Climate Change

An Information Statement of the American Meteorological Society

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The following is an 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 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. Climate Change Science Program. All these reports recognize the uncertainties in climate projections, and identify the scientific work needed to reduce those uncertainties. Although the statement has been drafted in the context of concerns in the United States, the underlying issues are inherently global in nature.

This summary of the current state of scientific understanding is based on the peer-reviewed scientific literature. We are grateful to our members who contributed considerable scientific help in its preparation. A few members offered alternative views on climate change or put quite different emphases on the uncertainties of climate projections. In the last fifteen years, scientific debates of this kind have stimulated much new research which deepened considerably our understanding of climate, and reduced the uncertainties in our projections. The scientific process of debate and investigation is the lifeblood of science; this essential process must continue.

How is climate changing?

Climate is changing in many ways. Global mean temperatures have been rising steadily over the last 40 years, with the six warmest years since 1860 occurring in the last decade. Regionally, the warming trend is greatest in northern latitudes, over land, and at night. Decreases in Arctic sea ice have been observed. Most studies indicate that ice loss has recently accelerated at the margins of Greenland and the West Antarctic ice sheet, whereas the East Antarctic ice sheet and the Greenland interior appear to be gaining mass. In the U.S. most of the observed warming has occurred in the West and in Alaska. However, there are regional variations in the signature of climate change, with warming in the western U.S. but little or no annual temperature change in the southeast U.S. in recent decades. Temperature rises have significant hydrologic effects. Freezing levels are rising in elevation, rain occurs instead of snow at mid-elevations, spring maximum snowpack is decreasing, snowmelt occurs earlier, and the spring runoff that supplies over two-thirds of the western U.S. streamflow is reduced.

Evidence for warming is also observed in seasonal changes with earlier springs, longer frost-free periods and longer growing seasons, and shifts in natural habitats and in migratory patterns of birds.

Sea levels are generally rising around the world and glaciers are generally in retreat. A component of sea level rise is attributed to expansion due to a long-term increase in ocean heat content. The impacts of even small rises in sea level on coastal zones are expected to be severe, particularly in conjunction with storm surges associated with vigorous weather systems.

Why is climate changing?

Climate has changed throughout geological history, for many natural reasons such as changes in the sun's energy received by Earth arising from slow orbital changes, or changes in the sun's energy reaching Earth's surface due to volcanic eruptions. In recent decades, humans have increasingly affected local, regional, and global climate by altering the flows of radiative energy and water through the Earth system (resulting in changes in temperature, winds, rainfall, etc.), which comprises the atmosphere, land surface, vegetation, ocean, land ice, and sea ice. Indeed, strong observational evidence and results from modeling studies indicate that, at least over the last 50 years, human activities are a major contributor to climate change.

Direct human impact is through changes in the concentration of certain trace gases such as carbon dioxide, chlorofluorocarbons, methane, nitrous oxide, ozone, and water vapor, known collectively as greenhouse gases. Enhanced greenhouse gases have little effect on the incoming energy of the sun, but they act as a blanket to reduce the outgoing infrared radiation emitted by Earth and its atmosphere; the surface and atmosphere therefore warm so as to increase the outgoing energy until the outgoing and incoming flows of energy are equal. Carbon dioxide accounts for about half of the human-induced greenhouse gas contribution to warming since the late 1800s, with increases in the other greenhouse gases accounting for the rest; changes in solar output may have provided an augmentation to warming in the first half of the 20th century.

Carbon dioxide concentration is rising mostly as a result of fossil-fuel burning and partly from clearing of vegetation; about 50% of the enhanced emissions remain in the atmosphere, while the rest of the Earth system continues to absorb the remaining 50%. In the last 50 years atmospheric CO_2 concentration has been increasing at a rate much faster than any rates observed in the geological record of the past several thousand years. Global annual-mean surface temperatures are rising at a rapid rate to values higher than at any time in the last 400 (and probably in the last 1000) years. Once introduced in the atmosphere, carbon dioxide remains for at least a few hundred years and implies a lengthy guarantee of sustained future warming. Further, increases in greenhouse gases are nearly certain to produce continued increases in temperature. Such changes in temperature lead to changes in clouds, pressure, winds, and rainfall in a complex sequence of further effects.

