CLIMATE REALITY CHECK

AFTER PARIS, COUNTING THE COST

BY DAVID SPRATT

FOREWORD BY IAN DUNLOP

"OUR CLIMATE IS NOT SAFE NOW, SO WHAT DOES DANGEROUS CLIMATE CHANGE MEAN?"

Prof. David Karoly, The Age, 4 December 2015

BREAKTHROUGH

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FOREWORD

"Recount", our Breakthrough report published in April 2015, emphasised the need for emergency action if the potentially catastrophic and irreversible impacts of climate change are to be avoided.

It explained why the international policy target of limiting warming to 2˚C above pre-industrial levels is too high, and why there is no remaining carbon budget if we are to have a realistic chance of holding warming to even the 2˚C level.

The Paris December 2015 climate summit in part acknowledged this, endorsing the goal "to hold the increase in global average temperature to well below 2˚C, and to pursue efforts to limit the temperature increase to 1.5˚C".

It is progress to have unanimous agreement from global and corporate leaders about the urgent need to meet these objectives. In political terms, the agreement was far more than expected, but in practical terms it is a disaster in which the chasm between rhetoric and scientific reality has dramatically widened. There is now an unjustified sense of complacency amongst many of the key players that the Paris objectives can be met by tweaking "business-as-usual" policies without radical change, as the glossy brochures and promises pouring forth since Paris from politicians, the corporate sector and international agencies demonstrate.

Ironically, climate change has accelerated rapidly over the last year, in part due to the unprecedented El Niño weather system generating record extreme events. But dangerous impacts from the underlying trend have also manifested far faster and more extensively than global leaders and negotiators are prepared to recognise.

The fundamental point being missed is that the "fat-tail" risks of climate change — the irreversible, positive-feedback tipping points which have long concerned scientists — are being triggered at today's warming of just 1˚C. This can be seen in the Arctic and the Antarctic, in our oceans, and not least with the destruction of the Great Barrier Reef. These are genuine, existential risks unlike anything previously experienced by humanity, which will result in a substantial reduction in global population unless rapidly addressed. They cannot be handled by existing risk-management techniques.

Given the latest evidence, it is almost impossible to now keep the temperature increase below 1.5˚C or even 2˚C with the current approaches. We have left it too late to solve the climate dilemma with a graduated response; emergency action, akin to placing economies on a war footing, remains essential.

This is not irrational alarmism, but an objective view of the latest science and evidence, as set out in this paper, which should be read and absorbed by every decision maker. New leadership, prepared to grasp and act on this reality, is essential.

IAN DUNLOP
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New Jersey coastline in the aftermath of Hurricane Sandy (Olsen/ New Jersey Army National Guard)

AFTER PARIS, COUNTING THE COST

George Monbiot wrote of the December 2015 Paris climate conference: "By comparison to what it could have been, it's a miracle. By comparison to what it should have been, it's a disaster." Big flaws in the deal mean it gives the impression that global warming is now being properly addressed, when in fact the measures fall alarmingly short of what is needed to avoid escalating climate change, and set the world on course for well over 3˚C of warming.

Prof. Kevin Anderson of the UK Tyndall Centre for Climate Change is fond of quoting the twentieth century quantum physicist and Nobel laureate Richard P. Feynman: "For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled."

We fool ourselves if we are not deeply alarmed by recent events. In 2015, atmospheric carbon dioxide (CO2) concentrations jumped by 3.05 parts per million (ppm), the largest year-to-year increase in 56 years of research data. 2015 was the fourth consecutive year that CO2 grew more than 2 ppm.[1] Methane levels also reached a new instrumental high, 254 per cent higher than the pre-industrial level.[2] And Arctic sea-ice extent hit a record winter low.

2015 was the hottest year on record by a significant margin. The UK Met Office says 2016 will be as hot or hotter, and observations support this forecast.[3] Scientists were stunned by NASA data that February 2016 was an "unprecedented" 1.65˚C warmer than the beginning of the twentieth century. That is 1.9˚C higher than the pre-industrial level.[4] The El Niño conditions contributed around 0.2˚C or more to the record figures[5] but, compared to previous big El Niños, we are experiencing blowout temperatures.

Prof. Michael Mann says, "We have no carbon budget left for the 1.5˚C target and the opportunity for holding to 2˚C is rapidly fading unless the world starts cutting emissions hard right now".[6] Other experts agree.

Prof. Stefan Rahmstorf of Germany's Potsdam University considers that we are now "in a kind of climate emergency"[7] and that at least 1.5˚C is "locked in".[8] More and more scientists agree.

Like the dramatic and unexpected Arctic "big melt" in 2007, these record temperatures confront us with the terrifying reality of global warming. Nature cannot be fooled. The recent data suggest it has taken just months for the Paris climate accord — with its escalating emissions to 2030 — to become a relic because of its gross inadequacy for the task the world now faces.

So what is the reality after Paris? What do recent research findings and observations teach us? And what does decisive leadership look like in the era of climate emergency?

1. CARBON EMISSIONS & TEMPERATURE

Human-caused carbon dioxide emissions increase the global average temperatures, such that the elevated temperatures remain roughly constant for many centuries.[9] One landmark research paper says that "any future anthropogenic emissions will commit the climate system to warming that is essentially irreversible on centennial timescales".[10]

In other words, we cannot, on human time scales and in the normal course of events, undo the elevated temperatures and damage done by CO_2 emissions. The only exception to this understanding would be the deployment of incoming solar radiation management or very large-scale CO_2 removal (negative-emission) technologies to cool the Earth. In the main, these technologies at present are at little more than a conceptual stage of development and not currently deployable at scale (see Section 15).[11]

2. "COMMITTED" WARMING

Accounting for inter-annual variability, global warming has now reached ~1˚C above the 1880-1920 level.[12] And warming is now ~1.2˚C above the 1750 pre-industrial level.[13]

If we were to cease burning fossil fuels today, the loss of aerosol cooling (see next section) would quickly add ~0.5˚C or more to temperatures, taking warming to ~1.7˚C above the pre-industrial level.[14] The more fossil fuels we burn, the higher this level of "committed" warming will become in the absence of yet unproven, large-scale, negative-emission and/or solar radiation technologies.

Each decade, human activity is adding ~20 ppm of CO_2 to the atmosphere,[15] enough to cause an extra ~0.2˚C of warming. So if the emissions trajectory over the next 15 years follows the Paris path — in which annual emissions would be ~10% higher in 2030 than they are today[16] — then by 2030 "committed" warming will have risen by ~0.3˚C to ~2˚C.

Analyst Bill Hare of Climate Analytics says: "if the Paris meeting locks in present climate commitments for 2030, holding warming below 2˚C could essentially become infeasible."[17] In this sense, Paris has locked out a less-than-2˚C outcome, unless immediate and radical emission reductions occur across the high-polluting, developed economies.[18]

3. FAUSTIAN BARGAIN

A by-product of burning fossil fuels is a group of substances known as aerosols (including black-carbon soot, organic carbon, sulphates and nitrates) which have a short-term (~one week) cooling impact generally estimated to be in the range of ~0.5–0.8˚C. For now, these aerosols are ameliorating the warming impact of increasing levels of greenhouse gases, including carbon dioxide, methane and nitrous oxide.

Reducing the use of fossil fuels, however, will also reduce the production of aerosols, and the loss of their cooling effect will increase the global temperature. But not stopping fossil fuel use will eventually cause global warming sufficient to threaten human civilisation.

