Climate Science for Health Professionals

A Presentation and Discussion of the
IPCC Working Group 1 Report

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Medact's Programme on Ecology and Climate

Climate change has been described as the greatest threat to public health in the 21st century.

This is the first of a series of reports that will be produced by Medact aimed at communicating the science of climate change to the wider health community.

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Acknowledgements

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Introduction

Health professionals are not climate scientists.

But climate science is of profound importance to health professionals. Global warming is already having a significant negative impact on human health; it threatens to be an overwhelming danger to human health in the coming decades.

For this reason, health professionals – especially those working in the field of health policy and public health protection – need some understanding of climate science as a basis for their active and assertive engagement in policy debates about how we respond to global warming.

The reports of the Intergovernmental Panel on Climate Change (IPCC), set up under the auspices of the United Nations, represent the most authoritative scientific understanding of global warming and climate change. Three scientific working groups have been constituted to cover different areas:

- Working Group 1 (WG1) – The physical scientific aspects of the climate system and climate change.
- Working Group 2 (WG2) – The vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adaptation.
- Working Group 3 (WG3) – Options for mitigating climate change through limiting or preventing greenhouse gas emissions and removing them from the atmosphere.

Last September, WG1 published its fifth and most recent report. It is more than 2000 pages long. This document highlights the key issues in a digestible form for health professionals, with some additional explanatory material. All quotes come directly from the IPCC-WG1 report, unless otherwise stated. For the sake of brevity, references underpinning the report have been excluded.

The IPCC-WG1 report is a scientific summation of the physical science of climate change. Because of the politicisation of climate science, the authors have taken great care to ensure that both empirical and modelled evidence is presented clearly.

In the report, they describe the degree of 'confidence' in the validity of any finding. This is based on the type, amount, reliability, quality, and consistency of evidence as well as the degree of agreement amongst scientists. Confidence is expressed qualitatively in terms of being high, medium and low.

They also describe the degree of certainty in a finding or prediction. This is based on statistical analyses and model results, as well as expert judgment. Certainty is expressed accordingly:

- **Virtually certain (99-100% probable)**
- **Very likely (90-100% probable)**
- **Likely (66-100% probable)**
- **About as likely as not (33-66% probable)**
- **Unlikely (0-33% probable)**
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What follows is a summary of the key facts around global warming and climate change which every health professional should know about.

Executive Summary

Introduction

This document presents a summary and discussion of a report produced by the Intergovernmental Panel on Climate Change (IPCC) on the physical science of climate change. The IPCC report is the most authoritative presentation of scientific consensus on: a) the degree to which the earth's temperature has risen; b) the effects this is having and will have on the climate, sea level and ocean acidification; and c) the causes for the rise in temperature.

Global Warming

Global warming is real. Combined land and ocean surface temperature data show an increase of about 0.89°C (0.69 - 1.08) over the period 1901– 2012 and about 0.72°C (0.49 -0.89) since 1951.

Furthermore, there is no doubt that human influence is a major cause for this rise in temperature. According to the IPCC report, it is 'extremely likely' that more than half of observed increase in temperature was caused by human influence.

The frequently cited observation that the rate of global warming has decreased over the last decade or so is due to natural variability related to a temporary reduction in the force of solar radiation, volcanic activity and changes in ocean circulation which can increase the rate of heat transfer from the surface to the lower depths of the ocean.

The main cause for global warming is increased energy being trapped in the earth-atmosphere system due to greenhouse gases (GHGs), in particular carbon dioxide.

Atmospheric concentrations of GHGs have reached levels that are unprecedented in at least the last 800,000 years; and is mainly due to fossil fuel combustion, cement production and land use changes.

Effects of global warming

Climate science is constrained by: a) the relative shortness of accurate climate records; b) limitations in the reliability and completeness of data; c) the presence of large natural variability across multi-decadal time scales; and d) an incomplete understanding of the drivers of climate and weather activity.

However, a growing body of evidence of changes can be attributed to global warming. These include changing weather patterns; sea level rise; increased atmospheric humidification; ocean acidification and deoxygenation; the melting of glaciers and the polar ice caps; and changes in snow cover. Many of the observed changes due to global warming since the 1950s are unprecedented over decades to millennia.

However, 'climate change' demonstrates significant regional variation. In a few parts of the world, for example, natural variation and other factors may result in a fall in average temperatures; and while the world as a whole will become wetter, some parts will experience greater dryness and a possible increase in the duration and severity of drought. This is suggestive of a destabilisation of the climate rather than a common or unidirectional change.

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Future Projections

Future projections of temperature and climate change cannot be determined with complete scientific certainty. In particular, the "non-linear and chaotic nature of the climate system imposes natural limits on the extent to which skilful predictions of climate statistics may be made".

Furthermore, future projections need to accommodate a wide range of different policy, technological, social and economic scenarios, including future GHG emissions, improvements in energy efficiency, changes in land use, patterns of economic development, and population growth.

Climate scientists have therefore developed predictions about future changes for different possible future scenarios including one that involves a rapid reduction in GHG emissions and one that sees GHG emissions continue to rise. IPCC predictions about the future are made using four different scenarios, and for the short term (up to the middle of this century) and the longer term (end of the century).

Some of these predictions are described in this report. However, the bottom line is that continued emissions of GHGs will cause further warming and changes in all components of the climate system.

Conclusions

Anthropogenic global warming is unequivocal. This rise in temperature has already caused changes to the climate and other aspects of the natural world, and will continue to do so even if GHG emissions were stopped immediately. If we are to limit climate change, there will need to be substantial and sustained reductions of GHGs.

Discussion

The precautionary principle states: "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically". Current public policy, however, is more reactionary than precautionary, requiring a high degree of certainty of harm before preventive action is taken, and emphasizing the management of risks rather than their prevention.

But global warming is already having significant and negative impacts on human health, and has the potential to be an overwhelming cause of social disruption, illness, malnutrition, conflict and mass migration in the future.

So what should health professionals do?

From a policy perspective, we can challenge on-going denial and scepticism about anthropogenic global warming, and use the precautionary principle to call for a rapid and large reduction in GHG emissions. There is enough evidence to indicate that the threats of global warming warrant an unprecedented degree of political, social and economic mobilisation to shift the basis of our economies and lifestyles from being dependent on fossil fuels, ecological degradation and unrestrained consumption; towards one that is based on renewable energy and sustainable living.

At a more local and immediate level, we can implement solutions to reduce our own carbon footprint – as individuals and members of local communities; and as workers within a carbon-intensive health system.

Over the coming months, Medact will be producing further reports about climate change. If you are interested in supporting this work and helping to build a progressive and science-based health movement around climate change, contact us here.

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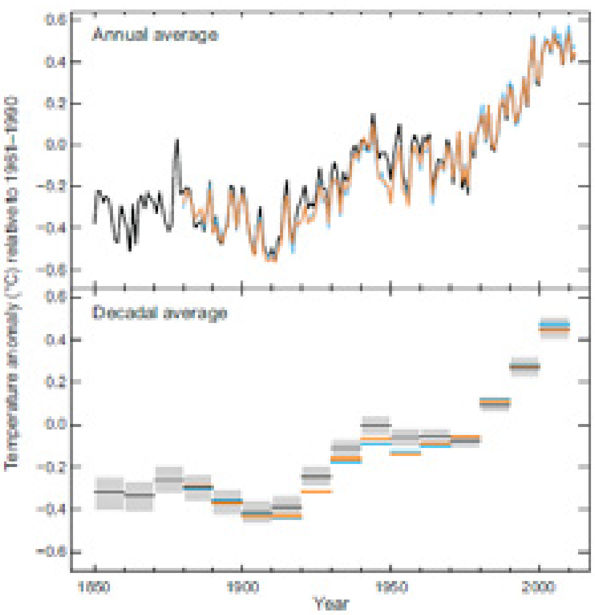
Global warming

Global warming is a real phenomenon. It is "*certain* that Global Mean Surface Temperature (GMST) has increased since the late 19th century. Combined land and ocean surface temperature data show an increase of about 0.89°C (0.69 – 1.08) over the period 1901– 2012 and about 0.72°C (0.49 -0.89) over the period 1951–2012". Each of the past three decades "has been significantly warmer than all previous decades with recorded data, and the first decade of the 21st century has been the warmest" (Figure 1). In the Northern Hemisphere, "1983 – 2012 was *likely* the warmest 30-year period of the last 1400 years (medium confidence)".

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" (Figure 2) and "*likely*" to have warmed between the 1870s and 1971. On a global scale, ocean warming is largest near the surface. The upper 75 m warmed by 0.11°C (0.09 to 0.13) per decade over the period 1971 to 2010, storing more than 60% of the net energy increase in the climate system during this period.

