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Betting on the best case: higher end warming is underrepresented in research

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E-mail: florianjehn@posteo.de**Keywords:** higher end warming, climate change, IPCC, existential risk**Abstract**

We compare the probability of different warming rates to their mentions in IPCC reports through text mining. We find that there is a substantial mismatch between likely warming rates and research coverage. 1.5 °C and 2 °C scenarios are substantially overrepresented. More likely higher end warming scenarios of 3 °C and above, despite potential catastrophic impacts, are severely neglected.

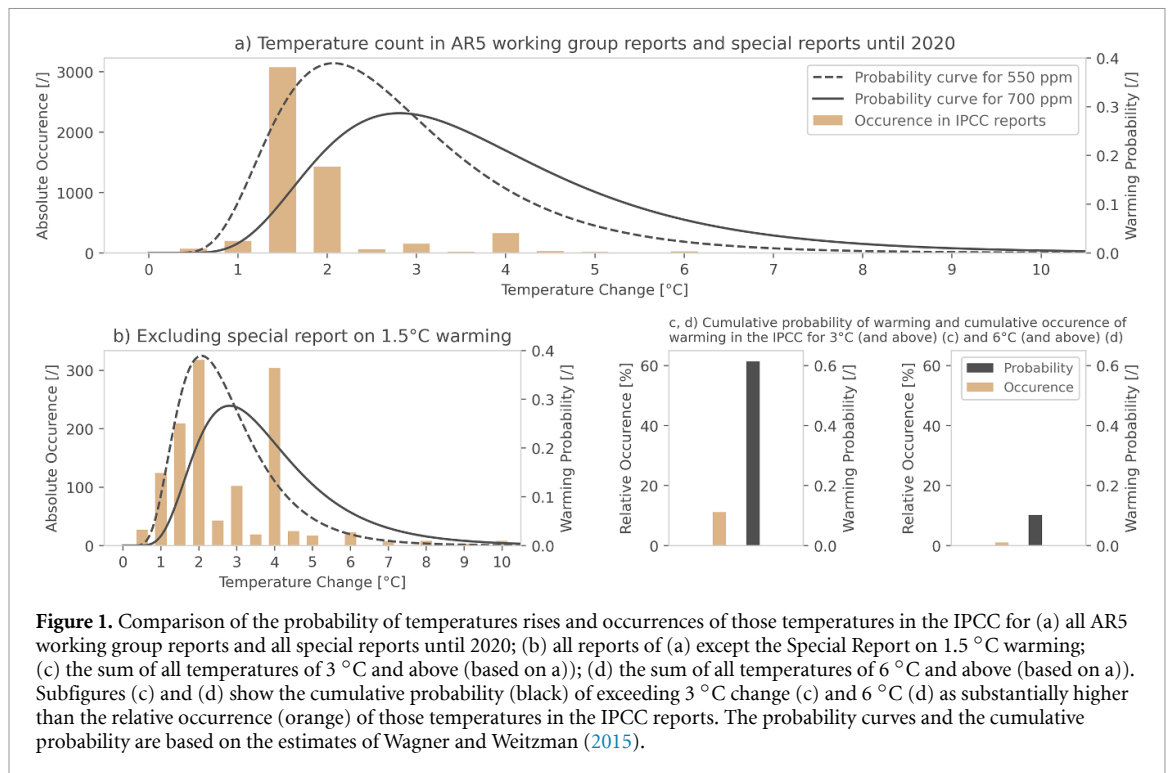
1. Introduction

Temperature rise of 3 °C above pre-industrial temperature is more likely than not by the end of the century, on most business as usual scenario. One recent estimate projected a rise of 2.0 °C–4.9 °C with a median of 3.2 °C (Raftery *et al* 2017). This covers likely ranges; however, climate change is heavy-tailed with surprisingly high likelihoods for high levels of warming. GHG concentrations of 700 ppm could produce a 10% chance of exceeding a temperature rise of 6 °C (Wagner and Weitzman 2015). Such concentrations would be passed by 2100 under six of the nine of the CMIP6 SSP-RF baseline and 6.0 W/m² forcing scenarios (Riahi *et al* 2017, Gidden *et al* 2019). The most recent estimates of equilibrium climate sensitivity show a similar distribution, narrowing the range of outcomes to exclude rises below 2 °C but not ruling out warming above 4.5 °C (Sherwood *et al* 2020).

Lower concentrations could still end in higher end warming outcomes due to tipping points and uncertainty over Earth system feedbacks and nonlinearities (Oreskes *et al* 1994, Booth *et al* 2012, Bodman *et al* 2013, Lenton *et al* 2019). These uncertainties make higher end warming climate change even more dangerous, as they leave the option open for far worse outcomes (Weitzman 2012). While concerning, such probabilistic distributions are not the same

as the spread of risk. The impacts of higher temperature ranges are both more uncertain but also likely to be disproportionately more severe (New *et al* 2011). Given that eventual temperature outcomes also depend on deeply uncertain factors like the amount of global cooperation to mitigate climate change, scientists can support policymakers to craft robust, long-term responses to climate change by exploring a wide range of plausible futures, through approaches like Robust Decision-Making (Lempert *et al* 2003). This makes understanding the effects and consequences of warming of 3 °C and above imperative.

