BEFORE THE MARLBOROUGH DISTRICT COUNCIL HEARINGS COMMITTEE

IN THE MATTER	of the Resource Management Act 1991 Marlborough District Council Proposed Marlborough Environment Plan
AND	
IN THE MATTER	of the Climate Change issues

STATEMENT OF EVIDENCE BY JAMES ARTHUR RENWICK

ON BEHALF OF CLIMATE KARANGA MARLBOROUGH

19 FEBRUARY 2018

I, **James Arthur Renwick**, atmospheric scientist, of Wellington swear:

1. I am a Professor in the School of Geography, Environment and Earth Sciences at Victoria University of Wellington.
2. I have read the code of conduct for expert witnesses and I agree to comply with it.
3. In this affidavit I describe what I understand to be the consensus of the global scientific community on the causes and effects of climate change, and the time frames for effectively mitigating those effects. I outline likely climate changes for New Zealand for a “low carbon” (global warming no more than 2°C above pre-industrial temperatures) and for a “high carbon” (warming 3-4°C or more) future, with emphasis on the Marlborough/eastern South Island region.

Qualifications

4. I hold a PhD in Atmospheric Sciences from the University of Washington (Seattle). I specialise in climate and atmospheric science including the dynamics and statistics of large-scale atmosphere circulation; climate variability and predictability; climate change; and numerical modelling of the climate.
5. I am a member of a number of leading scientific organisations including the World Climate Research Programme (WCRP) Joint Scientific Committee (and am co-chair of the WCRP Climate and Cryosphere Project), the World Meteorological Organisation Executive Council Panel of Experts on Polar Observations, the American Geophysical Union and the Royal Society of New Zealand. I was until recently the Chair of the Royal Society of New Zealand’s Climate Expert Panel.
6. I am widely published in the field of atmospheric and climate science and have extensive experience as a researcher in these fields. A copy of my curriculum vitae is attached. My achievements in the field include serving as a Lead Author for the Intergovernmental Panel on Climate Change (IPCC) in respect of the 5th Assessment Report (2010-2013) (AR5) and 4th Assessment Report (2004-2007) (AR4), and contributing towards the 2007 Nobel Peace Prize that was awarded to the IPCC and Albert Gore Jr.
7. In 2005 I was awarded the Kidson Medal of the N.Z. Meteorological Society, the highest New Zealand honour for atmospheric and climate sciences. In recent years, my research has been supported by two grants from the Marsden Fund, awarded for the periods 2005-2008 and 2014-2017. I have written a number of climate change-related reports for New Zealand businesses and government agencies and I have given evidence on climate change in court on a number of occasions over the past 20 years.

Global climate change

The following information is a brief summary of global climate change, based largely on the findings of the most recent (5th) Assessment Report of the Intergovernmental Panel on Climate Change, plus relevant recent literature. A more detailed description of the scientific evidence is presented in the Appendix.