Former NASA climate science chief Prof. James Hansen keenly observed this dilemma to be our Faustian bargain, in which the "devil's payment" will be extracted from humanity via increased global warming as we end fossil fuel use: "As long-lived CO_2 accumulates, continued balancing requires a greater and greater aerosol load. Such a solution… would be a Faustian bargain. Detrimental effects of aerosols, including acid rain and health impacts, will eventually limit the permissible atmospheric aerosol amount and thus expose latent greenhouse warming."[19]

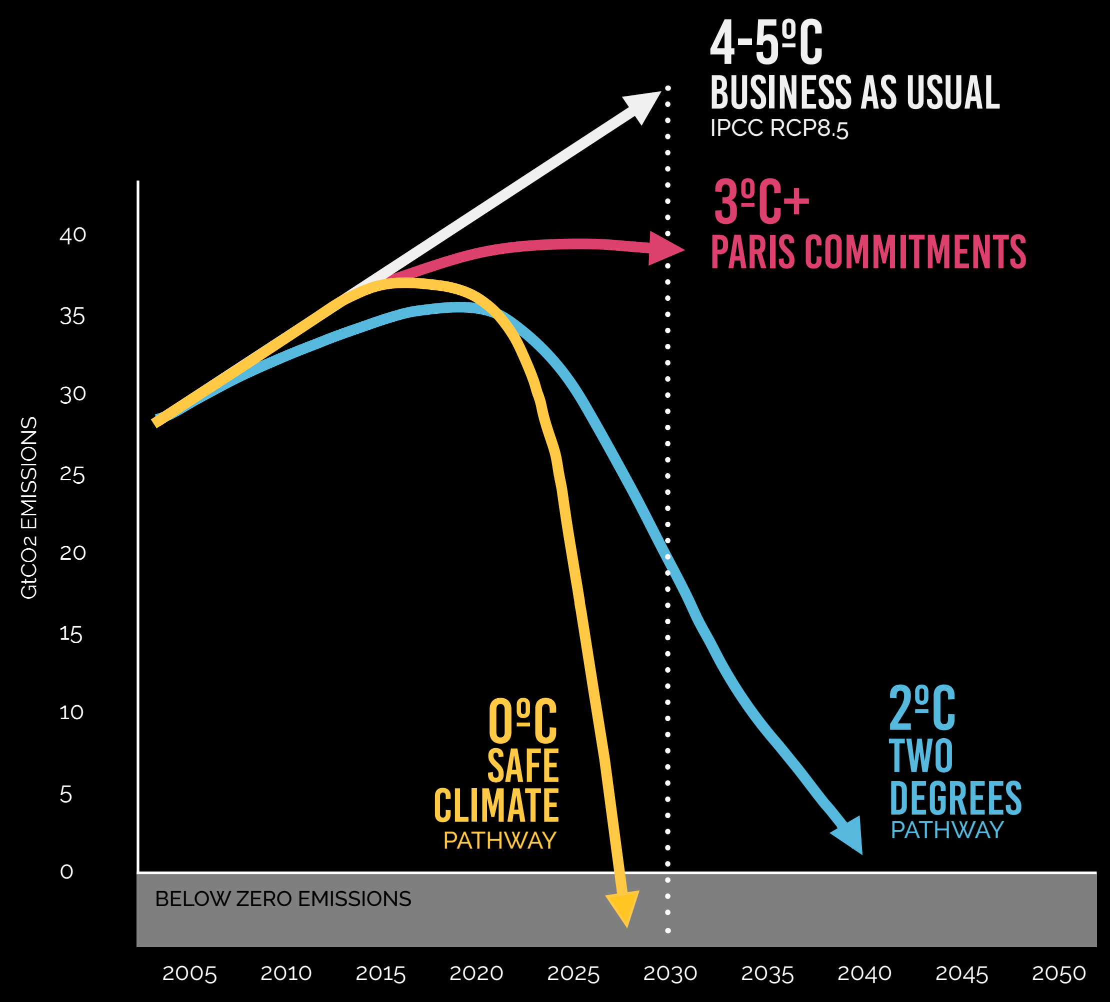
4. PARIS COMMITMENTS

Although the Paris deal gives the impression that global warming is now being properly addressed, in fact the measures fall alarmingly short of what is needed to avoid escalating climate change.[20] Amongst its "deadly flaws" is the lack of any obligation on the parties to upgrade their existing pledges before 2030.

Indeed, analysis reveals that the Paris voluntary commitments, with no further progress in the post-pledge period, would result in expected warming by 2100 of 3.5˚C (uncertainty range 2.0–4.6˚C).[21]

Claims that the Paris commitments represent a 2.7˚C path are dangerously overconfident as they are based on a highly uncertain assumption that countries will commit, in the future, to keep reducing emissions after 2030 at the rate they did before hand.[22]

PARIS COMMITMENTS COMPARED TO 2°C PATHWAY



SOURCES: WBGU special report 2009; Boyd, Stern & Ward (May 2015); IPCC 2014; Climate Action Tracker; Philip Sutton.

5. FEASIBILITY OF 1.5ºC GOAL

The Paris agreement's stated aims are to keep warming "well below 2˚C above pre-industrial levels" and to "pursue efforts to limit the temperature increase to 1.5˚C".

A goal far below 1.5˚C is highly desirable, because climate change is already dangerous.

"Committed" warming today is now 1.7˚C[23] and will be ~2˚C by 2030 if emissions proceed along the Paris pathway. So there is no carbon budget left for 1.5˚C: "And what about 1.5˚C stabilisation? We're already overdrawn", says Prof. Michael E Mann, one of the world's foremost climate scientists.[24]

Researchers say there are no model scenarios currently in the literature 'where global temperatures remain below 1.5˚C throughout this century". Current "overshoot" scenarios — exceeding 1.5˚C of warming and returning to below 1.5˚C by assuming the deployment of large-scale negative-emission technologies later in the century — impose challenging requirements, including "curtailing future energy demand... with only a slight increase over today's demand by 2100, despite rising populations and growing economies".[25]

The possibility of staying below 1.5˚C of warming for the whole of this century would require geo-engineering techniques such as the deployment of sulphate aerosols to reduce the amount of incoming solar radiation (see Section 15). Such approaches are not proven or safe technology, and are opposed by the large climate action NGOs, without exception. Likewise, the large-scale negative-emission technologies necessary to get warming back under 1.5˚C by 2100 in the "overshoot" scenarios are not presently deployable in an environmentally safe way and at manageable cost, and are strongly opposed by significant elements of the climate justice movement.

6. RELIANCE ON NEGATIVE EMISSIONS TECHNOLOGIES

Rather than requiring large emissions reductions in the short-to-medium term, the Paris agreement instead relies on being able to successfully suck the carbon pollution back from the atmosphere in the longer term, plumping for biomass energy with carbon capture and storage (BECCS) as the most promising negative-emissions technology.

BECCS is an unproven technology at scale and "negative-emission technologies... are currently at little more than a conceptual stage of development", yet the framing of the 2˚C goal and, even more the 1.5˚C one, is premised on the massive uptake of BECCS some time in the latter half of the century.[26]

Potsdam Institute head Prof. John Schellnhuber warns against "the illusion you can just extract huge amounts of carbon from the air in order to restore the atmosphere".[27]

The land-use intensity of BECCS is quite high, with values of ~1-1.7 hectares per ton of carbon per year.[28] In other words, if ALL the world's land currently devoted to cropping (~3 billion hectares) were devoted to BECCS, the drawdown would be ~3 billion tonnes of carbon per year — still only about 30% of the world's current annual emissions. Whether the storage of the compressed carbon dioxide in expired oil and gas fields and other underground geological sites would be secure and stable over the long term is another question for which there is yet no satisfactory answer.

CHANCES OF KEEPING BELOW 2ºC

Releasing a further...

2˚C is the boundary between dangerous & very dangerous climate change - how much can we chance?

7. CARBON BUDGETS

Any temperature target only has practical meaning if the risk of exceeding it is known, and the scale of the impacts of exceeding the target are also known. A low-impact risk target for atmospheric greenhouse gases is very much less than the current level: the IPCC reported that "to provide a 93% mid-value probability of not exceeding 2˚C, the concentration (of atmospheric greenhouse gases) would need to be stabilised at or below 350 parts per million carbon dioxide equivalent (ppm CO2e)" compared to the current level of ~485 ppm CO2e.[29]

The catastrophic consequences caused by 2˚C of warming demand a strong risk-management approach of having a very low probability of exceeding the target, and fully accounting for the likelihood of changes in the carbon cycle. Yet policymakers focus on "middle of the road" outcomes, and turn a collective blind eye to the bad possibilities that are much more likely to occur than is widely acknowledged (see Appendix).

While policy-makers and advocates often talk about a carbon budget of allowable fossil fuel use that would limit warming to 2˚C, the evidence shows we have no such budget for a sensible risk-management, low-risk probability of exceeding that target.[30] 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). And there is certainly no carbon budget for fossil fuel emissions after accounting for likely emissions resulting from future food production and deforestation.