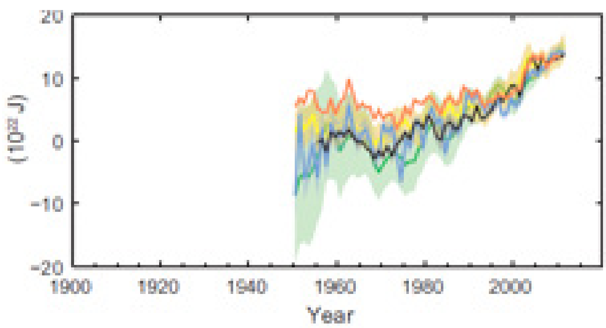
In explaining these trends, scientists have taken into account the "substantial multi-annual variability in the rate of warming" (including several periods exhibiting almost no linear trend), and have explained how the observed reduction in the surface warming trend over the period 1998 to 2012 (compared to the period 1951 to 2012) is due to the cooling effect of volcanic eruptions, the downward phase of the 11-year solar cycle, and natural changes to ocean circulation which has resulted in a faster rate of heat transfer from the surface to the deeper parts of the ocean. This is important because this apparent slow down in the rate of surface warming has been used by certain actors to deny global warming.

Figure 1: Temperature anomaly in globally averaged combined land and ocean surface temperature



Note: Temperature anomaly refers to the change in average temperature from a given historical baseline. In the IPCC reports, different baselines are used at different times. Sometimes it refers to a pre-industrial baseline, and at other times, as in Figure 1, the baseline used is the average temperature between 1961 and 1990 (marked by the green dotted line). It shows a temperature anomaly of about 0.5C. However, a baseline set to the preindustrial era would result in a much larger temperature anomaly.

Figure 2: Change in global average upper ocean heat content



Note: The different coloured lines indicate different data sets

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The causes of global warming

Global warming is the result of changes in the energy balance in the earth-atmosphere. The primary cause for the energy imbalance that results in global warming is the effect of greenhouse gases (GHGs) trapping a higher proportion of energy within the atmosphere.

The balance between the amount of solar energy absorbed by the earth-atmosphere system and the amount of energy radiated back into space is also affected by other factors such as the intensity of solar energy, the reflectivity of clouds or very small particles (aerosols) in the atmosphere (which have a net 'global cooling effect'), and changes to the nature of the surface areas of the planet.

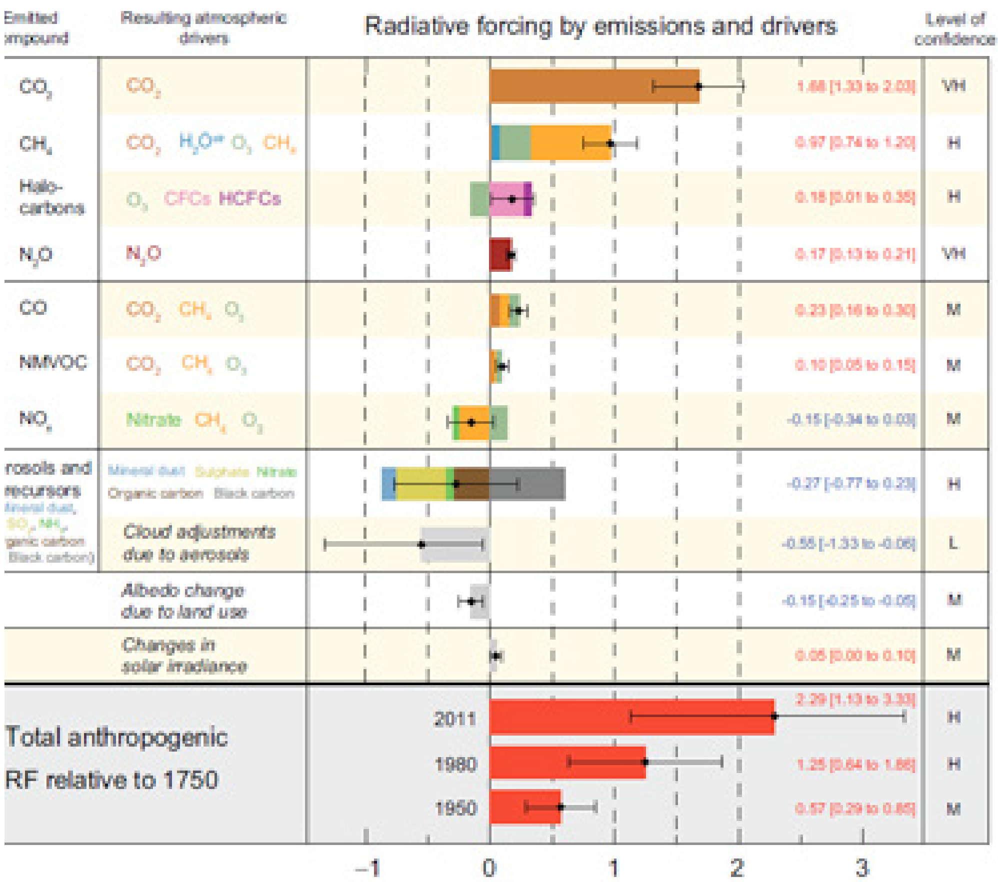
However, it is now "*virtually certain* that human influence has warmed the global climate system" and "*extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010" was caused by human influence. The contribution of GHGs to global warming "is *likely* to be between 0.5°C and 1.3°C over the period 1951–2010".

In making its conclusions, IPCC-WG1 has accounted for other causes of global temperature change including changes in the intensity of solar irradiance[1] and volcanic activity (which has a cooling effect). Urban Heat Island[2], and land-use land-cover change effects were also concluded to have had a negligible impact on large-scale trends, although they can have significant impacts for certain single discrete locations.

1 The monitoring of solar radiative fluxes began on a widespread basis in the mid-20th century, predominantly measuring the downward solar component, also known as surface solar radiation (SSR). There is evidence of substantial decadal changes in measures of SSR – specifically, a decline of SSR (popularly known as 'global dimming') from the 1950s until the mid-1980s, and a partial recovery since then ('brightening').

2 UHI effects arise mainly because the modified surface affects the storage and transfer of heat, water and airflow.

Figure 3: **Contribution of different emissions and drivers to RF relative to the year 1750**



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The term used to describe the effect of GHGs on the energy balance of the earth-atmosphere system is ‘radiative forcing’ (RF). RF is a measure of the balance of incoming and outgoing energy in the earth-atmosphere system and is expressed in Watts per square meter (W/m2). According to WG1, the total anthropogenic RF for 2011 relative to 1750 is 2.29 W/m2 [1.13 to 3.33], with anthropogenic RF having increased more rapidly since 1970 than during prior decades. In short, this is a measure of how much the earth’s energy balance has changed since industrialisation took place.

Figure 3 describes the contribution of different GHGs and other factors to this RF. Carbon dioxide is the most important of the various GHGs; followed by methane (CH4) and nitrous oxide (N2O). According to WG1, “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 40% since pre-industrial times”, primarily from fossil fuel combustion, cement production and land use changes (e.g. deforestation). Methane levels in 2011 exceeded pre-industrial levels by about 150%.

As can be seen in Figure 3, some gases and aerosols can have a ‘global cooling’ effect. The aerosol effect is important: “there is high confidence that aerosols and their interactions with clouds have offset a substantial portion” of RF from well-mixed GHGs. The uncertainty about the effects of aerosols also “contribute the largest uncertainty to the total RF estimate”. Land-related albedo change (changes in the reflecting power of a surface area) is also thought to have had a cooling effect on global temperatures.

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The effects of global warming

Interpretation of trends in climate variability is hampered by: a) the relative shortness of climate records; b) limitations in the reliability and completeness of data; c) the presence of large natural variability across multi-decadal time scales; and d) an incomplete understanding of the drivers of climate and weather activity.

However, there is a growing body of evidence of weather and climate changes that can be attributed to global warming. In their report, IPCC-WG1 notes that sea level rise, increased atmospheric humidification, ocean acidification, the deoxygenation of the oceans, changes in the water cycle, the melting of glaciers and the polar ice caps, changes in snow cover and evidence of climate extremes can all be partially attributable, with varying levels of scientific confidence[3], to "a large-scale warming resulting primarily from anthropogenic increases in GHGs".

However, 'climate change' demonstrates regional variation in trend changes – sometimes in opposite directions. This is more suggestive of a destabilisation of the climate rather than a common or unidirectional change. This is important because certain actors use the fact that climate trends show opposite results in different parts of the world to deny the presence of anthropogenic global warming.

