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WHAT LIES BENEATH

THE UNDERSTATEMENT OF EXISTENTIAL CLIMATE RISK

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FOREWORD

BY HANS JOACHIM SCHELLNHUBER

Hans Joachim Schellnhuber is a professor of theoretical physics specialising in complex systems and nonlinearity, founding director of the Potsdam Institute for Climate Impact Research (1992-2018) and former chair of the German Advisory Council on Global Change. He is a senior climate advisor to the European Union, the German Chancellor and Pope Francis.

What Lies Beneath is an important report. It does not deliver new facts and figures, but instead provides a new perspective on the existential risks associated with anthropogenic global warming.

It is the critical overview of well-informed intellectuals who sit outside the climate-science community which has developed over the last fifty years. All such expert communities are prone to what the French call *deformation professionelle* and the German *betriebsblindheit*.

Expressed in plain English, experts tend to establish a peer world-view which becomes ever more rigid and focussed. Yet the crucial insights regarding the issue in question may lurk at the fringes, as this report suggests. This is particularly true when the issue is the very survival of our civilisation, where conventional means of analysis may become useless.

This dilemma notwithstanding, the Intergovernmental Panel on Climate Change (IPCC) bravely perseveres with its attempts to assess the multiple cause-and-effect relationships which comprise the climate problem. After delivering five fully-fledged assessment reports, it is hardly surprising that a trend towards "erring on the side of least drama" has emerged.

There are many reasons, both subtle and mundane. Let me highlight just one of each.

Firstly, the IPCC is stricken with the *Probability Obsession*. Ever since statistics was established in the16th century, scientists have tried to capture the complex, stochastic behaviour of a given non-trivial object (such as a roulette wheel) by repeating the same experiment on that object many, many times. If there was a set of well-defined outcomes (such as the ball ending on the red or black of the wheel), then the probability of a specific outcome was simply the number of experiments delivering that outcome divided by the total number of experiments.

This sounds reasonable, but can we even imagine applying that approach to global warming? Strictly speaking, we would have to redo the Industrial Revolution and the greenhouse-gas emissions it triggered a thousand times or so, always starting with the Earth system in its 1750 pre-industrial state.

Then calculate the averaged observed outcome of that planetary experiment in terms of mean surface-temperature rise, global biological productivity, total number of climate refugees, and many other variables. This is a nonsensical notion.

Of course, climate scientists are not trying to treat the Earth like a roulette wheel, yet the statistical approach keeps on creeping into the assessments. How many times did the thermohaline circulation collapse under comparable conditions in the planetary past? How often did the Pacific enter a permanent El Niño state in the Holocene? And so on. These are valuable questions that can generate precious scientific insights.

But we must never forget that we are in a unique situation with no precise historic analogue. The level of greenhouse gases in the atmosphere is now greater, and the Earth warmer, than human beings have ever experienced. And there are almost eight billion of us now living on this planet.

So calculating probabilities makes little sense in the most critical instances, such as the methane-release dynamics in thawing permafrost areas or the potential failing of entire states in the climate crisis. Rather, we should identify *possibilities*, that is, potential developments in the planetary make-up that are consistent with the initial and boundary conditions, the processes and the drivers we know.

This is akin to scenario planning, now being proposed for assessing climate risks in the corporate sector, where the consequences of a number of future possibilities, including those which may seem highly unlikely, but have major consequences, are evaluated. This way one can overcome the probability obsession that not only fantasizes about the replicability of the singular, but also favours the familiar over the unknown and unexpected.

As an extreme example, the fact that our world has never been destroyed previously would conventionally assign probability zero to such an event. But this only holds true under steady-state assumptions, which are practically never warranted.

Secondly, there is the *Devil's Advocate Reward*. In the magnificent tradition of the Enlightenment, which shattered so many myths of the ancient regimes, scientists are trained to be sceptical about every proposition which cannot be directly verified by empirical evidence or derived from first principles (such as the invariability of the speed of light).

So, if a researcher comes up with an entirely new thought, experts tend to reflexively dismiss it as "speculative", which is effectively a death warrant in the academic world. Whereas those who criticize the idea will be applauded, rewarded and promoted! This phenomenon is evident in every seminar, colloquium or learned-society assembly.

In turn, this means that scientific progress is often driven from the periphery, or occasionally, by eminent personalities whose seniority is beyond doubt. This does not at all imply that hypotheses need not be vindicated in due course, but out-of-the-box thinking is vital given the unprecedented climate risks which now confront human civilisation.

In conclusion, one should not be overly critical of the IPCC, since the scientists involved are doing what scientists are expected to do, to the very best of their ability in difficult circumstances.

But climate change is now reaching the end-game, where very soon humanity must choose between taking unprecedented action, or accepting that it has been left too late and bear the consequences.

Therefore, it is all the more important to listen to non-mainstream voices who do understand the issues and are less hesitant to cry wolf.

Unfortunately for us, the wolf may already be in the house.

INTRODUCTION

Three decades ago, when serious debate on human-induced climate change began at the global level, a great deal of statesmanship was on display. There was a preparedness to recognise that this was an issue transcending nation states, ideologies and political parties which had to be addressed proactively in the long-term interests of humanity as a whole. This was the case even though the existential nature of the risk it posed was far less clear cut than it is today.

As global institutions, such as the United Nations Framework Convention on Climate Change (UNFCCC) which was established at the Rio Earth Summit in 1992, were developed to take up this challenge, and the extent of change this would demand of the fossil-fuel-dominated world order became clearer, the forces of resistance began to mobilise. Today, as a consequence, and despite the diplomatic triumph of the 2015 *Paris Agreement*, the debate around climate change policy has never been more dysfunctional, indeed Orwellian.

In his book *1984*, George Orwell describes a double-think totalitarian state where most of the population accepts "the most flagrant violations of reality, because they never fully grasped the enormity of what was demanded of them, and were not sufficiently interested in public events to notice what was happening. By lack of understanding they remained sane."[1]

Orwell could have been writing about climate change and policymaking. International agreements talk of limiting global warming to 1.5–2 degrees Celsius (°C), but in reality they set the world on a path of 3–5°C of warming. Goals are reaffirmed, only to be abandoned. Coal is "clean". Just 1°C of warming is already dangerous, but this cannot be admitted. The planetary future is hostage to myopic national self-interest. Action is delayed on the assumption that as yet unproven technologies will save the day, decades hence. The risks are existential, but it is "alarmist" to say so.

A one-in-two or one-in-three chance of missing a goal is normalised as reasonable. Moral hazard permeates official thinking, in that there is an incentive to ignore the risks in the interests of political expediency.

Climate policymaking for years has been cognitively dissonant, "a flagrant violation of reality". So it is unsurprising that there is a lack of understanding amongst the public and elites of the full measure of the climate challenge. Yet most Australians sense where we are heading: three-quarters of Australians see climate change as catastrophic risk,[2] and half see our way of life ending within the next 100 years.[3]

Politics and policymaking have norms: rules and practices, assumptions and boundaries, that constrain and shape them. In recent years, the previous norms of statesmanship and long-term thinking have disappeared, replaced by an obsession with short-term political and commercial advantage. Climate policymaking is no exception.

Since 1992, short-term economic interest has trumped environmental and future human needs. The world today emits 50% more carbon dioxide (CO_2) from the consumption of energy than it did 25 years ago, and the global economy has more than doubled in size. The UNFCCC strives "to enable economic development to proceed in a sustainable manner", but every year humanity's ecological footprint becomes larger and less sustainable. Humanity now requires the biophysical capacity of 1.7 Earths annually as it rapidly chews up natural capital.

A fast, emergency-scale transition to a post-fossil fuel world is absolutely necessary to address climate change. But this is excluded from consideration by policymakers because it is considered to be too disruptive. The orthodoxy is that there is time for an orderly economic transition within the current short-termist political paradigm. Discussion of what would be safe — less warming than we presently experience — is non-existent. And so we have a policy failure of epic proportions.

1 Orwell, G 1949, *Nineteen Eighty-Four. A Novel*, Secker and Warburg, London.

2 CommunicateResearch 2017, 'Global Challenges Foundation global risks survey', ComRes, 24 May 2017, <http://www.comresglobal.com/polls/global-challenges-foundation-global-risks-survey>.

3 Randle, MJ & Eckersley, R 2015, 'Public perceptions of future threats to humanity and different societal responses: a cross-national study', *Futures*, vol. 72, pp. 4-16.

Policymakers, in their magical thinking, imagine a mitigation path of gradual change to be constructed over many decades in a growing, prosperous world. The world not imagined is the one that now exists: of looming financial instability; of a global crisis of political legitimacy and "fake news"; of a sustainability crisis that extends far beyond climate change to include all the fundamentals of human existence and most significant planetary boundaries (soils, potable water, oceans, the atmosphere, biodiversity, and so on); and of severe global energy-sector dislocation.

In anticipation of the upheaval that climate change would impose upon the global order, the IPCC was established by the United Nations (UN) in 1988, charged with regularly assessing the global consensus on climate science as a basis for policymaking. The IPCC *Assessment Reports* (*AR*), produced every five-to-eight years, play a large part in the public framing of the climate narrative: new reports are a global media event. *AR5* was produced in 2013-14, with *AR6* due in 2022. The IPCC has done critical, indispensable work of the highest standard in pulling together a periodic consensus of what must be the most exhaustive scientific investigation in world history. It does not carry out its own research, but reviews and collates peer-reviewed material from across the spectrum of this incredibly complex area, identifying key issues and trends for policymaker consideration.

However, the IPCC process suffers from all the dangers of consensus-building in such a wide-ranging and complex arena. For example, IPCC reports, of necessity, do not always contain the latest available information. Consensus-building can lead to "least drama", lowest-common-denominator outcomes, which overlook critical issues. This is particularly the case with the "fat-tails" of probability distributions, that is, the high-impact but lower-probability events where scientific knowledge is more limited.

Vested-interest pressure is acute in all directions; climate denialists accuse the IPCC of alarmism, whereas many climate action proponents consider the IPCC to be far too conservative. To cap it all, the IPCC conclusions are subject to intense political oversight before being released, which historically has had the effect of substantially watering-down sound scientific findings.

These limitations are understandable, and arguably were not of overriding importance in the early period of the IPCC. However, as time has progressed, it is now clear that the risks posed by climate change are far greater than previously anticipated. We have moved out of the twilight period of much talk, but relatively limited climate impacts, into the harsh light of physically-evident existential threats. Climate change is now turning nasty, as we have witnessed recently in the North America, East and South Asia, the Middle East and Europe, with record-breaking heatwaves and wildfires, more intense flooding and more damaging hurricanes.

The distinction between climate science and risk is the critical issue, for the two are not the same. Scientific reticence — a reluctance to spell out the full risk implications of climate science in the absence of perfect information — has become a major problem. Whilst this is understandable, particularly when scientists are continually criticised by denialists and political apparatchiks for speaking out, it is extremely dangerous given the fat-tail risks of climate change. Waiting for perfect information, as we are continually urged to do by political and economic elites, means it will be too late to act. Time is not on our side. Sensible risk management addresses risk in time to prevent it happening, and that time is now.

Irreversible, adverse climate change on the global scale now occurring is an existential risk to human civilisation. Many of the world's top climate scientists — Kevin Anderson, James Hansen, Michael E. Mann, Michael Oppenheimer, Naomi Oreskes, Stefan Rahmstorf, Eric Rignot, Hans Joachim Schellnhuber, Kevin Trenberth and others — who are quoted in this report well understand these implications and are forthright about their findings, where we are heading, and the limitations of IPCC reports.

This report seeks to alert the wider community and business and political leaders to these limitations and urges change to the IPCC approach, to the wider UNFCCC negotiations, and to national policymaking. It is clear that existing processes will not deliver the transformation to a carbon-negative world in the limited time now available.

We urgently require a reframing of scientific research within an existential risk-management framework. This requires special precautions that go well beyond conventional risk management. Like an iceberg, there is great danger in "what lies beneath".

"We are climbing rapidly out of mankind's safe zone into new territory, and we have no idea if we can live in it."

Prof. Robert Corell, 2007

RISK
UNDERSTATEMENT

EXCESSIVE CAUTION

A 2013 study by Prof. Naomi Oreskes and fellow researchers examined a number of past predictions made by climate scientists. They found that scientists have been “conservative in their projections of the impacts of climate change” and that “at least some of the key attributes of global warming from increased atmospheric greenhouse gases have been under-predicted, particularly in IPCC assessments of the physical science”. They concluded that climate scientists are not biased toward alarmism but rather the reverse of “erring on the side of least drama, whose causes may include adherence to the scientific norms of restraint, objectivity, skepticism, rationality, dispassion, and moderation”. This may cause scientists “to underpredict or downplay future climate changes”.[4]

This tallies with the view of economist Prof. Ross Garnaut, who in 2011 reflected on his experience in presenting two climate reports to the Australian Government. Garnaut questioned whether climate research had a conservative “systematic bias” due to “scholarly reticence”. He pointed to a pattern across diverse intellectual fields of research predictions being “not too far away from the mainstream” expectations and observed that in the climate field that this “has been associated with understatement of the risks”.[5]

As far back as 2007, then NASA climate science chief Prof. James Hansen suggested that scientific reticence hinders communication with the public about the dangers of global warming and potentially large sea-level rises. More recently he wrote that “the affliction is widespread and severe. Unless recognized, it may severely diminish our chances of averting dangerous climate change.”[6]

Ten years after his 2006 climate report to the UK government, Sir Nicholas Stern reflected that “science is telling us that impacts of global warming — like ice sheet and glacier melting — are now happening much more quickly than we anticipated”.[7] In 2013, he said that “Looking back, I underestimated the risks… Some of the effects are coming through more quickly than we thought then.”[8]

A recent study of climate scientists found “a community which still identified strongly with an idealised picture of scientific rationality, in which the job of scientists is to get on with their research quietly and dispassionately”.[9] The study said most climate scientists are resistant to participation in public/policy engagement, leaving this task to a minority who are attacked by the media and even by their own colleagues.

Kevin Trenberth, head of climate analysis at the US National Center for Atmospheric Research and a lead author of key sections of the 2001 and 2007 IPCC reports, says: “We’re underestimating the fact that climate change is rearing its head… and we’re underestimating the role of humans, and this means we’re underestimating what it means for the future and what we should be planning for.”[10]

Prof. Michael E. Mann of Pennsylvania State University says the IPCC’s 2012 report on climate extremes missed an opportunity to provide politicians with a clear picture of the extent of the climate crisis: “Many scientists felt that report erred by underplaying the degree of confidence in the linkage between climate change and certain types of severe weather, including heat wave severity, heavy precipitation and drought, and hurricane intensity.”[11]

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4 Brysse, K, Oreskes, N, O’Reilly, J & Oppenheimer, M 2013, ‘Climate change prediction: Erring on the side of least drama?’, *Global Environmental Change*, vol. 23, no. 1, pp. 327-337.

