Climate Change

An Information Statement of the American Meteorological Society

(Adopted by AMS Council 20 August 2012)

The following is an AMS Information Statement intended to provide a trustworthy, objective, and scientifically up-to-date explanation of scientific issues of concern to the public at large.

Background

This statement provides a brief overview of how and why global climate has changed over the past century and will continue to change in the future. It is based on the peer-reviewed scientific literature and is consistent with the vast weight of current scientific understanding as expressed in assessments and reports from the Intergovernmental Panel on Climate Change, the U.S. National Academy of Sciences, and the U.S. Global Change Research Program. Although the statement has been drafted in the context of concerns in the United States, the underlying issues are inherently global in nature.

How is climate changing?

Warming of the climate system now is unequivocal, according to many different kinds of evidence. Observations show increases in globally averaged air and ocean temperatures, as well as widespread melting of snow and ice and rising globally averaged sea level. Surface temperature data for Earth as a whole, including readings over both land and ocean, show an increase of about 0.8°C (1.4°F) over the period 1901─2010 and about 0.5°C (0.9°F) over the period 1979–2010 (the era for which satellite-based temperature data are routinely available). Due to natural variability, not every year is warmer than the preceding year globally. Nevertheless, all of the 10 warmest years in the global temperature records up to 2011 have occurred since 1997, with 2005 and 2010 being the warmest two years in more than a century of global records. The warming trend is greatest in northern high latitudes and over land. In the U.S., most of the observed warming has occurred in the West and in Alaska; for the nation as a whole, there have been twice as many record daily high temperatures as record daily low temperatures in the first decade of the 21st century.

The effects of this warming are especially evident in the planet's polar regions. Arctic sea ice extent and volume have been decreasing for the past several decades. Both the Greenland and Antarctic ice sheets have lost significant amounts of ice. Most of the world's glaciers are in retreat.

Other changes, globally and in the U.S., are also occurring at the same time. The amount of rain falling in very heavy precipitation events (the heaviest 1% of all precipitation events) has increased over the last 50 years throughout the U.S. Freezing levels are rising in elevation, with rain occurring more frequently instead of snow at mid-elevations of western mountains. Spring maximum snowpack is decreasing, snowmelt occurs earlier, and the spring runoff that supplies over two-thirds of western U.S. streamflow is reduced. Evidence for warming is also observed in seasonal changes across many areas, including earlier springs, longer frost-free periods, longer growing seasons, and shifts in natural habitats and in migratory patterns of birds and insects.

Globally averaged sea level has risen by about 17 cm (7 inches) in the 20th century, with the rise accelerating since the early 1990s. Close to half of the sea level rise observed since the 1970s has been caused by water expansion due to increases in ocean temperatures. Sea level is also rising due to melting from continental glaciers and from ice sheets on both Greenland and Antarctica. Locally, sea level changes can depend also on other factors such as slowly rising or falling land, which results in some local sea level changes much larger or smaller than the global average. Even small rises in sea level in coastal zones are expected to lead to potentially severe impacts, especially in small island nations and in other regions that experience storm surges associated with vigorous weather systems.

Why is climate changing?

Climate is always changing. However, many of the observed changes noted above are beyond what can be explained by the natural variability of the climate. It is clear from extensive scientific evidence that the dominant cause of the rapid change in climate of the past half century is human-induced increases in the amount of atmospheric greenhouse gases, including carbon dioxide (CO_2), chlorofluorocarbons, methane, and nitrous oxide. The most important of these over the long term is CO_2, whose concentration in the atmosphere is rising principally as a result of fossil-fuel combustion and deforestation. While large amounts of CO_2 enter and leave the atmosphere through natural processes, these human activities are increasing the total amount in the air and the oceans. Approximately half of the CO_2 put into the atmosphere through human activity in the past 250 years has been taken up by the ocean and terrestrial biosphere, with the other half remaining in the atmosphere. Since long-term measurements began in the 1950s, the atmospheric CO_2 concentration has been increasing at a rate much faster than at any time in the last 800,000 years. Having been introduced into the atmosphere it will take a thousand years for the majority of the added atmospheric CO_2 to be removed by natural processes, and some will remain for thousands of subsequent years.

