A WMO information note

World Meteorological Organization
Weather · Climate · Water

A summary of current climate change findings and figures

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November 2013

1) There is a strong scientific consensus that the global climate is changing and that human activity contributes significantly to this trend. This consensus was confirmed by the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) in September 2013, when it finalized *The Physical Science Basis* volume of the *Fifth Assessment Report (AR5)*.[1] The report concludes that the "Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system." The report further states that "It is extremely likely [defined as 95-100% certainty] that human influence has been the dominant cause of the observed warming since the mid-20th century." (For a synopsis of the report's findings, see the two-page *Headline Statements from the Summary for Policymakers*.[2])

The IPCC assesses articles that climate scientists publish in peer-reviewed scientific journals, which is where most of the scientific debate on climate change takes place. Peer review, while not perfect, ensures that journals only accept articles that meet a high standard of scientific rigor and objectivity. Several surveys of the refereed literature on climate change science have confirmed that virtually all published papers accept the scientific basis of human-induced climate change.[3]

The scientific consensus about human-induced climate change is further attested to by a joint statement signed by 11 of the world's leading national science academies representing Brazil, Canada, China, France, Germany, Italy, India, Japan, Russia, the United Kingdom and the United States.[4] Many other science bodies have issued similar statements.[5]

While the fact that humanity's emissions of greenhouse gases (GHGs) contribute to climate change is no longer in dispute, scientists continue to investigate how the climate will respond to rising atmospheric levels of greenhouse gases over time and in the various regions of the world.

2) Human-induced climate change is caused by greenhouse gas emissions from industry, transport, agriculture and other vital economic sectors. Carbon dioxide makes the largest contribution. Fossil fuels (coal, oil and gas) are the greatest source of humanity's emissions of carbon dioxide (and of short-lived black carbon, which is soot resulting from incomplete

1 www.ipcc.ch
2 http://www.climatechange2013.org/images/uploads/WG1AR5_Headlines.pdf
3 For example: www.pnas.org/content/early/2010/06/04/1003187107.full.pdf+html; http://www.ametsoc.org/atmospolicy/documents/Chapter4.pdf; http://tigger.uic.edu/~pdoran/012009_Doran_final.pdf
4 www.nationalacademies.org/onpi/06072005.pdf
5 For example: www.ametsoc.org/policy/2012climatechange.html; www.aps.org/policy/statements/07_1.cfm; www.interacademies.net/File.aspx?id=4825; www.ucsusa.org/assets/documents/ssi/climate-change-statement-from.pdf.

combustion) as well as significant quantities of methane and nitrous oxide. Deforestation and other land-use changes also release large amounts of carbon dioxide. Methane is produced by cattle, rice paddies and the disposal and treatment of garbage and human waste. Fertilizers, industry and biomass burning release nitrous oxide. Industry has created a number of long-lived and potent greenhouse gases for specialized uses, such as CFCs, HCFCs, HFCs and sulphur hexafluoride.

Thanks to greenhouse gases from natural sources, the planet is some 30℃ (54℉) warmer than it would be otherwise. Most energy from the sun reaches the Earth in the form of visible light, which either scatters back out to space or penetrates the atmosphere to warm the surface. Because the Earth is much cooler than the sun, it emits energy as infrared, or thermal, radiation. Infrared radiation cannot pass straight through the air like visible light, so while most of the Earth's infrared radiation does eventually escape to space, some of it is blocked by greenhouse gases. As these gases increase, they trap more infrared energy in the lower atmosphere, further warming the Earth's surface. The correlation between carbon dioxide concentrations and global temperature over the past 800,000 years has been well demonstrated.

Solar variations are sometimes presented as making a significant contribution to climate change. Since 1750, the average amount of energy coming from the sun has either remained constant or increased slightly. However, if warming had been caused by a more active sun, scientists would expect to see warmer temperatures in all layers of the atmosphere. Instead, they have observed a cooling in the upper atmosphere and a warming at the surface and in the lower parts of the atmosphere. This is because greenhouse gases are trapping heat in the lower atmosphere before it can reach the stratosphere. Climate models that include only changes in solar irradiance are unable to reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.[6] Scientists have high confidence that the sun will have a much smaller impact on the 21st century's climate than will greenhouse gases.

3) The consensus view on climate change and greenhouse gases is based on multiple lines of evidence. They include the basic scientific laws of physics and chemistry, many different kinds of observations of both past and present climate conditions, and models that project future climate conditions. This is a major reason why researchers have a high level of confidence in their assessment that humanity's greenhouse gas emissions are contributing to climate change.

