

A photograph of an iceberg floating in the ocean. The tip of the iceberg is visible above the water line, while the much larger, jagged base is submerged below. The sky is a clear, pale blue with a few wispy clouds. The water is a deep, calm blue. The overall tone is serene but carries a heavy, cautionary message.

WHAT LIES BENEATH

THE SCIENTIFIC UNDERSTATEMENT OF CLIMATE RISKS

BY DAVID SPRATT & IAN DUNLOP

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OVERVIEW

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

Special precautions that go well beyond conventional risk management practice are required if the “fat tails” — the increased likelihood of very large impacts — 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, albeit 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 Intergovernmental Panel on Climate Change (IPCC). However, IPCC reports also tend toward reticence and caution, erring on the side of “least drama”, and downplaying 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, given 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 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 at present. Under-reporting on these issues contributes 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 UN Framework Convention on Climate Change negotiations if we are to address the real climate challenge.

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

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, even if the existential nature of the risk it posed was far less clear cut than it is today.

As global institutions were established to take up this challenge, such as the UN Framework Convention on Climate Change (UNFCCC) at the Rio Earth Summit in 1992, 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-speak 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.”

Orwell could have been writing about climate change and policymaking. International agreements talk of limiting global warming to 1.5–2°C, but in reality they set the world on a path of 3–5°C. Goals are reaffirmed, only to be abandoned. Coal is “clean”. Just 1°C of warming is already dangerous, but this cannot be said. 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 chance of missing a goal is normalised as reasonable.

Climate policymaking for years has been cognitively dissonant, “a flagrant violation of reality”. So it is unsurprising that there is a lack of a 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,¹ and half see our way of life ending within the next 100 years.²

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 48% more carbon dioxide (CO₂) 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 planets annually to survive as it rapidly chews up the 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

¹ CommunicateResearch 2017, ‘Global Challenges Foundation global risks survey’, *ComRes*, 24 May 2017, <<http://www.comresglobal.com/polls/global-challenges-foundation-global-risks-survey>>.

² 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.

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.

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; 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 Intergovernmental Panel on Climate Change (IPCC), was established by the 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 5–6 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 relatively low-probability events where scientific knowledge is more limited. Vested interest pressure is acute in all directions; climate denialists accuse the IPCC of alarmism, whereas 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. Climate change is now turning nasty, as we have witnessed in 2017 in the USA, 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 now 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.

Irreversible, adverse climate change on the global scale now occurring is an existential risk to human civilisation.³ Many of the world’s top climate scientists quoted in this report well understand these implications — James Hansen, Michael E. Mann, John Schellnhuber, Kevin Anderson, Eric Rignot, Naomi Oreskes, Kevin Trenberth, Michael Oppenheimer, Stefan Rahmstorf and others — and are forthright about their findings, where we are heading, and the limitations of IPCC reports.

³ Dunlop, I & Spratt, D 2017, *Disaster Alley: Climate change, conflict and risk*, Breakthrough National Centre for Climate Restoration, Melbourne.

This report seeks to alert the wider community and leaders to these limitations and urges change to the IPCC approach, and to the wider UNFCCC negotiations. It is clear that existing processes will not deliver the transformation to a low-carbon 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”.

EXCESSIVE CAUTION

A 2013 study by Naomi Oreskes and fellow researchers examined a number of past predictions made by climate scientists, and found they 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 [ESLD], whose causes may include adherence to the scientific norms of restraint, objectivity, skepticism, rationality, dispassion, and moderation”. ESLD may cause scientists “to underpredict or downplay future climate changes”.⁴

This tallies with the views 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 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

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”. 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.⁷

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...”

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 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>>.

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."⁸

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."⁹

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...".¹⁰

A good example is the 1.5°C target 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, 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."¹¹

POLITICISATION

Much has been written about the inadequacy of IPCC processes, and the politicisation of 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".¹²

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

⁸ Scherer, G 2012a, 'How the IPCC underestimated climate change', *Scientific American*, 6 December 2012, <<https://www.scientificamerican.com/article/how-the-ipcc-underestimated-climate-change>>.

⁹ Scherer, G 2012b, 'Climate science predictions prove too conservative', *Scientific American*, 6 December 2012, <<https://www.scientificamerican.com/article/climate-science-predictions-prove-too-conservative>>.

¹⁰ 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>>.