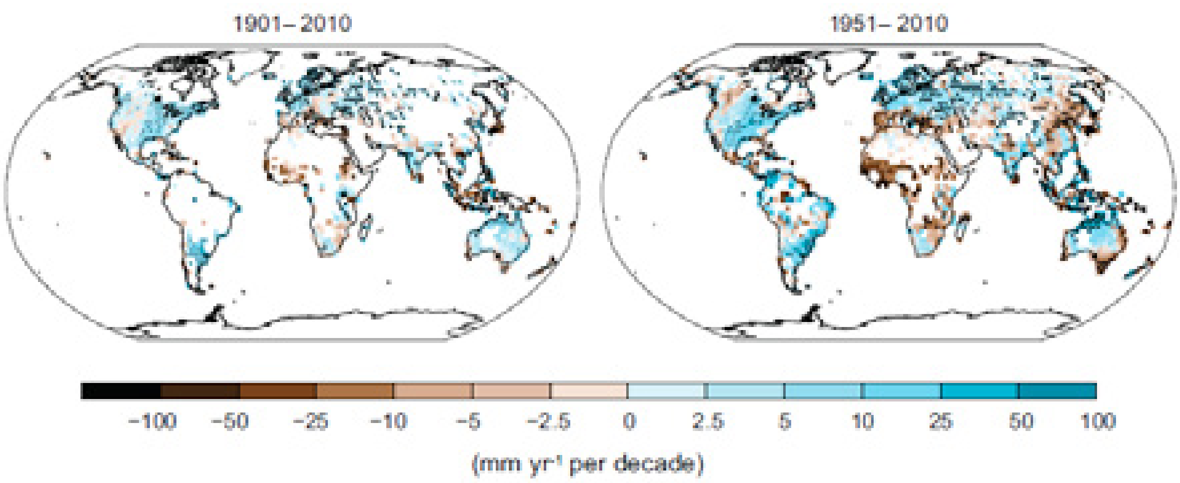
Temperature extremes

It is now "*very likely* that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century". According to WG1, it is "*very likely*" that the numbers of cold days and nights have decreased while the numbers of warm days and nights have increased for most regions of the globe since about 1950. There is "medium confidence that the length and frequency of warm spells, including heat waves, has increased since the middle of the 20th century", with the level of scientific confidence constrained mostly by a lack of data from Africa and South America. However, it is "*likely*" that heat wave frequency has increased since 1950 in large parts of Europe, Asia and Australia. [Recent high-profile heat waves include Europe in 2003, Australia in 2009, Russia in 2010 and USA in 2011/2012].

It is notable that some regions of the world exhibit trend changes in the opposite direction. In central North America and eastern USA, temperatures have cooled relative to significant warming elsewhere in the region – a finding associated with "changes in the hydrological cycle and land-atmosphere interaction and decadal and multi-decadal variability linked with the Atlantic and Pacific Oceans". There are also exceptions to warming trends noted in parts of South America. The presence of pockets of 'cooling' in some parts of the world does not contradict in any way the fact that the aggregate temperature of the earth's lands and oceans has risen.

3 For example, it is "*very likely*" that anthropogenic causes of global warming have contributed to: oceanic salinity changes since the 1960s; observed changes in the frequency and intensity of daily temperature extremes globally since the mid-20th century; global mean sea level rise; and Arctic sea ice loss since 1979. It is (only) "*likely*" that anthropogenic causes of global warming have contributed to "observed reductions in northern hemisphere snow cover since 1970". While there is "medium confidence" that human influence has contributed to the "intensification of heavy precipitation over the second half of the 20th century" in land regions; there is "low confidence" in attributing changes in drought over land areas since the mid-20th century.

Figure 4: **Observed change in annual precipitation over land**



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Rainfall

Because warmer air generally holds more water vapour, a warmer world is expected to be a wetter world. Since about 1950, the number of heavy precipitation events over land has increased in more regions than it has decreased. There is a high degree of scientific confidence in evidence of increases in either the frequency or intensity of heavy precipitation in North America, Central America and Europe (confidence is highest for central North America), and recent studies indicate that "heavy rain events are increasing in frequency and intensity" in South America. There is also evidence of increased flooding in northern high latitudes, where observed warming trends have been largest (though no clear evidence of a trend elsewhere).

Although changes in precipitation are "generally consistent with a wetter climate", global warming can also result in reductions of precipitation and an increased propensity towards drought in some areas. There is "medium confidence of an increase in dryness or drought in Eastern Asia, with high confidence that this is the case in the Mediterranean and West Africa". There is also evidence of a decrease in precipitation in southern Australia and western Asia, and "high confidence for the occurrence of droughts of greater magnitude and longer duration" since 1900 in many regions. Figure 4 shows this trend of both increased and decreased precipitation in different parts of the world.

Weather systems

Weather systems are complex, variable and dynamic. Global warming, and other human impacts such as deforestation, will affect weather systems at a global and regional level through a variety of pathways.

Evidence of changing weather systems includes a widening of the tropical belt since the 1970s, a weakening of the East Asian monsoon (low confidence), a pole-ward shift and intensification of the North Atlantic cyclone tracks from the 1950s to the early 2000s, and a pole-ward shift of storm tracks and jet streams since the 1970s (evidence of this is more robust for the Northern Hemisphere than for the Southern Hemisphere).

There are "no significant observed trends in global tropical cyclone frequency over the past century". However, at a regional level, it is "*virtually certain* that the frequency and intensity of the strongest tropical cyclones in the North Atlantic has increased since the 1970s". Tropical cyclone indices that incorporate frequency, duration and intensity also show "upward trends in the western North Pacific since the late 1970s".

As with temperature and precipitation, regional trends show marked variability. Evidence suggests "slight decreases in the frequency of tropical cyclones making landfall in the North Atlantic and the South Pacific". Studies also indicate "a decrease in extra-tropical cyclone activity and intensity over the last 50 years" for northern Eurasia, East Asia and along the southeast and southwest Canadian coasts, while winter cyclones have become "significantly more frequent, longer lasting, and stronger in the lower Canadian Arctic".

Confidence is low in the trend in indicators of "storminess" over the last century due to inconsistencies between studies or lack of long-term data from some parts of the world (particularly the southern hemisphere), and likewise for trends in extreme winds and weather events such as hail or thunderstorms "due to quality and consistency issues with analysed data".

The cryosphere (the frozen parts of the planet)

Global warming is melting the earth's cryosphere. The amount of ice contained in glaciers globally "has been declining every year for more than 20 years". Multiple lines of evidence also point to "very substantial Arctic warming since the mid-20th century" and "substantial losses in Arctic sea ice" (Figure 5). There is "medium confidence that over the past three decades, Arctic summer sea ice retreat was unprecedented. The average rate of ice loss from the Greenland ice sheet "has *very likely* substantially increased from 34 Gt/yr (-6 to 74) over the period 1992 to 2001, to 215 Gt/yr (157 to 274) over the period 2002 to 2011. The average rate of ice loss from the Antarctic ice sheet has *likely* increased from 30 Gt/yr (-37 to 97) over the period 1992–2001 to 147 Gt/yr (72 to 221) over the period 2002 to 2011; although there is low confidence in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades.

By contrast, there is low confidence in understanding the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and low confidence in estimates of natural internal variability.

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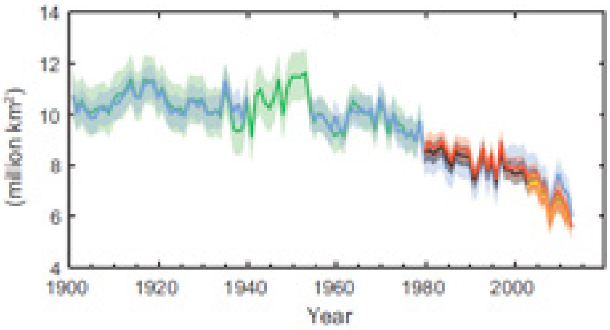
Figure 5: **Arctic Summer Sea Ice Extent**



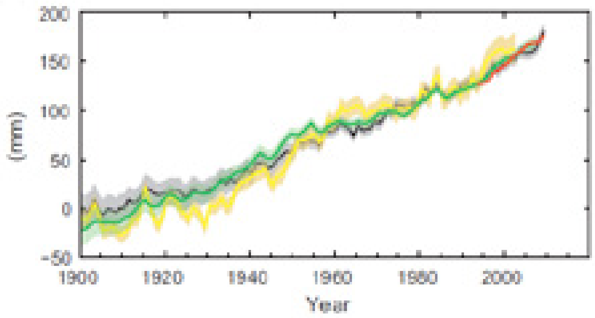
There is "very high confidence that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century", and "high confidence that permafrost temperatures have increased in most regions since the early 1980s". Observed warming was up to 3°C in parts of Northern Alaska (early 1980s to mid-2000s). In parts of the Russian European North, observed warming was up to 2°C (1971 to 2010) and a considerable reduction in permafrost thickness and area extent has been observed since 1975.

Sea level rise

Thermal expansion of water and melting of the cryosphere have resulted in sea level rise. It is "*virtually certain* that the rate of global mean sea level rise has accelerated during the last two centuries". At the same time, it is "*very likely*" that the mean rate was 1.7 mm/yr (1.5 to 1.9) between 1901 and 2010 and "*very likely* higher" at 3.2 mm/yr (2.8 to 3.6) between 1993 and 2010.

Ocean thermal expansion and glacier melting (mainly in the Arctic) account for about 75% of the observed sea level rise (high confidence). The rapid rate of sea level rise since the 1990s mirrors the proportion of melting ice and thermal expansion. But the contribution from the melting of the Greenland and Antarctic ice sheets has increased since the early 1990s. Land water storage changes (e.g. the damming of rivers, deforestation and groundwater mining) have also contributed to sea level rise (by increasing the volume of river run off into the sea), but only to a small extent.