Water vapor also is an important atmospheric greenhouse gas. Unlike other greenhouse gases, however, the concentration of water vapor depends on atmospheric temperature and is controlled by the global climate system through its hydrological cycle of evaporation-condensation-precipitation. Water vapor is highly variable in space and time with a short lifetime, because of weather variability. Observations indicate an increase in globally averaged water vapor in the atmosphere in recent decades, at a rate consistent with the response produced by climate models that simulate human-induced increases in greenhouse gases. This increase in water vapor also strengthens the greenhouse effect, amplifying the impact of human-induced increases in other greenhouse gases.

Human activity also affects climate through changes in the number and physical properties of tiny solid particles and liquid droplets in the atmosphere, known collectively as atmospheric aerosols. Examples of aerosols include dust, sea salt, and sulfates from air pollution. Aerosols have a variety of climate effects. They absorb and redirect solar energy from the sun and thermal energy emitted by Earth, emit energy themselves, and modify the ability of clouds to reflect sunlight and to produce precipitation. Aerosols can both strengthen and weaken greenhouse warming, depending on their characteristics. Most aerosols originating from human activity act to cool the planet and so partly counteract greenhouse gas warming effects. Aerosols lofted into the stratosphere [between about 13 km (8 miles) and 50 km (30 miles) altitude above the surface] by occasional large sulfur-rich volcanic eruptions can reduce global surface temperature for several years. By contrast, carbon soot from incomplete combustion of fossil fuels warms the planet, so that decreases in soot would reduce warming. Aerosols have lifetimes in the troposphere [at altitudes up to approximately 13 km (8 miles) from the surface in the middle latitudes] on the order of one week, much shorter than that of most greenhouse gases, and their prevalence and properties can vary widely by region.

Land surface changes can also affect the surface exchanges of water and energy with the atmosphere. Humans alter land surface characteristics by carrying out irrigation, removing and introducing forests, changing vegetative land cover through agriculture, and building cities and reservoirs. These changes can have significant effects on local-to-regional climate patterns, which adds up to a small impact on the global energy balance as well.

How can climate change be projected into the future?

Factors that have altered climate throughout history, both human (such as human emission of greenhouse gases) and natural (such as variation of the Sun’s energy emission, the Earth’s orbit about the Sun, and volcanic eruptions), will continue to alter climate in the future. Climate projections for decades into the future are made using complex numerical models of the climate system that account for changes in the flow of energy into and out of the Earth system on time scales much longer than the predictability limit (of about two weeks) for individual weather systems. The difference between weather and climate is critically important in considering predictability. Climate is potentially predictable for much longer time scales than weather for several reasons. One reason is that climate can be meaningfully characterized by seasonal-to-decadal averages and other statistical measures, and the averaged weather is more predictable than individual weather events. A helpful analogy in this regard is that population averages of human mortality are predictable while life spans of individuals are not. A second reason is that climate involves physical systems and processes with long time scales, including the oceans and snow and ice, while weather largely involves atmospheric phenomena (e.g., thunderstorms, intense snow storms) with short time scales. A third reason is that climate can be affected by slowly changing factors such as human-induced changes in the chemical composition of the atmosphere, which alter the natural greenhouse effect.

Climate models simulate the important aspects of climate and climate change based on fundamental physical laws of motion, thermodynamics, and radiative transfer. These models report on how climate would change in response to several specific “scenarios” for future greenhouse gas emission possibilities. Future climate change projections have uncertainties that occur for several reasons — because of differences among models, because long-term predictions of natural variations (e.g., volcanic eruptions and El Niño events) are not possible, and because it is not known exactly how greenhouse gas emissions will evolve in future decades. Future emissions will depend on global social and economic development, and on the extent and impact of activities designed to reduce greenhouse gas and black carbon emissions.