¹¹ Anderson, K 2015, 'Duality in climate science', *Nature Geoscience*, vol. 8, pp. 898–900.

¹² Barras, C 2007, 'Rocketing CO₂ prompts criticisms of IPCC', *New Scientist*, 24 October 2007, <<https://www.newscientist.com/article/mg19626274-800-rocketing-co2-prompts-criticisms-of-ipcc/>>.

in nature. The general result may be described as “middle of the road” reporting, in which 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 (see *Underestimating Risk* below).

As one example, the projected sea-level rise in the 2007 assessment 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”.¹³

This is the consensus problem at the scientific level, but there is a second problem at the political level. Whilst the full-length IPCC *Assessment Reports* are compiled by scientists, the shorter and more widely reported *Summary for Policymakers* (SPM) 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”.¹⁴

As early as the IPCC's first report in 1990, US, Saudi and Russian delegations acted in “watering down the sense of the alarm in the wording, beefing up the aura of uncertainty”.¹⁵ Prof. Martin Parry of the UK Met Office, co-chairman of an IPCC working group at the time, has 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”.¹⁶

In 2014, *The Guardian* reported of 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”.¹⁷

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 who was also part of the core writing team, suggests that politics got in the way.¹⁸

¹³ Scherer 2012a, op cit.

¹⁴ Ibid.

¹⁵ Leggett, J 1999, *The Carbon War: Global warming and the end of the oil era*, Routledge, New York.

¹⁶ Adam, D 2007, 'How climate change will affect the world', *The Guardian*, 20 September 2007, <<http://www.guardian.co.uk/environment/2007/sep/19/climatechange>>.

¹⁷ Ahmed, N 2014, 'IPCC reports 'diluted' under 'political pressure' to protect fossil fuel interests', *The Guardian*, 15 May 2014, <<https://www.theguardian.com/environment/earth-insight/2014/may/15/ipcc-un-climate-reports-diluted-protect-fossil-fuel-interests>>.

¹⁸ 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/>>.

UNDERESTIMATION OF RISKS

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 in the permafrost layer 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."¹⁹

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."²⁰

Prof. Ross Garnaut has also pointed to the "understatement of the risks". 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."²¹ 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".²²

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?'"²³ 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. 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."²⁴

¹⁹ Pittock, AB 2006, 'Are scientists underestimating climate change?', *EOS*, vol. 87, no. 34, pp. 340-41.

²⁰ Stern, N 2016, 'Economics: Current climate models are grossly misleading', *Nature*, vol. 530, pp. 407-409.

²¹ Steffen, W, Hughes, L & Pearce, A 2015, *Climate Change: Growing risks, critical choices*, Climate Council, Sydney.

²² Dunlop, I 2016, Foreword to Spratt, D 2016, *Climate Reality Check*, Breakthrough, Melbourne.

²³ 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.

²⁴ *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.

Integral to this approach is the issue of "fat tail" risks in which the likelihood of very large impacts is 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".²⁵

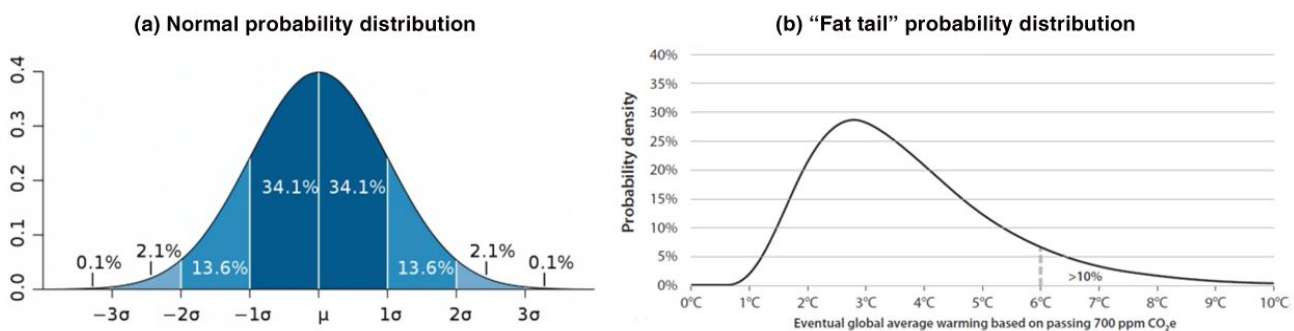


Figure 1: Normal probability distribution (left) and An estimate of the likelihood of warming due to a doubling of greenhouse gas concentrations, from Wagner & Weitzman "Climate Shock" (right)

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".²⁶ 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) above], 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.