Figure 6: **Global average sea level change**



Ocean chemistry

The greater concentrations of carbon dioxide in the atmosphere have resulted in the acidification of surface waters. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing the pH of ocean surface water to have decreased by 0.1 since the beginning of the industrial era (high confidence). There is also "medium confidence" that the observed global pattern of a decrease in oxygen in the oceans "can be attributed in part to human influences".

It is also "*very likely*" that regions of the ocean with high salt content have become saltier, while those regions with low salt content have become fresher since the 1950s. These different regional trends in ocean salinity provide indirect evidence that patterns of evaporation and precipitation over the oceans have changed (medium confidence).

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Scenario Building for the Future

What of the future?

Two aspects of climate science need to be considered: first, the scale, speed and distribution of further global warming; second, the impact of GHGs and temperature change on the climate, cryosphere and oceans. While there is *some* confidence in projections about the former, there is less confidence in predicting the precise nature of the changes to regional weather and climate.

There are several reasons why future projections of temperature and climate change cannot be determined with complete scientific certainty. One is that our understanding of the relationship between GHG emissions and global warming is limited by the complexity of the natural system being studied. The climate and the earth's temperature is influenced by a multitude of factors – natural and anthropogenic – with many negative and positive feedback loops, as well as significant regional variations. As noted by WG1, the "non-linear and chaotic nature of the climate system imposes natural limits on the extent to which skilful predictions of climate statistics may be made".

Furthermore, as the world heats up, the planet itself is changing in ways that make it less plausible to anticipate the future on the basis of past observations. Put another way, we are entering 'new territory' – and as we do so, our existing bank of empirical data becomes more limited as a basis for future prediction.

Finally, the future will and can be influenced by any number of possible, but unknown, changes to human activity. Future projections would therefore need to accommodate a wide range of policy, technological, social and economic scenarios, and factor in variables such as future GHG emissions, developments in technology, changes in land use, economic developments and population growth.

In order to help policy making, scientists have developed four different scenarios known as Representative Concentration Pathways (RCPs). Each RCP represents a different 'pathway' towards a final scenario of energy balance and GHG concentration by the year 2100. They are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models.

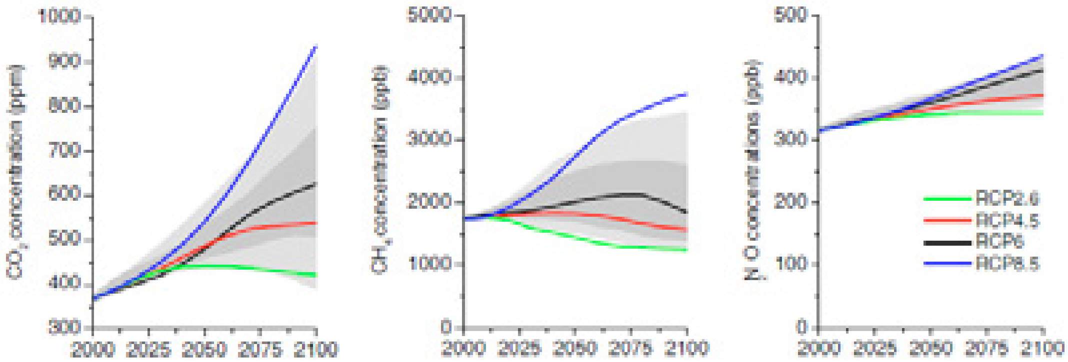
The four RCPs are: RCP2.6, RCP4.5, RCP6, and RCP8.5 – with each number representing a possible level of radiative forcing (RF) by the year 2100 relative to 1750. These four RCPs include one strong mitigation scenario leading to a very low level of RF (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high GHG emissions (RCP8.5). For RCP2.6, GHG emissions peak and then decline; while for RCP4.5, emissions rise and then stabilise by 2100. But for RCP6.0 and RCP8.5, RF does not peak by the year 2100.

Note: The WG1 report does not provide a clear description of the RCP models. The description here has been taken from two publications. One by Graham Wayne: The Beginner's Guide to RCPs. The other by van Vuuren and colleagues: The representative concentration pathways: an overview. Figures 7 – 13 are taken from the latter publication.

The four RCPs have been developed by different groups of scientists taking into account the best available data and evidence; whilst employing certain assumptions about the future. They thus provide a scientific platform that can be used to examine other potential scenarios and futures.

Figure 7 demonstrates the trends on the concentration of three key GHGs for each of the four RCP scenarios. For

Figure 7: Trends in concentrations of greenhouse gases



Virtually certain (99-100% probable) **Very likely** (90-100% probable) **Likely** (66-100% probable)
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example, RCP2.6 reaches a peak prescribed CO2 concentration before 2050 and then declines. For RCP4.5, RCP6.0 and RCP8.5, CO2 concentrations reach 538 ppm, 670 ppm and 936 ppm respectively by the year 2100. CO2 concentrations are about 400ppm now, having risen from about 280 ppm in the pre-industrial period.

Figure 8 shows the trends in emissions (not concentrations) for the same three main GHGs. It shows that to achieve the RCP2.6 scenario, there would need to be drastic policy intervention to reduce GHG emissions almost immediately. The RCP8.5 scenario, on the other hand, assumes more or less unabated emissions.

The projected trends in GHG concentrations and emissions for each RCP are based on assumptions about economic activity, energy sources, population growth and other socio-economic factors. Predictions are also made about the future trend of air pollutant emissions (e.g. SO2 and NOx), taking into account factors such as change in fossil-fuel and fertilizer use; more stringent air pollution control policy; and changes in energy consumption.

Figure 9 shows the mix of GHGs by 2100 for each RCP scenario relative to the RF level in 2000. Carbon dioxide is the most important gas in all four scenarios. Figure 10, in turn, shows the projected demographic and GDP trend for each RCP. As would be expected, RCP8.5 incorporates high population growth and lower income growth in developing countries. RCP2.6, on the other hand, projects low population growth and positive economic growth.

Figure 8: **Emissions of main greenhouse gases across the RCPs.**

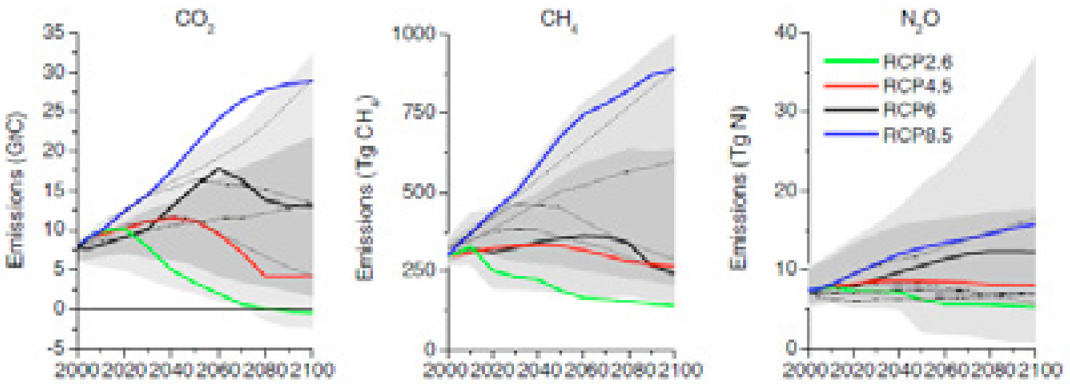
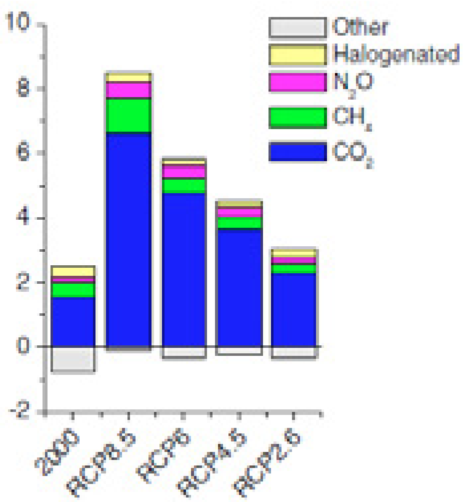


Figure 9: **Radiative forcing in 2100 (relative to pre-industrial values) per GHG category for each RCP**



Note: The WG1 report does not provide a clear description of the RCP models. The description here has been taken from two publications. One by Graham Wayne: The Beginner's Guide to RCPs. The other by van Vuuren and colleagues: The representative concentration pathways: an overview. Figures 7 – 13 are taken from the latter publication.