- **The laws of physics and chemistry.** Scientists have understood since the 19th century that the chemical composition of the atmosphere influences the temperature of the Earth. Carbon dioxide and other greenhouse gases, which together constitute less than one per cent of the atmosphere, keep the Earth warmer than it would otherwise be. The broad outlines of how the circulation patterns of the atmosphere and the oceans redistribute the sun's energy over the planet's surface are also well understood.

- **Observations of today's climate.** The climate is directly observed by thousands of weather stations; measuring instruments carried into the upper atmosphere by balloons, kites, airplanes and rockets; merchant ships that make observations of atmospheric and oceanic conditions; wind profilers, radar systems and other specialized sensors; a globally coordinated fleet of Argo buoys that monitor sea temperatures and currents; and remote-sensing satellites that measure cloud cover, temperature, water vapour, atmospheric chemistry, sea level, ice caps, forest cover, and other global climate variables. High-speed telecommunications systems and the Internet distribute vast amounts of data from these instruments to data processing and research centres. These climate observations show a clear warming signal that is greater than what can be attributed to non-human causes (such as volcanoes). They are gathered by agencies and networks that cooperate through the Global Climate Observing System (GCOS)[7] and WMO's Global Atmosphere Watch (GAW) programme[8].

[6] http://climate.nasa.gov/causes
[7] www.wmo.int/pages/prog/gcos/. GCOS is co-sponsored by WMO, UNESCO/IOC, ICSU and UNEP.
[8] http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html

- **Studies of past climates.** The Earth's climate has changed naturally over billions of years in response to variations in the sun's energy, the Earth's orbit, the atmosphere's chemical composition, the shape and position of continents and mountain ranges, plant and animal life, and other factors. Paleoclimatologists study these past climates using various kinds of evidence. Indirect evidence of ancient climates comes from changing ocean and lake levels and from tree rings, coral, ice cores drilled from ice caps and ocean and lake sediment. The more recent past can be studied through systematic global temperature records that started around 1850. These records and studies confirm that the speed at which modern climate change is occurring – the rate of change – is now much greater than in past periods that scientists have investigated. Understanding past climates and how they changed allows scientists to improve and test their models and understanding of today's climate.

- **Models of the climate system.** The climate system is extremely complex. The lower atmosphere responds to additional greenhouse gases by warming up, which leads in turn to changes in clouds, water vapour, snow and ice cover, and the oceans. Additional variables include pollution, deforestation, urbanization and other human activities. These diverse effects influence one another, and the resulting interactions can amplify or reduce climate change. Computer models allow scientists to model interactions between different parts of the climate system using equations of the physical laws governing the behaviour of the atmosphere, the oceans, land vegetation, ice caps, and other components. While these numerical representations of the very complex climate system inevitably contain uncertainties, their skill has improved considerably over the past 20 years. The modelling community cooperates through the World Climate Research Programme (WCRP) to compare and further improve models to ensure the best possible future projections.[9]

4) Atmospheric concentrations of the greenhouse gases that cause climate change continue to rise. Greenhouse gases in the atmosphere have increased to levels unprecedented in at least the last 800,000 years, reaching a new record high in 2012 (see table below). The period 1990 to 2012 saw a 32% increase in radiative forcing – a measure of the warming effect on the climate – because of increased atmospheric concentrations of greenhouse gases.

Table: Global abundances (relative number of molecules) of key greenhouse gases averaged over the twelve months of 2012 as well as changes relative to 2011 and 1750, and contributions to radiative forcing (a measure of how much a gas contributes to "global warming"), from the WMO Global Atmosphere Watch global greenhouse gas monitoring network. Source: WMO Greenhouse Gas Bulletin, no. 9, November 2013*

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)
Pre-industrial levels (1750)	278	700	270
Global abundance in 2012	393.1 ± 0.1 ppm	1819 ± 1 ppb	325.1 ± 0.1 ppb
2012 abundance relative to year 1750	141%	260%	120%
2011-12 absolute increase	2.2 ppm	6 ppb	0.9 ppb
2011-12 relative increase	0.56%	0.33%	0.28%
Mean annual absolute increase during last 10 years	2.02 ppm/yr	3.7 ppb/yr	0.80 ppb/yr
Contribution to radiative forcing relative to 1750**	+1.846 W m^{-2}	+0.507 W m^{-2}	+0.181 W m^{-2}