While there have been some valuable attempts to summarize available research (Wagner and Weitzman 2015, Wallace-Wells 2019), calls for action (Lenton *et al* 2019) and research projects focused on higher end climate impacts such as the HELIX project, it remains unclear if existing research coverage matches either the probabilistic or risk distribution of climate change. The best synthesis of climate change research are the assessment and special reports of the Intergovernmental Panel on Climate Change (IPCC 2013, 2014a, 2014b, 2018, 2019a, 2019b). They reflect expert consensus and are a reliable proxy for the current state of knowledge. To assess the focus of the IPCC on different warming scenarios in temperatures we text-mine available IPCC reports (IPCC 2013, 2014a, 2014b, 2018, 2019a, 2019b) and count how



often the different temperatures are mentioned in comparison to the probability of the temperatures projected for an increase of atmospheric CO₂ concentrations of 550 and 700 ppm based on the research of Wagner and Weitzman (Wagner and Weitzman 2015). We focus on those concentrations as 700 ppm are commonly exceeded end-of-century throughout many of the CMIP6 analytical scenarios, while 550 ppm would be reached if all currently stated climate policies and plans would be implemented (IEA 2020).

2. Results and discussion

Our results show a large mismatch between the amount of research and the probability of warming (figure 1(a)). 3 °C is the peak of probability for 700 ppm, but accounts for less than 3% of mentions. Temperatures of 3 °C or above (figure 1(c)) account for around two-thirds of the probabilistic mass for 700 ppm, but just over 10% of mentions. Similarly, a more dramatic temperature rise of 6 °C and above (figure 1(d)) is a 10% probability and only less than 1% of mentions. The picture is slightly better for 550 ppm, but higher end warming climate changes are underrepresented there as well. In addition, those numbers are likely to be underestimates of the neglectedness of higher end temperature rise, as many of the textual references do not refer to a change in global mean surface temperature. Overall, the percentage of true positive findings that actually relate to a change in global mean air temperature change varies substantially depending on the temperature (between 5 °C

and 10 °C), ranging from 0% for 10 °C to 57% for 7 °C. However, even those mostly refer to the temperature change since the last glacial maximum and possible values for the equilibrium climate sensitivity. For example, the AR5 report of working group II (IPCC 2014a) mentions 8 °C only three times, two of which relate to local temperature increases in the arctic and the thermal optimum of salmon.

There is a stark difference between warming probabilities and our knowledge. Over half of the textual references focus on a warming of 1.5 °C. This may be skewed by the 2018 ‘The Special Report on Global Warming of 1.5 °C (SR15)’ (IPCC 2018) which was requested by the Conference of the Parties (COP) to the UNFCCC at the 2015 Paris Climate Summit. When we remove the special report on 1.5 °C warming (IPCC 2018) (figure 1(b)) from our analysis, textual references to 1.5 °C drop, but are still markedly higher than the probability and mentions of scenarios higher than 4 °C. Our text mining results suggest that there is at least some research focused on 4 °C of warming. This is supported by its coverage in well-known grey literature, such as the World Bank’s ‘Turn Down the Heat’ series as well as the 2009 ‘4 Degrees and Beyond International Climate Conference’.

Our study indicates possible knowledge gaps in higher end warming climate change research. It is not a definitive conclusion, but a useful starting point to discuss the divergence between probability and risk distributions and climate change research focus to date. Our method only delivers a snapshot into the current climate change research and has some limitations. Mentions in IPCC reports do not neatly map onto the exact frequency of research. Furthermore,

400 ppm -	10	34	29	15	7	3	1	1	0	0	0	0	0	0	0	0	0	0	0
450 ppm -	3	19	27	21	13	8	4	2	1	1	0	0	0	0	0	0	0	0	0
500 ppm -	1	10	21	22	17	12	7	4	3	2	1	1	0	0	0	0	0	0	0
550 ppm -	0	5	15	19	18	14	10	7	4	3	2	1	1	0	0	0	0	0	0
600 ppm -	0	3	10	16	17	15	11	8	6	4	3	2	1	1	1	0	0	0	0
650 ppm -	0	2	7	13	15	15	12	10	7	5	4	3	2	1	1	1	0	0	0
700 ppm -	0	1	5	11	14	14	13	11	8	6	5	3	2	2	1	1	1	0	0
750 ppm -	0	1	4	9	12	13	13	11	9	7	5	4	3	2	2	1	1	1	1
800 ppm -	0	1	3	7	11	12	12	11	9	8	6	5	4	3	2	2	1	1	1
850 ppm -	0	0	2	6	9	11	12	11	10	8	7	5	4	3	3	2	1	1	1
900 ppm -	0	0	2	5	8	10	11	11	10	9	7	6	5	4	3	2	2	1	1
950 ppm -	0	0	1	4	7	9	11	11	10	9	7	6	5	4	3	3	2	2	1
1000 ppm -	0	0	1	3	6	9	10	10	10	9	8	7	5	4	4	3	2	2	1
IPCC Counts -	1	4	56	26	1	3	0	6	1	0	0	1	0	0	0	0	0	0	0
	0.5°C -	1°C -	1.5°C -	2°C -	2.5°C -	3°C -	3.5°C -	4°C -	4.5°C -	5°C -	5.5°C -	6°C -	6.5°C -	7°C -	7.5°C -	8°C -	8.5°C -	9°C -	9.5°C -