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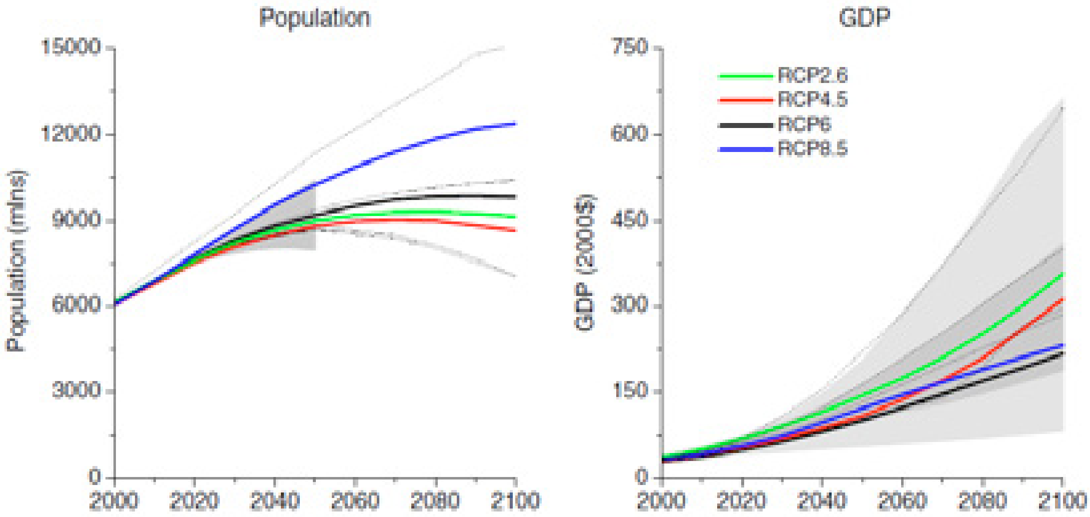
Figure 10: **Population and GDP projections of the four RCPs**



Each RCP also comprises a certain future energy scenario as shown in Figure 11. In RCP2.6, RCP4.5 and RCP6, it is assumed that primary energy use would be of the order of 750 to 900 EJ in 2100 – up to double the level of energy use today. RCP8.5, in contrast, is a highly energy-intensive scenario that results from high population growth and a lower rate of technology development. The assumed source of energy for each RCP is shown in Figure 12.

Figure 11: **Primary energy consumption (direct equivalent) and oil consumption for different RCPs**

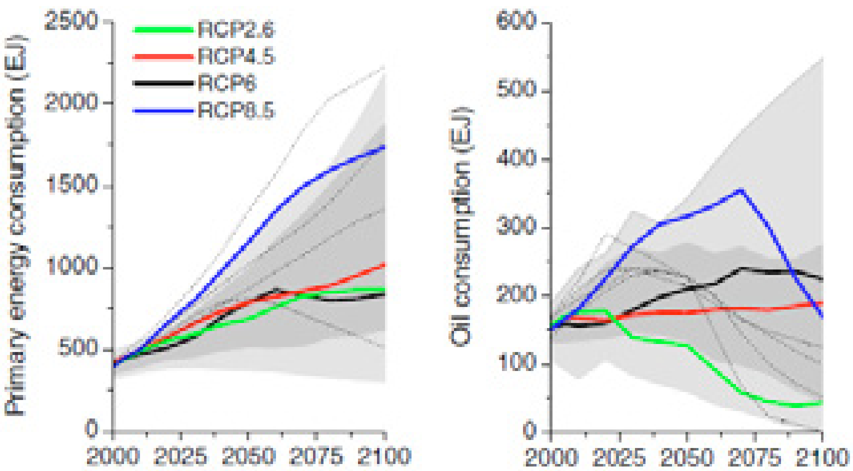


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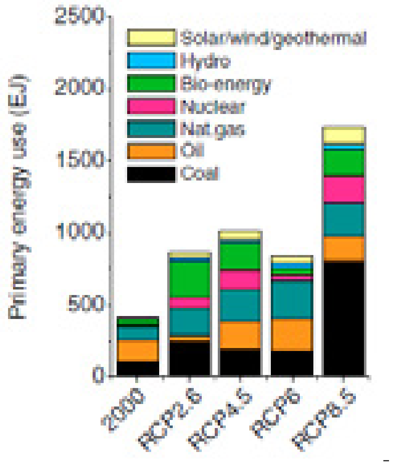
Figure 12: **Energy sources by sector for each RCP in 2100 compared to 2000**

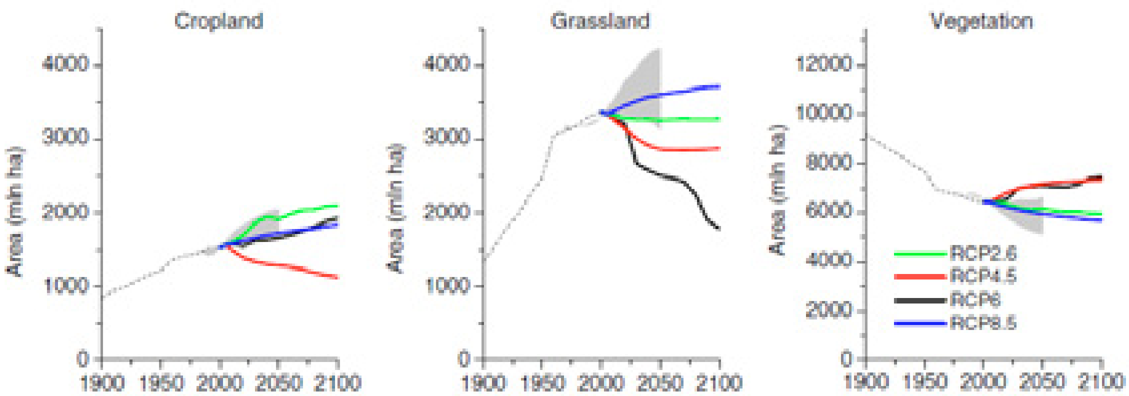


Among the variables considered are increasing energy demand, rising fossil-fuel prices and climate policy. All scenarios assume that the use of carbon capture and storage (CCS) technologies, renewable energy (e.g. wind, solar), bioenergy and nuclear power will have increased by 2100. The use of oil stays fairly constant in most scenarios, but declines in RCP2.6 (as a result of depletion and climate policy). An important element of the RCP2.6 is the use of bio-energy and CCS, resulting in negative emissions.

Finally, the RCP scenarios take into account future trends in land use which influence the climate system through, for example, direct emissions from land-use, hydrological and bio-geophysical effects and the mass of the remaining vegetation stock. The RCP scenarios cover a wide-range of land-use scenario projections related to growing cropland and increasing use of grasslands driven by rising population and changing dietary patterns, as well as policies to actively increase vegetation cover (see Fig. 13). In RCP8.5, the use of cropland and grasslands increases, mostly driven by an increasing global population. In RCP2.6, cropland also increases (but largely as a result of bio-energy production) while the use of grassland is more-or-less constant (based on the assumption that an increase in the production of animal products is met through a shift towards more intensive animal husbandry). RCP4.5 shows a different scenario based on the assumption that carbon in natural vegetation will be valued as part of global climate policy, resulting in greater reforestation and decreases in the use of cropland and grassland following considerable yield increases and dietary changes.

While the GHG concentrations and energy imbalance is fixed for each RCP scenario, the various other assumptions are not. The same final RCP scenario can result from different combinations of economic, technological, demographic, policy, and institutional futures. But the four RCP models provide a basis and standardised international methodology by which different social, economic and energy policies can be assessed – at both the global and regional level.

Figure 13: **Land use (crop land and use of grass land) across the RCPs**



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Future Scenarios: Global Temperature

What do the RCP scenarios represent in terms of future temperature change? Once again, there is little in the way of scientific certainty, with the effect of aerosols being an important source of uncertainty. This uncertainty is demonstrated by the fact that "differences in global mean surface air temperature across RCP scenarios for a single climate model are typically smaller than across (different) climate models for a single RCP scenario".

Table 1 shows the projected median temperature anomaly for each RCP relative to 1986-2005 as reported by IPCC-WG1. It shows that even for RCP2.6 (which projects a rapid cessation of GHG emissions), global warming will continue and probably rise by 1°C relative to 1986-2005. For RCP8.5, the projected median temperature anomaly by the middle of this century is 2°C. However, according to IPCC-WG1, "the global mean surface temperature change by the middle of this century relative to 1986–2005 will *likely* be in the range of 0.3°C to 0.7°C (medium confidence)", assuming no major volcanic eruptions[4] or secular changes in total solar irradiance[5] before 2035.

4 A future volcanic eruption similar to the 1991 eruption of Mount Pinatubo would cause a rapid drop in global mean surface air temperature of several tenths °C in the following year, with recovery over the next few years.

5 While future changes in solar irradiance could influence global mean surface air temperature increases, "there is high confidence that this influence will be small in comparison to the influence of increasing concentrations of GHGs".

The projected increases in global mean surface temperatures for 2081–2100 relative to 1986–2005 are higher, except for RCP2.6. The ranges are 1.1°C to 2.6°C for RCP4.5; and 1.4°C to 3.1°C for RCP6.0; and 2.6°C to 4.8°C for RCP8.5.