Human activity also affects climate through changes in the number and physical properties of tiny particles (aerosols) suspended in the atmosphere, and through changes in the land surface. Aerosols arise from dust, sea salt, and air pollution. They absorb and redirect radiation emitted by the sun and Earth. They also modify the ability of clouds to reflect sunlight and to form precipitation. Most aerosols originating from human activity act to cool the planet and so partly counteract greenhouse gas effects; this effect will diminish as clean-air legislation leads to reduced emissions of fine aerosols. Stratospheric aerosols emitted by occasional large sulfur-rich volcanic eruptions can cause temporary (1–3 years) reductions in surface temperature. By contrast, carbon soot from wildfires and biomass burning warms the planet, so that decreases in soot would reduce warming. Aerosols have much shorter lifetimes in the atmosphere than most greenhouse gases and exhibit large regional variations in concentration and properties. A deeper understanding of their global and regional roles is a high priority for climate science.

Changes in the land surface also change the surface water and energy budgets and act to redirect the incoming solar energy. Humans alter land surface characteristics through irrigation practices, removal and reintroduction of forests, agricultural changes to vegetative cover, reduction of soil water recharge by soil compaction, and modification of heat storage by cities and reservoirs. Many of these lead to changes in the reflectivity of the surface. Although net global effects are not expected to be large, such changes can have significant effects on regional and local climate patterns.

The interaction of all these effects on climate is complex. For example, decreases of stratospheric ozone have likely contributed to the recent contraction and intensification of the polar vortex around Antarctica, producing warming in the Antarctic Peninsula, the northern most peninsula that points toward South America, and cooling over Antarctica. As a further example, the east–west difference in U.S. temperature trends may be tied to the spatial patterns of global ocean warming, or to differences in aerosol distribution and effects, or to natural climate variations that affect atmospheric circulation, cloudiness, and precipitation within the nation. Accurate characterization of the influence of each of the greenhouse gases, of aerosols, of oceans and natural climate variability, and of land-surface influences, along with their combined effects, is a high priority for the climate science research community.

How can climate change be projected in the future?

Climate will continue to change due to natural and human causes. The most comprehensive projections of future climate rely on numerical models of the climate system, of which there are many. Climate models are complex computer codes based on measurements and on fundamental physical laws of motion, thermodynamics, and radiative transfer. These are expressed in mathematical equations representing changes of winds in the atmosphere; currents in the ocean; exchanges of heat and moisture between the atmosphere and Earth's surface; the release of latent heat by condensation during the formation of clouds and raindrops; and the absorption of sunshine and emission of infrared radiation.

Climate models were developed from weather forecast models through coupling with models of the ocean, land surface and vegetation, cryosphere, etc., so as to represent the complexity of the climate system. Changes in the means and extremes of temperature and precipitation in response to increasing greenhouse gases can be projected over decades to centuries even though the timing of individual weather events cannot be projected. Unlike daily weather forecasts, there is limited historical basis of experience on which to judge the accuracy of climate projections. Confidence must be assessed by other methods. These include inferences from prehistoric paleoclimate evidence, and careful process-study observations of the causal chain between energy flow changes and climate pattern responses. A useful demonstration of the validity of current climate models is their ability to reproduce the global mean temperature changes of the 20th century when (and only when) they include all known natural and human-induced climate forcings.

Weather predictions beyond a few days are nowadays based on ensembles of simulations that estimate the range of probable outcomes. The same ensemble concept is used for projections of climate change, where uncertainty arises from the limitations of models and from the emission scenarios used to represent the effects of human activity. Model limitations include uncertainties in the way in which processes that operate at scales smaller than the resolved scale of the model are represented, as well as those that arise from components of the Earth system not currently included in models. Among the most important uncertainties are changes in clouds, which can either cool or warm the climate. Recent satellite evidence rules out the possibility that cloud changes could offset most greenhouse warming and suggests that they might even add to it. The emission scenarios used to drive the climate model projections are uncertain since they depend on socioeconomic responses to climate change; these uncertainties have been factored into future assessments.

How will climate change in the future?

There will be inevitable climate changes from the greenhouse gases already added to the Earth system. Their effect is delayed several decades because the thermal inertia of the oceans ensures that the warming lags behind the driving forcing. For the next several decades there is a clear consensus on projected warming rates from human influences among different models and different emission scenarios.

Many of the trends observed in recent decades are projected to continue. The model projections all show greater warming in northern polar regions, over land areas, and in the winter season, consistent with observed trends. However, considerable uncertainty still exists in the degree to which the land will warm more than the oceans, and this contributes significantly to uncertainties in future projections of global sea level rise. Nevertheless, where coastal elevations are low, small rises lead to large inland intrusions of sea water. In the coming century, these rises are expected to accelerate as the oceans absorb more heat and the melting of land ice-sheets increases. With its large mass and high capacity for heat storage, the ocean will continue to slowly warm to great depths and thus expand for several centuries. Moreover, paleoclimatic observations and ice-sheet modeling indicate that the melting of the Greenland and possibly the West Antarctic ice sheets will eventually cause global sea level to rise on the order of meters if warming continues at its present rate beyond the 21st century.