5 Garnaut, R 2011, *Update Paper 5: The science of climate change*, Garnaut Climate Change Review Update, Canberra, pp. 53-55.

6 Hansen, J 2007, ‘Scientific reticence and sea level rise’, *Environmental Research Letters*, vol. 2, no. 2, 024002.

7 McKee, R 2016, ‘Nicholas Stern: cost of global warming “is worse than I feared”’, *The Guardian*, 6 November 2016.

8 Stewart, H & Elliott, L 2013, ‘Nicholas Stern: “I got it wrong on climate change – it’s far, far worse”’, *The Guardian*, 27 January 2013.

9 Hoggett, P & Randall, R 2016, ‘Socially constructed silence? Protecting policymakers from the unthinkable’, Transformation, 6 June 2016, <https://www.opendemocracy.net/transformation/paul-hoggett-rosemary-randall/socially-constructed-silence-protecting-policymakers-fr>.

10 Scherer, G 2012a, ‘How the IPCC underestimated climate change’, *Scientific American*, 6 December 2012.

11 Scherer, G 2012b, ‘Climate science predictions prove too conservative’, *Scientific American*, 6 December 2012.

Prof. Kevin Anderson of the University of Manchester says there is "an endemic bias prevalent amongst many of those building emission scenarios to underplay the scale of the 2°C challenge. In several respects, the modelling community is actually self-censoring its research (focus) to conform to the dominant political and economic paradigm…"[12]

A good example is the 1.5°C goal agreed to at the Paris December 2015 climate policy conference. IPCC assessment reports until that time (and in conformity with the dominant political paradigm) had not devoted any significant attention to 1.5°C emission-reduction scenarios or 1.5°C impacts, and the Paris delegates had to request the IPCC to do so as a matter of urgency. This is a clear case of politics driving the science research agenda. Research needs money, and too often money is allocated according to the political priorities of the day.

Anderson says it is incumbent on the scientific community to communicate research clearly and candidly to those delivering on the climate goals established by civil society, and "to draw attention to inconsistencies, misunderstandings and deliberate abuse of the scientific research. It is not our job to be politically expedient with our analysis or to curry favour with our funders. Whether our conclusions are liked or not is irrelevant."[13]

THINKING THE UNTHINKABLE

Successful risk management requires thinking "outside the box" to avoid a failure of imagination, but this is a skill rarely found at the senior levels of government and global corporations.

A 2016 report, *Thinking the unthinkable,* based on interviews with top leaders around the world, found that: "A proliferation of 'unthinkable' events… has revealed a new fragility at the highest levels of corporate and public service leaderships. Their ability to spot, identify and handle unexpected, non-normative events is… perilously inadequate at critical moments."[13]

The report findings are highly relevant to understanding the failure of climate policymaking, and the failure to adequately communicate and think about the full range of potential climate warming risks. It found that:

- The emerging picture is both scary and of great concern. Remarkably, there remains a deep reluctance, or what might be called "executive myopia" amongst top leaders in both the public and private sectors, to see and contemplate even the possibility that "unthinkables" might happen, let alone how to handle them.
- The rate and scale of change is much faster than most are even prepared to concede or respond to. At the highest board and C-suite levels, executives and their public service equivalents confess to often being overwhelmed.
- Time is at such a premium that the pressing need to think, reflect and contemplate in the ways required by the new "unthinkables" is largely marginalised.

Often blind eyes were turned, either because of a lack of will to believe the signs, or an active preference to deny and then not to engage.

While the phrase, "Thinking the unthinkable", has an attractive rhetorical symmetry, a more appropriate and accurate phrase might in many cases therefore be "Thinking the unpalatable".

These deficiencies are clearly evident at the upper levels of climate policymaking, nationally and globally. They must be corrected as a matter of extreme urgency.

12 Anderson, K 2016, 'Going beyond 'dangerous' climate change', LSE presentation, 4 February 2016, <http://www.lse.ac.uk/newsAndMedia/videoAndAudio/channels/publicLecturesAndEvents/player.aspx?id=3363>.

13 Anderson, K 2015, 'Duality in climate science', *Nature Geoscience*, vol. 8, pp. 898–900.

14 Gowing, N & Langdon, C 2016, *Thinking the Unthinkable: A new imperative for leadership in the digital age*, Chartered Institute of Management Accountants, London.

THE UNDERESTIMATION OF RISK

There are fundamental challenges in understanding and communicating risks. These include "the importance of complex interactions in shaping risks, the need for rigorous expert judgment in evaluating risks, and the centrality of values, perceptions, and goals in determining both risks and responses".[15]

IPCC reports have underplayed high-end possibilities and failed to assess risks in a balanced manner. The failure to fully account for potential future changes to permafrost (frozen carbon stores on land and under the seabed) and other carbon-cycle feedbacks is just one example.

Dr Barrie Pittock, a former leader of the Climate Impact Group in CSIRO, wrote in 2006 that "until now many scientists may have consciously or unconsciously downplayed the more extreme possibilities at the high end of the uncertainty range, in an attempt to appear moderate and 'responsible' (that is, to avoid scaring people). However, true responsibility is to provide evidence of what must be avoided: to define, quantify, and warn against possible dangerous or unacceptable outcomes."[16]

The situation has not improved. Sir Nicholas Stern said of the IPCC's *Fifth Assessment Report:* "Essentially it reported on a body of literature that had systematically and grossly underestimated the risks [and costs] of unmanaged climate change."[17]

Prof. Ross Garnaut has also pointed to the "understatement of the risks", in that we seem to be playing scientific catch-up, as reality is consistently on the most pessimistic boundary of previous projections. The Australian Climate Council reported in 2015: "Changes in the climate system are occurring more rapidly than previously projected, with larger and more damaging impacts now observed at lower temperatures than previously estimated."[18] Such a situation is not a satisfactory basis on which to plan our future.

Former senior coal fossil fuel executive and government advisor, Ian Dunlop, notes that "dangerous impacts from the underlying (warming) trend have also manifested far faster and more extensively than global leaders and negotiators are prepared to recognise".[19]

Researchers say it is important to carry out analyses "to identify what risky outcomes are possible — cannot be ruled out — starting with the biggest ones. In such analyses, it is useful to distinguish between two questions: 'What is most likely to happen?' and 'How bad could things get?'"[20]

In looking at how to reframe climate change assessments around risk, it is important to:

> " … deal adequately with low-probability, high-consequence outcomes, which can dominate calculations of total risk, and are thus worthy of special attention. Without such efforts, we court the kinds of 'failures of imagination' that can prove so costly across risk domains. Traditional climate assessments have focused primarily on areas where the science is mature and uncertainties well characterized. For example, in the IPCC lexicon, future outcomes are considered 'unlikely' if they lie outside the central 67% of the probability distribution. For many types of risk assessment, however, a 33% chance of occurrence would be very high; a 1% or 0.1% chance (or even lower probabilities) would be more typical thresholds."[21]

They emphasise that "the envelope of possibilities", that is, the full range of possibilities for which one must be prepared, is often more important than the most likely future outcome, especially when the range of outcomes includes those that are particularly severe. They conclude that the "application of scientific rather than risk-based norms in communicating climate change uncertainty has also made it easier for policymakers and other actors to downplay relevant future climate risks".[22]

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15 Mach, K, Mastrandrea, MD, Bilir, TE & Field, CB 2015, 'Understanding and responding to danger from climate change: the role of key risks in the IPCC AR5', *Climatic Change*, vol. 136, pp. 427-444.

16 Pittock, AB 2006, 'Are scientists underestimating climate change?', *EOS*, vol. 87, no. 34, pp. 340-41.

17 Stern, N 2016, 'Economics: Current climate models are grossly misleading', *Nature*, vol. 530, pp. 407-409.

18 Steffen, W, Hughes, L & Pearce, A 2015, *Climate Change: Growing risks, critical choices*, Climate Council, Sydney.

19 Dunlop, I 2016, Foreword to Spratt, D 2016, *Climate Reality Check*, Breakthrough, Melbourne.

20 Weaver, C, Moss, R, Ebi, K, Gleick, P, Stern, P, Tebaldi, C, Wilson, R & Arvai, J 2017, 'Reframing climate change assessments around risk: recommendations for the US National Climate Assessment', *Environmental Research Letters*, vol. 12, no. 8, 080201.

21 ibid.

22 ibid.

A prudent risk-management approach means a tough and objective look at the real risks to which we are exposed, especially those high-end events whose consequences may be damaging beyond quantification, and which human civilization as we know it would be lucky to survive. It is important to understand the potential of, and plan for, the worst that can happen, and be pleasantly surprised if it doesn't. Focusing on middle-of-the-road outcomes, and ignoring the high-end possibilities, may result in an unexpected catastrophic event that we could, and should, have seen coming.

Prof. Robert Socolow of Princeton University says the IPCC "should communicate fully what the science community does and does not understand about high consequence outcomes.The policymaking community needs information about both probable and improbable outcomes."[23]

Integral to this approach is the issue of lower-probability, high-impact consequences known as fat-tail risks, in which the likelihood of very large impacts is actually greater than we would expect under typical statistical assumptions. A normal distribution, with the appearance of a bell curve, is symmetric in probabilities of low outcomes (left of curve) and high outcomes (right of curve) as per Figure 1(a). But, as Prof. Michael E. Mann explains, "global warming instead displays what we call a 'heavy-tailed' or 'fat-tailed' distribution, there is more area under the far right extreme of the curve than we would expect for a normal distribution, a greater likelihood of warming that is well in excess of the average amount of warming predicted by climate models,"[24] as per Figure 1(b).

In *Climate Shock: The Economic Consequences of a Hotter Planet*, economists Gernot Wagner and Martin Weitzman explore the implications of this fat-tail distribution for climate policy, and "why we face an existential threat in human-caused climate change".[25] Mann explains:

" Let us consider… the prospects for warming well in excess of what we might term "dangerous" (typically considered to be at least 2°C warming of the planet). How likely, for example, are we to experience a catastrophic 6°C warming of the globe, if we allow greenhouse gas concentrations to reach double their pre-industrial levels (something we're on course to do by the middle of this century given business-as-usual burning of fossil fuels)? Well, the mean or average warming that is predicted by models in that scenario is about 3°C, and the standard deviation about 1.5°C. So the positive tail, defined as the +2 sigma limit, is about 6°C of warming. As shown by Wagner & Weitzman [Figure 1(b)], the likelihood of exceeding that amount of warming isn't 2% as we would expect for a bell-curve distribution. It's closer to 10%!

In fact, it's actually even worse than that when we consider the associated risk. Risk is defined as the product of the likelihood and consequence of an outcome. We just saw that the likelihood of warming is described by a heavy-tailed distribution, with a higher likelihood of far-greater-than-average amounts of warming than we would expect given typical statistical assumptions. This is further compounded by the fact that the damages caused by climate change — i.e. the consequence — also increases dramatically with warming. That further increases the associated risk.

With additional warming comes the increased likelihood that we exceed certain tipping points, like the melting of large parts of the Greenland and Antarctic ice sheet and the associated massive rise in sea level that would produce… Uncertainty is not our friend when it comes to the prospects for dangerous climate change."[26]

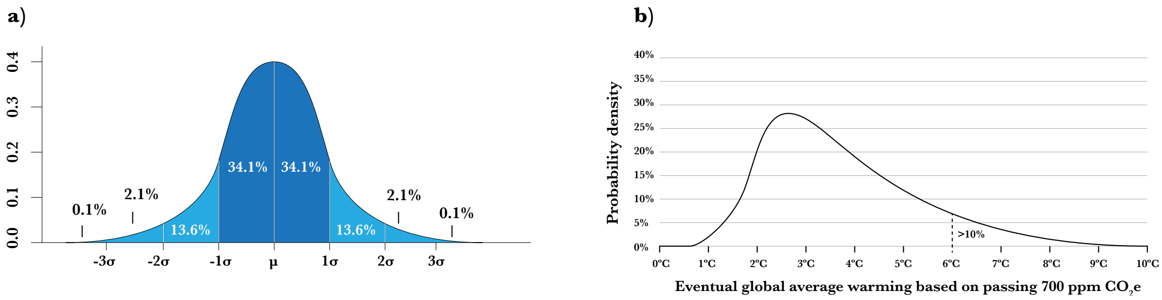

Figure 1: Normal and "fat tail" probability distributions. (a) Normal probability distribution, and (b) an estimate of the likelihood of warming due to a doubling of greenhouse gas concentrations exhibiting a "fat tail" distribution (Credit: Wagner & Weitzman 2015, *Climate Shock: The Economic Consequences of a Hotter Planet).*

23 Socolow, R. 2011, 'High-consequence outcomes and internal disagreements: tell us more, please', *Climatic Change*, vol. 108, pp. 775-790.

24 Mann, M 2016, 'The 'fat tail' of climate change risk', *Huffington Post*, 11 September 2016.

25 Ibid.

26 Ibid.

As Mann notes, risk is defined as the product of the likelihood and consequence of an outcome. This is illustrated in Figure 2, which although applied to the question of climate sensitivity (see discussion on pp. 22-23), has general applicability. The likelihood of a high-end outcome may be relatively low (right side of curve in (a)), but impacts increase at the high-end (b), showing the high risk of very unlikely events (c).

IPCC reports have not given attention to fat-tail risk analysis, in part because the reports are compiled using a consensus method, as discussed above. Prof. Stefan Rahmstorf of Potsdam University says that:

> " The magnitude of the fat-tail risks of global warming is not widely appreciated and must be discussed more. For over two decades I have argued that the risk of a collapse of the Atlantic meridional overturning circulation (AMOC) in this century is perhaps five per cent or so, but that this is far too great a risk to take, given what is at stake. Nobody would board an aircraft with a five per cent risk of crashing."[27]

He adds that: "Defeatism and doomerism is not the same as an accurate, sincere and sober discussion of worst-case risks. We don't need the former, we do need the latter." It should be noted that Rahmstorf was one of the authors of research released in April 2018 showing that, in fact, there has already been a 15% slowdown in the AMOC since the mid-twentieth century.[28]

"When all the new knowledge that challenges the old is on the more worrying side, one worries about whether the asymmetry reflects some systematic bias… I have come to wonder whether the reason why most of the new knowledge confirms the established science or changes it for the worse is scholarly reticence."