Changes in the means and extremes of temperature and precipitation in response to increasing greenhouse gases can be projected over decades to centuries into the future, even though the timing of individual weather events cannot be predicted on this time scale. Because it would take many years for observations to verify whether a future climate projection is correct, researchers establish confidence in these projections by using historical and paleoclimate evidence and through careful study of observations of the causal chain between energy flow changes and climate-pattern responses. A valuable demonstration of the validity of current climate models is that when they include all known natural and human-induced factors that influence the global atmosphere on a large scale, the models reproduce many important aspects of observed changes of the 20^{th}-century climate, including (1) global, continental, and subcontinental mean and extreme temperatures, (2) Arctic sea ice extent, (3) the latitudinal distribution of precipitation, and (4) extreme precipitation frequency.

Model limitations include inadequate representations of some important processes and details. For example, a typical climate model does not yet treat fully the complex dynamical, radiative, and microphysical processes involved in the evolution of a cloud or the spatially variable nature of soil moisture, or the atmospheric interactions with the biosphere. Nevertheless, in spite of these limitations, climate models have demonstrated skill in reproducing past climates, and they agree on the broad direction of future climate.

How is the climate expected to change in the future?

Future warming of the climate is inevitable for many years due to the greenhouse gases already added to the atmosphere and the heat that has been taken up by the oceans. Amelioration might be possible through devising and implementing environmentally responsible geoengineering approaches, such as capture and storage measures to remove CO_2 from the atmosphere. However, the potential risks of geoengineering may be quite large, and more study of the topic (including other environmental consequences) is needed. The subject of geoengineering is outside the scope of this statement (for more information see AMS Statement on Geoengineering).

In general, many of the climate-system trends observed in recent decades are projected to continue. Those projections, and others in this section, are largely based on simulations conducted with climate models, and assume that the amount of greenhouse gas in the atmosphere will continue to increase due to human activity. Global efforts to slow greenhouse gas emissions have been unsuccessful so far. However, were future technologies and policies able to achieve a rapid reduction of greenhouse gas emissions — an approach termed “mitigation” — this would greatly lessen future global warming and its impacts.

Confidence in the projections is higher for temperature than for other climate elements such as precipitation, and higher at the global and continental scales than for the regional and local scales. The model projections show that the largest warming will occur in northern polar regions, over land areas, and in the winter season, consistent with observed trends.

In the 21st century, global sea level also will continue to rise although the rise will not be uniform at all locations. With its large mass and high capacity for heat storage, the ocean will continue to slowly warm and thus thermally expand for several centuries. Model simulations project about 27 cm (10 inches) to 71 cm (28 inches) of global sea level rise due to thermal expansion and melting of ice in the 21st century. Moreover, paleoclimatic observations and ice-sheet modeling indicate that melting of the Greenland and the West Antarctic ice sheets will eventually cause global sea level to rise several additional meters by 2500 if warming continues at its present rate beyond the 21st century.

Atmospheric water content will increase globally, consistent with warmer temperatures, and consequently the global hydrological cycle will continue to accelerate. For many areas, model simulations suggest there will be a tendency towards more intense rain and snow events separated by longer periods without precipitation. However, changes in precipitation patterns are expected to differ considerably by region and by season. In some regions, the accelerated hydrological cycle will likely reinforce existing patterns of precipitation, leading to more severe droughts and floods. Further poleward, the greater warming at high latitudes and over land likely will change the large-scale atmospheric circulation, leading to significant regional shifts in precipitation patterns. For example, the model simulations suggest that precipitation will increase in the far northern parts of North America, and decrease in the southwest and south-central United States where more droughts will occur.

Climate-model simulations further project that heavy precipitation events will continue to become more intense and frequent, leading to increased precipitation totals from the strongest storms. This projection has important implications for water-resource management and flood control. The simulations also indicate the likelihood of longer dry spells between precipitation events in the subtropics and lower-middle latitudes, with shorter dry spells projected for higher latitudes where mean precipitation is expected to increase. Continued warming also implies a reduction of winter snow accumulations in favor of rain in many places, and thus a reduced spring snowpack. Rivers now fed by snowmelt will experience earlier spring peaks and reduced warm-season flows. Widespread retreat of mountain glaciers is expected to eventually lead to reduced dry season flows for glacier-fed rivers. Drought is projected to increase over Africa, Europe, and much of the North American continental interior, and particularly the southwest United States. However, natural variations in world ocean conditions at decadal scale, such as those in the North Pacific and North Atlantic basins, could offset or enhance such changes in the next few decades. For the longer term, paleoclimatic observations suggest that droughts lasting decades are possible and that these prolonged droughts could occur with little warning.