Temperature change will not be regionally uniform. The Arctic region will warm more rapidly than the global mean[6], and mean warming over land will be larger than over the ocean (very high confidence)". In some parts of the world, there may even be cooling – "one model exhibits marked cooling in 2081–2100 over large parts of the Northern hemisphere, and a few models indicate slight cooling in the North Atlantic". It is "*very likely*" that ocean temperatures will increase in the near-term, with the strongest ocean warming projected for the surface in tropical and Northern Hemisphere subtropical regions.

6 This polar amplification is not found in Antarctic regions due to deep ocean mixing, ocean heat uptake and to the persistence of the Antarctic ice sheet"

Table 1: Projected change in global mean surface air temperature rise for the mid- and late 21st century relative to the reference period of 1986–2005.

RCP	Temperature anomaly relative to 1986-2005 by mid 21st century (oC)	Temperature anomaly relative to 1986-2005 by end 21st century (oC)
2.6	1.0 (0.4 - 1.6)	1.0 (0.3 - 1.7)
4.5	1.4 (0.9 - 2.0)	1.8 (1.1 - 2.6)
6.0	1.3 (0.8 - 1.8)	2.2 (1.4 - 3.1)
8.5	2.0 (1.4 - 2.6)	3.7 (2.6 - 4.8)

Virtually certain (99-100% probable) **Very likely** (90-100% probable) **Likely** (66-100% probable)
About as likely as not (33-66% probable) **Unlikely** (0-33% probable) **Very unlikely** (0-10% probable) **Exceptionally unlikely** (0-1% probable)

Figure 14: Global average surface temperature change relative to 1986–2005

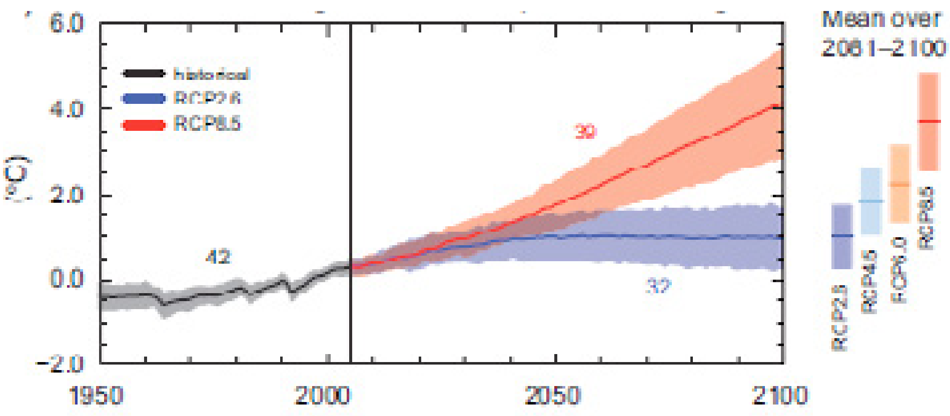

Figure 14 shows the projected trajectory of temperature rise for RCP2.4 and RCP8.5 (with uncertainty ranges) as well as the expected end point temperatures for RCP4.5 and RCP6.0.

With respect to the preindustrial period, global temperature rises are "*likely*" to exceed 2°C for RCP6.0 and RCP8.5 (high confidence), and "*more likely than not*" to exceed 2.0°C for RCP4.5. Temperature change above 2°C under RCP2.6 "is *unlikely*" (medium confidence) and warming above 4°C by 2081–2100 is "*unlikely*" in all RCPs (high confidence) except for RCP8.5 where it is "as *likely as not*" (medium confidence). IPCC-WG1 also states that it is "*more likely than not*" that the mean global mean surface air temperature for the period 2016–2035 will be more than 1°C above the mean for 1850–1900, and "*very unlikely*" that it will be more than 1.5°C above the 1850-1900 mean (medium confidence).

The principal driver of long-term warming is total emissions of CO2. To limit the warming caused by anthropogenic CO2 emissions so that it is "*likely*" to be less than 2°C relative to the preindustrial period, "CO2 emissions from all anthropogenic sources would need to be limited to a cumulative budget of about 1000 GtC over the entire industrial era" (of which just over half was already emitted by 2011). The effect of other factors means that a lower cumulative CO2 budget is required so that global warming is "*likely*" to be less than 2°C relative to the preindustrial period. Table 2 shows the maximum cumulative CO2 emissions required to limit global warming to less than 2°C at different levels of probability.

The challenge of limiting cumulative CO2 emissions so that there is an acceptable probability of avoiding a greater than 2°C in global warming is revealed by the evidence that rates of CO2 emissions are continuing to rise. Averaged over 2002–2011, annual CO2 emissions from fossil fuel combustion and cement production were 8.3 Gt/yr [7.6 to 9.0]; but for 2011, they were about 9.5 Gt/yr (8.7 to 10.3) – 54% higher than the 1990 level. Net CO2 emissions from anthropogenic land use change were 0.9 Gt/yr (0.1 to 1.7) on average during 2002 to 2011.

Table 2: Cumulative CO2 budget required to limit global warming to less than 2°C at different levels of chance

Level of chance for limiting global warming to 2°C (relative pre-industrial)	Cumulative CO2 emissions by 2011	Maximum cumulative CO2 emissions (not taking into account other causes of global warming)	Limit of cumulative CO2 emissions (taking into account other causes of global warming)
More than 33%	515 GtC	1570 GtC	900 GtC
More than 50%	515 GtC	1210 GtC	820 GtC
More than 66%	515 GtC	1000 GtC	790 GtC

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Future scenarios: The effects

A large fraction of anthropogenic climate change resulting from CO2 emissions is irreversible on a multi-century time scale, unless there is a large net removal of CO2 from the atmosphere over a sustained period. Even if there were after a complete cessation of net anthropogenic CO2 emissions, surface temperatures would remain approximately constant at elevated levels for many centuries.

Furthermore, some aspects of climate will continue to change even if temperatures are stabilised. Processes related to vegetation change, changes in the ice sheets, deep ocean warming and associated sea level rise and potential feedbacks linking for example ocean and the ice sheets have their own intrinsic long timescales and may result in significant changes hundreds to thousands of years after global temperature is stabilized. For example, due to the slow scale of heat transfer from the ocean surface to depth, ocean warming will continue for centuries.

Generally speaking, confidence or certainty in predictions about the short-term future is lower than it is for the more long-term future. This may seem counter-intuitive, but is due to the fact that unpredictable factors related to natural internal variability could have a greater effect relative to anthropogenic factors in the short-term.

Temperature extremes

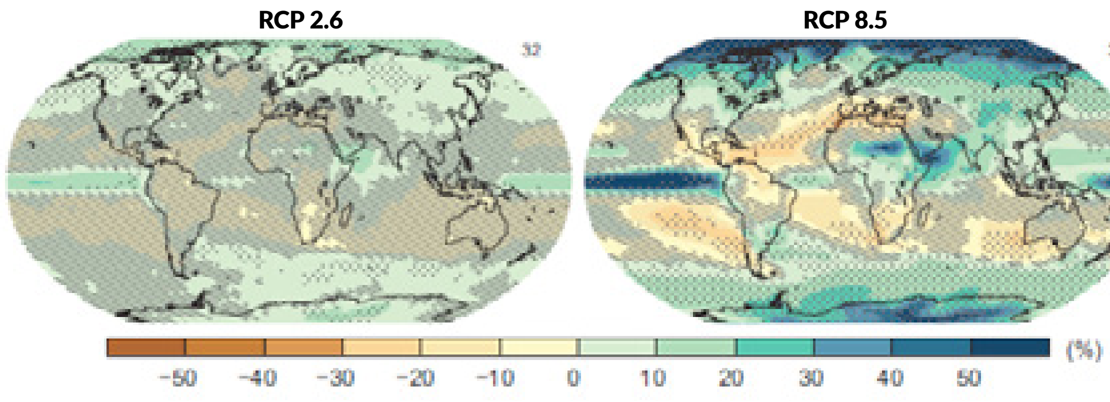
In most regions, the frequency of warm days and warm nights will "*likely* increase in the next decades, while that of cold days and cold nights will decrease". Models also project "near-term increases in the duration, intensity and spatial extent of heat-waves and warm spells". In the longer term, because unpredictable natural variability will be relatively less influential, it is "*virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes" on both daily and seasonal time scales. Increases in the frequency, duration and magnitude of hot extremes along with heat stress are expected, though occasional cold winter extremes will continue to occur.

Rainfall and precipitation

It is "*virtually certain* that, in the long term, global precipitation will increase", *likely* "by 1-3% per °C rise for scenarios other than RCP2.6". The frequency and intensity of heavy precipitation events over land "will *likely* increase on average in the near term, and "a shift to more intense individual storms and fewer weak storms is *likely* as temperatures increase" in the longer term. Extreme precipitation events (in terms of intensity and frequency) over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent by the end of this century as temperature increases.