Prof. Ross Garnaut, 2011

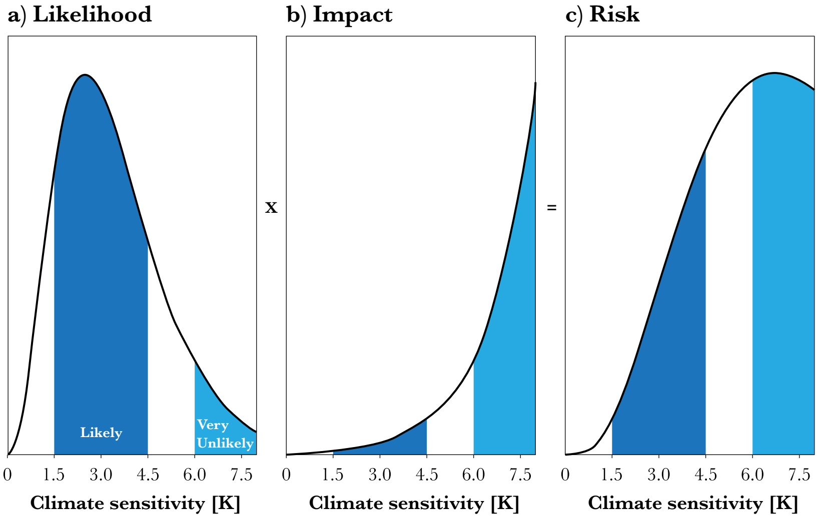

Figure 2: Schema of climate-related risk. (a) Event likelihood and (b) Impacts produce (c) Risk. Lower likelihood events at the high end of the probability distribution have the highest risk (Credit: RT Sutton/E Hawkins).

27 Rahmstorf, S, pers. comm., 8 August 2017.

28 Caesar, L, Rahmstorf, S, Robinson, A, Feulner, G. & Saba, V 2018, "Observed fingerprint of a weakening Atlantic Ocean overturning circulation', Nature, vol. 556, pp. 191-192.

EXISTENTIAL RISK TO HUMAN CIVILISATION

In 2016, the World Economic Forum survey of the most impactful risks for the years ahead elevated the failure of climate change mitigation and adaptation to the top of the list, ahead of weapons of mass destruction, ranking second, and water crises, ranking third. By 2018, following a year characterised by high-impact hurricanes and extreme temperatures, extreme-weather events were seen as the single most prominent risk. As the survey noted: "We have been pushing our planet to the brink and the damage is becoming increasingly clear."[29]

Climate change is an existential risk to human civilisation: that is, an adverse outcome that would either annihilate intelligent life or permanently and drastically curtail its potential.

Temperature rises that are now in prospect, after the *Paris Agreement*, are in the range of 3–5°C. At present, the *Paris Agreement* voluntary emission reduction commitments, if implemented, would result in planetary warming of 3.4°C by 2100,[30] without taking into account "long-term" carbon-cycle feedbacks. With a higher climate sensitivity figure of 4.5°C, for example, which would account for such feedbacks, the Paris path would result in around 5°C of warming, according to a MIT study.[31] A study by Schroder Investment Management published in June 2017 found — after taking into account indicators across a wide range of the political, financial, energy and regulatory sectors — the average temperature increase implied for the *Paris Agreement* across all sectors was 4.1°C.[32]

Yet 3°C of warming already constitutes an existential risk. A 2007 study by two US national security think-tanks concluded that 3°C of warming and a 0.5 metre sea-level rise would likely lead to "outright chaos" and "nuclear war is possible", emphasising how "massive non-linear events in the global environment give rise to massive nonlinear societal events".[33] The Global Challenges Foundation (GCF) explains what could happen:

> "If climate change was to reach 3°C, most of Bangladesh and Florida would drown, while major coastal cities — Shanghai, Lagos, Mumbai — would be swamped, likely creating large flows of climate refugees. Most regions in the world would see a significant drop in food production and increasing numbers of extreme weather events, whether heat waves, floods or storms. This likely scenario for a 3°C rise does not take into account the considerable risk that self-reinforcing feedback loops set in when a certain threshold is reached, leading to an ever increasing rise in temperature. Potential thresholds include the melting of the Arctic permafrost releasing methane into the atmosphere, forest dieback releasing the carbon currently stored in the Amazon and boreal forests, or the melting of polar ice caps that would no longer reflect away light and heat from the sun."[34]

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29 World Economic Forum, 2018, *The Global Risks Report 2018: 13th Edition*, World Economic Forum, Geneva.

30 Climate Action Tracker 2017, 'Improvement in warming outlook as India and China move ahead, but Paris Agreement gap still looms large", 13 November 2017, <http://climateactiontracker.org/publications/briefing/288/Improvement-in-warming-outlook-as-India-and-China-move-ahead-but-Paris-Agreement-gap-still-looms-large.htm>.

31 Reilly, J, Paltsev, S, Monier, E, Chen, H, Sokolov, A, Huang, J, Ejaz, Q, Scott, J, Morris, J & Schlosser, A 2015, *Energy and Climate Outlook: Perspectives from 2015*, MIT Program on the Science and Policy of Global Change, Cambridge MA.

32 Schroder Investment Management 2017, *Climate change: calibrating the thermometer*, Schroders Investment Management, London.

33 Campbell, K, Gulledge, J, McNeill, JR, Podesta, J, Ogden, P, Fuerth, L, Woolsley, J, Lennon, A, Smith, J, Weitz, R & Mix, D 2007, *The Age of Consequences: The foreign policy and national security implications of global climate change*, Centre for Strategic and International Studies & Centre for New American Security, Washington.

34 Global Challenges Foundation 2017, *Global Catastrophic Risks 2017*, Global Challenges Foundation, Stockholm.

Warming of 4°C or more could reduce the global human population by 80% or 90%,[35] and the World Bank reports "there is no certainty that adaptation to a 4°C world is possible".[36] Prof. Kevin Anderson says a 4°C future "is incompatible with an organized global community, is likely to be beyond 'adaptation', is devastating to the majority of ecosystems, and has a high probability of not being stable".[37] This is a commonly-held sentiment amongst climate scientists. A recent study by the European Commission's Joint Research Centre found that if the global temperature rose 4°C, then extreme heatwaves with "apparent temperatures" peaking at over 55°C will begin to regularly affect many densely populated parts of the world, forcing much activity in the modern industrial world to stop.[38] ("Apparent temperatures" refers to the Heat Index, which quantifies the combined effect of heat and humidity to provide people with a means of avoiding dangerous conditions.)

In 2017, one of the first research papers to focus explicitly on existential climate risks proposed that "mitigation goals be set in terms of climate risk category instead of a temperature threshold", and established a "dangerous" risk category of warming greater than 1.5°C, and a "catastrophic" category for warming of 3°C or more. The authors focussed on the impacts on the world's poorest three billion people, on health and heat stress, and the impacts of climate extremes on such people with limited adaptation resources. They found that a 2°C warming "would double the land area subject to deadly heat and expose 48% of the population (to deadly heat). A 4°C warming by 2100 would subject 47% of the land area and almost 74% of the world population to deadly heat, which could pose existential risks to humans and mammals alike unless massive adaptation measures are implemented."[39]

A 2017 survey of global catastrophic risks by the Global Challenges Foundation found that: "In high-end [climate] scenarios, the scale of destruction is beyond our capacity to model, with a high likelihood of human civilization coming to an end."[40] 84% of 8000 people in eight countries surveyed for the Foundation considered climate change a "global catastrophic risk".[41]

Existential risk may arise from a fast rate of system change, since the capacity to adapt, in both the natural and human worlds, is inversely proportional to the pace of change, amongst other factors. In 2004, researchers reported on the rate of warming as a driver of extinction.[42] Given we are now on a 3–5°C warming path this century, their findings are instructive:

- If the rate of change is 0.3°C per decade (3°C per century), 15% of ecosystems will not be able to adapt.
- If the rate should exceed 0.4°C per decade, all ecosystems will be quickly destroyed, opportunistic species will dominate, and the breakdown of biological material will lead to even greater emissions of CO_2.

At 4°C of warming "the limits for adaptation for natural systems would largely be exceeded throughout the world".[43] Ecological breakdown of this scale would ensure an existential human crisis.

By slow degrees, these existential risks are being recognised. In May 2018, an inquiry by the Australian Senate into national security and global warming recognised "climate change as a current and existential national security risk… defined as 'one that threatens the premature extinction of Earth-originating intelligent life or the permanent and drastic destruction of its potential for desirable future development'".[44] In April 2018, the Intelligence on European Pensions and Institutional Investment think-tank warned business leaders that "climate change is an existential risk whose elimination must become a corporate objective".[45] However the most recent IPCC *Assessment Report* did not consider the issue. Whilst the term "risk management" appears in the 2014 IPCC *Synthesis Report* fourteen times, the terms "existential" and "catastrophic" do not appear.

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35 Anderson, K 2011, 'Going beyond dangerous climate change: Exploring the void between rhetoric and reality in reducing carbon emissions', LSE presentation, 11 July 2011.

36 World Bank 2012, *Turn Down the Heat: Why a 4°C warmer world must be avoided*, World Bank, New York.

37 Roberts, D 2011 "The brutal logic of climate change", Grist, 6 December 2011, <https://grist.org/climate-change/2011-12-05-the-brutal-logic-of-climate-change/>.

38 Ayre, J 2017, 'Extreme heatwaves with 'apparent temperatures' as high as 55° celsius to regularly affect much of world', Clean Technica, 11 August 2017, <https://cleantechnica.com/2017/08/11/extreme-heatwaves-apparent-temperatures-high-55-celsius-regularly-affect-much-world-4-celsius-warming-pre-industrial-levels/>.

39 Xu, Y & Ramanathan, V 2017, 'Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes', *Proceedings of the National Academy of Sciences*, vol. 114, pp. 10315-10323.

40 Global Challenges Foundation 2017, op cit.

41 Goering, L 2017, '8 in 10 people now see climate change as a 'catastrophic risk' – survey', Thomson Reuters Foundation, 23 May 2017, <http://news.trust.org/item/20170523230148-a90de>.

42 Leemans, R, & Eickhout, B 2004, 'Another reason for concern: regional and global impacts on ecosystems for different levels of climate change', *Global Environmental Change*, vol. 14, pp. 219–228.

43 Warren, R 2011, 'The role of interactions in a world implementing adaptation and mitigation solutions to climate change', *Philosophical Transactions of the Royal Society A*, vol. 369, pp. 217-241.

44 Commonwealth of Australia 2018, *Inquiry into the Implications of climate change for Australia's national security*, Foreign Affairs, Defence and Trade Committee, Department of the Senate, Parliament House, Canberra.

45 Murray, D & Murtha, A 2018, 'Climate risk: Running out of time', Intelligence on European Pensions and Institutional Investment, April 2018, <https://www.ipe.com/reports/special-reports/thought-leadership/climate-risk-running-out-of-time/10023906.article>.

Existential risks require a particular approach to risk management. They are not amenable to the reactive (learn from failure) approach of conventional risk management, and we cannot necessarily rely on the institutions, moral norms, or social attitudes developed from our experience with managing other sorts of risks. Because the consequences are so severe — perhaps the end of global human civilisation as we know it — "even for an honest, truth-seeking, and well-intentioned investigator it is difficult to think and act rationally in regard to… existential risks".[46]

Existential risk management requires brutally honest articulation of the risks, opportunities and the response time frame, the development of new existential risk-management techniques outside conventional politics, and global leadership and integrated policy. Since it is not possible to recover from existential risks, "we cannot allow even one existential disaster to happen; there would be no opportunity to learn from experience",[47] but at the moment we are facing existential disasters on several climate fronts, seemingly without being able even to articulate that fact.

The failure of both the research community and the policymaking apparatus to consider, advocate and/or adopt an existential risk-management approach is itself a failure of imagination with catastrophic consequences.

PUBLIC SECTOR DUTY OF CARE ON CLIMATE RISK

Private-sector company directors internationally are facing legal action and personal liability for having refused to understand, assess and act upon climate risk, or for misrepresenting that risk. Compensation is being sought from carbon polluters for damage incurred from climate impacts. Legal opinions suggest similar action in Australia would be firmly based.

Such a duty of care extends to the public sector, including not only ministers and senior public servants, but regulators and board members of statutory authorities. As a general principle, officials in the public sector should not be held to a lower standard of account than employees of publicly listed companies. That duty has already been successfully tested in the courts in The Netherlands.

The first duty of a government is to protect the people. A government derives its legitimacy and hence its authority from the people, and so has a fiduciary duty to act in accordance with the interests of all the people with integrity, fairness and accountability.

In the climate arena, this duty has been recognised in several quarters, including by Australian Prudential Regulatory Authority Executive Director Geoff Summerhayes and Australian Securities and Investments Commissioner John Price.

This duty has a particular sharpness in the new era of disruption and existential risk that will manifest as a consequence of the global failure, and the failure of successive Australian governments, to rein in global warming.

In these circumstances, our public sector leaders have a number of specific duty-of-care responsibilities which at present are being ignored. Being a climate denier does not absolve ministers and parliamentarians of the fiduciary responsibility to set aside personal prejudice and act in the public interest.

The Australian Public Service Impartiality Value requires advice given to government to be "apolitical, frank, honest, timely and based on the best available evidence", but the overriding impression is that the federal bureaucracy, with some notable exceptions, is not treating climate change with anywhere near the seriousness and urgency it demands. Dismal reports such as the December 2017 *Review of Climate Change Policy.* are a scientifically reticent whitewash of wholly inadequate and inconsistent policies

It is entirely appropriate, when the political system fails, for affected parties to take legal action to correct such failure.

46 Bostrom, N & Cirkovic, MM 2008, *Global Catastrophic Risks*, Oxford University Press, Oxford.
47 Op. cit.

“We’ve reached a point where we have a crisis, an emergency, but people don’t know that. ...There’s a big gap between what’s understood about global warming by the scientific community and what is known by the public and policymakers”.

Prof. James Hansen, 2008


SCIENTIFIC
UNDERSTATEMENT

CLIMATE MODELS

Climate modelling is at the core of the work by the IPCC, and in developing future emission and warming scenarios, but it is often too conservative and underestimates future impacts.

A 2007 report on climate change and national security by the US Center for Strategic and International Studies and the Center for a New American Security recognised that: “Recent observations indicate that projections from climate models have been too conservative; the effects of climate change are unfolding faster and more dramatically than expected” and that “multiple lines of evidence” support the proposition that the 2007 IPCC reports’ “projections of both warming and attendant impacts are systematically biased low”. For instance:

> “ The models used to project future warming either omit or do not account for uncertainty in potentially important positive feedbacks that could amplify warming (e.g., release of greenhouse gases from thawing permafrost, reduced ocean and terrestrial CO_2 removal from the atmosphere), and there is some evidence that such feedbacks may already be occurring in response to the present warming trend. Hence, climate models may underestimate the degree of warming from a given amount of greenhouse gases emitted to the atmosphere by human activities alone. Additionally, recent observations of climate system responses to warming (e.g., changes in global ice cover, sea-level rise, tropical storm activity) suggest that IPCC models underestimate the responsiveness of some aspects of the climate system to a given amount of warming.”[48]

In 2015, researchers reported on the long-term feedbacks that global climate models ignore, as illustrated in Figure 3, where grey bars within the middle blue ellipse signify processes that are assumed to be (partly) inactive or non-existent in global climate models, but in reality are not.[49]

In the 2017 *Fourth National Climate Assessment,* US government agencies found that “positive feedbacks (self-reinforcing cycles) within the climate system have the potential to accelerate human-induced climate change and even shift the Earth’s climate system, in part or in whole, into new states that are very different from those experienced in the recent past”, and whilst some feedbacks and potential state shifts can be modelled and quantified, “others can be modeled or identified but not quantified and some are probably still unknown”. Hence:

> “ While climate models incorporate important climate processes that can be well quantified, they do not include all of the processes that can contribute to feedbacks, compound extreme events, and abrupt and/or irreversible changes. For this reason, future changes outside the range projected by climate models cannot be ruled out. Moreover, the systematic tendency of climate models to underestimate temperature change during warm paleoclimates suggests that climate models are more likely to underestimate than to overestimate the amount of long-term future change.”[50]

At the 2017 climate policy conference in Bonn, Phil Duffy, the Director of the Woods Hole Institute, explained that “the best example of reticence is permafrost… It’s absolutely essential that this feedback loop not get going seriously, if it does there is simply no way to control it.” He says the scientific failure occurs because “none of this is in climate models and none of this is considered in the climate policy discussion… climate models simply omit emissions from the warming permafrost, but we know that is the wrong answer because that tacitly assumes that these emissions are zero and we know that’s not right”.[51]

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48 Campbell et al. 2007, op cit.