Anderson and Bows have shown that even with a too-high goal of holding temperatures to 2˚C (with only a 66% probability of success), for developed economies to play a fair role they would have to cut their emissions by 40% delete reduction by 2018, 70% delete reduction by 2024, and 90% by 2030 from 1990 levels.[31]

8. CARBON CYCLE FEEDBACKS

There is an unacceptable risk that before 2˚C of warming is reached, significant "long-term" feedbacks will be triggered, in which warmer conditions make carbon sinks (stores) such as the oceans and forests less efficient at storing carbon, and polar warming triggers the large-scale release of greenhouse gases from melting terrestrial permafrost and frozen methane deposits on the ocean floor.

This escalating release of greenhouse gases generates even more warming in a cycle of reinforcing feedbacks that could make an effective human response extremely difficult.

It is conventionally considered that these feedbacks 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 Palaeocene–Eocene Thermal Maximum, a period with one of the largest extinction events on record.[32] 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.

A recent study makes use of projections from the most recent IPCC report to estimate that up to 200 billion tonnes of carbon could be released due to melting permafrost and cause up to 0.5˚C extra warming.[33] Some carbon stores have already reached a tipping point, and are now becoming carbon emitters rather than carbon sinks.

These include Arctic tundra.[34] One research paper concluded 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." [35]

In February 2013, scientists using radiometric dating techniques on Russian cave formations to measure melting rates warned that a 1.5°C global rise in temperature compared to the pre-industrial level was enough to start a general permafrost melt. [36]

In the first half of 2015, new lines of evidence were published suggesting that more elements of the system may be heading towards tipping points or experiencing qualitative change. These include the slowing of the major sea current known as the Atlantic conveyor, likely as a result of climate change; accelerating ice mass loss from Antarctic ice shelves and the vulnerability of East Antarctica glaciers; declining carbon efficiency of the Amazon forests and other sinks; rapid thinning of Arctic sea-ice; and the vulnerability of Arctic permafrost, exemplified by the proliferation of Siberian methane craters. [37]

9. CRYOSPHERE THRESHOLDS

In late 2015, a chilling report on *Thresholds and closing windows: Risks of irreversible cryosphere climate change* [38] warned that the Paris commitments will not prevent the Earth "crossing into the zone of irreversible thresholds" in polar and mountain glacier regions, and that crossing these boundaries may result in processes that cannot be halted unless temperatures were returned to below the pre-industrial level.

It warns that: "These thresholds are drawing closer… some of these changes may close during the 2020–2030 (Paris) commitment period."

The consequences would include the loss of reliable water resources from mountain glaciers for millions of people; the melting of polar ice sheets that would set the world on a course to a sea-level rise of 4–10 metres or more; and fisheries and ecosystem loss from polar ocean acidification.

The report says it is not well understood outside the scientific community that cryosphere dynamics are slow to manifest but once triggered "inevitably forces the Earth's climate system into a new state, one that most scientists believe has not existed for 35–50 million years".

Observational estimates based on model simulations and the record of past climates make it appear very likely that "the loss of certain vulnerable parts of our planet's ice sheets will become unstoppable at temperatures and CO_2 concentrations at, or very close to those of today". The "best estimate" for "the threshold for Greenland melt to become irreversible" is 1.6˚C, a threshold beginning near today's levels and well below the 2.7–3.5˚C estimate from the Paris Accord.

10. ACCELERATING SEA-LEVEL RISE

Climate warming causes the ocean volume to expand. It melts polar and mountain glaciers. Both raise the sea level. The questions are how far, and how fast?

Most of sea-level rise for this century have been 0.5–2 metres, and centred around 1 metre, but this is only the tip of the iceberg. Prof. Kenneth Miller says: "The natural state of the Earth with present CO_2 levels is one with sea levels about 70 feet (21 metres) higher than now."[39] Other research scientists agree it is likely to be more than 20 metres.[40] The long-term sea-level rise associated with a 2˚C warming would submerge parts of Australia on which 25-50% of the population lives.[41]

Major recent studies show a number of polar ice sheets are unstable and heading toward collapse. As to how fast the seas will rise, one answer is "several metres" this century, according to Prof. James Hansen and 17 highly-regarded co-authors, who map a potential path to the "loss of all coastal cities" and the arrival of "super storms" not previously experienced by humans.[42] Superstorm Sandy and Cyclone Haiyan may be precursors of such a future.

This research surveys evidence from the previous warm Eemian interglacial period around 120,000 years ago. At that time there were of rapid fluctuations in sea level, and the research identifies a mechanism in the Earth's climate system not previously understood, which points to a much more rapid rise in sea levels than currently anticipated. Increasing ocean stratification occurs when cooler surface layers from melting ice sheets trap warmer waters underneath, accelerating their impact on the melting of ice shelves and outlet glaciers. This in turn increases ice sheet mass loss, and generates more cool surface melt water in a positive feedback.

The consequences include the slowing or shutting down of key ocean currents including the Gulf Stream System, which would increase temperature differentials between tropical and sub-polar waters, and drive "super storms" such that "All hell will break loose in the North Atlantic and neighbouring lands." [43]

The projected coolIng pattern of waters around Antarctica and the north Atlantic waters from the injection of fresh ice-melt water is already visible in the observed data and is already contributing to a circulation decline of the Gulf Stream System and cooling of some European countries. [44]

Another significant new study [45] dovetails with the Hansen study and concludes that "Antarctica has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500", doubling previous forecasts for total sea level rise this century to 2 metres and more. "People should not look at this as a futuristic scenario of things that may or may not happen. They should look at it as the tragic story we are following right now," says Eric Rignot, an expert on Antarctica's ice sheet and an earth sciences professor at the University of California. [46]

Retreat of Jakobshavn Glacier, Greenland.

11. THE FATE OF CORAL REEFS

The Great Barrier Reef is home to 600 different types of corals. It has greater diversity than any other UNESCO World Heritage site. But it is dying.

Record high water temperatures in the Coral Sea in early 2016 caused unprecedented destruction of the Reef, when corals stressed by water more than 1˚C hotter than normal expelled the zooxanthellae algae with which they live in a symbiotic relationship.

This "bleaching" — so named because algae give corals their colour and their loss leaves the coral structures white and lifeless — is the worst such event on record. Of 911 reefs included in an initial survey, 500 were severely bleached. Of the 522 reefs surveyed in the pristine and isolated northern sector, 81% were severely bleached. Scientists found: "North of Port Douglas, we're already measuring an average of close to 50% mortality of bleached corals. At some reefs, the final death toll is likely to exceed 90%." Around Lizard Island there is almost no living coral left. Before this mass bleaching started, the Great Barrier Reef had lost 50% of its coral cover. It takes several months for the full mortality to take effect, but the final death rate in the northern sector will be much higher than 50%.[47]

This means that significantly more than 60% of the Reef's coral cover has been lost in just three decades due to the effects of tropical cyclones, crown-of-thorns starfishes and reduced water quality, as well as climate change.

Moderately bleached corals can recover, but with severe bleaching mortality is high. Colonies may start to re-grow after healthy upstream reefs spawn; but it takes 10–15 years for reefs to regain health and that only happens if there is no further bleaching over that time. An adequate recovery time is crucial, somewhat like forests after a fire.

The global average land and sea surface temperature for January–March 2016 rose to 1.5˚C above the 1880-1900 baseline, compared to the average warming of 1˚C over recent years.

Researchers at the University of Melbourne say that for the Coral Sea there is "at least a 175 times increase in likelihood of hot (water temperature) March months because of the human influence on the climate", and that whilst the decaying 2015 El Niño event may have affected the likelihood of bleaching events, there was "no substantial influence for the Coral Sea region as a whole", which can be warmer than normal for different reasons.

They also found that: "March 2016 was clearly extreme in the observed weather record, but using climate models we estimate that by 2034 temperature anomalies like March 2016 will be normal". [48] In this scenario, reefs simply will not have the 10–15 years' recovery time they need, and will fall into a death spiral of more frequent bleaching events followed by increasingly inadequate recovery periods.

In 2009, Australian scientists contributed to an important research paper which found that preserving more than 10% of coral reefs worldwide would require limiting warming to below 1.5˚C.[49]

This year we have learned that, in fact, just 1˚C of average global warming is deadly for the Reef. Pioneer coral researcher Charlie Veron told the Royal Society in 2009: "The safe level of atmospheric carbon dioxide for coral reefs is ~320 ppm (and) sets the safe limit for a healthy planet during a time of abrupt greenhouse-driven climate change."[50] Today's level is 400 ppm and rising.