²⁵ Mann, M 2016, 'The 'fat tail' of climate change risk', *Huffington Post*, 11 September 2016, <http://www.huffingtonpost.com/michael-e-mann/the-fat-tail-of-climate-change-risk_b_8116264.html>.

²⁶ Ibid.

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.²⁷

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 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.” 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.”²⁸

It is now clear that 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.²⁹ Temperature rises that are now in prospect, ever after the *Paris Agreement*, are in the range of 3–5°C. The *Paris Agreement* voluntary emission reduction commitments, if implemented, would result in the planet warming by 3°C, 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 lead to around 5°C of warming, according to a MIT study.³⁰ 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 across all sectors was 4.1°C.³¹

Warming of 4°C or more could reduce the global human population by 80% or 90%,³² and the World Bank reports “there is no certainty that adaptation to a 4°C world is possible”.³³ A 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”.³⁴ A recent study by the European Commission’s Joint Research Centre found that if global temperatures rise 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. At 55°C or so, much activity in the modern industrial world would have to stop. (“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.)³⁵

²⁷ Ibid.

²⁸ Rahmstorf, S, pers. comm., 8 August 2017.

²⁹ Dunlop and Spratt 2017, op cit.

³⁰ 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.

³¹ Schroder Investment Management 2017, *Climate change: calibrating the thermometer*, Schroders Investment Management, London, <www.schroders.com/globalassets/global-assets/english/pdf/c00140-climatedashboard_section.pdf>.

³² Anderson, K 2011, ‘Going beyond dangerous climate change: Exploring the void between rhetoric and reality in reducing carbon emissions’, LSE presentation, 11 July 2011, <<http://www.slideshare.net/DFID/professor-kevin-anderson-climate-change-going-beyond-dangerous>>; Fyall, J 2009, ‘Warming will ‘wipe out billions’, *The Scotsman*, 29 November 2009, <<http://www.webcitation.org/5ul6K9Jmt?url=http://news.scotsman.com/latestnews/Warming-will-39wipe-out-billions39.5867379.jp>>.

³³ World Bank 2012, *Turn Down the Heat: Why a 4°C warmer world must be avoided*, World Bank, New York.

³⁴ Campbell, K, Gullede, 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.

³⁵ Ayre, J 2017, ‘Extreme heatwaves with ‘apparent temperatures’ as high as 55° celsius to regularly affect much of world’, *CleanTechnica*, 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/>>.

CLIMATE MODELS

The 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 report’s “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 CO₂ 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.³⁶

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, Arctic sea ice 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.³⁷

Glaciologist Prof. Eric Rignot, says that “One of the problems of IPCC is the strong desire to rely on physical models.”³⁸ He explains:

For instance, in terms of sea-level rise projection, the IPCC tends 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 right, the Southern Ocean right, 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.

³⁶ Campbell et al., op cit.

³⁷ Oppenheimer, M, O’Neill, B, Webster, M & Agrawala, S 2007, ‘The Limits of Consensus’, *Science*, vol. 317, pp. 1505-1506.

³⁸ Rignot, E, pers. comm., 8 August 2017.

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.

- **Full coupled GCMs (global climate models or general circulation models)** 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.³⁹
- **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”.⁴⁰ 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 metre based on GCM results.⁴¹

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 paleoclimate research.

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. In some cases, passing one threshold will trigger further threshold events, for example where substantial greenhouse gas releases from 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 a threshold point.

Progress toward a tipping point is often driven by positive feedbacks, in which a change in a component leads to other changes that eventually “feed back” onto the original component to amplify the change. A classic case in global warming is

³⁹ Rahmstorf, S 2007, 'A semi-empirical approach to projecting future sea-level rise, *Science* vol. 315, pp. 368-370.

⁴⁰ Ibid.

⁴¹ Ibid.

the ice–albedo feedback, where decreases in the ice cover area change surface reflectivity, trapping more heat and producing further ice loss.

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 CO₂ (a thousand years).⁴² It is crucial that we understand as much as possible about near-term tipping points for this reason.