** ppm = parts per million and ppb = parts per billion*
** * Measured as watts per meter squared as calculated by NOAA (*www.esrl.noaa.gov/gmd/aggi/aggi.html)

Carbon dioxide (CO_2), the most important long-lived greenhouse gas emitted by human activities, is responsible for 84% of the increase in radiative forcing over the past decade (water vapour is also a powerful GHG but human activities only indirectly affect its levels). The annual mean level of CO_2 in the atmosphere in 2012 was 393.1 parts per million (ppm), or 141% of the pre-industrial level of 278 ppm. (In April 2012 the monthly mean at some Arctic sites exceeded the symbolic threshold of 400 ppm for the first time since modern records began).

[9] www.wcrp-climate.org/. WCRP is co-sponsored by WMO, UNESCO/IOC and ICSU.

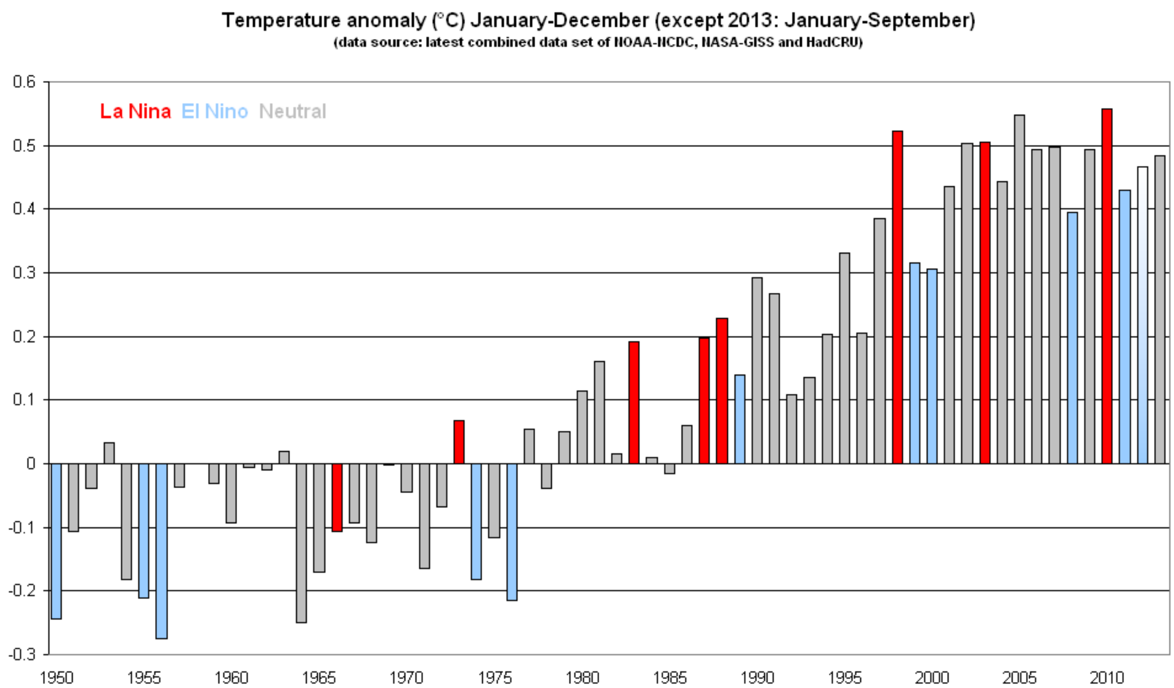
Although methane (CH_4), the second most important long-lived greenhouse gas, is present in the atmosphere in much lower quantities than CO_2, molecule for molecule it has a greater impact. About 40% of emissions are from natural sources such as termites and wetlands and 60% from man-made sources. Atmospheric methane reached a new high of about 1 819 parts per billion (ppb) in 2012, or 260% of the pre-industrial level, due to increased emissions from man-made sources. Since 2007, atmospheric methane has been increasing again after several years of levelling-off.

Nitrous oxide (N_2O) is emitted into the atmosphere by both natural (about 60%) and man-made sources (approximately 40%). Its atmospheric concentration in 2012 was about 325.1 parts per billion, which is 0.9 ppb above the previous year and 120% of the pre-industrial level. Nitrous oxide also plays an important role in the destruction of the stratospheric ozone layer which protects us from the harmful ultraviolet rays of the sun.