49 Knutti, R, & Rugenstein MAA 2015, ‘Feedbacks, climate sensitivity and the limits of linear models’, *Philosophical Transactions of the Royal Society A*, vol. 373, 20150146.

50 USGCRP 2017, *Climate Science Special Report: Fourth National Climate Assessment*, Volume I, [Wuebbles, DJ, DW Fahey, KA Hibbard, DJ Dokken, BC Stewart & TK Maycock (eds.)], US Global Change Research Program, Washington, DC, USA..

51 UPFSI 2017, ‘James Hansen: Scientific Reticence A Threat to Humanity and Nature’, media conference, Bonn, 19 November 2017, <https://www.youtube.com/watch?v=S7z61UZoppM>

There is a consistent pattern in the IPCC of presenting detailed, quantified (numerical) modelling results, but then briefly noting more severe possibilities — such as feedbacks that the models do not account for — in a descriptive, non-quantified form. Sea levels, polar ice sheets and some carbon-cycle feedbacks are three examples. Because policymakers and the media are often drawn to headline numbers, this approach results in less attention being given to the most devastating, high-end, non-linear and difficult-to-quantify outcomes.

Consensus around numerical results can result in an understatement of the risks. Oppenheimer et al. point to the problem:

> " The emphasis on consensus in IPCC reports has put the spotlight on expected outcomes, which then become anchored via numerical estimates in the minds of policymakers… it is now equally important that policymakers understand the more extreme possibilities that consensus may exclude or downplay… given the anchoring that inevitably occurs around numerical values, the basis for quantitative uncertainty estimates provided must be broadened to give observational, paleoclimatic, or theoretical evidence of poorly understood phenomena comparable weight with evidence from numerical modeling… One possible improvement would be for the IPCC to fully include judgments from expert elicitations."[52]

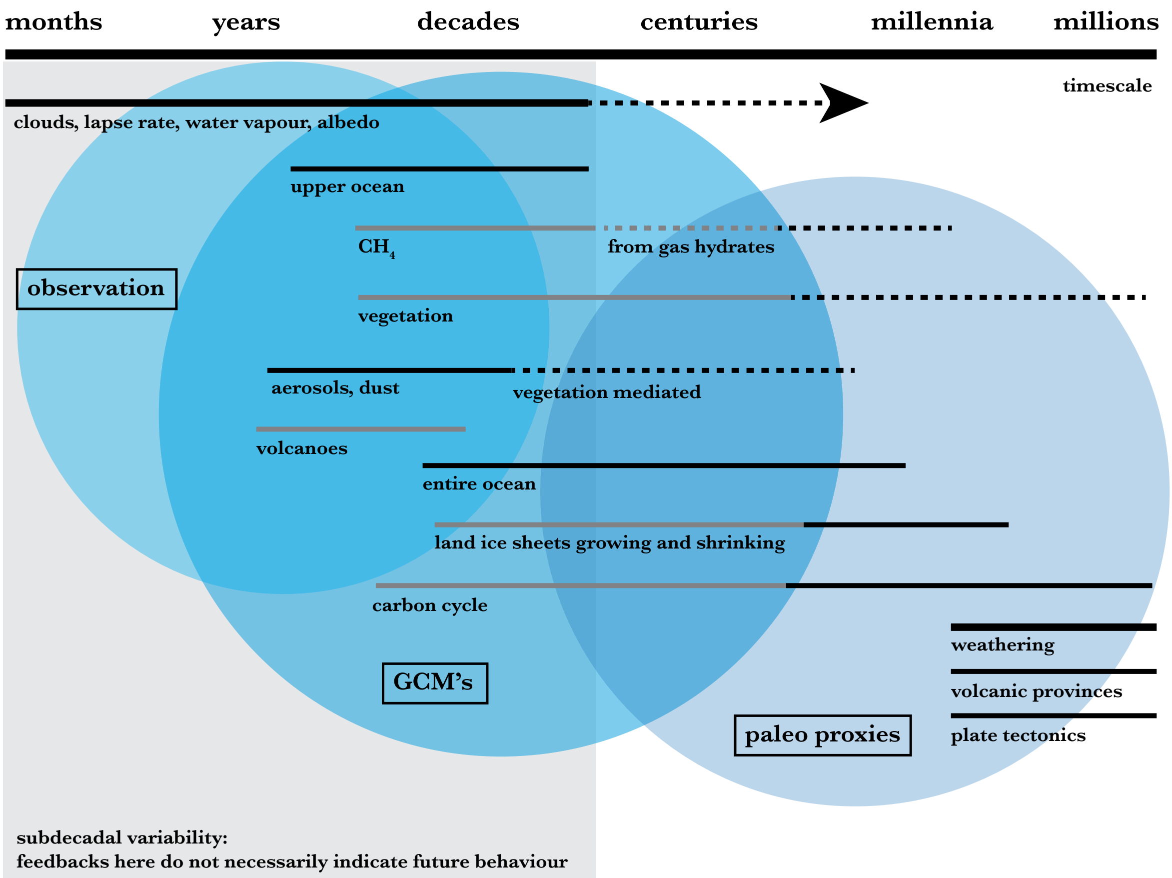

Figure 3: Timescales of climate processes and inclusions of feedbacks in climate models. The coloured ellipses each cover different methods used to estimate climate sensitivity: observations (left), global climate models (GCMs) (centre) and paleoclimate proxies (right). Light grey bars indicate processes that act on timescales that a GCM can resolve, but are usually assumed to be (partly) inactive or non-existent. Dashed lines indicate timescales where specific feedbacks are weaker or only operate under certain circumstances. The arrow for clouds, lapse rate, water vapour and albedo indicates that those feedbacks operate on short timescales but, because the surface warming takes centuries or more to equilibrate, these feedbacks continue to change and affect the overall response of the systems up to millennia (Credit: Knutti & Rugenstein 2015).

52 Oppenheimer, M, O'Neill, B, Webster, M & Agrawala, S 2007, 'The Limits of Consensus', *Science*, vol. 317, pp. 1505-1506.

Glaciologist Prof. Eric Rignot, says that "one of the problems of IPCC is the strong desire to rely on physical models". He explains:

> " For instance, in terms of sea-level rise projection, the IPCC tends to downplay the importance of semi-empirical models. In the case of Antarctica, it may be another ten years before fully-coupled ice sheet–ocean–sea ice–atmosphere models get the southern hemisphere atmospheric circulation, the Southern Ocean and the ice sheet right using physical models, with the full physics, at a high spatial resolution. In the meantime, it is essential to move forward our scientific understanding and inform the public and policy makers based on observations, basic physics, simpler models, well before the full-fledged physical models eventually get there."[53]

It is important to understand the distinction between full climate models and the semi-empirical approach, because IPCC reports appear to privilege the former at the expense of the latter. Sea-level-rise projections are a good example of this.

FULLY-COUPLED MODELS

Fully-coupled global climate models or general circulation models (GCMs) are mathematical representations of the Earth's climate system, based on the laws of physics and chemistry. Run on computers, they simulate the interactions of the important drivers of climate, including atmosphere–oceans–land surface–ice interactions, to solve the full equations for mass and energy transfer and radiant exchange. Models are tested in the first instance by hindsight: how well, once loaded with the observed climate conditions (parameters) at a time in the past, do they reproduce what has happened since that point. They are limited by the capacity of modellers to understand the physical processes involved, so as to be able to represent them in quantitative terms. For example, ice sheet dynamics are poorly reproduced, and therefore key processes that control the response of ice flow to a warming climate are not included in current ice sheet models. GCMs are being improved over time, and new higher-capacity computers allow models of finer resolution to be developed.[54]

SEMI-EMPIRICAL MODELS

A semi-empirical model is a simpler, physically plausible model of reduced complexity that exploits statistical relationships. It combines current observations with some basic physical relationships observed from past climates, and theoretical considerations relating variables through fundamental principles, to project future climate conditions. For example, semi-empirical models "can provide a pragmatic alternative to estimate the sea-level response".[55] Observing past rates of sea-level change from the climate record when the forcing (energy imbalance in the system) was similar to today, gives insights into how quickly sea levels may rise in the next period. Thus a semi-empirical approach to projecting future sea-level rise may relate the global sea-level rise to global mean surface temperature. This approach was used by Rahmstorf in 2007, to project a 0.5–1.4 metres sea-level rise by 2100, compared to the IPCC's 2007 report, based on GCMs, which gave a figure of 0.18–0.59.[56]

Semi-empirical models rely on observations from climate history (paleoclimatology) to establish relationships between variables. In privileging GCMs over semi-empirical models, the IPCC downplays insights from Earth's climate history.

53 Rignot, E, pers. comm., 8 August 2017.
54 Rahmstorf, S 2007, 'A semi -empirical approach to projecting future sea-level rise, *Science* vol. 315, pp. 368-370.
55 Ibid.
56 Ibid.

TIPPING POINTS

A tipping point may be understood as the passing of a critical threshold in an Earth climate system component — such as major ocean and atmospheric circulation patterns, the polar ice sheets, and the terrestrial and ocean carbon stores — which produces a step change in the system.

Progress toward a tipping point is often driven by positive feedbacks, in which a change in a component leads to further changes that eventually "feed back" onto the original component to amplify the effect. A classic case in global warming is the ice–albedo feedback, where decreases in the area of polar sea ice change surface reflectivity, trapping more heat from the sun and producing further sea-ice loss.

In some cases, passing one threshold will trigger further threshold events, for example, where substantial greenhouse gas releases from polar permafrost carbon stores increase warming, releasing even more permafrost carbon in a positive feedback, but also pushing other systems, such as polar ice sheets, past their threshold point.

In a period of rapid warming, most major tipping points once crossed are irreversible in human time frames, principally due to the longevity of atmospheric CO_2 (a thousand years).[57] For this reason, it is crucial that we understand as much as possible about near-term tipping points.

Large-scale human interventions in slow-moving earth system tipping points might allow a tipping point to be reversed; for example, by a large-scale atmospheric CO_2 drawdown program, or solar radiation management.

The scientific literature on tipping points is relatively recent. Our knowledge is limited because a system-level understanding of critical processes and feedbacks is still lacking in key Earth climate components, such as the polar regions, and "no serious efforts have been made so far to identify and qualify the interactions between various tipping points".[58]

As discussed above, climate models are not yet good at dealing with tipping points. This is partly due to the nature of tipping points, where a particular and complex confluence of factors abruptly change a climate system characteristic and drive it to a different state. To model this, all the contributing factors and their forces have to be well identified, as well as their particular interactions, plus the interactions between tipping points. Researchers say that "complex, nonlinear systems typically shift between alternative states in an abrupt, rather than a smooth manner, which is a challenge that climate models have not yet been able to adequately meet".[59]

The GCF says that despite scientific evidence that risks associated with tipping points "increase disproportionately as temperature increases from 1°C to 2°C, and become high above 3°C",[60] political negotiations have consistently disregarded the high-end scenarios that could lead to abrupt or irreversible climate change. In its *Global Catastrophic Risks 2017* report, the Foundation concludes that "the world is currently completely unprepared to envisage, and even less deal with, the consequences of catastrophic climate change".[61]

The IPCC has published few projections regarding tipping-point thresholds, nor emphasised the importance of building robust risk-management assessments of them in the absence of adequate quantitative data.

57 Solomon, S, Plattner, GK, Knutti, R & Friedlingstein, P 2008, 'Irreversible climate change due to carbon dioxide emissions', *Proceedings of the National Academy of Sciences*, vol. 106, no. 6, pp. 1704–1709.

58 Schellnhuber, HJ 2009, 'Tipping elements in the Earth system', *Proceedings of the National Academy of Sciences*, vol. 106, no. 49, pp. 20561–20563.

59 Duarte, C, Lenton, T, Wadhams, P & Wassmann, P 2012, 'Abrupt climate change in the Arctic', *Nature Climate Change*, vol. 2, pp. 60–62.

60 GFC 2017, op. cit.

61 ibid.

CLIMATE SENSITIVITY

The question of climate sensitivity is a vexed one. Climate sensitivity is the amount by which the global average temperature will rise due to a doubling of the atmospheric greenhouse gas level, at equilibrium. (Equilibrium refers to the state of a system when all the perturbations have been resolved and the system is in balance.)

IPCC reports have focused on what is generally called Equilibrium Climate Sensitivity (ECS). The 2007 IPCC report gives a best estimate of climate sensitivity of 3°C and says it "is likely to be in the range 2°C to 4.5°C". The 2014 report says that "no best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies" and only gives a range of 1.5°C to 4.5°C. This was a backward step.[62]

What the IPCC reports fail to make clear is that the ECS measure omits key "long-term" feedbacks that a rise in the planet's temperature can trigger. These include the permafrost feedback and other changes in the terrestrial carbon cycle, a decrease in the ocean's carbon-sink efficiency, and the melting of polar ice sheets creating a cold ocean-surface layer underneath that accelerates the melting of ice shelves and hastens the rate of ice-mass loss.

Climate sensitivity which includes these feedbacks — known as Earth System Sensitivity (ESS) — does not appear to be acknowledged in the 2014 IPCC reports at all. Yet, there is a wide range of literature which suggest an ESS of 4–6°C.[63]

It is conventionally considered that these "long-term" feedbacks — such as changes in the polar carbon stores and the polar ice sheets — operate on millennial timescales. Yet the rate at which human activity is changing the Earth's energy balance is without precedent in the last 66 million years, and about ten times faster than during the Paleocene–Eocene Thermal Maximum 55 million years ago, a period with one of the largest extinction events on record.

The rate of change in energy forcing is now so great that these "long-term" feedbacks have already begun to operate within short time frames. The IPCC is not forthcoming on this issue. Instead it sidesteps with statements (from 2007) such as this: "Models used to date do not include uncertainties in climate–carbon cycle feedback... because a basis in published literature is lacking... Climate–carbon cycle coupling is expected to add CO_2 to the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain." This is the type of indefinite language that politicians and the media are likely to gloss over, in favour of a headline number.