Figure 2. Probabilities of warming for CO₂ concentrations from 400 to 1000 ppm (based on Wagner and Weitzman (2015)) and the relative occurrence of this warming in the IPCC reports for all AR5 working groups and all special reports until 2020 (both in %). The probability for the temperatures refer to the shown value ±0.25 °C.

the frequency of mentions says little about the quality or extent of individual studies. The subject of IPCC special reports are often as reflective of political requests as research needs. Moreover, we use one prominent 2015 estimate of the probabilistic distribution of concentrations and temperatures, but future studies could look to use others (or even a combination of them). There are also other ways to approach our analysis that might result in different numbers (Brown and Caldeira 2017). We searched in Web of Science and Google Scholar for ‘Climate Change’ and ‘X °C’, The results have a very similar distribution to our IPCC-based results, but it is difficult to settle on concrete numbers, due to a high, but hard to quantify rate of false positive results, especially at higher temperatures. To address the rate of false positives in our analysis we looked at all temperature mentions in IPCC reports between 5 °C and 10 °C and checked if they were referring to global mean temperature rise or something else. We found no discernible trend in the rate of false positives.

There are multiple reasons to believe that the results presented here are robust. First, given the sheer difference in magnitude of our results, especially for 700 ppm. Second, the gap we highlight in our results is relatively insensitive to the CO₂ concentration used. Even at CO₂ concentrations of 600 ppm there is still a large research gap higher end warming. The research focus and the probability of warming only overlap around 450 ppm if we include all

reports or at 550 ppm if we exclude the 1.5 °C special report (figures 1(a), (b) and 2). However, given that currently CO₂ concentrations are already above 410 ppm it seems unlikely that we will be able to limit our greenhouse gas emissions to such levels without radical systemic socioeconomic changes. Higher end temperature rise is neglected while research that is ‘betting on the best case’ of 1.5 °C or 2 °C proliferates. Third, the IPCC itself has previously noted in the Fifth Assessment Report (AR5) that quantitative estimates of aggregate impacts above 3 °C are rare (IPCC 2014b). This is echoed in summaries of climate science in popular literature, which has to rely on less literature for scenarios above 3 °C and just a few, more speculative geological studies for 6 °C and higher (Lynas 2020). However, it should be noted that the research gap is a larger issue in the impact reports.

There are several potential reasons for this divergence between probability and risk in relation to actual research. The most obvious is that the research community is simply meeting the demands of policymakers. The goal of limiting warming to 2 °C first was formally adopted under the 2010 Cancun Accords, before being enshrined in the 2015 Paris Agreement on Climate Change, alongside the aspirational goal of holding warming to 1.5 °C. Both of these temperature goals are significantly overrepresented in existing research according to our study. The divergence may also partially reflect the conservative outcomes of the consensus procedures of the IPCC, and the

tendency of climate science to err on the side of ‘least drama’. This in turn is likely shaped by a history of climate scientists being accused of alarmism by well-funded misinformation campaigns (Oreskes and Conway 2012).

Regardless of the explanation, the problem of a misalignment between research coverage and probability and risk persists. Why is there a special report for 1.5 °C warming, but none for a warming of 3 °C and above, even though the latter currently seems more probable and would be more impactful? We hope this paper provides a starting point for discussion on how research should coincide with future probabilities and risks. Such a conversation and realignment of priorities is overdue. It is also direly needed given that the heavy-tails of climate change could constitute a threat of global catastrophe or even human extinction (Lynas 2020, Ord 2020).

3. Methods

To count the temperature mentioned in the IPCC reports (IPCC 2013, 2014a, 2014b, 2018, 2019a, 2019b) all text was extracted from the PDFs of the full reports. The text was then mined for the mentions of the temperatures in the format ‘X°C’. The warming probability was calculated from the probability density function of figure 3.2 in Climate Shock (Wagner and Weitzman 2015), which was graciously provided by Gernot Wagner. The probability of the temperatures in figure 2 of this paper refers to the probability of the temperature ± 0.25 °C. All code and data used can be found at the repository of this paper (Jehn 2021). This also contains lists that show how often the temperatures were found in the individual IPCC reports.

Data availability statement

All data, code, and materials (except the IPCC reports) used in the analyses is available in the repository of this paper (Jehn 2021).

The data that support the findings of this study are openly available at the following URL/DOI: [10.5281/zenodo.4311470](https://zenodo.org/record/4311470).

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