Corals' calcium carbonate structures are vulnerable to higher levels of carbonic acid, a consequence of the draw-down of increasing amounts of carbon dioxide from the atmosphere into the world's oceans. The last time oceans became acidic as fast as they are today, 96% of marine life became extinct. Parts of the Southern Ocean have already become acidic enough to dissolve sea snails' shells.

Coral reefs provide food and resources for over 500 million people along tropical coastlines, as well as coastal protection against storm surges.[51] If the world's coral systems are lost, coastal ecosystems will only be able to provide 20–50% of the fish protein that they do today for those half a billion people.

Australia's neighbours are particularly vulnerable. The Coral Triangle — encompassing Indonesia, Philippines, Malaysia, Papua New Guinea, the Solomon Islands and Timor Leste — contains 76% of the world's reef building corals and over 35% of the world's coral-reef fish species. It is the richest place on earth in terms of biodiversity.

The 100 million people who live along the coasts of these islands depend on healthy ecosystems such as coral reefs, mangroves and seagrass beds to provide food, building materials, coastal protection, and support industries such as fishing and tourism.[52]

The 2016 mass bleaching extended from Tanzania to French Polynesia, devastating reefs in Australia's Kimberley region, at India's Lakshadweep Archipelago, at Reunion Island in the western Indian Ocean, around the Seychelles, Christmas Island and in New Caledonia, as well as the Great Barrier Reef. This climate catastrophe is truly global.

"WHEN ARE WE GOING TO STOP PRETENDING THAT +2°C IS SAFE FOR THE GREAT BARRIER REEF, WHEN +1°C ALREADY BLEACHES 93% OF IT?"

Prof. Terry Hughes, ARC Centre of Excellence for Coral Reef Studies, James Cook University, 21 May 2016

Coral bleaching at Lizard Island (XL Catlin Seaview Survey)

12. ONE-DEGREE IMPACTS

Evidence suggests tipping points for events, which may be irreversible on century time scales, are being crossed already. The Arctic is warming two-to-three times as fast as the global average.[53] Even before we reached 1˚C of global warming, a dynamic had been established that will lead to sea-ice-free Arctic summer conditions, with severe consequences for the future stability of permafrost and frozen methane stores, and for sea-level rises, as well as for accelerated global warming as ice sheets retreat and the Earth's albedo (reflectivity) decreases.[54]

One of the most significant research findings in 2014 was that the "tipping point" has already been crossed for the Amundsen Sea sector of West Antarctica at under 1˚C of warming. Scientists found that the retreat of ice was "unstoppable" (unless temperatures return to the level of the 1970s). The consequences include that: "sea levels will rise one metre worldwide… [the ice's] 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."[55] (Note: "millions" would seem a significant understatement.)

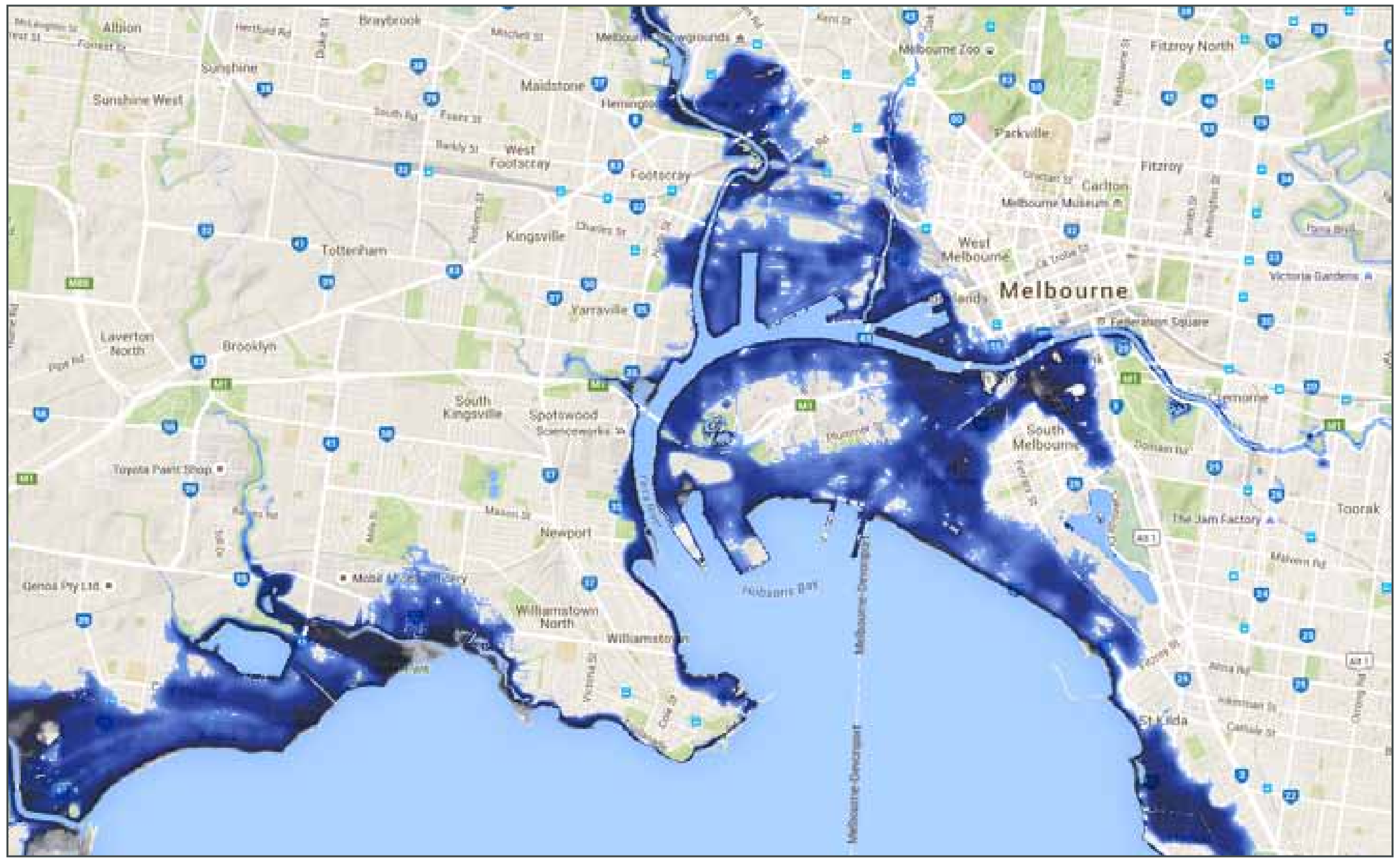
While a one-metre sea-level rise may sound manageable, it would destroy some nations, flood some of the world's richest river-delta agricultural lands or render them unusable due to salination, and likely create climate-change-driven failed states. In Bangladesh, a one-metre sea level rise would inundate 15-17% of the land and threaten more than a million hectares of agricultural land. The Mekong River Commission warns that a one-metre sea-level rise would wipe out nearly 40% of the Mekong Delta.[56] A one-metre rise would flood one-fourth of the Nile Delta, forcing more than 10% of Egypt's population from their homes. Nearly half of Egypt's crops, including wheat, bananas and rice, are grown in the delta.[57]

Current climate trends, if not arrested and reversed rapidly, will likely lead to a substantial displacement of, and reduction in, global population, with attendant mass social conflict and migration, early signs of which are already evident in the Middle East and North Africa.