It should be noted that carbon budgets — the amount of carbon that could be emitted before a temperature target is exceeded — are generally based on a climate sensitivity mid-range value around 3°C. Yet this figure may be too low. Fasullo and Trenberth found that the climate models that most accurately capture observed relative humidity in the tropics and subtropics and associated clouds were among those with a higher sensitivity of around 4°C.[64] Sherwood et al. also found a sensitivity figure of greater than 3°C.[65] Zhai et al. found seven models that are consistent with the observed seasonal variation of low-altitude marine clouds yield an ensemble-mean sensitivity of 3.9°C.[66] Recently it has been demonstrated the models that best capture current conditions have a mean value of 3.7°C compared to 3.1°C by the raw model projections.[67]

The work on existential climate risks by Xu and Ramanathan, cited above, is also important in assessing what is an appropriate climate sensitivity for risk-management purposes, for three reasons.

62 References to the IPCC are drawn from the relevant Working Group, Synthesis and the Summary for Policymakers reports.

63 The Geological Society 2013, *An addendum to the Statement on Climate Change: Evidence from the geological record*, The Geological Society, London, December 2013; Hansen, J, Sato, M, Russell, G & Kharecha, P 2013, 'Climate sensitivity, sea level and atmospheric carbon dioxide', P*hilosophical Transactions of the Royal Society A*, vol. 371, no. 2001, 20120294.

64 Fasullo, J & Trenberth, K 2012, 'A less cloudy future: the role of subtropical subsidence in climate sensitivity', *Science*, vol. 338, no. 6108, pp. 792-794.

65 Sherwood, S, Bony, S & Dufresne, JL 2014, 'Spread in model climate sensitivity traced to atmospheric convective mixing', *Nature*, vol. 505, pp. 37-42.

66 Zhai, C, Jiang, J & Su, H 2015, 'Long-term cloud change imprinted in seasonal cloud variation: More evidence of high climate sensitivity', *Geophysical Research Letters*, vol. 42, no. 20, pp. 8729-8737.

67 Brown, P & Caldeira, K 2017, 'Greater future global warming inferred from Earth's recent energy budget', *Nature*, vol. 552, pp. 45-50.

They say that:

1. Taking into account the biogeochemical feedbacks (such as less efficient land/ocean sinks, including permafrost loss) effectively increases carbon emissions to 2100 by about 20% and can enhance warming by up to 0.5°C, compared to a baseline scenario.
2. Warming has been projected to increase methane emissions from wetlands by 0–100% compared with present-day wetland methane emissions. A 50% increase in wetland methane emissions by 2100 in response to high-end warming of 4.1–5°C could add at least another 0.5°C.
3. It is important to use high-end climate sensitivity because some studies have suggested that climate models have underestimated three major positive climate feedbacks: positive ice albedo feedback from the retreat of Arctic sea ice; positive cloud albedo feedback from retreating storm track clouds in mid-latitudes; and positive albedo feedback by the mixed-phase (water and ice) clouds. When these are taken into account, the ECS is more than 40% higher than the IPCC mid-figure, at 4.5-4.7°C, before adding up to another 1°C of warming as described in 1. and 2. above.[68]

In research published in 2016, Friedrich et al. show that climate models may be underestimating climate sensitivity because it is not uniform across different circumstances, but in fact higher in warmer, interglacial periods (such as the present) and lower in colder, glacial periods.[69] Based on a study of glacial cycles and temperatures over the last 800,000 years, the authors conclude that in warmer periods climate sensitivity averages around 4.88°C. The higher figure would mean warming for 450 parts per million (ppm) of atmospheric CO_2 (a figure on current trends we will reach within 25 years) would be around 3°C, rather than the 2°C bandied around in policy making circles. Professor Michael Mann, of Penn State University, says the paper appears "sound and the conclusions quite defensible".[70]

"We are now at a tipping point that threatens to flip the world into a full blown climate emergency."

Tony de Brum, Mary Robinson and Kelly Rigg, 2013

68 Xu, Y & Ramanathan, V 2017, 'Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes', *Proceedings of the National Academy of Sciences*, vol. 114, pp. 10315-10323.

69 Friedrich, T, Timmermann, A, Timm, OE & Ganopolski, A 2016, 'Nonlinear climate sensitivity and its implications for future greenhouse warming', *Science Advances*, vol. 2, no. 11, e1501923.

70 Johnston, I 2016, 'Climate change may be escalating so fast it could be "game over", scientists warn', *Independent*, 9 November 2016.

CARBON BUDGETS

A carbon budget is an estimate of the total future human-caused greenhouse gas emissions, in tons of carbon, CO_2 or CO_2 equivalent, that would be consistent with limiting warming to a specified figure, such as 1.5°C or 2°C, with a given risk of exceeding the target, such as a 50%, 33% or 10% chance.

The discussion of carbon budgets is frequently opaque. Often, it is difficult to ascertain whether the assumptions are realistic, for example whether a budget includes non-CO_2 forcings such as methane and nitrous oxide. Too often, the risk of failure is not clearly spelt out, especially the fat-tail risks. Contrary to the tone of the IPCC reports, the evidence shows we have no carbon budget for 2°C for a sensible risk-management, low-probability (of a 10%, or one-in-ten) chance of exceeding that target. The IPCC reports fail to say there is no carbon budget if 2°C is considered a cap (an upper boundary not to be exceeded) as per the *Copenhagen Accord*, rather than a target (an aspiration which can be significantly exceeded). The IPCC reports fail to say that once projected emissions from future food production and deforestation are taken into account, there is no carbon budget for fossil-fuel emissions for a 2°C target.[71]

Carbon budgets are routinely proposed that have a substantial and unacceptable risk of exceeding specified targets and hence entail large and unmanageable risks of failure.

Research published in December 2017 compared "raw" climate models (used by the IPCC) with models that are "observationally informed" and best capture current conditions. The latter produce 15% more warming by 2100 than the IPCC suggests, thus reducing the carbon budget by around 15% for the 2°C target. Hence, as one example, the actual warming for the RCP4.5 emissions path is in reality likely to be higher, similar to that projected by raw models for RCP6.0.[72] (RCPs are representative concentration pathways of greenhouse gas emission trajectories. RCP2.6 is the lowest and RCP8.5 is the highest.) This is consistent with findings five years earlier that climate model projections which show a greater rise in global temperature are likely to prove more accurate than those showing a lesser rise.[73]

As well, the IPCC uses a definition of global mean surface temperature that underestimates the amount of warming over the pre-industrial level. When estimates for the effect of calculating (1) warming for total global coverage rather than for the coverage for which observations are available, (2) warming using surface air temperature measurements (SATs) over the entire globe instead of the observational blend of sea surface temperatures (SSTs) and SATs, and (3) warming from a pre-industrial, instead of a late-nineteenth century baseline, are taken into account, the underestimation is around 0.3°C. This results in a significant overestimation of allowable emissions.[74]

For example, for stabilization at 2°C, allowable emissions decrease by as much as 40% when earlier than nineteenth-century climates are considered as a baseline.[75]

There are also problems with carbon budgets which incorporate "overshoot" scenarios, in which warming exceeds the target before being cooled by carbon drawdown. Pam Pearson, Director of the International Cryosphere Climate Initiative, says that most cryosphere thresholds are determined by peak temperature, and the length of time spent at that peak, warning that "later, decreasing temperatures after the peak are largely irrelevant, especially with higher temperatures and longer duration peaks". Thus "overshoot scenarios", which are now becoming the norm in policymaking circles, hold much greater risks.[76]

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71 Raupach, M 2013, pers. comm, 20 October 2013, based on Raupach, M, Harman, IN & Canadell, GJ 2011, *Global climate goals for temperature, concentrations, emissions and cumulative emissions*, The Centre For Australian Weather and Climate Research, Melbourne 2011, discussed at http://www.climatecodered.org/2014/05/thereal-budgetary-emergency-burnable.html; Arora, VK, Scinocca, JF, Boer, GJ, Christian, RJ, Denman, KL, Flato, GM, Kharin, VV, Lee, WG & Merryfield, WJ 2015, 'Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases', *Geophysical Research Letters*, vol. 38, L05805; Meinshausen, M 2008, 'The EU, the IPCC and the science of climate change: The 2°C target', IES Autumn lecture series, 8 October 2008, Brussels; Anderson, K & and Bows, A 2008, 'Reframing the climate change challenge in light of post-2000 emission trends, *Philosophical Transactions of the Royal Society A*, vol. 366, pp. 3863-3882.

72 Brown, P & Caldeira, K 2017, 'Greater future global warming inferred from Earth's recent energy budget', *Nature*, vol. 552, pp. 45-50.

73 Fasullo, JT & Trenberth, KE 2012, 'A Less Cloudy Future: The Role of Subtropical Subsidence in Climate Sensitivity', *Science*, vol. 338, pp. 792-794.

74 Schurer, AP, Cowtan, K, Hawkins, E, Mann, ME, Scott, V & Tett, SFB 2018, 'Interpretations of the Paris climate target', *Nature Geoscience*, vol 11, pp. 220.

75 Schurer, A, Mann, ME, Hawkins, E, Tett, SFB & Hegerl, GC 2017, 'Importance of the pre-industrial baseline for likelihood of exceeding Paris goals', *Nature Climate Change*, vol. 7, pp. 563-568.

76 UPFSI 2017, op cit.

PERMAFROST AND THE CARBON CYCLE

The failure to adequately consider long-term feedbacks in IPCC estimates of climate sensitivity in climate models, and hence in projections of future warming, lies at the heart of the problem with the IPCC reporting process. Over century time-scales, amplifying feedbacks may ultimately contribute 28–68% of total warming, yet they comprise only 1–7% of current warming.[77] The land sink (storage capacity) for CO_2 appears much smaller than is currently factored into some climate models.[78] Thus, future patterns of warming may be distinctly different from past patterns, making it difficult to predict future warming by relying on past observations.

SOIL CARBON

A 2016 study concluded that a soil carbon-cycle feedback "has not been incorporated into computer models used to project future climate change, raising the possibility that such models are underestimating the amount of warming that is likely to occur".[79] The projected loss of soil carbon resulting from climate change is a potentially large but highly uncertain feedback to warming, however there is likely to be strong carbon-climate feedbacks from colder northern soils.[80]

FORESTS

At the moment about one-third of human-caused CO_2 emissions are absorbed by trees and other plants. But rapid climate warming and unusual rainfall patterns are jeopardising many of the world's trees, due to more frequent drought, pest outbreaks and fires. This is starting to have profound effects on the Earth's carbon cycle.

In 2009, researchers found that 2°C of warming could cut in half the carbon sink of tropical rainforests.[81] Some tropical forests — in the Congo, and in Southeast Asia — have already shifted to a net carbon source. The tropics are now a net carbon source, with losses owing to deforestation and reductions in carbon density within standing forests being double that of gains resulting from forest growth.[82] Other work has projected a long-term, self-reinforcing carbon feedback from mid-latitude forests to the climate system as the world warms.[83]

There has been an observed decline in the Amazon carbon sink. Negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to non-forest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation. Researchers say the severe droughts of 2005, 2010 and 2015-16 could well represent the first flickers of this ecological tipping point, and say the whole system is oscillating.[84]

PERMAFROST

The world's permafrost holds 1.5 trillion tons of frozen carbon, more than twice the amount of carbon in the atmosphere. On land, it covers an area of 15 million square kilometres. The Arctic is warming faster than anywhere else on Earth, and some permafrost degradation is already occurring. Large-scale tundra wildfires in 2012 added to the concern, as have localised methane outbursts.

The 2007 IPCC assessment on permafrost did not venture beyond saying: "Changes in snow, ice and frozen ground have with high confidence increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions and led to changes in some Arctic and Antarctic ecosystems". It reported with "high confidence" that "methane emissions from tundra… and permafrost have accelerated in the past two decades, and are likely to accelerate further". It offered no projections regarding permafrost melt.

77 Proistosescu, C & Huybers, P 2017, 'Slow climate mode reconciles historical and model-based estimates of climate sensitivity', *Science Advances*, vol. 3, e1602821.

78 Bradford, A 2017, 'A leaky sink', *Nature Climate Change*, vol. 7, pp. 475-476

79 Crowther T. et al. 2016, 'Quantifying global soil carbon losses in response to warming', *Nature*, vol. 540, pp. 104-108.

80 Koven, C, Hugelius, G, Lawrence, DM & Wieder, WR 2017, 'Higher climatological temperature sensitivity of soil carbon in cold than warm climates', *Nature Climate Change*, vol. 7, pp. 817-822.

81 Murray, J 2009, 'Research warns two degree rise will halve rainforest "carbon sink"', Business Green, 3 March 2009, <http://www.businessgreen.com/business-green/news/2237656/research-warns-two-degree>.

82 Baccini, A, Walker, W, Carvalho, L, Farina, M, Sulla-Menashe, D & Houghton, RA 2017, 'Tropical forests are a net carbon source based on aboveground measurements of gain and loss', *Science*, vol. 358, pp. 230-234.

83 Melillo, JM, Frey, SD, DeAngelis, KM, Werner, WJ, Bernard, MJ, Bowles, FP, Pold, G, Knorr, MA & Grandy, AS 2017, 'Long-term pattern and magnitude of soil carbon feedback to the climate system in a warming world', *Science*, vol. 358, pp. 101-105.

84 Lovejoy, T & Nobre, C 2018, 'Amazon Tipping Point', *Science Advances*, vol. 4, eaat2340.

Yet, in 2005, Lawrence and Slater had shown that a doubling of CO_2 levels by 2100 — a path to 3°C of warming — would reduce the land permafrost area by more than half and melt much of the top three metres.[85] (In 2017, permafrost area loss was estimated to be 4 million square kilometres for each 1°C of warming.)

The 2014 *Summary for Policymakers* (*SPM)* said: "It is virtually certain that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 meters) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (medium confidence)." That was it.

The effect of the permafrost carbon feedback has not been included in the IPCC scenarios, including the 2014 report.[86] This is despite clear evidence that "the permafrost carbon feedback will change the Arctic from a carbon sink to a source after the mid-2020s and is strong enough to cancel 42–88% of the total global land sink". In 2012, researchers found that, for the 2100 median forecasts, there would be 0.23–0.27°C of extra warming due to permafrost feedbacks. Some scientists consider that 1.5°C appears to be something of a "tipping point" for extensive permafrost thaw.[87]

A 2014 study estimated that up to 205 billion tonnes equivalent of CO_2 could be released due to melting permafrost. This would cause up to 0.5°C extra warming for the high emissions scenario, and up to 0.15°C of extra warming for a 2°C scenario. The authors say that: "Climate projections in the IPCC *Fifth Assessment Report*, and any emissions targets based on those projections, do not adequately account for emissions from thawing permafrost and the effects of the permafrost carbon feedback on global climate."[88]

But, even if human greenhouse gas emissions are stabilised, permafrost carbon loss may continue for many years and simulations suggest that 225 to 345 billion tonnes of CO_2 may eventually be released to the atmosphere for the stabilization target of 2°C.[89]

Recently attention has turned to the question of the stability of large methane hydrate stores below the ocean floor on the shallow East Siberian Arctic Shelf (ESAS). (Methane hydrates are cage-like lattices of ice within which methane molecules are trapped.)