- Warming of the climate system is unequivocal, and human influence on the climate system is clear. Warming since the mid-20th century is almost all a result of human activity, primarily the increased atmospheric concentrations of greenhouse gases. Carbon dioxide concentrations have increased by more than 40% since pre-industrial times, reaching their highest levels for approximately 3 million years.
- In the global average, the last three years (2015, 2016, and 2017) were the warmest on record. Each of those years were more than 1°C above pre-industrial temperatures. The five year average 2013-2017 was the warmest five year period on record globally, since records began in the late 19th century.
- Ice is melting on all continents, and over the Arctic Ocean. This is affecting regional water availability and is contributing to sea level rise.
- The rate of sea level rise is higher than it has been for at least 2,000 years. The rate of sea level rise has approximately doubled since the mid-20th century and will accelerate further as the Greenland and Antarctic ice sheets melt more rapidly.
- Future scenarios for climate changes are based on a range scenarios for future emissions of greenhouse gases, known as "Representative Concentration Pathways" (RCPs). The lowest, RCP2.6, is "low-carbon" and aligns approximately with the requirements of the Paris Agreement. The highest, RCP8.5, is "high-carbon" and assumes continued increases in the rate of emissions through to 2100.
- Future global climate changes depend on the emissions scenario. Under RCP2.6, the globe would see around 1°C more warming from the present. Under RCP8.5, there would be around another 4°C of warming this century.
- Under all scenarios, the contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, or "the wet get wetter and the dry get drier".
- Global mean sea level rise for 2081–2100 (relative to 1986–2005) will likely be 0.26 to 0.55m for RCP2.6, and 0.45 to 0.82m for RCP8.5. For RCP8.5, for the year 2100 (as opposed to the average between 2081 and 2100) sea level rise is likely to be 0.52 to 0.98m. Sea levels may rise significantly more, should the collapse of marine-based sectors of the Antarctic ice sheet commence this century.
- Recent research has identified the possibility of significant and rapid contributions to sea level rise from Antarctic ice melt mostly through the mechanism known as "marine ice sheet instability". If triggered, it would commit the globe to several metres of sea level rise over coming centuries. Current understanding suggests that only with the RCP2.6 scenario for future climate forcing is there little melt of ice from Antarctica. Estimates of the upper limits of sea level rise this century therefore need to be revised significantly upwards. For example, with this new understanding, the RCP8.5 scenario would be associated with a median global sea level rise by 2100 of between 1.8m and 2.9m.
- The Paris Agreement calls on the countries of the world to limit global warming to well below 2°C above pre-industrial temperatures, and pursue efforts to stop the warming at 1.5°C. At current emission rates, the 1.5°C budget of carbon dioxide will have been emitted during the 2020s, and the 2°C budget by the 2030s. Based on the rate of global temperature rise over the past 50 years, 1.5°C warming would be reached by 2040, and 2°C warming by 2070.
- To avoid collapse of the West Antarctic ice sheet and an eventual commitment to 10m or more of sea level rise, significant reductions in emissions must begin virtually immediately. What humanity chooses to do in the next decade will determine global sea levels and coastlines for the next 10,000 years.
- To have a good chance of fulfilling the Paris Agreement, recent work suggests that global emissions would need to start reducing by 2020, to halve between 2020 and 2030, then halve again by 2040, and so on.
- Many aspects of climate change will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes ("tipping points") increase as the magnitude of the warming increases. Beyond large sea level rises, other abrupt changes include rapid release of methane from thawing permafrost or seafloor clathrates, shutdown of the deep ocean circulation, and complete loss of Arctic sea ice in summer. Given the globe's present trajectory, release of methane from permafrost (which would accelerate warming further) is possible this century, and summer sea ice over the Arctic Ocean is likely to be mostly gone by mid-century. Other abrupt changes are considered very unlikely at this stage.
- The above suggests that there is considerable urgency around reductions of global emissions of greenhouse

gases, an urgency that is not yet reflected in national- or international-scale actions. In my opinion, the 1.5°C warming limit will be exceeded before 2050, and even the 2°C limit is likely to be exceeded before 2100. Hence, it is prudent to assume a large amount of climate change when planning adaptation measures, infrastructure developments, and community responses. Most built infrastructure has an expected lifetime of around a century, meaning that planning should be based around expected changes for 2100 and beyond.