The Syrian conflict was preceded by the worst long-term drought and crop failures since civilisation began in the region, resulting in 800,000 people losing their livelihoods by 2009, and 2–3 million being driven into extreme poverty.[58] The eastern Mediterranean has experienced significant decreases in winter rainfall over the past four decades.[59]

Central Melbourne & Bayside

2-metre sea-level rise plus 1-metre storm surge. (coastalrisk.com.au)



13. DAMAGE BEFORE 2°C

The damage that will eventually be caused by the current level of warming of just 1˚C is beyond adaptation for many nations and peoples, yet much higher temperature targets have been the goal of policy-makers. Prof. James Hansen maintains that it is "well understood by the scientific community" that goals to limit human-made warming to 2˚C are "prescriptions for disaster", because "we know that the prior interglacial period about 120,000 years ago was less than 2˚C warmer than pre-industrial conditions and sea level was at least five to nine metres higher, so it's crazy to think that 2˚C is a safe limit".[60]

The 2009 Copenhagen climate conference of governments agreed that there should be a scientific review of the 2˚C cap. It was completed in 2015 for the secretariat of the UN Framework Convention on Climate Change and concluded that that 2˚C is not a safe temperature cap and that a 1.5˚C cap, while causing less damage than the 2˚C cap, is also not safe.[61]

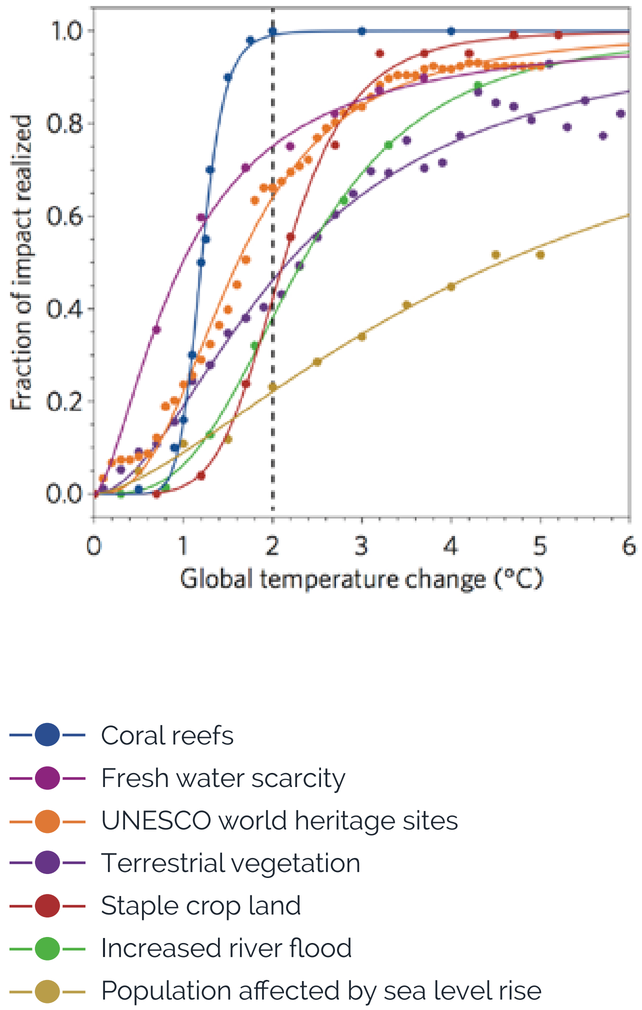
Scientists have found evidence of 41 cases of regional abrupt changes in the ocean, sea ice, snow cover, permafrost and terrestrial biospheres, many of which occur for global warming levels of less than 2˚C. Although most climate models predict one or more abrupt regional shifts, any specific occurrence typically appears in only a few models.[62]

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.[63]

Before or around +1.5˚C, more significant events are likely to occur, including a decline in the efficiency of terrestrial and ocean carbon stores, and the already-documented accelerating ice-mass loss from the Greenland ice sheet and West Antarctic glaciers. New research looks at the damage to system elements — including water security, staple crops land, coral reefs, vegetation and UNESCO World Heritage sites — as the temperature increases. The findings are sobering. Almost all the damage from climate change to vulnerable categories like coral reefs, freshwater availability and plant life could happen before 2˚C warming is reached, as the chart from this research results dramatically shows.[64]

Additionally, temperatures below 2˚C could trigger the release of CO2 and methane from natural carbon stores (eg. permafrost, ocean-floor methane deposits, forests and peat deposits) on such a scale that human efforts to contain the level of future warming to manageable levels could be rendered ineffective.

Maximum potential climate change impacts for various sectors as determined by the sigmoidal fit



14. HOLOCENE CONDITIONS

Human civilisation has flourished over the last 11,000 years under relatively stable climate conditions and sea levels in a period known as the Holocene, which provided a "safe operating space" for global societal development. [65] However, we have already left the Holocene temperature range. Reestablishing Holocene conditions of less than 325 ppm CO2e would be safe for humanity, especially given that so much of human civilisation comprises coastal settlement and delta/flood plain agriculture.

If a significant proportion of coastal settlement were to be overwhelmed by rising sea levels and forced to retreat, what then would be "safe" for humanity?

Even a small global warming above the level of the Holocene begins to generate a disproportionate warming on the Antarctic and Greenland ice sheets.[66] Even a moderate sea level rise of 1–2 metres in less than a century would produce a change in coastlines that is unprecedented for human civilisation.

Current atmospheric greenhouse gas levels (~400ppm CO2 and ~485 CO2e) are likely to be the highest in the last 15 million years, and never previously experienced by humans. The current conditions, if maintained over centuries to millennia (that is, until the system reaches equilibrium), would likely produce temperatures 3–6°C warmer and sea level rises of 25 metres or more, based on evidence of past climates.[67] There is a widespread view amongst scientists that "a 4°C future is incompatible with an organised global community, is likely to be beyond 'adaptation', is devastating to the majority of ecosystems and has a high probability of not being stable".[68]

Given the current state of the atmosphere, getting back to Holocene-like greenhouse gas conditions would require a rapid end to human-caused emissions, and the deployment at massive scale of efficacious biological and other carbon dioxide drawdown measures to reduce the level of atmospheric greenhouse gases for many, many decades and perhaps a century or more.

Vietnam drought 2016 (Thanh Nien News)

15. CLIMATE INTERVENTIONS

For thirty years, efforts to tackle climate change have focused almost entirely on emissions reduction. But the modest scale and slow pace of action, plus better scientific understanding of what constitutes dangerous climate change, have led to the realisation that what is required is not just a slowing or stabilisation of the warming, but instead a cooling of the earth to below its current temperature.

To cool the earth requires two steps. The first is an end to human emissions, to stop making warming worse. The second is to remove excess CO2 from the atmosphere and/or solar radiation management, which reflects a small amount of the incoming sunlight back to space.

Solar radiation management (SRM) and carbon dioxide removal (CDR) may be termed climate interventions or engineering: "purposeful actions intended to produce a targeted change in some aspects of the climate".[69] They could only make a practical contribution if they complement dramatic emissions reduction efforts, and their net benefit depends upon their technical effectiveness, cost, risk and governance.

SRM techniques are designed to produce immediate surface cooling by employing aerosol-cooling sulphates or similar into the lower stratosphere, or boosting the earth's reflectivity in some other way. The cooling effect would be almost immediate (within months) and substantial and the cost relatively low.[70]

SRM techniques have not demonstrated clear net benefits because of as yet not-fully-understood but damaging side effects.[71] They may not be able to simultaneously restore all features of the climate (e.g., temperature and rain/snow distribution) and do not address the issue of dangerous levels of ocean acidification. There are crucial unresolved ethical, political and governance issues. SRM could actually reduce the incentive to curb anthropogenic CO2 emissions.

Some CDR techniques such as reforestation and afforestation are proven and safe, but limited in scale. Covering 3% of the world's surface with forests would be equivalent to negating just 10% of the world's current greenhouse gas emissions (a billion tonnes of carbon annually). Other CDR techniques include biochar, land management, accelerated weathering, bioenergy with carbon capture and sequestration (BECCS), direct capture and sequestration, ocean fertilization, and seaweed and algal farming.

Many of these are unproven, high cost at present, slow to implement, not currently deployable at the scale needed, and have implications for land use and the maintenance of food production and traditional land ownership, farming and biodiversity protection, because of the large spatial areas required (See section 6 above).