Weather patterns will continue to vary from day to day and from season to season, but the frequency of particular patterns and extreme weather and climate events may change as a result of global warming. Model simulations project an increased proportion of global hurricanes that are in the strongest categories, namely 4 and 5 on the Saffir-Simpson scale, although the total counts of hurricanes may not change or may even decrease. Some regional variations in these trends are possible. Simulations also indicate that midlatitude storm tracks will shift poleward. Interannual variations of important large-scale climate conditions (such as El Niño and La Niña) will also continue to occur, but there may be changes in their intensity, frequency, and other characteristics, resulting in different responses by the atmosphere. Heat waves and cold snaps and their associated weather conditions will continue to occur, but proportionately more extreme warm periods and fewer cold periods are expected. Indeed, what many people traditionally consider a cold wave is already changing toward less severe conditions. Frost days (those with minimum temperature below freezing) will be fewer and growing seasons longer. Drier conditions in summer, such as those anticipated for the southern United States and southern Europe, are expected to contribute to more severe episodes of extreme heat. Critical thresholds of daily maximum temperature, above which ecosystems and crop systems (e.g., food crops such as rice, corn, and wheat) suffer increasingly severe damage, are likely to be exceeded more frequently.

The Earth system is highly interconnected and complex, with many processes and feedbacks that only slowly are becoming understood. In particular, the carbon cycle remains a large source of uncertainty for the projection of future climate. It is unclear if the land biosphere and oceans will be able to continue taking up carbon at their current rate into the future. One unknown is whether soil and vegetation will become a global source rather than a sink of carbon as the planet warms. Another unknown is the amount of methane that will be released due to high-latitude warming. There are indications that large regions of the permafrost in parts of Alaska and other northern polar areas are already thawing, with the potential to release massive amounts of carbon into the atmosphere beyond those being directly added by human activity. The portion of the increased CO_2 release that is absorbed by the world ocean is making the ocean more acidic, with negative implications for shell- and skeleton-forming organisms and more generally for ocean ecosystems. These processes are only now being quantified by observation and introduced into climate models, and more research is required to fully understand their potential impacts. As impacts of climate change are of regional and local nature, more research is also required to improve climate projections at local and regional scales, and for weather and climate extremes in particular.

Final remarks

There is unequivocal evidence that Earth's lower atmosphere, ocean, and land surface are warming; sea level is rising; and snow cover, mountain glaciers, and Arctic sea ice are shrinking. The dominant cause of the warming since the 1950s is human activities. This scientific finding is based on a large and persuasive body of research. The observed warming will be irreversible for many years into the future, and even larger temperature increases will occur as greenhouse gases continue to accumulate in the atmosphere. Avoiding this future warming will require a large and rapid reduction in global greenhouse gas emissions. The ongoing warming will increase risks and stresses to human societies, economies, ecosystems, and wildlife through the 21st century and beyond, making it imperative that society respond to a changing climate. To inform decisions on adaptation and mitigation, it is critical that we improve our understanding of the global climate system and our ability to project future climate through continued and improved monitoring and research. This is especially true for smaller (seasonal and regional) scales and weather and climate extremes, and for important hydroclimatic variables such as precipitation and water availability.

Technological, economic, and policy choices in the near future will determine the extent of future impacts of climate change. Science-based decisions are seldom made in a context of absolute certainty. National and international policy discussions should include consideration of the best ways to both adapt to and mitigate climate change. Mitigation will reduce the amount of future climate change and the risk of impacts that are potentially large and dangerous. At the same time, some continued climate change is inevitable, and policy responses should include adaptation to climate change. Prudence dictates extreme care in accounting for our relationship with the only planet known to be capable of sustaining human life.

[This statement is considered in force until August 2017 unless superseded by a new statement issued by the AMS Council before this date.]

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