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 CO₂ 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”.⁴³

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”.⁴⁴

The IPCC has made no projections regarding tipping-point thresholds, nor emphasised the importance of building robust risk-management assessments of them in the absence of quantitative data.

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 often 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: “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.

What the IPCC reports fail to make clear is that the ECS measure omits key “long-term” carbon-cycle feedbacks that a significant rise in the planet’s temperature will trigger, such as the permafrost feedback and other changes in the terrestrial carbon cycle, or a decrease in the ocean’s carbon-sink efficiency.

⁴² 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, pp. 1704–1709.

⁴³ Schellnhuber, J 2009, ‘Tipping elements in the Earth system’, *Proceedings of the National Academy of Sciences*, vol. 106, no. 6, pp. 20561–20563.

⁴⁴ Duarte, C, Lenton, T, Wadhams, P & Wassmann, P 2012, ‘Abrupt climate change in the Arctic’, *Nature Climate Change*, vol. 2, pp. 60–62.

Climate sensitivity which includes these feedbacks — known as Earth System Sensitivity (ESS) — appears not 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.⁴⁵

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, 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 CO₂ 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. Sherwood et al. also found a sensitivity figure of greater than 3°C. And Zhai et al. found that seven models that are consistent with the observed seasonal variation of low-altitude marine clouds yield an ensemble-mean sensitivity of 3.9°C.⁴⁶

In research published in late 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.⁴⁷ 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 of atmospheric CO₂ (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".⁴⁸

⁴⁵ The Geological Society 2013, *An addendum to the Statement on Climate Change: Evidence from the geological record*, The Geological Society, London, December 2013, <<https://www.geolsoc.org.uk/~media/shared/documents/policy/Statements/Climate%20Change%20Statement%20Addendum%202013%20Final.pdf>>; Hansen, J, Sato, M, Russell, G & Kharecha, P 2013, 'Climate sensitivity, sea level and atmospheric carbon dioxide', *Philosophical Transactions of the Royal Society A*, vol. 371, no. 2001, 20120294.

⁴⁶ 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; Sherwood, S, Bony, S & Dufresne, JL 2014, 'Spread in model climate sensitivity traced to atmospheric convective mixing', *Nature*, vol. 505, pp. 37-42; 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.

⁴⁷ 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.

⁴⁸ Johnston, I 2016, 'Climate change may be escalating so fast it could be 'game over', scientists warn', *Independent*, 9 November 2016, <<http://www.independent.co.uk/news/science/climate-change-game-over-global-warming-climate-sensitivity-seven-degrees-a7407881.htm>>.

PERMAFROST

Related to the issue of climate sensitivity is the question of the stability of permafrost (frozen carbon stores on land and under seabed). Scientists estimate that the world's permafrost holds 1.5 trillion tons of frozen carbon, more than twice the amount of carbon in the atmosphere. The Arctic is warming faster than anywhere else on earth, and researchers are seeing soil temperatures climb rapidly. 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". However, the report offered no projections regarding permafrost melt.

The 2014 *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 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (medium confidence)." That was it. (RCPs are representative concentration pathways of greenhouse gas emission trajectories. RCP2.6 is the lowest and RCP8.5 is the highest.)

The effect of the permafrost carbon feedback on climate has not been included in the IPCC assessment emission scenarios, including the 2014 report.⁴⁹ 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". As far back as 2005, a major study found that if we stabilize CO₂ concentrations in the air at 550 ppm, permafrost would plummet from over 4 million square miles today to 1.5 million square miles. 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.⁵⁰

A 2014 study made use of projections from the most recent IPCC report to estimate that up to 205 gigatons equivalent of CO₂ 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."⁵¹

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 a cage-like lattice of ice inside of which are trapped methane molecules.)

⁴⁹ UNEP 2012, *Policy Implications of Warming Permafrost*, United Nations Environment Program, Nairobi, <<http://wedocs.unep.org/handle/20.500.11822/8533>>.

⁵⁰ 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.

⁵¹ 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.

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 massive 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, who said that the release of a single giant “pulse” of methane from thawing Arctic permafrost beneath the East Siberian Sea could come with a \$60 trillion global price tag.⁵²

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”.⁵³

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.⁵⁴

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

New data obtained by complex biochemical, geophysical and geological studies conducted in 2011-2016 resulted in the conclusion 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.⁵⁵

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

CARBON BUDGETS

A carbon budget is an estimate of total allowable fossil fuel use, in tons of carbon or CO₂, that would limit warming to a specified figure, such as 1.5°C or 2°C, with a given risk of over-shooting the target, such as a 50%, 33% or 10% risk.