In addition to long-lived greenhouse gases, short-lived emissions of black carbon (which recent research suggests has a greater warming effect than previously understood) and dust (which has a cooling effect) also influence the climate.

The chemical composition of the atmosphere is monitored by over 50 countries participating in the WMO Global Atmosphere Watch network.[10]

5) Global temperatures continue to climb. The global average temperature is estimated to have risen by 0.85℃ (1.5℉) from 1880 to 2012. Although the rate of warming varies from year to year due to natural variability such as the El Niño cycle and volcanic eruptions, the human-induced warming trend has clearly continued (see diagram below).



The 2001-2010 decade was the warmest since modern temperature monitoring began around 160 years ago. The atmosphere's global combined land- and sea-surface mean temperature for the decade is estimated at 0.47℃ (0.8℉) above the 196 1-1990 average of 14.0℃ (57.2℉). Globally, 2010 is the warmest year recorded since modern measurement began, closely followed by 2005. No single year since 1985 has recorded a below-average mean.

[10] www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html

The 2001-2010 decade was also the warmest recorded for each continent. Average temperatures above the 1961-1990 level dominated every continent in every year of the decade, with the exception of Australia in 2001. Europe and Asia recorded the largest average temperature anomaly for the decade (+0.97℃), while South America recorded the lowest decadal temperature anomaly among the continents (+0.41℃). [11]

2011 was an estimated 0.40℃ (0.72℉) above the 1961-1990 average and the warmest year that featured a cooling La Niña event. 2012 was the ninth warmest year since records began in 1850. The global land and ocean surface temperature for the year was about 0.46℃ (0.83℉) above the 1961–1990 average of 14.0℃. After the end of the La Niña in April 2012, the global land and ocean temperatures rose increasingly above the long-term average with each consecutive month.[12] In January 2013, NOAA and NASA announced that 2012 was the warmest year on record for the United States.[13]

Although the long-term global average temperature is clearly rising, some regions of the planet have nevertheless experienced unusual cold. This can result from natural variability, but also, paradoxically, it may sometimes be caused by global warming itself. For example, researchers are exploring whether today's warming of the Arctic may actually be contributing to recent cold winters in North America and northern Eurasia by altering weather and pressure patterns.[14] In addition, natural variability can cause the global average temperature to vary from year to year

To project into the future, climate modellers use different scenarios describing how human activities may influence greenhouse gas emissions and concentrations over the course of the 21st century. The IPCC assessment of these models' results concludes that global average temperatures will likely rise by 0.3℃ to 0.7℃ (0. 5 – 1.3℉) in the period 2016-2035 compared to the period 1986-2005. Averaged over the period 2081-2100, the global surface temperature is likely to exceed pre-industrial levels by more than 1.5℃ (2.7℉) unless ambitious reductions are made in emissions, by more than 2℃ for most intermediate emissions scenarios and for high emissions scenarios, and by more than 4℃ (7.2℉) for the highest emissions scenarios. Under most scenarios, the global warming trend would continue into the 22nd century.

According to the IPCC, to have a greater than two in three chance of limiting the global warming caused by carbon dioxide emissions alone to below 2℃ would require that cumulative CO_2 emissions stay below about 1 000 gigatonnes of carbon (GtC). As of 2011, more than half this amount, or 515 GtC, has already been emitted since 1861-1880. When the effects of other greenhouse gases are included, cumulative CO_2 would need to be even lower – some 790 GtC – to keep below a 2℃ warming.

A temperature difference of a half degree Centigrade can be highly significant for the global average climate. Over at least the past one thousand years, the global temperature has varied by less than one degree C. The ending of the last ice age saw global average temperatures rise by 3 to 8℃ (5.4-14.4℉) over a period of a few thousand years.[15] This led to the retreat of ice sheets that were 3-4 km (1.9-2.5 miles) thick and caused sea levels to rise by 120m (393 feet) to reach today's levels.

6) The Arctic and the cryosphere are changing rapidly. The state of sea-ice cover in the 20th century is relatively well documented, largely because of intensive exploration of the Arctic and the

[11] http://library.wmo.int/opac/index.php?lvl=notice_display&id=15110

[12] These WMO figures are averages of the global temperature records maintained by the world's leading climate monitoring centres: the Met Office Hadley Center, Climate Research Unit (Had-CRU); the National Climatic Data Center – National Oceanic and Atmospheric Administration (NCDC-NOAA); and the National Aeronautics and Space Administration – Goddard Institute for Space Studies (NASA-GISS). Additional information is drawn from the ERA-Interim reanalysis-based data set maintained by the European Centre for Medium-Range Weather Forecasts (ECMWF). See www.wmo.int/pages/publications/showcase/documents/WMO_1085_en.pdf and http://library.wmo.int/pmb_ged/wmo_1108_en.pdf.