Climate change and New Zealand

- New Zealand national average temperatures have risen approximately 1°C in the past century[1], in line with global mean change. The influence of human-induced climate change has already been detected in temperature rise (Dean and Stott 2009), the occurrence of floods (Dean et al 2013), and of droughts (Harrington et al 2014, 2016).
- New Zealand's climate is virtually certain to continue warming through the 21st century, with further changes in extreme events. Floods, landslides, droughts and storm surges are very likely (at least 90% probability) to become more frequent and intense, and snow and frost are very likely to become less frequent. Large areas of eastern New Zealand are likely to have lower soil moisture, although western New Zealand is likely to receive more rain. An increase in mean temperatures of 0.7 to 1.0°C is likely by the 2040s and 0.7 to 3.0°C by the 2090s, compared to the 1990s.
- A report published in 2016 by the Royal Society of New Zealand[2] discussed the effects of a "low carbon" future (approximately equivalent to meeting the Paris Agreement 2°C limit) and of a "high carbon" future (equivalent to continuing to increase emissions above present-day levels with no mitigation). The summary below uses the Royal Society report, combined with the latest figures for sea level rise in Ministry for the Environment guidance[3]. In summary, the expected effects on New Zealand under these two future scenarios are:
  (a) **High-carbon world**: In a high carbon world, we can expect temperatures to rise by between another 2.5 and 5°C this century, averaged across the country. Annual average rainfall is projected to decrease by about 10% in the east and north of the country, with droughts currently considered as severe (i.e. those droughts that typically occur only once every 20 years or so) becoming several times more frequent in those areas. Western regions would see annual average rainfall increase by up to 10%, or more, especially in the south. Extreme rainfall is projected to increase in frequency, especially where average rainfalls increase. Sea-level rise is expected to accelerate, to reach a median level of 0.79m or as high as 1.05m by 2100, relative to 1986–2005 levels (global mean rate plus 10%, approximately). Sea levels could rise further this century depending on the response of the major ice sheets, and would keep rising at a high rate for many centuries after that (estimated to reach on average 1.41m or as high as 1.88m by 2150) Ocean water would continue to become more acidic (less alkaline), possibly reaching levels of acidity not seen for tens of millions of years.
  (b) **Low-carbon world**: In a low carbon world, temperatures would still climb as some level of climate change is already locked in due to current and past emissions. New Zealand temperatures would rise by up to another 1°C this century, averaged across the country. Even this level of further warming would likely lead to drying (in the annual average) in the east and north of the country with increased drought risk, plus averaged rainfall increases of a few percent in western areas, especially in the South Island. The occurrence of extreme rainfalls would increase somewhat, mostly in western regions. Sea levels would continue to rise on average by 0.46m by 2100, but continue to rise beyond 2100, even if global temperatures have stabilised, as land-based ice will continue to melt and the oceans would continue to warm as they adjust to a warmer atmosphere (estimated to reach 0.69m by 2150). Ocean water would also become more acidic, but at a slower rate than has been seen in the past few decades.

Implications for Marlborough

- The Ministry for the Environment provides an outline of regional impacts of climate change. The following text is based on the summary for Marlborough[4] and on more general climate change information for New

1 https://www.niwa.co.nz/climate/information-and-resources/nz-temperature-record

2https://royalsociety.org.nz/what-we-do/our-expert-advice/all-expert-advice-papers/climate-change-implications-for-new-zealand/, accessed 11 Dec 2017

3 http://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-local-government

4 http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/how-might-climate-change-affect-my-region/marlborough

Zealand as outlined above.

(a) Temperature extremes: The number of “hot” days (above 25°C) are projected to increase by a factor of two (low-carbon) to four (high-carbon) while the number of frosts is projected to decrease by between 30 and 80%.

(b) Drought: By 2090, the time spent in drought ranges from minimal change (low-carbon) through to more than double compared to 1995 (high-carbon). More frequent droughts are likely to lead to water shortages, increased demand for irrigation and increased risk of wild fires. Droughts are expected to increase in frequency and intensity over time.

(c) Extreme rainfall: Extreme heavy rainfall events are expected to become only slightly more frequent and intense in the low-carbon scenario, but may increase significantly (10% or more) in the high-carbon scenario.

(d) Coastal hazards: Sea level rise to 2100 could be as low as 45cm or as high as 1.1m, with scope for significant further rise through the 22^{nd} century. Even under RCP2.6, sea levels are likely rise around 70cm by 2150. Under RCP8.5, sea level rise could reach nearly 2m by 2150, and there would likely be a commitment to several more metres of rise over the following centuries. Every 10cm of sea level rise approximately triples the risk of a given coastal inundation event. With 50cm of sea level rise, the 1-in-100-year coastal inundation event would occur at least annually, and would occur with virtually every tide after 1m of sea level rise. Coastal roads and infrastructure will face significantly increased risk from coastal erosion and inundation.

(e) Biosecurity: Climate change could increase the spread of pests and weeds. It is anticipated that pest and disease regimes for all fruit crops could change, particularly through warmer winters. Crop diseases such as fungi and viruses may penetrate into the region where currently they are excluded by lower temperatures.

(f) Agriculture: Warmer temperatures, a longer growing season and fewer frosts could provide opportunities to grow new crops. Farmers might benefit from faster growth of pasture and better crop growing conditions. Horticultural crops, such as kiwifruit and wine grapes, are likely to show the greatest gains from higher average temperatures. However, benefits may be limited by negative effects of climate change such as prolonged drought or greater frequency and intensity of storms, and effects on pest species.

(g) Aquaculture: Increasing acidification of ocean waters reduces the availability of carbonates for shell-building by marine organisms. Under the high-carbon scenario, the ability of key species (e.g. mussels) to grow their shells would be significantly impaired.