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-CO₂ forcings such as methane and nitrous oxide. Too often, the risk of failure is not clearly spelt out, especially “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-risk 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

⁵² Whiteman, G, Hope, C & Wadhams, P 2013, ‘Climate science: Vast costs of Arctic change’, *Nature*, vol. 499, pp. 401–403.

⁵³ Ahmed, N 2013, ‘Ice-free Arctic in two years heralds methane catastrophe – scientist’, *The Guardian*, 25 July 2103, <https://www.theguardian.com/environment/earth-insight/2013/jul/24/arctic-ice-free-methane-economy-catastrophe>

⁵⁴ Tomsk Polytechnic University 2017, Russian scientists deny climate model of IPCC’, *Eureka Alert*, 15 August 2017, https://www.eurekaalert.org/pub_releases/2017-08/tpu-rsd081517.php

⁵⁵ *ibid.*

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 likely emissions resulting from future food production and deforestation are taken into account, there is no carbon budget for fossil fuel emissions for a 2°C target.⁵⁶

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.

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 it 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."⁵⁷

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 2030.⁵⁸ Of this, the 2007 IPCC report said nothing.

There was a similar, mind-numbing drop in Arctic sea-ice extent again in the summer of 2012, again far in advance of the models. By 2012, the summer minimum sea-ice volume was one-third of that just 30 years earlier.

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 had 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

⁵⁶ 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.climatecoded.org/2014/05/the-real-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 & 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.

⁵⁷ Scherer 2012a, op. cit.

⁵⁸ 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.

region", so their ensemble mean trend in September Arctic sea-ice extent "is approximately 30 years behind the observed trend".⁵⁹

Because climate models are missing key real-world interactions and generally have been poor at dealing with Arctic sea-ice retreat, expert elicitations play a key role in considering whether the Arctic has passed a very significant and "dangerous" tipping point.⁶⁰ But the IPCC has not done this.

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 7 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 that 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".⁶¹

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.⁶²

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

⁵⁹ 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.

⁶⁰ 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.

⁶¹ 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, <<https://www.newscientist.com/article/dn9717-greenland-ice-cap-may-be-melting-at-triple-speed>>.

⁶² AFP 2008, 'Climate change gathers steam, say scientists', *Space Daily*, 30 November 2008, <<http://www.spacedaily.com/2006/081130055637.szeh21pj.html>>.

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.⁶³

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.⁶⁴

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.⁶⁵

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 to imagine how the rate of Greenland ice sheet deglaciation can other than continue 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 tipping points would have consequences that are practically irreversible on time scales of relevance to humanity."⁶⁶ 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 meter 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.⁶⁷

⁶³ Mooney, C, 2015, 'Greenland has lost a staggering amount of ice — and it's only getting worse', *Washington Post*, 16 December 2015, <<https://www.washingtonpost.com/news/energy-environment/wp/2015/12/16/greenland-has-lost-a-staggering-amount-of-ice-and-its-only-getting-worse/>>.

⁶⁴ Robinson, A, Calov, R & Ganopolski, A 2012, 'Multistability and critical thresholds of the Greenland ice sheet', *Nature Climate Change*, vol. 2, pp. 429–432.

⁶⁵ Maslowski, Kinney et al. 2012, op cit.

⁶⁶ 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>>.

⁶⁷ 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.

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 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 1 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.”⁶⁸

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”.⁶⁹ 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 CO₂, contributing 10 metres or more of sea-level rise in the longer run, and 5 metres in the first 200 years.⁷⁰

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 rise of 2 mm per year. By 2007, the researchers found that the range of 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”.⁷¹

⁶⁸ 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.

⁶⁹ DeConto, R & Pollard, D 2016, ‘Contribution of Antarctica to past and future sea-level rise’, *Nature*, vol. 531, pp. 591–597.

⁷⁰ 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.

⁷¹ Rahmstorf 2007, op cit.