The impact of CDR would be slow and "will not have an appreciable effect on global climate for decades" and hence does not provide an opportunity for rapid reductions of global temperature. [72]

The use of carbon capture and storage technology to store liquid CO2 either from power and industrial plants or direct capture from the atmosphere in disused oil and gas fields and other geological formations is being deployed and has substantial business-sector and policymakers' support in establishing a liquid CO2 market perhaps larger than the existing oil industry. There is concern about the ethics and efficacy of such an approach, and the safety and stability of such storage, especially in geological formations other than disused oil and gas fields and in deep ocean sediments. At the moment, most CDR options are much more expensive than emissions reduction costs, so in the first instance emissions reduction is the better option in giving more "bang for the buck", though some deployment of carbon drawdown will help drive it down the cost curve. CDR becomes important when the marginal cost is less than that of reducing emissions, only then, "with declining costs and stronger regulatory commitment, atmospheric CO2 removal could become a valuable component of the portfolio of long-term approaches to reducing CO2". [73]

The bottom line remains a question of least-worst options. The US National Academy of Sciences poses a question most of us would hope does not materialize: "If, despite mitigation and adaptation, the impacts of climate change still become intolerable (e.g., massive crop failures throughout the tropics), society would face very tough choices regarding whether and how to deploy albedo modification until such time as mitigation, carbon dioxIde removal, and adaptation actions could significantly reduce the impacts of climate change." It concludes that despite the moral hazard risk that albedo modification research may distract from the mitigation effort, "the potential risks from climate change appear to outweigh the potential risks from the moral hazard associated with a suitably designed and governed research program". [74]

It must be emphasized that none of these technologies is currently viable at scale in terms of technical effectiveness, cost, risk and governance.

16. DISCUSSION

Over the medium-to-long term, living with 2˚C or more of warming will, in Prof. James Hansen's words, condemn "our biggest, most prosperous and populated cities to an underwater existence". [75] Climate change is already dangerous, especially for the world's most vulnerable people and species. Yet, there is no pathway to keeping warming below 1.5˚C without unproven solar radiation management. In light of the Paris commitments over the next 15 years, it is also very difficult to construct pathways that do not exceed 2˚C thresholds and prevent more significant tipping points from being crossed, unless large-scale climate interventions are also adopted.

Humanity faces an existential crisis. What can be done about the immediate challenges this poses?

HOW DO WE RESOLVE THESE CHALLENGES?

• **The immediate goal of any climate strategy must be to avoid passing further significant tipping points, including those related to the carbon cycle, ice sheets and sea levels.** We must seek actions that form the least-worse path for future emissions, greenhouse gas levels and temperatures.

• **No matter what we do, there will be severe and unavoidable consequences, especially for peoples and ecosystems most vulnerable to a hotter climate.** We must focus on preparing for and adapting to the changes that are now inevitable, while working to achieve negative emissions and reduce warming in a manner that causes the least damage.

• **The best path is one that includes emergency-scale action to get to zero emissions as fast as possible and by 2030.** After a natural disaster such as an earthquake or flood, we know that deploying maximum resources as quickly and efficiently as possible will produce the best result. We must respond to the climate disaster in the same way. This requires a whole-of-government effort based on conscious recognition that climate warming now represents a near-term threat to human civilisation. It requires a strong regulatory approach, because simply pushing and prodding the market within a neo-liberal framework cannot get the job done. A rescue plan must lay out the many steps to solving the problem: a plan to drive rapid emissions reductions; a plan for a just transition out of fossil fuels; a plan for the labour, skills and investment to do it; a plan for sustainable modes of work and leisure; and so on. The transition will be economically and socially disruptive because old, carbon-intensive industries must die, and current lifestyles in the high-income economies are not sustainable.

• **Innovation has astounded us.** Forty years ago when solar PV cells were ~$A100 a watt, who would have imagined that in 2015 they would be around 30 cents? We have many of the technologies we need, including battery storage rapidly falling in cost and new-generation electric vehicles that will make the petrol car obsolete. The obstacles are largely social and political, with a lack of commitment and poor regulatory systems slowing change for technologies that are already mature or rapidly sliding down the cost curve. Where technological challenges remain, we need a huge innovation and deployment effort on many fronts, including a search for efficacious climate interventions.

• **It is clear that a zero emissions strategy can't deliver, by itself, the degree of protection that would be desirable and that might be possible.** We need to set aside the reflex taboo that some people have begun to build up around CO_2 drawdown or solar radiation management and openly and rigorously assess if these interventions are able to contribute in strategically important ways to a least worst, or most beneficial, climate outcome for all people and species, especially the most vulnerable.

• **Some claim that climate intervention technologies can justify continuing high fossil fuel use and are unethical.** It is clear however that these technologies can only be effective over the longer term if allied to a zero-emissions plan. And surely not finding the path of least damage is not ethical in the face of intolerable future climate change impacts, such as massive crop failures throughout the tropics. We have a responsibility to investigate these through a large-scale research-and-development effort.

• **Radical emissions reductions can be driven more quickly by demand reduction than by replacing the energy supply system,** though of course both are essential. It is often said that the era of fossil fuels is coming to an end,[76] but it is not coming soon enough, however: the Paris path sees emissions increasing to 2030 and new coal power stations are still being planned and built. Energy-efficiency policies can reduce energy demand at a lower cost and more quickly than building new energy supply infrastructure.[77]

• **A great social mobilization is needed to transform society**. Technological innovation in the energy sector by itself is insufficient to bring about the necessary change in energy use and production. When people are educated and motivated and act in concert, great social transformation can be achieved.

IDEAS LEADERSHIP

The reasons for failing to do what is obviously in our collective best interest have been widely canvassed, but one striking element is the lack of public ideas leadership. Only a handful of public figures in Australia have ever canvassed the main issues discussed here. Timidity and a relentless bright-siding infuse the public conversation, as if people cannot bear to hear the truth.

But what if the public is more prepared for the conversation than are our public ideas leaders?

Melanie Randle and Richard Eckersley recently investigated the perceived probability of threats to humanity and different responses to them (nihilism, fundamentalism and activism) in the US, UK, Canada and Australia. They found that:

> Overall, a majority (54%) rated the risk of our way of life ending within the next 100 years at 50% or greater, and a quarter (24%) rated the risk of humans being wiped out at 50% or greater. The responses were relatively uniform across countries, age groups, gender and education level, although statistically significant differences exist. Almost 80% agreed "we need to transform our worldview and way of life if we are to create a better future for the world" (activism). About a half agreed that "the world's future looks grim so we have to focus on looking after ourselves and those we love" (nihilism), and over a third that "we are facing a final conflict between good and evil in the world" (fundamentalism). The findings offer insight into the willingness of humanity to respond to the challenges identified by scientists and warrant increased consideration in scientific and political debate.[78]

So here is the great irony: people have a fair, intuitive sense of what might be coming, but our ideas leaders cannot talk about it.

Now is the time to press those who aspire to leadership on climate issues and action to ask the questions that prompted this discussion paper. If the propositions are contentious, we must debate them. Repressing troubling thoughts does not resolve them — they will come back to haunt us with increasing intensity.

APPENDIX: BEWARE THE "FAT TAIL" CLIMATE

The question "How should we respond to climate change, avoid catastrophe and get back to safer conditions?" is often posed in "risk-management" terms. But what does this mean? We have tended to underestimate the rate of climate change impacts.[79] 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".[80]

Too often, policy is based on least-drama, consensus scientific projections that downplay what Prof. Ross Garnaut called the "bad possibilities", that is, the relatively low-probability outcomes with very high impacts. But these events may be more likely than is often assumed, as Prof. Michael E. Mann explains:

> One of the most under-appreciated aspects of the climate change problem is the so-called "fat tail" of risk. In short, the likelihood of very large impacts is greater than we would expect under typical statistical assumptions… With additional warming comes the increased likelihood that we exceed certain "tipping points", such as the melting of large parts of the Greenland and Antarctic ice sheet and the associated massive rise in sea level that would produce.[81]

As one example of this "fat tail" risk, a greenhouse concentration may have a "most likely" outcome of ~3°C of warming, but a greater than 10% risk of warming of greater than 6°C! [82]

Prof. Garnaut suggests climate research had a conservative "systematic bias" due to "scholarly reticence".[83] Prof. Nicholas Stern wrote in similar vein about the IPCC Fifth Assessment Report: "Essentially it reported on a body of literature that had systematically and grossly underestimated the risks of unmanaged climate change".[84]

As far back as 2007, Prof. James Hansen said that scientific reticence hinders communication with the public about dangers of global warming and a potentially large sea level rise.[85] More recently Hansen wrote that: "the affliction is widespread and severe. Unless recognized, it may severely diminish our chances of averting dangerous climate change".[86]

Scientific reticence also facilitates criticism of the presentation of climate science that is not the middle-of-the-road version. Such charges were made against *Climate Code Red: The case for emergency action*.[87] But the evolution of climate warming since publication shows that book was not wide of the mark, because "the worst" it discussed on many key issues has already become our bitter harvest. The book's core proposition that we need an emergency-level response coincides with what many scientists are now saying.[88]

Two climate research scientists who reviewed the present report said it reflected most of the recent climate system insights correctly, and one said it leant toward the more "pessimistic perceptions". But that is exactly the distinction that has to be drawn between the science and the risks it implies. Waiting for catastrophe to happen before acting means that it is too late to act. It is precisely this scenario that proper risk management is designed to avoid.