(h) Public health: There may be an increase in the occurrence of water-borne and food-borne diseases, increased respiratory illness, infectious disease, heart disease and stroke, and mental health.

Appendix – Summary of the scientific consensus on climate change

The scientific evidence for the phenomena of global climate change and their anthropogenic causes is contained in a vast corpus of the writings of the scientific community on the subject. The IPCC's AR5 and AR4 are derived from the wider scientific literature and those reports provide a summary of the scientific understanding on the effects and causes of climate change, and the steps required to mitigate those effects in order to avoid or reduce the harm arising as a result.

The IPCC reports are an assessment of the available literature, collated and summarised by a team of between 10 and 20 authors for each chapter of each of the three Working Group Reports. All Reports adhere to the IPCC guidance for expressing uncertainty[5] which stipulates protocols for expressing confidence, grounded in statistical analysis, understanding of physical processes, and expert judgement. Confidence statements are built around a combination of the quality of available evidence and the level of agreement between different lines of evidence. The confidence scale for expressing uncertainty is defined as: Virtually certain (99-100% probability), Very likely (90-100%), Likely (66-100%), About as likely as not (33-66%), Unlikely (0-33%), Very unlikely (0-10%), and Exceptionally unlikely (0-1%).

Scientific consensus on the evidence of climate change

As outlined in the Summary for Policy Makers in the AR5 WGI report, the following key points concerning observed changes in the climate were identified:

- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased
- Each of the last three decades (to 2010) has been successively warmer at the Earth's surface than any preceding decade since 1850, when reliable records began.
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (high confidence). It is virtually certain that the upper ocean (0−700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971.
- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (high confidence).
- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence). Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.
- The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by more than 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

The scientific consensus on the causes of climate change

The Summary for Policy Makers of the Report of Working Group 1 of AR5 identified the following drivers of climate change:

- Total radiative forcing is positive (i.e. the surface of the earth is absorbing more energy than it is emitting to space), and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750.
- The atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have all increased since 1750 due to human activity. Concentrations of CO_2, CH_4, and N_2O now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. The mean rates of increase in atmospheric concentrations over the past century are, with very high confidence, unprecedented in the last 22,000 years.
- Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing (excess of incoming over outgoing radiative energy), observed warming, and understanding of the climate system.
- Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some

5 https://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf

climate extremes. This evidence for human influence has grown since AR4. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century

- Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing.

Scientific consensus on the future effects of climate change

Future scenarios for climate changes are based on a range of possible future emissions of greenhouse gases and other atmospheric constituents. Such emissions profiles are described in terms of "Representative Concentration Pathways" (RCPs), which define the changing radiative balance of the earth (van Vuuren et al. 2011). The lowest, RCP2.6, is matched to a radiative imbalance of 2.6 Watts of energy (excess of incoming over outgoing) per square metre at the earth's surface in 2100. The highest, RCP8.5, is matched to a radiative imbalance of 8.5 Watts of energy (excess of incoming over outgoing) per square metre at the earth's surface in 2100. For reference, the current radiative imbalance as a result of greenhouse gas increase is around 2.3 Watts per square metre. All RCPs chart a path of radiative forcings (and associated atmospheric greenhouse gas concentrations) through the 21st century and in some cases have been extended to 2300. RCP2.6 is the only one to consider significant mitigation of greenhouse gas emissions, including the deployment of carbon capture and storage technologies in the latter part of the 21st century associated with decreases in CO_2 concentrations in the atmosphere after 2070. RCP8.5 represents a "business as usual" scenario through the 21st century where fossil fuel use continues to increase from present-day consumption patterns. If the drivers of anthropogenic climate change continue without mitigation:

- Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.
- Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.
- Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.
- The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation.
- It is very likely that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease.
- Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios, the rate of sea level rise will very likely exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.
- Global mean sea level rise for 2081–2100 relative to 1986–2005 will likely be in the ranges of 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5 (medium confidence). For RCP8.5, for the year 2100 (as opposed to the average between 2081 and 2100) sea level rise is likely to be 0.52 to 0.98 m, with a rate during 2081 to 2100 of 8 to 16 mm/yr (medium confidence). Based on current understanding, 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. However, there is medium confidence that this additional contribution would not exceed several tenths of a metre of sea level rise during the 21st century. The basis for higher projections of global mean sea level rise in the 21st century has been considered and it has been concluded that there is currently insufficient evidence to evaluate the probability of specific levels above the assessed likely range. This is a very active area of research.
- Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere (high confidence). Further uptake of carbon by the ocean will increase ocean acidification.
- Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past,

present and future emissions of CO_2.