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."⁷²

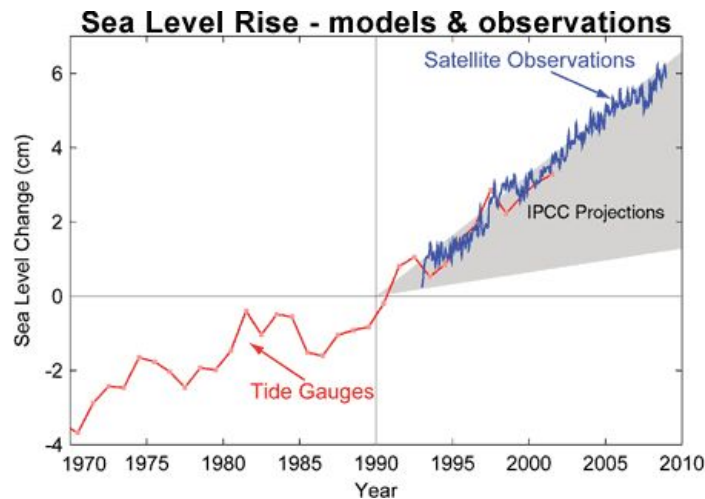


Figure 2: Observed sea-level rise 1970-2010 from tide gauge data (red) and satellite measurements (blue) compared to model projections for 1990-2010 from the IPCC Third Assessment Report (grey band). (Source: *The Copenhagen Diagnosis*, 2009)

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 m relative to 1990, with 1.1–1.2 m the midrange of the projection". And: "Current estimates of sea-level rise range from 0.50 m to over 2 m by 2100."⁷³

Yet extraordinarily, the 2014 IPCC assessment report repeated the mistake and actually produced a numerically smaller figure (0.55 m as compared to 0.59 m 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 m for RCP2.6, and of 0.45 to 0.82 m 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 which they had quantified?

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 early 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

⁷² Hansen 2007, op cit.

⁷³ Australian Government, 2009, *Climate Change Risks to Australia's Coasts: A first pass national assessment*, Australian Government, Canberra; CSIRO/BoM/Department of Climate Change 2009, *Science Update 2009*, no. 2, November 2009, Australian Government, Canberra.

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”.⁷⁴

The fact of the matter is that today the discussion amongst experts is for a sea-level rise this century of at least 1 metre, and perhaps in excess of 2 metres. The US Department of Defence uses scenarios of 1 and 2 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 less than 1°C of warming, West Antarctic glaciers are in “unstoppable” meltdown for 1-4metres of sea-level rise, only add to grave concern that the IPCC reports are simply irrelevant on this matter.

POLITICAL CONSENSUS

The IPCC and the UNFCCC are the twin climate processes of the United Nations.

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 *Summary for Policymakers* is agreed. The decision-making is inclusive (by consensus), making outcomes hostage to national interests and lowest-common-denominator politics.

The COP 21 *Paris Agreement*⁷⁵ 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°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 emissions.

⁷⁴ NOAA 2017, *Global and regional sea-level rise scenarios for the United States*, NOAA, Silver Spring MA, <https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf>.

⁷⁵ UN 2015, *Paris Agreement*, United Nations, New York, <http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf>.

GOALS ABANDONED

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”.⁷⁶ 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.⁷⁷

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.⁷⁸ 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 major ocean current known as the Atlantic conveyor, likely as a result of climate change; accelerating ice-mass loss from Greenland; 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.

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 its lags in its publication process, and a “burning embers” representation of the risks that again looks too conservative.⁷⁹

An expert panel recently concluded that warming would need to be limited to 1.2°C to save the Great Barrier Reef.⁸⁰ That is probably too optimistic, but with a warming trend of 1.05–1.1°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”.

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.⁸¹

⁷⁶ 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>.

⁷⁷ 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.

⁷⁸ Livina & Lenton 2013, op. cit.; Rignot, Mouginit et al. 2014, op. cit.; DeConto & Pollard 2016, op. cit.

⁷⁹ 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.

⁸⁰ Hannam, P 2017, ‘Warming limit of 1.2 degrees needed to save Great Barrier Reef: expert panel’, *The Age*, 2 August, <<http://www.theage.com.au/environment/climate-change/warming-limit-of-12-degrees-needed-to-save-great-barrier-reef-expert-panel-2017-0728-gxkwp.html>>.

⁸¹ Werrell, CE & Femia, F 2013, *The Arab Spring and Climate Change*, edn., Centre for American Progress/Stimson/The Center for Climate and Security, Washington.

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). The *Paris Agreement* made no references to time-frames sufficient to allow ecosystems to adapt naturally to climate change, suggesting this goal has been (literally) dropped.