However, this trend will not be apparent in all regions. Figure 15 illustrates the projected pattern of both increasing and decreasing average precipitation across different parts of the globe for RCP2.6 and RCP8.5. Zonal mean precipitation will "*very likely* increase in high and some of the mid latitudes", but will "*more likely than not* decrease in the subtropics". There is also medium confidence that the intensity and duration of drought is "*more likely than not*" to occur in some regions – with the frequency and intensity of drought having already "*likely* increased" in the Mediterranean and West Africa since 1950.

Figure 15: **Change in average precipitation (1986–2005 to 2081–2100) for RCP2.6 and RCP8.5**



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At a global level, monsoon systems "are *likely* to strengthen in the 21st century with increases in area and intensity". Monsoon onset dates are *likely* to become earlier or not to change much and the monsoon season is *very likely* to lengthen. Future increase in precipitation extremes related to the monsoon is "*very likely* in South America, Africa, East Asia, South Asia, Southeast Asia and Australia". There is also "medium confidence that the Indian summer monsoon circulation will weaken", but consist of more precipitation.

Cryosphere

The earth's cryosphere will continue to shrink and melt over time. By the end of the 21st century, the global glacier volume, excluding glaciers on the periphery of Antarctica, is projected to decrease by 15 to 55% for RCP2.6, and by 35 to 85% for RCP8.5 (medium confidence).It is "*very likely*" that the Arctic sea ice cover will continue shrinking and thinning over the course of the 21st century as global mean surface temperature rises (see Figure 16). Projections of average reductions in Arctic sea ice extent in September for 2081–2100 compared to 1986–2005 range from 43% for RCP2.6 to 94% for RCP8.5 (medium confidence). "A nearly ice-free Arctic Ocean in September before mid-century is *likely* under RCP8.5 (medium confidence)". A decrease in sea ice extent and volume in the Antarctic "are also expected, but with low confidence".

It is "*very likely*" that Northern Hemisphere snow cover will reduce over the coming century, and a retreat of permafrost extent "is *virtually certain*". Projections of the decrease of Northern Hemisphere spring snow cover by the end of the 21st century range from 7% (RCP2.6) to 25% (RCP8.5), while projections of a decrease in near-surface permafrost area range from 37% (RCP2.6) to 81% (RCP8.5) (medium confidence).

Sea Level Rise

It is "*very likely*" that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971–2010 for all RCP scenarios due to thermal expansion and loss of mass from glaciers and ice sheets. Table 3 shows the projected average sea level rise relative to 1986-2010 (i.e. not accounting for much of the sea level rise that has already taken place) by the middle and end of the 21st century for each RCP. This is also represented graphically in Figure 17.

Figure 16: Northern Hemisphere September sea ice extent (5-year running mean)

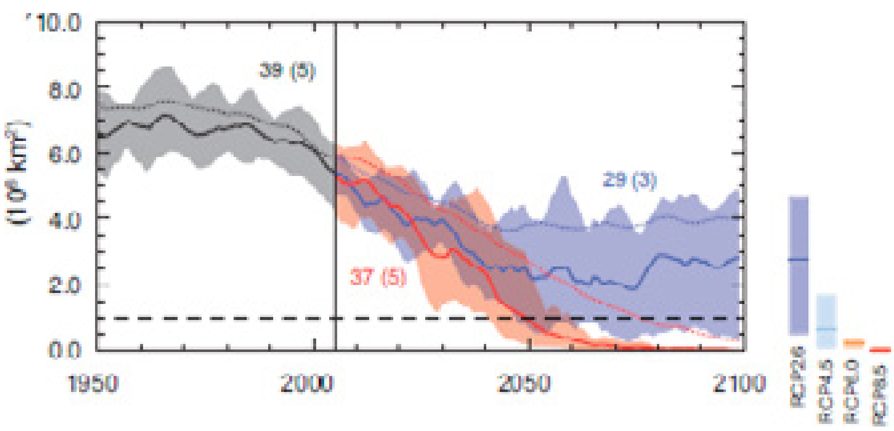

Table 3: Global Mean Sea Level Rise (m) for each RCP

RCP	Mean SLR relative to 1986-2010 by mid 21st century	Mean SLR relative to 1986-2010 by mid 21st century
2.6	0.24 (0.17-0.32)	0.40 (0.26-0.55)
4.5	0.26 (0.19-0.33)	0.47 (0.32-0.63)
6.0	0.25 (0.18-0.32)	0.48 (0.33-0.63)
8.5	0.30 (0.22-0.38)	0.63 (0.45-0.82)

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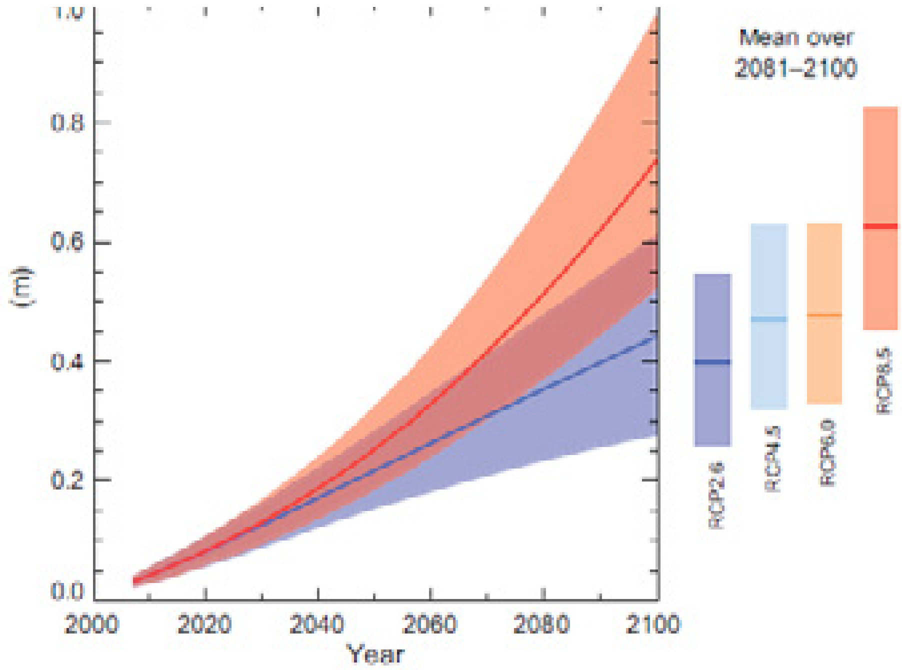
Figure 17: Global Mean Sea Level Rise



It is also "*very likely*" that there will be a significant increase in the occurrence of future 'sea level extremes' by 2050 and 2100, and "*likely*" that annual mean wave heights will increase in the Southern Ocean as a result of enhanced wind speeds. Southern Ocean generated swells are *likely* to affect heights, periods, and directions of waves in adjacent basins. It is "*very likely*" that wave heights and the duration of the wave season will increase in the Arctic Ocean.

Ocean chemistry

Ocean uptake of anthropogenic CO2 will continue under all four RCPs through to 2100 (very high confidence), and a global increase in ocean acidification is projected for all RCP scenarios. The corresponding decrease in surface ocean pH by the end of 21st century is in the range of 0.06 to 0.07 for RCP2.6, 0.14 to 0.15 for RCP4.5, 0.20 to 0.21 for RCP6.0, and 0.30 to 0.32 for RCP8.5 (see Figure 18). As with other effects of GHGs and global warming, there will be significant regional variations as shown in Figure 19.

Figure 18: Global ocean surface pH

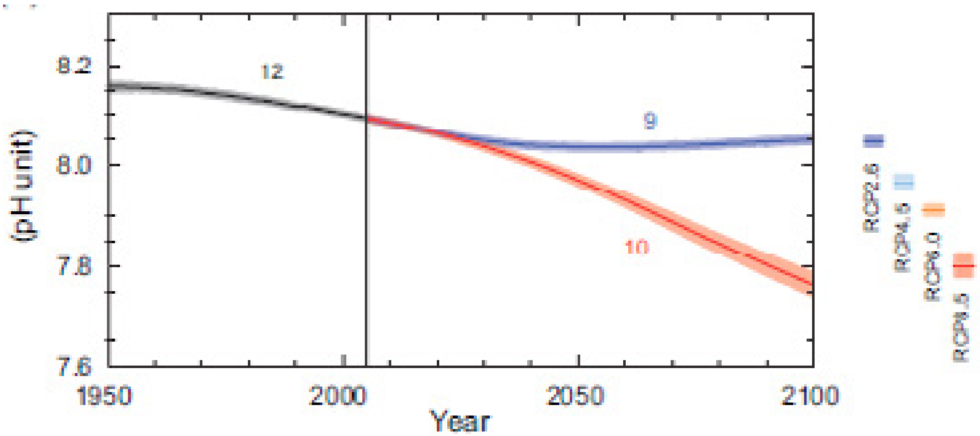


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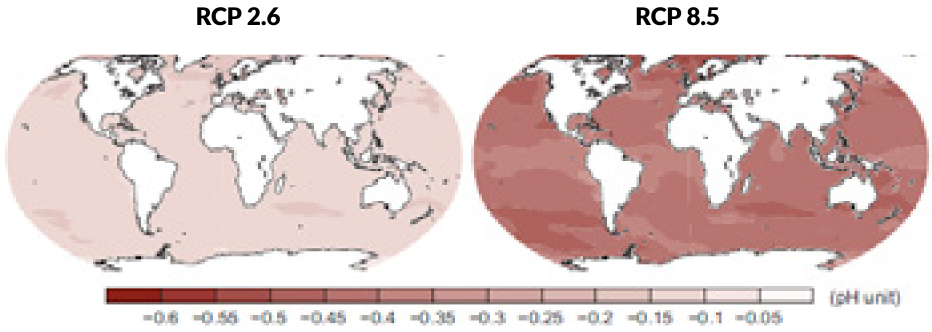
Figure 19: **Change in ocean surface pH (1986–2005 to 2081–2100) for RCP2.6 and RCP8.5**