[13] www.ncdc.noaa.gov/sotc/national/2012/13

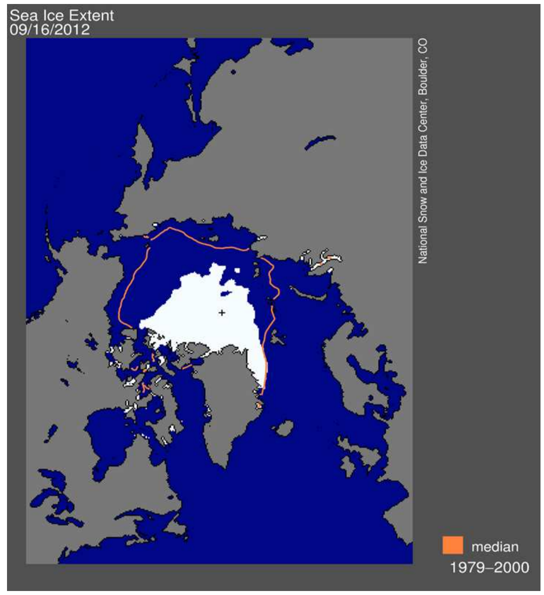
[14] www.arctic.noaa.gov/future/warm_arctic_cold_continent.html

[15] http://www.climatechange2013.org/images/uploads/WGIAR5_WGI-12Doc2b_FinalDraft_Chapter05.pdf,

existence of monitoring services based on research activities, ship observations, aerial reconnaissance and (since the 1970s) remote-sensing satellites.

Until the 1960s, Arctic sea ice covered 14-16 million km^2 in late winter and 7-9 million km^2 at the end of the summer. Since the end of the 1960s, sea-ice cover in the Arctic has been showing systematic and marked declines in both extent and thickness. The period 2005 to 2010 included five years with the lowest September extents on record, with 2007 reaching a then-record minimum extent of 4.28 million km^2, or 39% below the long term average. Since the 1960s, the average rate of Arctic sea ice decline at summer's end was estimated at 700,000-800,000 km^2 per decade.[16]

The Arctic summer of 2012 witnessed even more dramatic changes, with a record low Northern Hemisphere snow extent in June, a record low sea-ice extent in September, record high permafrost temperatures in northernmost Alaska, and the longest duration of melting on the Greenland ice sheet ever observed in modern times, with a rare, nearly ice sheet-wide surface melt in July. The Arctic reached its lowest annual sea ice extent since the start of satellite records on 16 September, estimated at 3.41 million square kilometres. This was 18% less than the previous record low of 18 September 2007. The 2012 minimum extent was 49 percent, or almost 3.3 million square kilometres (nearly the size of India), below the 1979–2000 average minimum. Some 11.83 million square kilometres of Arctic ice melted between March and September 2012.



In assessing these changes, the Arctic Report Card 2012 produced by NOAA and other international partners states that "multiple observations provide strong evidence of widespread, sustained changes driving the Arctic environmental system into a new state … Changes in the sea ice cover, snow cover, glaciers and Greenland ice sheet are reducing the overall surface reflectivity, with bright, white surfaces that reflect summer sunlight being replaced by darker surfaces, e.g., ocean and land, which absorb sunlight. These conditions increase the capacity to store heat within the Arctic system, which enables more melting – a positive feedback … Thus, we arrive at the conclusion that it is very likely that major changes will continue to occur in the Arctic in years to come, particularly in the face of projections that indicate continued global warming." [17]

Outside the Arctic, the cryosphere is also melting: over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink worldwide, and Northern Hemisphere spring snow has continued to decrease in extent. The average rate of ice loss from the Greenland ice sheet has increased more than six-fold from the period 1992-2001 to 2002-2011 (from 34 gigatonnes per year to 215). Glaciers were losing 275 gigatonnes of ice per year over the period 1993 – 2009.