These stores are protected from the warmer ocean temperatures above by a layer of frozen sub-sea permafrost. The concern is that warmer water could create taliks (areas of unfrozen permafrost) through which large-scale methane emissions from the hydrates could escape into the water column above, and into the atmosphere. This possibility was raised in 2013 by Whiteman, Hope and Wadhams.[90]

Prof. Peter Wadhams explained that "the loss of sea ice leads to seabed warming, which leads to offshore permafrost melt, which leads to methane release, which leads to enhanced warming, which leads to even more rapid uncovering of seabed", and this is not "a low probability event".[91]

More than a few experts derided these claims. The model estimates reported by the IPCC are that the degradation of ESAS permafrost cannot exceed several metres this century, and the formation of taliks that would allow the release of large amounts of methane will take hundreds or thousands of years. Thus the IPCC considers the potential contribution of the ESAS into the emissions of methane as insignificant.[92]

But researchers say that model is no longer correct. In August 2017, they announced that:

> " In some areas of the East Siberian Arctic Shelf the roof of the subsea permafrost had already reached the depth of hydrates' stability the destruction of which may cause massive releases of bubble methane… The results of our study ensure fundamentally new insights of the mechanism of processes responsible for the state of subsea permafrost in the East Siberian Arctic Shelf which, according to various estimates, concentrates up to 80% and more of entire subsea permafrost in the Northern Hemisphere, under which there are huge hydrocarbon reserves in the forms of hydrates, oil and free gas."[93]

A deceptively optimistic picture is painted when the potential impacts from the degradation of permafrost and methane hydrates are underplayed.

85 Lawrence, DM & Slater, AG 2005, 'A projection of severe near-surface permafrost degradation during the 21st century', *Geophysical Research Letters*, vol. 32, L22401.

86 UNEP 2012, Policy Implications of Warming Permafrost, United Nations Environment Program, Nairobi.

87 MacDougall, A, Avis, C & Weaver, AJ 2012, 'Significant contribution to climate warming from the permafrost carbon feedback', *Nature Geoscience*, vol. 5, pp. 719–721; Schaefer, K, Zhang, T, Bruhwiler & Barrett, A 2011, 'Amount and timing of permafrost carbon release in response to climate warming', *Tellus B*, vol. 63, no. 2, pp. 165-180; Vaks, A, Gutareva, OS, Breitenbach, SF, Avirmed, E, Mason, AJ, Thomas, AL, Osinzev, AV & Henderson, GM 2013, 'Speleothems reveal 500,000-year history of Siberian permafrost', *Science*, vol. 340, no. 6129, pp. 183-186.

88 Schaefer, K, Lanuit, H, Romanovsky, V, Schuur, E & Witt, R 2014, 'The impact of the permafrost carbon feedback on global climate', *Environmental Research Letters*, vol. 9, no. 8, 085003.

89 Burke, EJ, Chadburn, SE, Huntingford, C & Jones, CD 2018, 'CO2 loss by permafrost thawing implies additional emissions reductions to limit warming to 1.5 or 2°C', *Environmental Research Letters*, vol. 13, 024024.

90 Whiteman, G, Hope, C & Wadhams, P 2013, 'Climate science: Vast costs of Arctic change", *Nature*, vol. 499, pp. 401–403.

91 Ahmed, N 2013, 'Ice-free Arctic in two years heralds methane catastrophe – scientist', *The Guardian*, 25 July 2103 .

92 Tomsk Polytechnic University 2017, Russian scientists deny climate model of IPCC', Eureka Alert, 15 August 2017, <https://www.eurekalert.org/pub_releases/2017-08/tpu-rsd081517.php>.

93 Ibid.

ARCTIC SEA ICE

In 2007, the IPCC reported: "Satellite data since 1978 show that annual average Arctic sea-ice extent has shrunk by 2.7% per decade" and "late summer sea ice is projected to disappear almost completely towards the end of the twenty-first century".

That same year, the summer retreat of Arctic sea ice wildly out-distanced all 18 IPCC computer models. One scientist exclaimed that is was melting "one hundred years ahead of schedule". Many models, including those on which the 2007 IPCC report had relied, did not fully capture the dynamics of sea-ice loss.

Prof. Michael E. Mann says sea-ice modellers had "speculated that the 2007 minimum was an aberration… a matter of random variability, noise in the system, that sea ice would recover.… that no longer looks tenable".[94]

Yet, two years earlier, Prof. Tore Furevik of the Geophysical Institute in Bergen had already demonstrated that actual Arctic sea-ice retreat had been greater than estimates in any of the Arctic models reported by the IPCC. By 2007, a wider range of scientists had presented evidence that the Arctic may be free of all summer sea-ice as early as 2030.[95] Of this, the 2007 IPCC report said nothing.

There was a similar, mind-numbing drop in Arctic sea ice in 2012 to levels unseen in millennia, with the summer minimum sea-ice volume just one-third of that just 30 years earlier, increasing the margin by which IPCC projections had been too conservative.

Yet, in an astonishing understatement, the 2014 IPCC report said: "Year-round reductions in Arctic sea ice are projected for all RCP scenarios." It said a nearly ice-free Arctic Ocean in the summer was likely for the highest emissions scenario only.

In reality, summer ice is thinning faster than every climate projection, tipping points have been crossed for sea-ice-free summer conditions, and today scientists say an ice-free summer Arctic could be just years away, not many decades.

Model limitations "are hindering our ability to predict the future state of Arctic sea ice" and the majority of general climate models "have not been able to adequately reproduce observed multi-decadal sea-ice variability and trends in the pan-Arctic region", so their trend in September Arctic sea-ice extent "is approximately 30 years behind the observed trend".[96]

The loss of sea ice reduces the planet's reflectivity and adds to warming, but this positive feedback is not fully incorporated into models in circumstances where the rate of sea-ice loss is more rapid than expected in the models, as is occurring now. To keep global temperature increase below 2°C, global CO_2 emissions would need to reach zero levels 5–15 years earlier and the carbon budget would need to be reduced by 20–51% to offset this additional source of warming.[97]

Because climate models are missing key real-world interactions and generally have been poor at dealing with the rate of Arctic sea-ice retreat, expert elicitations play a key role in considering whether the Arctic has passed a very significant and dangerous tipping point.[98] But the IPCC has not done this.

94 Scherer 2012a, op. cit.

95 Serreze, MC, Holland, MM & Stroeve, J 2007, 'Perspectives on the Arctic's shrinking sea ice cover', *Science*, vol. 315, no. 5818, pp. 1533-1536; Stroeve, J, Holland, MM, Meier, W, Scambos, T & Serreze, M 2007, 'Arctic sea ice decline: Faster than forecast?', *Geophysical Research Letters*, vol. 34, no. 9, L09501.

96 Maslowski, W, Kinney, JC, Higgins, M & Roberts, A 2012, 'The future of Arctic sea ice', *The Annual Review of Earth and Planetary Sciences*, vol. 20, pp. 625-654.

97 Gonzalez-Eguino, M, Neumann, MB, Arto, I, Capellán-Perez, I & Faria, SH 2017, 'Mitigation implications of an ice-free summer in the Arctic Ocean', *Earth's Future*, vol. 5, pp. 59-66.

98 Livina, VN & Lenton, TM 2013, 'A recent tipping point in the Arctic sea-ice cover: abrupt and persistent increase in the seasonal cycle since 2007', *The Cryosphere*, vol. 7, pp. 275-286; Maslowski, Kinney et al 2012., op. cit.

POLAR ICE-MASS LOSS

In 1995, the IPCC projected "little change in the extent of the Greenland and Antarctic ice sheets… over the next 50-100 years". The 2001 IPCC report suggested that neither the Greenland nor the Antarctic ice sheets would lose significant mass by 2100.

The 2007 IPCC report said there were "uncertainties… in the full effects of changes in ice sheet flow", and a suggestion that "partial loss of ice sheets on polar land could imply metres of sea-level rise… Such changes are projected to occur over millennial time scales". The reality is very different.

GREENLAND ICE SHEET

In 2007, the IPCC reported: "Contraction of the Greenland Ice Sheet is projected to continue to contribute to sea-level rise after 2100. Current models suggest virtually complete elimination of the Greenland Ice Sheet and a resulting contribution to sea-level rise of about seven metres if global average warming were sustained for millennia in excess of 1.9 to 4.6°C relative to pre-industrial values."

This was despite two 2006 studies, which found the Greenland ice cap "may be melting three times faster than indicated by previous measurements", warnings that "we are close to being committed to a collapse of the Greenland Ice Sheet" and reports that rising Arctic regional temperatures are already at "the threshold beyond which glaciologists think the [Greenland] ice sheet may be doomed".[99]

The 2007 assessment "did not take into account the potential melting of Greenland, which I think was a mistake", said Robert Watson, Chief Scientific Advisor for Britain's Department for Environmental Affairs and chairman of the IPCC's 2001 assessment.[100]

By 2014, the IPCC was reporting that "over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass, likely at a larger rate over 2002 to 2011". The loss of the Greenland Ice Sheet would be a period "over a millennium or more", with a threshold between 1°C and 4°C of warming. In fact, the annual rate of loss had doubled in the period 2003 to 2010 compared with the rate throughout the 20th century.[101]

By this time, many leading cryosphere scientists were saying informally that Greenland had passed its tipping point, "is already lost", and similar sentiments. And a year before, a significant research paper had estimated the tipping point for Greenland Ice Sheet as 1.6°C (with an uncertainty range of 0.8 to 3.2°C). And there was clear satellite evidence of accelerating ice-mass loss.[102]

The loss of ice mass from Greenland is accelerating, which is drawing increasing levels of concerns from scientists. "What keeps cryosphere scientists up at night are irreversible thresholds, particularly West Antarctica and Greenland," says Pam Pearson, Director of the International Cryosphere Climate Initiative.[103]

Current-generation climate models are not yet all that helpful for predicting Greenland ice-mass loss. They have a poor understanding of the processes involved, and the acceleration, retreat and thinning of outlet glaciers are poorly or not represented.[104]

In the case of Greenland, the adverse consequences for policymaking of the IPCC's method of privileging global climate model results over observations, historical data and expert elicitations can be clearly seen. It is hard not to imagine the rate of Greenland Ice Sheet deglaciation continuing to accelerate as the climate continues to warm, reflectivity declines, and late summer ocean conditions become sea-ice free.

In 2012, then NASA climate science chief James Hansen told Bloomberg that: "Our greatest concern is that loss of Arctic sea ice creates a grave threat of passing two other tipping points – the potential instability of the Greenland Ice Sheet and methane hydrates… These latter two

99 Rignot, E & Kanagaratnam, P 2006, 'Changes in the velocity structure of the Greenland ice sheet', *Science*, vol. 311, no. 5763, pp. 986-90; Chen, JL, Wilson, CR & Tapley, BD 2006, 'Satellite gravity measurements confirm accelerated melting of Greenland ice', *Science*, vol. 313, pp. 1958–60; Young, K 2006, "Greenland ice cap may be melting at triple speed", *New Scientist*, 10 August, 2006.

100 AFP 2008, 'Climate change gathers steam, say scientists', Space Daily, 30 November 2008, <http://www.spacedaily.com/2006/081130055637.szeh21pj.html>.

101 Mooney, C, 2015, 'Greenland has lost a staggering amount of ice — and it's only getting worse', *Washington Post*, 16 December 2015.

102 Robinson, A, Calov, R & Ganopolski, A 2012, 'Multistability and critical thresholds of the Greenland ice sheet', *Nature Climate Change*, vol. 2, pp. 429–432.

103 UPFSI 2017, op cit.

104 Maslowski, Kinney et al. 2012, op cit.

tipping points would have consequences that are practically irreversible on time scales of relevance to humanity."[105]

On this very grave threat, the IPCC is mute.

ANTARCTIC ICE SHEET

The 2007 IPCC assessment proffered: "Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance." Reality and new research would soon undermine this one-sided reliance by the IPCC on models with poor cryosphere performance.

By the 2014 IPCC assessment, the story was: "Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic Ice Sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. There is medium confidence that this additional contribution would not exceed several tenths of a metre of sea-level rise during the 21st century." And: "Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment." This was another blunder.

Observations of accelerating ice mass loss in West Antarctica were well established by this time.[106]

It is likely that the Amundsen Sea sector of the West Antarctic Ice Sheet has already been destabilized. Ice retreat is unstoppable for the current conditions, and no acceleration in climate change is necessary to trigger the collapse of the rest of the West Antarctic Ice Sheet, with loss of a significant fraction on a decadal-to-century time scale. One of the most significant research findings in 2014 was that the tipping point has already passed for one of these "long-term" events. Scientists found that "the retreat of ice in the Amundsen Sea sector of West Antarctica was unstoppable, with major consequences – it will mean that sea levels will rise one metre worldwide… Its disappearance will likely trigger the collapse of the rest of the West Antarctic ice sheet, which comes with a sea-level rise of between 3–5 metres. Such an event will displace millions of people worldwide."[107]

This was a world away from the IPCC report of the same year.

In 2016, another significant study concluded that: "Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500."[108] Compare this to the IPCC report, just a year earlier, that Antarctica's contribution to rising sea levels would "not exceed several tenths of a meter… during the 21st century".

As well, partial deglaciation of the East Antarctic ice sheet is likely for the current level of atmospheric CO_2, contributing ten metres or more of sea-level rise in the longer run, and five metres in the first 200 years.[109]

The increasing rate of change in Antarctica was brought to light with the publication, in June 2018, of the most-comprehensive-yet analysis of changes to the ice sheet. The new data showed that ocean-driven melting has caused rates of ice loss from West Antarctica to triple from 53 ± 29 billion to 159 ± 26 billion tonnes per year from 1992 to 2017.[110] Forty percent of the total ice mass loss over that period has occurred in the last five years, suggesting a recent and significant acceleration in the loss rate.

Over the same period, ice-shelf collapse had increased the rate of ice loss from the Antarctic Peninsula almost five-fold from 7 ± 13 billion to 33 ± 16 billion tonnes per year. Two West Antarctic glaciers – Pine Island and Thwaites — are of particular concern, with the latter "increasingly being viewed as posing a potential planetary emergency because of its enormous size and its role as a gateway that could allow the ocean to someday access the entirety of West Antarctica, turning the marine-based ice sheet into a new sea".[111]

This is the scenario Prof. James Hansen warned about a decade ago in a paper on sea-level rise and scientific reticence: "Let us say that the ice sheet contribution is one centimetre for the decade 2005-2015 and that it doubles each decade until the West Antarctic Ice Sheet is largely depleted. That time constant yields sea-level rise of the order of five metres this century. Of course I can not prove that my choice of a ten-year doubling time for non-linear response is accurate, but I would bet $1000 to a donut that it is a far better estimate than a linear response for the ice sheet component of sea-level rise [of around 0.5 metre]."[112]

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105 Bloomberg, 2012, 'Arctic sea ice heads for record low', Bloomberg, 17 August 2012, <http://www.bloomberg.com/news/2012-08-17/arctic-sea-ice-heads-for-record-low-as-melt-exceeds-forecasts.html>.

