1870s-1880s', *Acta Borealia: A Nordic Journal of Circumpolar Societies* 29, no. 2 (2012): 197-215.

Spring, Ulrike, 'Materialising the Aurora Borealis: Carl Weyprecht and Scientific Documentation of the Arctic', in Klemun, Marianna and Ulrike Spring (eds.), *Expeditions as Experiments:*

Practising Observation and Documentation (New York: Springer Publishing, 2016): pp. 141-162.

Spufford, Francis, *I May be Some Time: Ice and the English Imagination* (London: St Martin’s Press, 1999).

Staley, Richard, 'Sensory studies, or when physics was psychophysics: Ernst Mach and physics between physiology and psychology, 1860-71', *History of Science* 59, no. 1 (2018): 93-118.

Stauning, P., 'Danish Auroral Science History', *History of Geo and Space Sciences* 2 (2011): 1-28.

Steinicke, Wolfgang, 'The M51 Mystery: Lord Rosse, Robinson, South and the Discovery of Spiral Structure in 1845', *Journal of Astronomical History and Heritage* 15 (2012): 19-29.

Stoker, Peiter H., 'The IGY and Beyond: A Brief History of Ground-Based Cosmic-Ray Detectors', *Advances in Space Research* 44 (2009): 1081-1095.

Stoller, Paul, *The Taste of Ethnographic Things: The Senses in Anthropology* (Philadelphia: University of Pennsylvania Press, 1989).

Stothers, Richard, 'Ancient Aurorae', *Isis* 70, no. 1 (1979): 85-95.

Stuart, Sam, *The Histories of the International Polar Years and the Inception and Development of the International Geophysical Year: Annals of the International Geophysical Year* vol. 1 (Amsterdam: Elsevier, 1959).

Sullivan, Walter T., *Assault on the Unknown: The International Geophysical Year* (New York: McGraw Hill, 1961).

Summers, D., *The Judgment of Sense: Renaissance Naturalism and the Rise of Aesthetics* (Cambridge University Press, 1990).

Taylor, Charles J., 'First International Polar Year, 1882-83', *Arctic* 34 (1981): 370-376.

Thomas, Sophie, *Romanticism and Visuality: Fragments, History, Spectacle* (New York: Routledge, 2008).

Thompson, A.S., J.M. MacKenzie and R. David, *The Arctic in the British imagination 1818–1914* (Manchester University Press, 2017).

Thompson, Emily, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America* (Cambridge: The MIT Press, 2004).

Tucker, Jennifer, *Nature Exposed: Photography as Eyewitness in Victorian Science* (Baltimore: JHU Press, 2005).

Tucker, Jennifer, 'Objectivity, Collective Sight and Scientific Personae', *review of Objectivity by Lorraine Daston and Peter Galison, Victorian Studies* 50, no. 4 (2008): 648-657.

Tucker, Jennifer, 'Photography and the Making of Modern Science', in Pasternak, Gil (ed.), *The Handbook of Photography Studies* (Abingdon: Routledge, 2020): pp. 235-255.

Vetter, Jeremy, 'Introduction', in Vetter, Jeremy (ed.), *Knowing Global Environments: New Historical Perspectives on the Field Sciences* (New Jersey: Rutgers University Press, 2011): pp. 1-16.

Vetter, Jeremy, *Field Life: Science in the American West during the Railroad Era* (Pittsburgh: University of Pittsburgh Press, 2016).

von Hardenberg, Wilko Graf and Martin Mahony, 'Introduction – Up, down, round and round: Verticalities in the history of science', *Centaurus* 62 (2020): 595-611.

Wilder, Kelley E., 'Visualising Radiation: The Photographs of Henri Becquerel', in Daston, Lorraine and Elizabeth Lunbeck (eds.), *Histories of Scientific Observation* (Chicago: University of Chicago Press, 2011): pp. 349-369.

Wood, Kevin R. and James E. Overland, 'Climate Lessons from the First International Polar Year', *Bulletin of the American Meteorological Society* 87 (2006): 1685-1698.

Wråkberg, Urban, 'IPY Field Stations: Functions and Meanings', in Shadian, Jessica and Monica Tennberg (eds.), *Legacies and Change in Polar Sciences: Historical, Legal and Political Reflections on the Polar Year* (2009): pp. 73-100.

Wylie, John, 'Depths and Folds: On Landscape and the Gazing Subject', *Environment and Planning D: Society and Space* 24 (2006): 519-535.

Young, Diane, 'The Colour of Things', in Tilley, Christopher, Webb Keane, Susanne Küchler, *et al.* (eds.), *Handbook of Material Culture* (New York: Sage Publications, 2006): pp. 173-185.

Yusoff, Kathryn, 'Climates of Sight: Mistaken Visibilities, Mirages and 'Seeing Beyond' in Antarctica', in Cosgrove, Denis and Veronica della Dora (eds.), *High Places: Cultural Geography of Mountains, Ice and Science* (2008): pp. 48-64.

Yusoff, Kathryn, 'Configuring the Field: Photography in Early Twentieth-Century Antarctic Exploration', in Naylor, Simon and James R. Ryan (eds.), *New Spaces of Exploration: Geographies of Discovery in the Twentieth Century* (London: Bloomsbury Publishing, 2009): pp. 52-77.

Zanini, A, M. Storini and O. Saavedra, 'Cosmic Rays at High Mountain Observatories', *Advances in Space Research* 44 (2009): 1160-1165.

Zhang, Dora, 'Naming the Indescribable: Woolf, Russell, James and the Limits of Description', *New Literary History* 45 (2014): 51-70.

Uncategorized References

Dora, Veronica della, 'From the Radio Shack to the Cosmos: Listening to Sputnik during the International Geophysical Year (1957-1958)', *Isis* 114, no. 1 (2023): 123-149.

Lovell, Bernard A. C. to Størmer, Carl, 16 November 1949, letter, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.

Lovell, Bernard A. C. to Feather, N., 28 January 1957, *Jodrell Bank Archive, University of Manchester*, correspondence series 7, International Geophysical Year 1955-1956.