Extreme Weather Events

There is low confidence in projecting the future frequency and intensity of extreme weather events. For example, the low confidence in projections of changes in intensity and frequency of tropical cyclones in all basins to the mid-21st century "reflects the small number of studies exploring near-term tropical cyclone activity, the differences across published projections of tropical cyclone activity, and the large role for natural variability and non-greenhouse forcing of tropical cyclone activity up to the mid-21st century". Similarly, there is low confidence in a global-scale trend in drought due to lack of direct observations, dependencies of inferred trends on the index choice and geographical inconsistencies in the trends.

At a global level, the frequency of tropical cyclones will either decrease or remain essentially unchanged, but show a likely increase in both global mean tropical cyclone maximum wind speed and precipitation rates. However, the future influence of climate change on tropical cyclones is likely to vary by region. For example, in the near term, "precipitation will *likely* be more extreme near the centres of tropical cyclones making landfall in North and Central America, East Africa, West, East, South and Southeast Asia as well as in Australia and many Pacific islands" but there is increased confidence in projections of the frequency of the most intense storms being "*more likely than not*" to increase substantially in some basins

.

Weather and climate extremes – experienced as extreme cold and heat, heavy rain, flooding, drought or strong winds – are important because they illustrate, in a tangible and visible way, the kind of future we are likely to experience unless we curb GHG emissions. Although it is not possible to attribute individual events to global warming because of natural variability, the following recent events are worth noting.

In Nikkaluokta, a Swedish village above the Arctic circle, the temperature on 3 December 2013 was an unusually warm 4.7C which then dropped to -40.8C before rising again to 7.7C on 10 December. The 48.5C rise in under 48 hours was one of the greatest ever recorded. Last year, one of the strangest weather maps for North America was produced: while New York was an unusually warm 21 C, slightly inland and further north, temperatures were down to -27C.

Last year, Northeast Brazil experienced its worst drought in 50 years followed by massive floods. As much rain fell in a few hours in June 2013 in central Europe as normally falls in two months: the Czech Republic, Austria, south and east Germany, Switzerland, Slovakia, Belarus, Poland, Hungary and Serbia all experienced heavy flooding. In Sudan, massive floods forced more than 250,000 people from their homes. In the western-north Pacific, 30 major storms had been recorded by early November 2013, of which thirteen were of typhoon-strength (the biggest being typhoon Haiyan (the most powerful tropical cyclone to make landfall in recorded history).

Source material available here, here, here and here

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Abrupt change

The prospect of sudden, abrupt and extreme changes occurring has been assessed. The rapid and observed shrinkage of the Arctic sea ice is already seen by many as an abrupt *and rapid change (see for example, this report from the US National Research Council).*

The IPCC-WG1 report states that "several components or phenomena in the climate system could potentially exhibit abrupt or nonlinear changes". Examples include changes to the Atlantic Meridional Overturning Circulation; the Arctic and Greenland ice sheets; the Amazon forest; and monsoonal circulations. However, while there is information for some events and their potential consequences, "in general there is low confidence and little consensus on the likelihood of such events over the 21st century".

According to IPCC-WG1, it is "*very unlikely*" that the Atlantic Meridional Overturning Circulation will undergo an abrupt transition or collapse in the 21st century for the scenarios considered. It also states that there is "high confidence" that sustained warming beyond a certain threshold would lead to the near-complete loss of the Greenland ice sheet and cause a global mean sea level rise of up to 7 m in the long term. 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 the pre-industrial period. The report also states that abrupt and irreversible ice loss of the Antarctic ice sheet is possible, but that current evidence and understanding is insufficient to make a quantitative assessment.

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Discussion and conclusion

(from Medact, not the IPCC WG1)

IPCC-WG1 is unequivocal about the fact that the global warming is occurring as a result of human activity. Warming is undeniably affecting the weather, melting the cryosphere and causing the sea level to rise. There is clear evidence of climate change and an increase in the frequency of extreme weather. It's important to note that the effects of global warming show regional differences. In some parts of the world, cooling and extreme cold weather events may be experienced, partly the result of natural variability; and while the world as a whole will become wetter, some parts will experience greater dryness and even an increase in the duration and severity of drought.

It is not possible to predict how the climate and other aspects of our planet will continue to change with any degree of uncertainty. But we can state that global warming is a real and serious threat. Exceeding a temperature rise of 2 degrees centigrade is likely to be dangerous. Exceeding a temperature rise of more than 3 or 4 degrees could be catastrophic.

IPCC Working Groups 2 and 3, which are due to report soon, are making a more detailed assessment of the social and ecological impacts of global warming, as well as the options for mitigating climate change through limiting or preventing GHG emissions, and removing them from the atmosphere. However, it's worth noting the most important message of WG1: **Limiting any further disruption and destabilisation of the earth's climate and weather systems, as well as further ocean acidification, will require substantial and sustained reductions of GHG emissions.**

How we reduce GHG emissions is possibly the most important challenge facing human civilisation. It is virtually undeniable that this will require us to stop using fossil fuels as our primary source of energy; and to rapidly make greater use of renewable energy. The role of nuclear energy remains controversial.

Similarly, the role of geo-engineering is controversial. According to IPCC-WG1, "limited evidence precludes a comprehensive quantitative assessment of both Solar Radiation Management (SRM) and Carbon Dioxide Removal (CDR)". Both CDR and SRM methods "carry side effects and long-term consequences on a global scale". There are also biogeochemical and technological limitations to CDR methods and "insufficient knowledge to quantify how much CO2 emissions could be partially offset by CDR on a century timescale". Furthermore, while SRM methods, if realizable, "have the potential to substantially offset a global temperature rise", they would also modify the global water cycle, and would not reduce ocean acidification.

The precautionary principle – a principle that forms a core part of normal public health practice – is important here. Put simply, it states that,"when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically". Current public policy, however, is more reactionary than precautionary, requiring a high degree of certainty of harm before preventive action is taken, and emphasizing the management of risks rather than their prevention.

Worse still, certain governments, politicians and influential actors continue to deny global warming and refuse to accept the need for a rapid reduction in the emission of GHGs. Here in the UK, we are burning more coal today than we were ten years ago. In Australia, the current government is expanding its coal industry and has dismantled actions taken by the previous government to reduce GHGs. In the US, a majority of the US Congress is still in denial about man made climate change and the US is set to massively expand domestic oil production.

On top of all this, we also need to contend the fact that global warming is not the only stressor on our planet. Resource depletion, land degradation and ever-growing human consumption and population, are also exerting enormous pressure on ecosystems and society. The extinction rate of a wide range of animals and plants, as well as the rapid dying of coral reefs, are just two of several ecological threats to our future wellbeing.

Virtually certain (99-100% probable)	**Very likely** (90-100% probable)	**Likely** (66-100% probable)	
About as likely as not (33-66% probable)	**Unlikely** (0-33% probable)	**Very unlikely** (0-10% probable)	**Exceptionally unlikely** (0-1% probable)

So what do we do?

When the IPCC's WG2 and WG3 report later this year, we will need to take serious note of the findings and look for the social, economic and technological solutions that are *likely* to be most effective and equitable. But in the meantime, the health community can do two things:

First, from a policy perspective, we can challenge any on-going denial and scepticism about anthropogenic global warming, and use the precautionary principle to call for a rapid and large reduction in GHG emissions. There is enough evidence to show that the threats of global warming warrant an unprecedented degree of political will, as well as social and economic mobilisation to shift the basis of our economies and lifestyles from being dependent on fossil fuels, ecological degradation and unrestrained consumption; towards one that is based on renewable energy and sustainable living.

Second, at a more local and immediate level, we can implement solutions to reduce our own carbon footprint – as individuals and members of local communities; and as workers within a carbon-intensive health system.

Over the coming months, Medact will be producing a series of further reports that will cover the findings of WG1 and WG2; as well as reports on the potential roles of nuclear and renewable energy. The health community will need to be a part of the change required at a wider societal level – both in the UK and globally.

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