106 Velicogna, I 2009, 'Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE', *Geophysical Research Letters*, vol. 36, L19503.

107 Rignot, E, Mouginot, J, Morlighem, M, Seroussi, H & Scheuchl, B 2014, 'Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011', *Geophysical Research Letters*, vol. 41, pp. 3502–3509.

108 DeConto, R & Pollard, D 2016, 'Contribution of Antarctica to past and future sea-level rise', *Nature*, vol. 531, pp. 591–597.

109 Pollard, D, DeConto, R & Alley, R 2015, 'Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure', *Earth Planetary Science Letters*, vol. 412, pp. 112– 121.

110 The IMBIE Team 2018, "Mass balance of the Antarctic Ice Sheet from 1992 to 2017", *Nature*, vol. 558, pp. 219–222.

111 Mooney, C 2018, "Antarctic ice loss has tripled in a decade. If that continues, we are in serious trouble", *Washington Post*, 13 June 2018.

112 Hansen, J 2007, op. cit.

SEA LEVEL RISE

The fate of the world's coastlines has become a classic example of how the IPCC, when confronted with conflicting science, tends to go for the "least drama" position.

In the 2001 assessment report, the IPCC projected a sea-level rise of 2 millimetres per year. By 2007, the researchers found that the range of the 2001 predictions were lower than the actual rise. Satellite data showed that levels had risen by an average of 3.3 millimetres per year between 1993 and 2006.

The worst-case scenario in the 2007 report, which looked mostly at thermal expansion of the oceans as temperatures warmed, projected up to 0.59 metre of sea-level rise by century's end. In an extraordinary verbal contortion, it then said it did "not assess the likelihood, nor provide a best estimate or an upper bound for sea-level rise… The projections do not include uncertainties in climate–carbon cycle feedbacks nor the full effects of changes in ice sheet flow, therefore the upper values of the ranges are not to be considered upper bounds for sea-level rise. They include a contribution from increased Greenland and Antarctic ice flow at the rates observed for 1993-2003, but this could increase or decrease in the future."

Yet, in early 2007, Rahmstorf had presented a "semi-empirical relation… that connects global sea-level rise to global mean surface temperature" which resulted "in a projected sea-level rise in 2100 of 0.5 to 1.4 meters above the 1990 level".[113]

Many climate scientists received the 2007 IPCC report's suggestion of a sea-level rise of 18–59 centimetres by 2100 with dismay, because it seriously underestimated the problem. Even before the 2007 report appeared, Hansen warned of a "scientific reticence" which "in a case such as ice-sheet instability and sea-level rise (results in) a danger in excessive caution. We may rue reticence, if it serves to lock in future disasters."[114]

Within a year, a report from the US Geological Survey warned that sea-level rise will "substantially exceed" official UN projections and could top 1.5 metres by the end of the century.[115] And by 2009, various studies offered drastically higher projections than the IPCC. Australian Government reports noted: "Recent research, presented at the Copenhagen Climate Congress in March 2009, projected sea-level rise from 0.75 to 1.9 metres relative to 1990, with 1.1–1.2 metres the midrange of the projection." And: "Current estimates of sea-level rise range from 0.50 metre to over 2 metres by 2100."[116]

Yet extraordinarily, the 2014 IPCC assessment report repeated the mistake and actually produced a numerically smaller figure (0.55 metre as compared to 0.59 metre in 2007) despite mounting evidence of polar ice-mass loss: "Global mean sea-level rise will continue during the 21st century, very likely at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will likely be in the ranges of 0.26 to 0.55 metre for RCP2.6, and of 0.45 to 0.82 metre for RCP8.5." And then, having noted estimates for sea-level rise to 2100 of between 1.15 metres and 2.4 metres, the report said: "Considering this inconsistent evidence, we conclude that the probability of specific levels above the likely range cannot be reliably evaluated." If some work could not be "reliably evaluated", how could they be sure of the much lower estimates that they had quantified?

113 Rahmstorf 2007, op cit.

114 Hansen 2007, op cit.

115 Randerson, J 2008, 'Sea level could rise by 150cm, US scientists warn', *The Guardian*, 16 December 2008.

116 Australian Government, 2009, *Climate Change Risks to Australia's Coasts: A first pass national assessment*, Australian Government, Canberra; CSIRO 2009, *Science Update 2009*, no. 2, November 2009, Australian Government, Canberra.

This event shot down any shreds of IPCC credibility on sea-level rise that may have lingered after 2007.

An updated NOAA sea-level rise report, released in August 2017, recommends a revised worst-case sea-level rise scenario of 2.5 metres by 2100, 5.5 metres by 2150 and 9.7 metres by 2200. It says sea-level science has “advanced significantly over the last few years, especially (for) land-based ice sheets in Greenland and Antarctica under global warming”, and hence the “correspondingly larger range of possible 21st century rise in sea level than previously thought”. It points to “continued and growing evidence that both Antarctica and Greenland are losing mass at an accelerated rate”, which “strengthens an argument for considering worst-case scenarios in coastal risk management”.[117]

Today the discussion amongst experts is for a sea-level rise this century of at least one metre, and perhaps in excess of two metres. The US Department of Defence uses scenarios of one and two metres for risk assessments. Evidence (cited above) that Antarctica by itself has the potential to contribute more than a metre of sea-level rise by 2100, and that at 1°C of warming, West Antarctic glaciers are in “unstoppable” meltdown for one-to-four metres of sea-level rise, only add to grave concern that the IPCC reports are simply irrelevant on this matter.

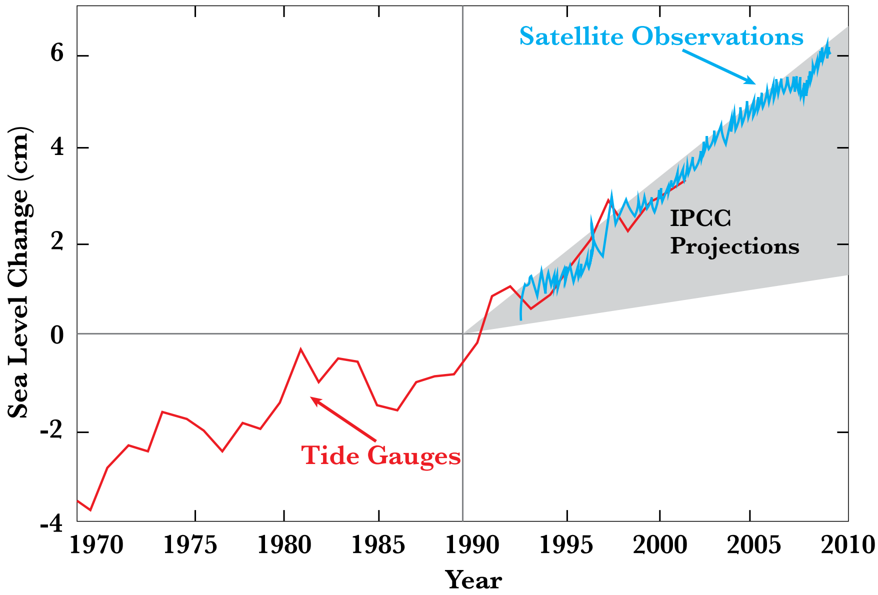

Figure 4: Observed sea-level rise 1970-2010 from tide gauge data (red) and satellite measurements (blue) compared to model projections for 1990-2010 from the IPCC (grey band). (Source: *The Copenhagen Diagnosis*, 2009)

117 NOAA 2017, *Global and regional sea-level rise scenarios for the United States*, NOAA, Silver Spring MA.

“Political reality must be grounded in physical reality or it’s completely useless.”

Prof. Hans Joachim Schellnhuber, 2009

POLITICAL
UNDERSTATEMENT

POLITICISATION

Much has been written about the inadequacy of IPCC processes, and the politicisation of its decision-making.

Scientists say one reason the IPCC's work is too conservative is that unwieldy processes mean reports do not take the most recent research into account. The cutoff point for science to be considered in a report is so far in advance of publication that the reports are out of date upon release. This is a crucial failure in a field of research that is rapidly changing. Inez Fung at the Berkeley Institute of the Environment, California says that for her research to be considered in the 2007 IPCC report, she had to complete it by 2004. This is a typical experience that she identifies as "an awful lag in the IPCC process".[118]

IPCC *Assessment Reports* are compiled by working groups of scientists within guidelines that urge the building of consensus conclusions from evidence presented, though that evidence itself may be diverse and sometimes contradictory in nature. The general result may be described as middle-of-the-road reporting. Propositions supported by the greater quantity of research papers presented win out against propositions that might be outliers in terms of quantity of papers presented, though the latter may be no less scientifically significant.

The higher-impact possibilities may have less research available for consideration, but there are good risk-management reasons for giving such possibilities more prominence, even if the event probability is relatively low.

For example, the projected sea-level rise in the 2007 report was well below the subsequent observations. This occurred because scientists compiling the report could not agree on how much would be added to sea-level rise by melting polar ice sheets, and so left out the data altogether to reach "consensus". Science historian Naomi Oreskes calls this "consensus by omission".[119]

This is the consensus problem at the scientific level, but there is also a problem at the political level. In the first instance, the powerful coordinating authors for reports are selected by political representatives of the 195 member nations of the IPCC.

In the second instance, whilst the full-length IPCC *Assessment Reports* are compiled by scientists, the shorter and more widely reported SPMs require consensus from diplomats in "a painstaking, line-by-line revision by [political] representatives from more than 100 world governments — all of whom must approve the final summary document".[120]

As early as the IPCC's first report in 1990, the United States, Saudi Arabian and Russian delegations acted in "watering down the sense of the alarm in the wording, beefing up the aura of uncertainty".[121] Prof. Martin Parry of the UK Met Office, co-chairman of an IPCC working group at the time, exposed the arguments between scientists and political officials over the 2007 IPCC *SPM*: "Governments don't like numbers, so some numbers were brushed out of it."[122]

In 2014, *The Guardian* reported increasing evidence that "the policy summaries on climate impacts and mitigation by the IPCC were significantly 'diluted' under political pressure from some of the world's biggest greenhouse gas emitters, including Saudi Arabia, China, Brazil and the United States".[123]

118 Barras, C 2007, 'Rocketing CO2 prompts criticisms of IPCC', *New Scientist*, 24 October 2007.
119 Scherer 2012a, op cit.
120 Ibid.
121 Leggett, J 1999, *The Carbon War: Global warming and the end of the oil era*, Routledge, New York.
122 Adam, D 2007, 'How climate change will affect the world', *The Guardian*, 20 September 2007.
123 Ahmed, N 2014, 'IPCC reports 'diluted' under 'political pressure' to protect fossil fuel interests', *The Guardian*, 15 May 2014.

One of the 2014 report's more powerful sections was deleted during last minute negotiations over the text. The section tried to specify other measures that would indicate whether we are entering a danger zone of profound climate impact, and just how dramatic emissions cuts will have to be in order to avoid crossing that threshold. Prof. Michael Oppenheimer, an eminent climate scientist at Princeton University who was also part of the core writing team, suggests that politics got in the way.[124]

Oliver Gedden, head of the EU Research Division at the German Institute for International and Security Affairs in Berlin, says climate scientists and economists who counsel policymakers are being pressured to extend their models and options for delivering mitigation later, which has "introduced dubious concepts, such as repaying 'carbon debt' through 'negative emissions' to offset delayed mitigation — in theory".[125] He says that climate researchers who advise policymakers feel that they have two options, to be pragmatic or be ignored: "Many advisers are choosing pragmatism… Each year, mitigation scenarios that explore policy options for transforming the global economy are more optimistic — and less plausible… The scientific community must defend its independence from outside interference."[126]

"It may seem impossible to imagine that a technologically advanced society could choose, in essence, to destroy itself, but that is what we are now in the process of doing."

Elizabeth Kolbert, Field Notes from a Catastrophe, 2006

124 Leggett, J 2014, 'Why two crucial pages were left out of the latest UN climate report', Jeremy Leggett, 4 November 2014, <http://www.jeremyleggett.net/2014/11/why-two-crucial-pages-were-left-out-of-the-latest-u-n-climate-report/>.

125 Geden, O 2015, 'Climate advisers must maintain integrity', *Nature*, vol. 52, pp. 27-28.

126 ibid.

GOALS ABANDONED

The IPCC and the UNFCCC are the twin climate science and policy development organisations of the UN.

Conferences of the Parties (COPs) under the UNFCCC are political fora, populated by professional representatives of national governments, and subject to the diplomatic processes of negotiation, trade-offs and deals. In this sense, the COPs are similar in process to that of the IPCC by which the *SPM* are agreed by diplomats. The decision-making is inclusive (by consensus), making outcomes hostage to national interests and lowest-common-denominator politics.

The COP 21 *Paris Agreement*[127] is almost devoid of substantive language on the cause of human-induced climate change and contains no reference to "coal", "oil", "fracking", "shale oil", "fossil fuel" or "carbon dioxide", nor to the words "zero", "ban", "prohibit" or "stop". By way of comparison, the term "adaptation" occurs more than eighty times in 31 pages, though responsibility for forcing others to adapt is not mentioned, and both liability and compensation are explicitly excluded. The *Agreement* has a goal but no firm action plan, and bureaucratic jargon abounds, including the terms "enhance" and "capacity" appearing more than fifty times each.

The proposed emission cuts by individual nations under the *Paris Agreement* are voluntary (unilateral), without an enforceable compliance mechanism. In this sense, the *Agreement* cannot be considered "binding" on signatories. The voluntary national emission reduction commitments are not critically analysed in the *Agreement*, but noted to be inadequate for limiting warming to 2°C.

The Paris voluntary national commitments would result in emissions in 2030 being higher than in 2015 and are consistent with a 3.4°C warming path, and significantly higher if the warming impacts of carbon-cycle feedbacks are considered. Unless dramatically improved upon, the present commitments exclude the attainment of either the 1.5°C or 2°C targets this century without wholly unrealistic assumptions about negative-emission technologies.

The UNFCCC primary goal is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".[128] But what is "dangerous"? Traditionally, policymakers have focused on the 2°C target, but the *Paris Agreement* emphasises "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C".

With the experience of global warming impacts so far, scientists have distinguished between "dangerous" (1-2°C band) and "extremely dangerous" (above 2°C) climate warming.[129]

But we now have evidence that significant tipping points — for example, summer sea-ice-free Arctic conditions, the loss of West Antarctic glaciers and a multi-metre sea-level rise — have very likely been passed at less than 1°C of warming.[130] As well, evidence is accumulating that around the current level of warming more elements of the system may be heading towards tipping points or experiencing qualitative change. These include the slowing of the Thermohaline Circulation (the Atlantic conveyor), likely as a result of climate change; accelerating ice-mass loss from Greenland and Antarctica; declining carbon efficiency of the Amazon forests and other sinks; and the vulnerability of Arctic permafrost stores. Warming of 1.5°C would set sea-level rises in train sufficient to challenge significant components of human civilisation, besides reducing the world's coral ecosystems to remnant structures.