The melting of the Antarctic ice sheet has also accelerated, with most of the losses coming from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica.[20] While surface temperatures of the eastern part of the continent have remained fairly stable, temperatures on the west coast have risen by nearly 3°C (5.4°F), making it one of the fastest warming areas in the world and causing many glaciers to retreat and ice shelves to collapse. Satellite observations since the 1970s show a small increase in the overall extent of Antarctic sea ice for reasons that are not yet fully understood.

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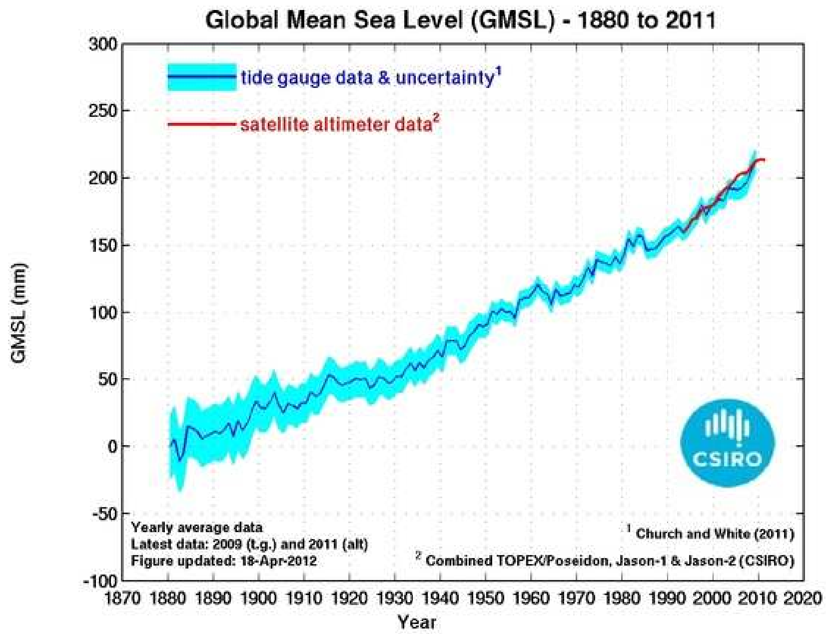
[16] http://nsidc.org/
[17] www.arctic.noaa.gov/reportcard/index.html

7) Sea levels are changing globally. More than 90% of the extra energy accumulated between 1971 and 2010 due to rising greenhouse gas concentrations went into the ocean. This additional heat causes the upper layers of the oceans to expand. Water from melting glaciers and ice caps adds further to the volume of the sea. Local variations in currents and in land movement mean that the rise in sea levels is not uniform, so some coastal regions are more affected than others. As warming penetrates deeper into the oceans and ice continues to melt, sea levels will continue to rise long after atmospheric temperatures have levelled off.



The rate of increase of global mean sea levels between 1993 and 2010, as observed by satellites, ocean buoys and land gauges, was some 3.2 mm per year, double the observed 20th century trend of 1.7 mm per year. As a result, global sea levels were about 19 cm (7.5 inches) higher in 2010 than in 1901. Depending on the level of future greenhouse gas concentrations, sea levels are projected to rise by a further 32-98 cm (13-39 inches) (compared to 1986-2005 levels) over the course of the 21st century (by 2081-2100); the higher end of this range would cause enormous damage to cities and other coastal settlements, infrastructure and ecosystems. During the last interglacial (that is, the period before the last ice), when the climate was 2℃ warmer than pre-industrial levels, maximum global sea levels were an estimated six meters higher than they are today. [18]

Meanwhile, seawater has become more acidic (its pH has decreased by 0.1) since the beginning of the industrial era because the oceans absorb 25% of humanity's carbon dioxide emissions; it will continue to acidify during the 21st century.