As with a bushfire, a flood, a plane malfunction or any other potential disaster, it is prudent to plan for the worst that can happen, and be pleasantly surprised if it does not. To hope and plan only for "middle-of-the-road" outcomes, which characterises most climate policy-making, including in Australia, is foolish.

A prudent risk-management approach would consider the full range of real risks to which we are exposed, including those "fat tail" existential events whose consequences would be damaging beyond quantification, and which human civilization as we know it would be lucky to survive. If we focus on the "middle of the road" and ignore the worst possibilities, we may end up in a fatal crash.

"THIS IS BIGGER THAN US. THIS IS WHAT CLIMATE CHANGE LOOKS LIKE, THIS IS WHAT SCIENTISTS HAVE BEEN TELLING PEOPLE, THIS IS SYSTEM COLLAPSE."

Fire ecologist David Bowman on the January 2016 Tasmanian World Heritage bushfires [89]

Fire-killed ancient pencil pines at Lake Mackenzie, Tasmanian Wilderness World Heritage Area. Photographed 30 Jan 2016 © Rob Blakers

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"SOME COASTAL CITIES WILL DROWN FOR WHAT WE HAVE DONE AND WILL DO."

Prof. Stefan Rahmstorf, University of Melbourne forum, 22 October 2015

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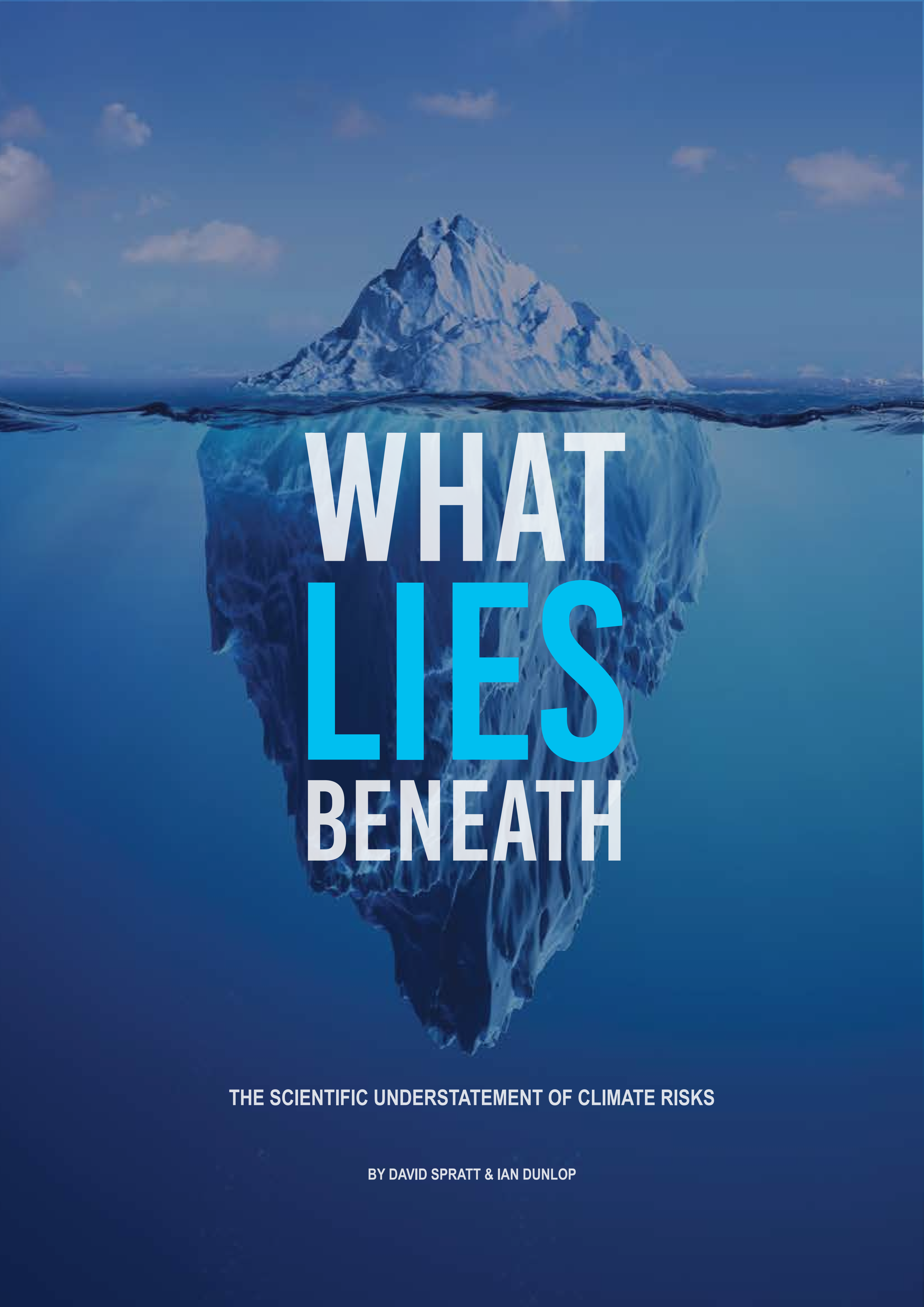

WHAT LIES BENEATH

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 (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 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 that 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 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".

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]

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". The study said most

[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, <https://www.theguardian.com/environment/2016/nov/06/nicholas-stern-climate-change-review-10-years-on-interview-decisive-years-humanity>

[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, <https://www.theguardian.com/environment/2013/jan/27/nicholas-stern-climate-change-davos>

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. [9]

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]

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 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."[13]

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

[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, <https://www.scientificamerican.com/article/how-the-ipcc-underestimated-climate-change>.

[11] 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>.

[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.

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".[14]

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, 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".[15]

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”.[16]

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”.[17] 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".[18]

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".[19]

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.[20]

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[14] Barras, C 2007, ‘Rocketing CO_2 prompts criticisms of IPCC’, *New Scientist*, 24 October 2007, <https://www.newscientist.com/article/mg19626274-800-rocketing-co2-prompts-criticisms-of-ipcc/>.

[15] Scherer 2012a, op cit.

[16] Ibid.

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

[18] 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>.

[19] 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>.

[20] 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."[21]

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."[22]

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."[23] 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".[24]

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?'"[25] 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.[26]

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

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

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

[24] Dunlop, I 2016, Foreword to Spratt, D 2016, *Climate Reality Check*, Breakthrough, Melbourne.

[25] 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.

[26] 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 who 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".[27]

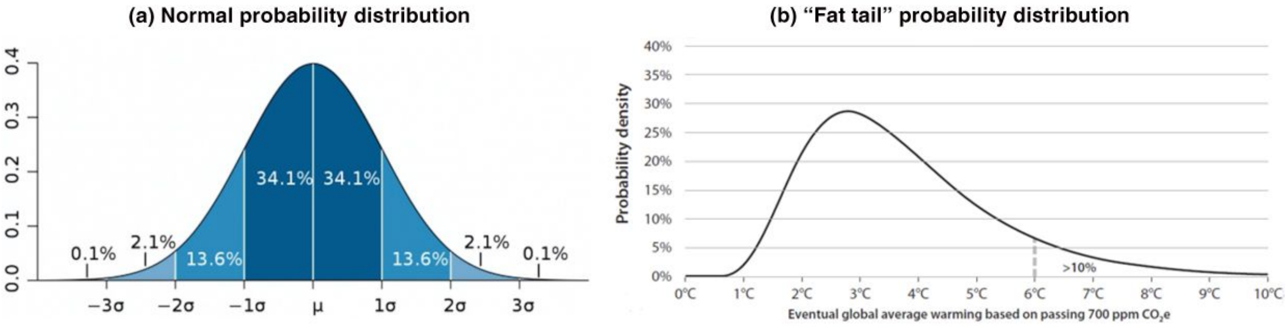

Figure 1: Normal probability distribution (left) and An estimate of the likelihood of warming due to a doubling of greenhouse gas concentrations, from Wagner & Weitzman "Climate Shock" (right)

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".[28] 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.