- A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. Due to the long time-scales of heat transfer from the ocean surface to depth, ocean warming will continue for centuries. Depending on the scenario, about 15 to 40% of emitted CO_2 will remain in the atmosphere for longer than 1,000 years.
- Sustained mass loss by ice sheets would cause larger sea level rise, and some part of the mass loss might be irreversible. There is high confidence that sustained warming greater than some threshold would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7m. Current estimates indicate that the threshold is greater than about 1°C (low confidence) but less than about 4°C (medium confidence) global mean warming with respect to pre-industrial. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment.

This is likely to have the following negative human impacts:

- Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.
- Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise.
- Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development.
- Climate change is projected to undermine food security. Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (high confidence). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (medium confidence). Global temperature increases of ~4°C or more above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (high confidence). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (robust evidence, high agreement), intensifying competition for water among sectors (limited evidence, medium agreement).
- Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (high confidence). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (high confidence). In urban areas climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (very high confidence). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas.
- Climate change is projected to increase displacement of people (medium evidence, high agreement). Populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (medium confidence).
- Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases.

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (high confidence). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations >1000 ppm CO_2-eq), warming is more likely than not to exceed 4°C above pre-industrial levels by 2100. The risks associated with temperatures at or above 4°C include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities and limited potential for adaptation in some cases (high confidence). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels.

Scientific consensus on the required mitigation of greenhouse gas emissions to avoid or reduce the risks of the dangerous effects of climate change

Since the atmospheric lifetime of carbon dioxide is centuries to millennia (Solomon et al. 2009, 2010), it is not so much the rate at which CO_2 is emitted than the total amount (or “budget”) emitted that is important for determining the eventual amount of climate change.

Policymakers meeting as part of the UNFCCC “Conference of the Parties” in Copenhagen in 2009 and in Cancun in 2010 came to the consensus view that to avoid dangerous anthropogenic interference with the climate system, global temperature increase must be kept below 2°C relative to pre-industrial levels. However, the scientific evidence suggests that in some respects, significant and potentially dangerous change may occur in association with temperature rises of less than 2°C.

The scientific consensus on required mitigation and the effect of that mitigation is set out in the report of Working Group III of AR5:

- Limiting the warming caused by anthropogenic CO_2 emissions alone with a probability of >33%, >50%, and >66% to less than 2°C since the period 1861–1880, will require cumulative CO_2 emissions from all anthropogenic sources to stay between 0 and about 1570 GtC (5760 $GtCO_2$), 0 and about 1210 GtC (4440 $GtCO_2$), and 0 and about 1000 GtC (3670 $GtCO_2$) since that period, respectively. These upper amounts are reduced to about 900 GtC (3300 $GtCO_2$), 820 GtC (3010 $GtCO_2$), and 790 GtC (2900 $GtCO_2$), respectively, when accounting for non-CO_2 forcings as in RCP2.6. An amount of 515 [445 to 585] GtC (1890 [1630 to 2150] $GtCO_2$), was already emitted by 2011. The likelihood of various warming scenarios relative to emissions levels is illustrated in the table below from the Working Group III summary for policy makers.

Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters, the 10th to 90th percentile of the scenarios is shown.[1, 2] [Table 6.3]