127 UN 2015, *Paris Agreement*, United Nations, New York, <http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf>.

128 UNFCCC n.d., 'First steps to a safer future: Introducing The United Nations Framework Convention on Climate Change', United Nations, <http://unfccc.int/essential_background/convention/items/6036.php>.

129 Anderson, K & Bows, A 2011 'Beyond 'dangerous' climate change: emission scenarios for a new world', *Philosophical Transactions of the Royal Society A vol.* 369, pp. 20–44.

130 Livina & Lenton 2013, op. cit.; Rignot, Mouginot et al. 2014, op. cit.; DeConto & Pollard 2016, op. cit.

In other words, climate change is already dangerous, but the UNFCCC processes have not acknowledged this reality, proposing higher warming targets as policy goals. Nor has the IPCC process, with the lags in its publication process, and a "burning embers" representation of the risks that again looks too conservative.[131]

An expert panel recently concluded that warming would need to be limited to 1.2°C to save the Great Barrier Reef.[132] That is probably too optimistic, but with a current warming trend of about 1.1°C and 2016 global average warming above 1.2°C, it also demonstrates that climate change is already dangerous.

The question as to what would be safe for the protection of people and other species is not addressed by policymakers.

If climate change is already dangerous, then by setting the 1.5°C and 2°C targets, the UNFCCC process has abandoned the goal of preventing "dangerous anthropogenic influence with the climate system" for this century.

The UNFCCC key goals "to ensure that food production is not threatened" and achieving "a time-frame sufficient to allow ecosystems to adapt naturally to climate change" have been discarded for all practical purposes. Food production is already threatened by rising sea levels and inundation, shifting rainfall patterns and desertification, and extreme heatwave and wildfire episodes. Such events became a driver of the Arab Spring and a threat multiplier in the Syrian conflict and in Darfur.[133]

Ecosystems, including coral reefs, mangroves and kelp forests in Australia, are degrading fast as the world's sixth mass extinction gathers pace. Major ecosystems are now severely degraded and climate policymakers have no realistic agreement to save or restore them, from the Arctic to the Amazon, from the Great Barrier Reef to the Sahel.

The *Paris Agreement* recognised the "fundamental priority of safeguarding food security" (note the change from the original goal to "ensure" food production is not threatened). It made no reference to earlier commitments to act within time-frames sufficient to allow ecosystems to adapt naturally to climate change, suggesting this goal has been (literally) dropped.

131 O'Neill, B, Oppenheimer, M, Warren, R, Hallegatte, S, Kopp, RE, Portner, HO, Scholes, R, Birkmann, J, Foden, W, Mach, K, Marbaix, P, Mastrandrea, M, Price, J, Takahashi, K, van Ypersele, JP & Yohe, G 2017, 'IPCC reasons for concern regarding climate change risks', *Nature Climate Change*, vol. 7, pp. 28–37.

132 Hannam, P 2017, 'Warming limit of 1.2 degrees needed to save Great Barrier Reef: expert panel', *The Age*, 2 August 2017.

133 Werrell, CE & Femia, F 2013, *The Arab Spring and Climate Change*, edn., Centre for American Progress/Stimson/The Center for Climate and Security, Washington.

A FAILURE OF IMAGINATION

At the London School of Economics in 2008, Queen Elizabeth questioned: "Why did no one foresee the timing, extent and severity of the Global Financial Crisis?" The British Academy answered a year later: "A psychology of denial gripped the financial and corporate world… [it was] the failure of the collective imagination of many bright people… to understand the risks to the system as a whole."[134]

A "failure of imagination" has also been identified as one of the reasons for the breakdown in US intelligence around the 9/11 attacks in 2001.

Prof. Max Bazerman of Harvard University has asked why societies fail to implement wise strategies to prevent "predictable surprises", a term he coined to describe events that catch organisations and nations off-guard, despite necessary information being available to anticipate the event. Bazerman identifies five psychological patterns that help to explain the failure to act on climate:

> " … positive illusions lead us to conclude that a problem doesn't exist or is not severe enough to merit action… we interpret events in an egocentric, or self-serving, manner… we overly discount the future, despite our contentions that we want to leave the world in good condition for future generations… we try desperately to maintain the status quo and refuse to accept any harm, even when the harm would bring about a greater good [and] we don't want to invest in preventing a problem that we have not personally experienced or witnessed through vivid data."[135]

Bazerman suggests that many political leaders will not want to act until great, demonstrable harm has already occurred.

This problem is widespread at senior levels of government and global corporations. A 2016 report, *Thinking the Unthinkable* (see page 9), based on interviews with top leaders around the world, found that: "A proliferation of 'unthinkable' events… has revealed a new fragility at the highest levels of corporate and public service leaderships. Their ability to spot, identify and handle unexpected, non-normative events is… perilously inadequate at critical moments… Remarkably, there remains a deep reluctance, or what might be called 'executive myopia', to see and contemplate even the possibility that 'unthinkables' might happen, let alone how to handle them."[136]

Such failures are manifested in two ways in climate policy. At the political, bureaucratic and business levels in the underplaying of the high-end risks and in failing to recognise that the existential risks of climate change are totally different from other risk categories. And, at the research level, as embodied in IPCC reports, in underestimating climate change impacts, along with an under-emphasis on, and poor communication of, the high-end risks. The IPCC reports have not provided a sufficient evidentiary base to answer a key question for normative policymaking: what would be safe? As noted previously, IPCC processes paid little attention to less than 2°C scenarios until prompted to do so by the political sector.

Climate policymaking at all levels of government uses the reports of the IPCC as the primary physical science basis. The failure of the IPCC to report in a balanced manner on the full range of risks and to fully account for high-end outcomes leaves policymakers ill-informed. This undermines the capacity of governments and communities to make the correct decisions to protect their well-being, or indeed to protect human civilisation as a whole, in the face of existential risks.

134 Stewart, H 2009, 'This is how we let the credit crunch happen, Ma'am …', *The Guardian*, 26 July.
135 Bazerman, M 2006, 'Climate change as a predictable surprise', *Climatic Change*, vol. 77, pp. 179–193.
136 Gowing, N & Langdon, C 2016, op cit.

ADDRESSING EXISTENTIAL CLIMATE RISK

This report demonstrates the risk that both the speed and extent of future human-induced climate change impacts has been badly underestimated. At the social level lies the massive inertia of global leaders, who still have great reluctance in accepting that their approach must fundamentally change if humanity, and nature, are to have sustainable futures.

The UNFCCC formally aims for climate policies which "enable economic development to proceed in a sustainable manner". In practice, priority is given to short-term economic considerations. Thus the emphasis has been on ensuring that the emissions-reduction paths developed for policymakers are not economically disruptive.

For example, in 2006 and 2008 respectively, both Sir Nicholas Stern and Prof. Ross Garnaut, in their initial reports to the UK and Australian governments, canvassed the 450 ppm and the 550 ppm atmospheric CO_2 targets. Whilst both concluded that 450 ppm would inflict significantly less damage, they nevertheless advocated starting with the 550 ppm figure because they considered the lower goal would be too economically disruptive. (550 ppm is roughly equivalent to 3°C of warming before carbon cycle feedbacks are considered, and truly devastating for people and nature). They have since acknowledged that evidence of accelerating climate impacts has rendered this approach dangerously complacent.

Rapid reduction of carbon emissions is still excluded from consideration by policymakers because it is deemed to be too economically dislocating. The fact that the present political path of 3°C or more of warming would result in a world overwhelmed by extreme climate impacts, leading to outright chaos, is avoided. The dominant neo-liberal framing of progress, through globalisation and deregulation, suppresses regulatory action which would address the real climate challenge because it undermines the prevailing political–economic orthodoxy.

Discussion around policy choices gives primary emphasis to the role of markets. The commodification of carbon pollution for the purposes of market trading, and the virtue of carbon pricing, are emphasised by policymakers as the most desirable method for achieving decarbonisation. However, these discussions have become unrealistic. They accept the continuing expansion of fossil fuels in the first half of the 21st century, eventually counteracted by massive expansion of negative emission technologies, such as carbon capture and storage and BECCS — which do not even exist at scale — in the second half of the century to draw down excess carbon from the atmosphere. But, by that time it will be too late to prevent irreversible, catastrophic climate impacts.

In so doing, policymakers are complicit today in destroying the very conditions which make human life possible. There is no greater crime against humanity.

After three decades of global inaction, climate change is now an existential risk to humanity. It implies large negative consequences, which will be irreversible, resulting in major reductions in global and national population, mass species extinction, economic disruption and social chaos, unless carbon emissions are rapidly reduced. The risk is immediate, in that it is being locked in today by our insistence on expanding and sustaining the use of fossil fuels when the carbon budget to stay below sensible temperature increase limits is already exhausted.

As one of the countries most exposed to climate impact, and in the top half dozen carbon polluters worldwide when exports are included, this should be a major concern to Australia. Instead, it is ignored, with many parliamentarians refusing to even accept that human-induced climate change is happening.

In signing and ratifying the 2015 *Paris Agreement*, the global community, Australia included, committed to the objectives of limiting global average temperature increase to "well below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C", and "to reach global peaking of greenhouse gas emissions as soon as possible, in accordance with best available science", recognising that "climate change represents an urgent and potentially irreversible threat to human societies and the planet". To meet those objectives, climate action must be reframed around two principles:

- Human-induced climate change represents an immediate and existential threat to humanity; and
- An emergency response is essential if that threat is to be properly addressed.

Such a response should seek to normatively achieve these clearly defined objectives.

SUMMARY

Human-induced climate change is an existential risk to human civilisation: an adverse outcome that will either annihilate intelligent life or permanently and drastically curtail its potential, unless carbon emissions are rapidly reduced.

Special precautions that go well beyond conventional risk management practice are required if the increased likelihood of very large climate impacts — known as “fat tails” — are to be adequately dealt with. The potential consequences of these lower-probability, but higher-impact, events would be devastating for human societies.

The bulk of climate research has tended to underplay these risks, and exhibited a preference for conservative projections and scholarly reticence, although increasing numbers of scientists have spoken out in recent years on the dangers of such an approach.

Climate policymaking and the public narrative are significantly informed by the important work of the IPCC. However, IPCC reports also tend toward reticence and caution, erring on the side of “least drama”, and downplaying the more extreme and more damaging outcomes.

Whilst this has been understandable historically, given the pressure exerted upon the IPCC by political and vested interests, it is now becoming dangerously misleading with the acceleration of climate impacts globally. What were lower-probability, higher-impact events are now becoming more likely.

This is a particular concern with potential climatic tipping points — passing critical thresholds which result in step changes in the climate system — such as the polar ice sheets (and hence sea levels), and permafrost and other carbon stores, where the impacts of global warming are non-linear and difficult to model with current scientific knowledge.

However the extreme risks to humanity, which these tipping points represent, justify strong precautionary management. Under-reporting on these issues is irresponsible, contributing to the failure of imagination that is occurring today in our understanding of, and response to, climate change.

If climate policymaking is to be soundly based, a reframing of scientific research within an existential risk-management framework is now urgently required. This must be taken up not just in the work of the IPCC, but also in the UNFCCC negotiations if we are to address the real climate challenge.

Current processes will not deliver either the speed or the scale of change required.

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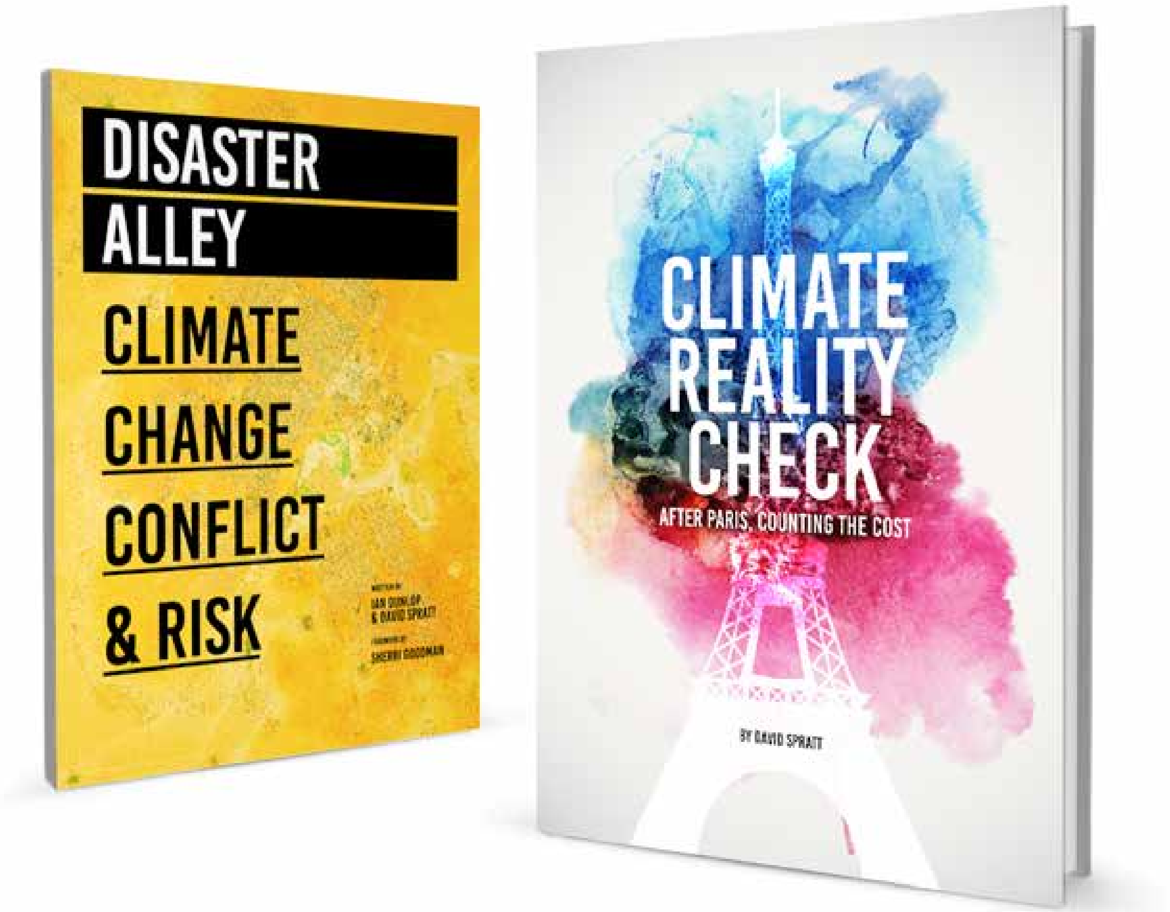

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