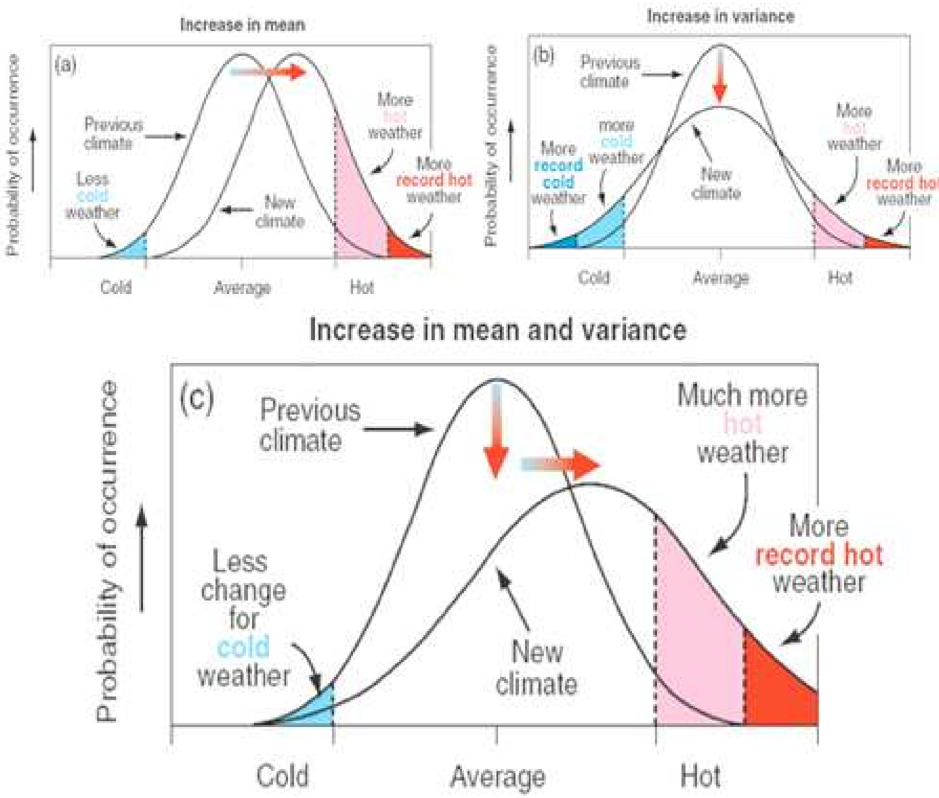
8) Recent trends in extreme events are consistent with the expected impacts of climate change. Human influence has very likely contributed to global changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and it is likely that human influence has more than doubled the probably of heatwaves occurring in some locations. It is also likely that human-induced climate change has affected the global water cycle since 1960. A lack of longer term data makes it difficult to evaluate trends in the intensity, frequency and duration of cyclones, hurricanes and typhoons.

The first 12 years of the 21st century have seen record temperatures, Arctic ice melt, exceptional heat waves in Western Europe (2003) and Russia (2010), the most costly ever Atlantic hurricane (Katrina in 2005), and major floods in many parts of the world, including in Pakistan in 2010, which affected more than twenty million people. Many other extremes were also experienced elsewhere

[18] www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf

in the world. The year 2013 has been marked by extreme heat in Australia, drought in Brazil and the United States, and record summer heat in parts of China.

As illustrated by the diagram below, higher average temperatures increase the likelihood of extreme hot weather. Because warm air can hold more water vapour – itself a greenhouse gas – there is a greater chance of extreme events and floods. More warmth intensifies the hydrological cycle and contributes to both heavier rainfall in some areas and increased evaporation. Global warming could also lead to greater climate variability. Higher sea levels increase the potential for coastal flooding and the impact of storm surges.



Source : IPCC 2001

While climate scientists believe that it is not yet possible to attribute individual events to climate change, they increasingly conclude that many recent events would have occurred in a different way or would not have occurred at all in the absence of climate change. Studies are currently ongoing to determine what percentage of various types of extreme event can be attributed to climate change, and how climate change affects the probability of such events occurring.[19]

9) Climate science can support practical actions for adapting to climate change impacts. Over the past 10 or 20 years climate science has become sufficiently robust to guide governments, organizations and individuals in managing climate risks and opportunities. For example, improved observations combined with a better understanding of how the oceans and the atmosphere interact have led to better predictions of seasonal patterns, particularly in the tropics. The most important such pattern is the El Niño/Southern Oscillation (ENSO), which is linked via "teleconnections" to major climate fluctuations around the world.

Depending on the user's needs, vulnerability assessments can combine climate data and information products with non-climate data, such as agricultural production figures, health trends, population distributions in high-risk areas, road and infrastructure maps for the delivery of goods, and other socio-economic variables. These integrated data sets can support efforts to prepare for

[19] www.cgd.ucar.edu/cas/ace/

and adapt to new climate conditions and their impact on such variables as water supplies, health services, extreme events and farm productivity.

A growing number of countries are providing science-based climate information and prediction for the specific needs of a broad array of public and private sector users. They are collaborating with others through the Global Framework for Climate Services (GFCS) to build greater capacity for using these climate services.[20]

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[20] www.gfcs-climate.org