<table>
<tr><th rowspan="3">CO_2eq Concentrations in 2100 [ppm CO_2eq]
Category label (concentration range)[9]</th><th rowspan="3">Subcategories</th><th rowspan="3">Relative position of the RCPs[5]</th><th colspan="2">Cumulative CO_2 emissions[3] [$GtCO_2$]</th><th colspan="2">Change in CO_2eq emissions compared to 2010 in [%][4]</th><th colspan="5">Temperature change (relative to 1850–1900)[5, 6]</th></tr>
<tr><th rowspan="2">2011–2050</th><th rowspan="2">2011–2100</th><th rowspan="2">2050</th><th rowspan="2">2100</th><th rowspan="2">2100 Temperature change [°C][7]</th><th colspan="4">Likelihood of staying below temperature level over the 21st century[8]</th></tr>
<tr><th>1.5 °C</th><th>2.0 °C</th><th>3.0 °C</th><th>4.0 °C</th></tr>
<tr><td>< 430</td><td colspan="11">Only a limited number of individual model studies have explored levels below 430 ppm CO_2eq</td></tr>
<tr><td>450 (430–480)</td><td>Total range[1, 10]</td><td>RCP2.6</td><td>550–1300</td><td>630–1180</td><td>−72 to −41</td><td>−118 to −78</td><td>1.5–1.7 (1.0–2.8)</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500 (480–530)</td><td>No overshoot of 530 ppm CO_2eq</td><td></td><td>860–1180</td><td>960–1430</td><td>−57 to −42</td><td>−107 to −73</td><td>1.7–1.9 (1.2–2.9)</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2eq</td><td></td><td>1130–1530</td><td>990–1550</td><td>−55 to −25</td><td>−114 to −90</td><td>1.8–2.0 (1.2–3.3)</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550 (530–580)</td><td>No overshoot of 580 ppm CO_2eq</td><td></td><td>1070–1460</td><td>1240–2240</td><td>−47 to −19</td><td>−81 to −59</td><td>2.0–2.2 (1.4–3.6)</td><td rowspan="3">More unlikely than likely[12]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2eq</td><td></td><td>1420–1750</td><td>1170–2100</td><td>−16 to 7</td><td>−183 to −86</td><td>2.1–2.3 (1.4–3.6)</td></tr>
<tr><td>(580–650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>1260–1640</td><td>1870–2440</td><td>−38 to 24</td><td>−134 to −50</td><td>2.3–2.6 (1.5–4.2)</td></tr>
<tr><td>(650–720)</td><td>Total range</td><td>1310–1750</td><td>2570–3340</td><td>−11 to 17</td><td>−54 to −21</td><td>2.6–2.9 (1.8–4.5)</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720–1000)</td><td>Total range</td><td>RCP6.0</td><td>1570–1940</td><td>3620–4990</td><td>18 to 54</td><td>−7 to 72</td><td>3.1–3.7 (2.1–5.8)</td><td rowspan="2">Unlikely[11]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000</td><td>Total range</td><td>RCP8.5</td><td>1840–2310</td><td>5350–7010</td><td>52 to 95</td><td>74 to 178</td><td>4.1–4.8 (2.8–7.8)</td><td>Unlikely[11]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

- Based on the above, to have at least a 50% chance of limiting global warming to less than 2°C since the period 1861–1880, there is a total budget of 820Gt of carbon that may be emitted. By 2011, 515Gt had already been emitted. At current rates, the remaining 305Gt will have been emitted by the 2030s. Hence, significant emissions reductions are required globally, starting as soon as possible.
- Recent research suggests that global emissions would need to start reducing by 2020, to halve between 2020 and 2030, then halve again by 2040, and so on (Rockström et al 2017).

In 2016, New Zealand became a signatory to the Paris Agreement, which states that parties to the Agreement will act to hold 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 above pre-industrial levels.

There is a body of research suggesting that 1.5 degrees or less is the level that ought to be the limit for global warming, as summarised in a recent UNFCCC review.[6]

Recent developments in scientific knowledge

Since the IPCC AR5 was finalised, further research has been published that is pertinent to climate changes and to mitigation targets internationally. In particular:

- The contribution of Antarctic ice sheet loss to sea level rise is an area of large uncertainty and of intensive research. Several papers published in the past four years, e.g. Joughin et al. (2014), Rignot et al. (2014), Dutton et al. (2015), Golledge et al. (2015), Trusel et al. (2015), and DeConto and Pollard (2016), have identified the possibility of significant and rapid contributions to sea level rise from Antarctic ice melt mostly through the mechanism known as "marine ice sheet instability". The processes involved would allow rapid loss of major ice shelves and subsequent commitment to significant loss of ice from the West and East Antarctic ice sheets, implying several metres of sea level rise over coming centuries. This recent research sheds light on the processes responsible for global sea levels being 10-20 metres higher than present when CO_2 levels were last as high as they are now (around 3 million years ago). Current understanding suggests that only with Representative Concentration Pathway (RCP) 2.6 scenario for future climate forcing there is little melt of ice from Antarctica (DeConto and Pollard 2016; Golledge et al 2015).
- Further, melting beneath the Antarctic ice shelves is already occurring; in particular, "a significant increase in ocean heat influx into [the Amundsen Sea] sub-ice-shelf cavities took place in the mid-2000s" (Khazendar et al. 2016).
- It has also been demonstrated that the upper-bound estimates of sea level rise reported in AR5 (up to one metre by 2100 and one and a half metres by 2200) "are implausible under current understanding of physical and mechanisms and potential triggers" (Ritz et al. 2015). In other words, estimates of the upper limits of sea level rise this century need to be revised significantly upwards. It has recently been estimated that "business as usual" emissions (the RCP8.5 scenario) would be associated with a median global sea level rise by 2100 of 1.84m and an upper bound (95 percentile) of 2.92m (Le Bars et al. 2017).
- There have been new estimates of ocean heat content change, which show an acceleration in the rate of heat uptake by the oceans in the last 20 years. A lot of this warming is occurring around the Southern Oceans beneath the edges of the Antarctic ice shelves, where marine ice sheet instability is known to be a risk (Cheng et al. 2017).
- During 2015 and 2016, high temperatures caused a pan-tropical episode of bleaching of corals on the Australian coast. Recent research demonstrates that local measures to preserve the coral have had no effect, due to the effect of warming seas. Hughes et al (2017) have noted that "securing a future for coral reefs, including intensively managed ones such as the Great Barrier Reef, ultimately requires urgent and rapid action to reduce global warming." In 2017, the Great Barrier Reef experienced another mass bleaching event, following the extensive 2016 bleaching. Such severe bleaching events were not expected to occur until the 2040s – 2050s.[7]
- Temperature observations compiled based on NASA Goddard Institute of Space Studies (GISS) records which show that in 2016, global mean surface temperatures exceeded 1.2°C above "pre-industrial" temperatures. The years 2015, 2016, and 2017 are the three warmest in the global record (going back to 1880), all of which were more than 1°C warmer than temperatures in the late 19th century. In terms of the goal stated in the Paris Agreement to hold temperature increases to well below 2°C and pursuing efforts to limit it to 1.5°C, there is approximately 0.9°C and 0.4°C headroom before these limits are exceeded, respectively. Based on the rate of global temperature rise over the past 50 years, 1.5°C warming would be reached by 2040, and 2°C warming by 2070.

6 http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf
7 AR5, Report of WG II, chapter 5.

- In recent years, global carbon dioxide concentrations have also been increasing at record rates. The global average atmospheric concentration exceeded 400 parts per million during 2016: a level that has not been seen for approximately three million years.

Taken together, this research reinforces the view that, compared to the summary in the IPCC AR5, some changes are happening significantly faster than assessed in 2013 and some risks (e.g. increased sea level rise) are greater than assessed.

A large proportion of scenarios that are generated in the literature where warming is limited to 2ºC or 1.5ºC assume the use of negative emissions, or future removals of carbon dioxide from the atmosphere, for example biofuels combined with carbon capture and storage (BECCS).

Regarding BECCS, Anderson and Peters (2016) have recently demonstrated that:

- Integrated assessment models used to generate future emissions scenarios often assume perfect knowledge of future technologies and give less weight to future costs, and hence when applied to temperature targets tend to factor in negative emissions heavily;
- Studies suggest it is impossible to reach 1.5oC of warming with a 50% chance without significant negative emissions;
- However, both biofuels and carbon capture and storage (CCS) face “major and perhaps insurmountable obstacles”
- Only one large-scale demonstration plant exists today for BECCS, while “other negative emission technologies have not moved beyond theoretical studies or small scale demonstrations”;
- BECCS is thus a “highly speculative technology”;
- While the appropriateness of reliance on negative emissions technologies is generally an issue of risk, the risk is of immense, irreversible harm – “if we rely on [negative emissions technologies] and they are not deployed or are unsuccessful at removing CO2 from the atmosphere at the levels assumed, society will be locked into a high-temperature pathway”; there will be a “rapid temperature rise reminiscent of the 4oC business as usual pathway feared before the Paris Agreement.
- If the emphasis on risk aversion in the Paris Agreement in particular is to have any meaning, negative emission technologies should not form the basis of the mitigation agenda; relying on negative emissions creates a “moral hazard par excellence”.

The above suggests that there is considerable urgency around reductions of global emissions of greenhouse gases, an urgency that is not yet reflected in national-scale actions around the world.

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