[27] 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>.

[28] 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.[29]

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."[30]

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.[31] 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.[32] 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.[33]

Warming of 4°C or more could reduce the global human population by 80% or 90%,[34] and the World Bank reports "there is no certainty that adaptation to a 4°C world is possible".[35] 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".[36] 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.)[37]

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[29] Ibid.

[30] Rahmstorf, S, pers. comm., 8 August 2017.

[31] Dunlop and Spratt 2017, op cit.

[32] 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.

[33] 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>.

[34] 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>.

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

[36] 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.

[37] 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 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.[38]

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.[39]

Glaciologist Prof. Eric Rignot, says that “One of the problems of IPCC is the strong desire to rely on physical models."[40] 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.

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[38] Campbell et al., op cit.

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

[40] 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.[41]
- **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".[42] 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.[43]

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

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

[42] Ibid.

[43] 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 CO_2 (a thousand years).[44] 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 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".[45]

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 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".[46]

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.

[44] 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.

[45] Schellnhuber, J 2009, 'Tipping elements in the Earth system', *Proceedings of the National Academy of Sciences,* vol. 106, no. 6, pp. 20561–20563.

[46] 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.[47]

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 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. 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. [48]

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.[49] 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 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".[50]

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[47] 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.

[48] 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.

[49] 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.

[50] 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.[51] 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 CO_2 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.[52]

A 2014 study made use of projections from the most recent IPCC report to estimate that up to 205 gigatons 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."[53]

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.)

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

[52] 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.

[53] 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.[54]

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".[55]

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.[56]

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.[57]

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 CO_2, 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-CO_2 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

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

[55] 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

[56] 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

[57] 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,.[58]

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 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."[59]

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.[60] 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

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[58] 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.

[59] Scherer 2012a, op. cit.

[60] 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".[61]

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.[62] 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".[63]

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.[64]

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

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[61] 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.

[62] 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.

[63] 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>.

[64] 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.[65]

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.[66]

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.[67]

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."[68] 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.[69]

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[65] 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>.

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

[67] Maslowski, Kinney et al. 2012, op cit.

[68] 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>.

[69] 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."[70]

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".[71] 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 10 metres or more of sea-level rise in the longer run, and 5 metres in the first 200 years.[72]

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".[73]

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[70] 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.

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

[72] 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.

[73] 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."[74]

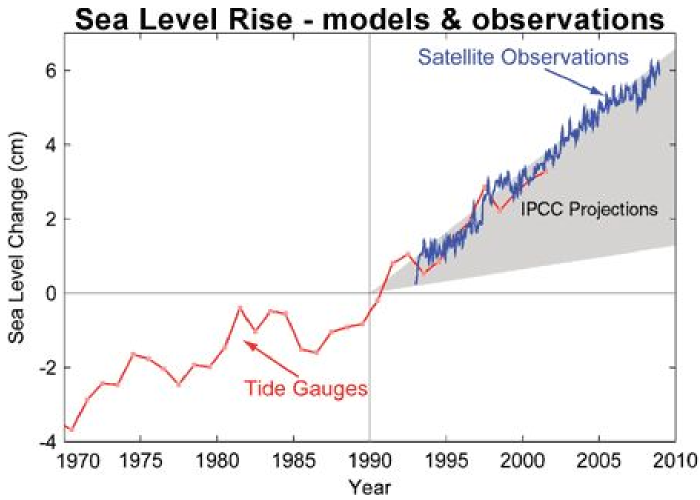

Figure 2: Observed sea-level rise 1970-2010 from tide gauge data (red) and satellite measurements (blue) compared to model projections for 1990-2010 from the IPCC Third Assessment Report (grey band). (Source: *The Copenhagen Diagnosis*, 2009)

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."[75]

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

[74] Hansen 2007, op cit.

[75] 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".[76]

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*[77] 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.

[76] 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 >.

[77] 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".[78] 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.[79]

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.[80] 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.[81]

An expert panel recently concluded that warming would need to be limited to 1.2°C to save the Great Barrier Reef.[82] 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.[83]

[78] 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>.

[79] 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.

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

[81] 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.

[82] 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-gxkwph.html>.

[83] 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 Institute[84]

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.”[85]

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.”[86]

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.

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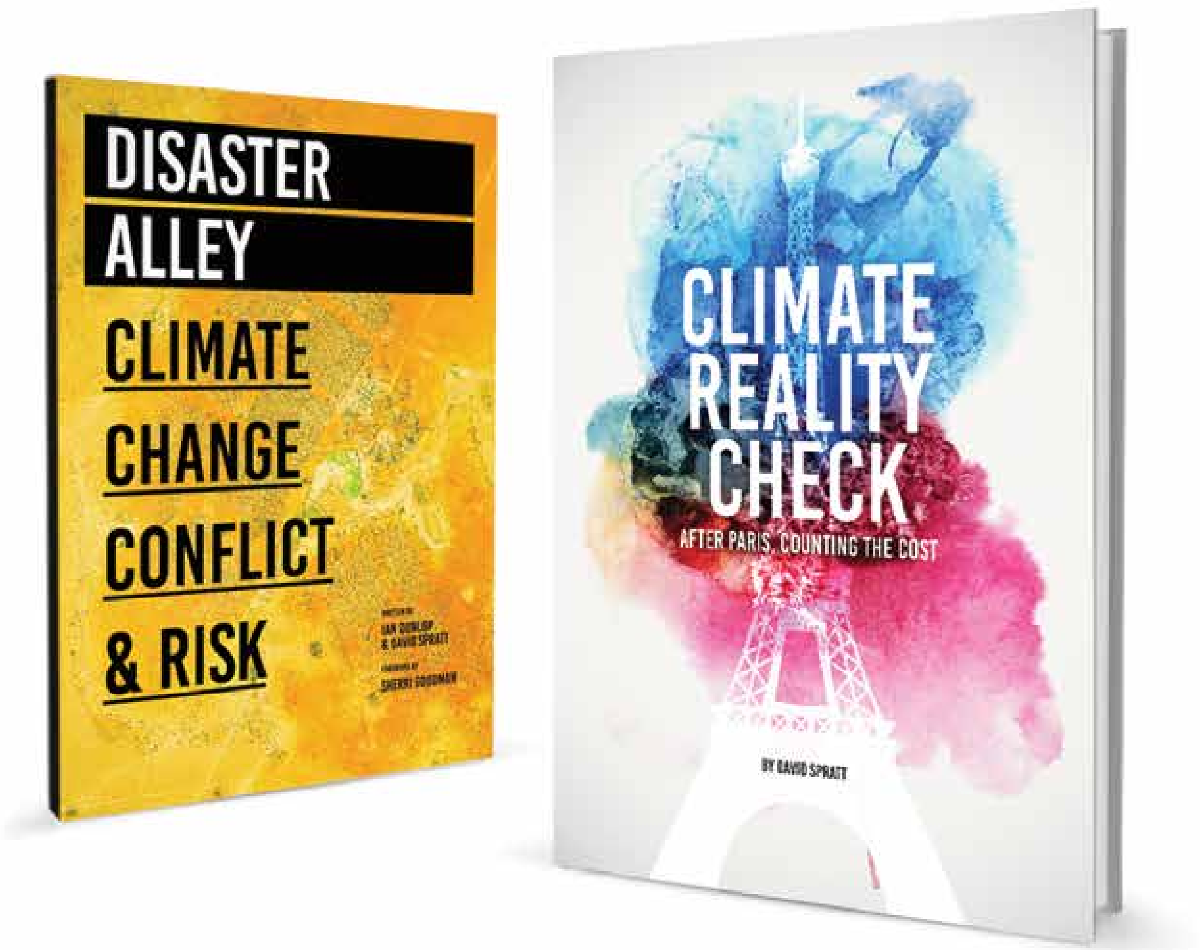
[84] Leahy, S 2009, ‘Climate Change: Four degrees of devastation’, *Inter Press Service*, 9 October 2009, <http://www.ipsnews.net/2009/10/climate-change-four-degrees-of-devastation/>.

[85] 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>.

[86] 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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