Because climate change is already dangerous, a reframing of the objective for international policymaking is required.

A FAILURE OF IMAGINATION

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

— Prof. Hans Joachim Schellnhuber, director of the Potsdam Institute⁸²

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.”⁸³

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.

A similar failure is occurring in our understanding of and response to climate change today.

The problem is widespread at 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... 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.”⁸⁴

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 is 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.

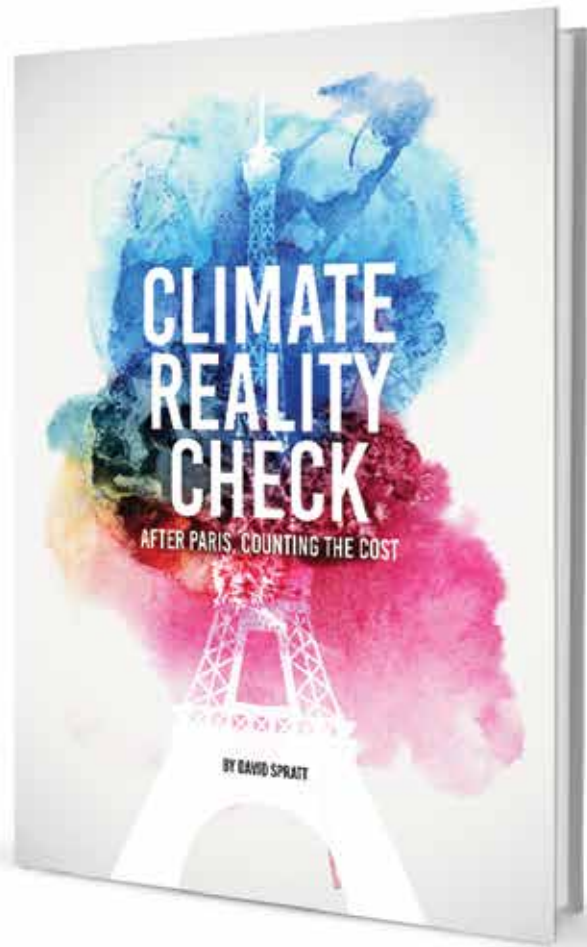
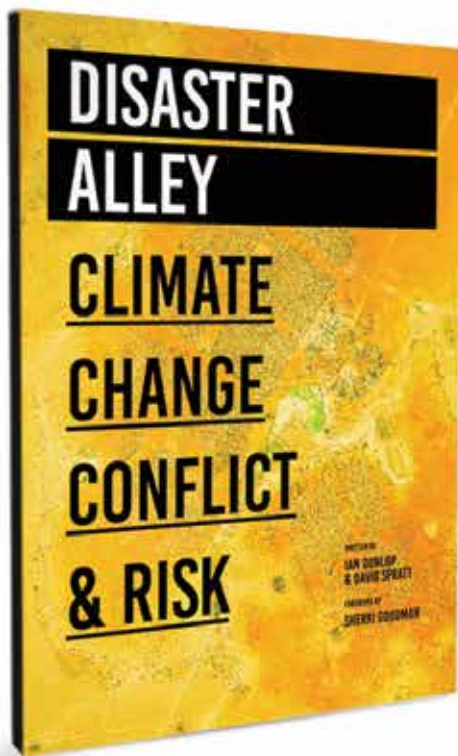
⁸² Leahy, S 2009, ‘Climate Change: Four degrees of devastation’, *Inter Press Service*, 9 October 2009, <<http://www.ipsnews.net/2009/10/climate-change-four-degrees-of-devastation/>>.

⁸³ Stewart, H 2009, ‘This is how we let the credit crunch happen, Ma’am ...’, *The Guardian*, 26 July, <<https://www.theguardian.com/uk/2009/jul/26/monarchy-credit-crunch>>.

⁸⁴ Gowing, N & Langdon, C 2016, *Thinking the Unthinkable: A new imperative for leadership in the digital age*, Chartered Institute of Management Accountants, London.

Climate policymaking at all levels of government use the reports of the IPCC as the primary physical science basis. The failure of the IPCC to report in a balanced manner the full range of risks and to fully account for high-end outcomes leaves policymakers ill-informed and 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.

A reframing of the scientific research within an existential risk-management framework is now urgently required, if policymaking is to be soundly based.



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