Confidence in projections is higher for temperature than other elements, such as rainfall. The atmospheric water content is likely to increase globally in line with warmer temperatures and consequently the global hydrological cycle will accelerate. However, changes in precipitation patterns will differ considerably by region and by season. In some regions, the accelerated hydrological cycle will act to reinforce existing patterns of rainfall, leading to persistent droughts and floods. In other regions, the greater warming at high latitudes and over land will change the large-scale atmospheric circulation, leading to significant regional shifts in the patterns of rainfall. For example, annual precipitation for the U.S. is projected to rise across the northern states, and decrease across the southern states.

Precipitation is expected to become more intense (i.e., precipitation rates and total precipitation in storms will increase), with implications for water resource management and flooding. Moreover, continued warming also implies a net long-term reduction of winter snow accumulations (in favor of rain), and thus a reduced spring snowpack, with consequently deficient dry-season river flows; widespread retreat of mountain glaciers will also eventually lead to reduced dry-season flows. Prolonged episodes of wet and dry conditions could both become more frequent, an outcome seemingly paradoxical but physically plausible. Drought is projected to increase over the continental interior and particularly the southwest U.S. However, natural decadal time-scale variations in world ocean conditions can cause similar effects. Paleoclimatic observations suggest that droughts lasting decades are possible, and that these prolonged droughts could occur without warning.

Weather patterns will continue to vary from day to day and from season to season, but it is likely that the frequency of extreme weather will change. A growing body of recent scientific work suggests that hurricanes have become more intense over the last several decades. There is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date. Though hurricanes are projected to intensify with further warming of sea surface temperatures, significant uncertainty remains as to how other influences on hurricane strength will change in the future. Midlatitude storm tracks are likely to shift poleward, with fewer but more intense storms.

Longer-term variations such as El Niño and La Niña will also continue to occur but the intensity and frequency of occurrence may change. Climate change should be assessed on the basis of changes over long time periods. It should not be assessed on a single unusual weather event, nor even on several years of anomalous weather. Heat waves and cold snaps, and the weather conditions giving rise to them, will continue to occur, but there will be proportionately more extreme warm periods and fewer cold periods. Projections for fewer frost days (those with minimum temperature below freezing) and longer growing seasons are consistent with observed changes in the second half of the 20th century over most areas of the U.S., particularly the West. Drier conditions in summer, such as those expected over the southern U.S. and southern Europe, will contribute to more severe episodes of extreme heat. Critical temperature thresholds above which ecosystems and crop systems (e.g., food crops such as rice and wheat) suffer increasingly severe damage are likely to be exceeded more frequently. On the other hand, longer growing seasons and CO_2 fertilization enhancing plant growth may potentially lead to some benefits.

Sustained global economic growth is increasing not only long-lived greenhouse gases in the atmosphere but is also leading to increases in shorter-lived species which affect both climate and air quality such as aerosols and low-level ozone. Air quality is likely to become a major issue affecting human health and life expectancy. Increasing urbanization will exacerbate the urban heat island effect and lead to a greater number of days with poor air quality. In some locations, surface ozone concentrations are projected to rise above levels considered harmful to humans, plants and other ecosystems.

The Earth system is highly interconnected and complex, with many processes and feedbacks that are just beginning to be detected and understood. The continued ability of the biosphere to take up carbon at its current rate is uncertain; the issue is whether the soil and land vegetation will become a source rather than a sink of carbon as the planet warms. The portion of increased carbon dioxide 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. There are indications that regions of permafrost, for example in Alaska, are already melting with the potential to release massive amounts of carbon into the atmosphere. Such an event has the potential to produce abrupt and catastrophic changes in climate. These processes are only now being quantified and introduced into climate models, and remain a large source of uncertainty.

Final remarks

Despite the uncertainties noted above, there is adequate evidence from observations and interpretations of climate simulations to conclude that the atmosphere, ocean, and land surface are warming; that humans have significantly contributed to this change; and that further climate change will continue to have important impacts on human societies, on economies, on ecosystems, and on wildlife through the 21st century and beyond. Focusing on the next 30 years, convergence among emission scenarios and model results suggest strongly that increasing air temperatures will reduce snowpack, shift snowmelt timing, reduce crop production and rangeland fertility, and cause continued melting of the ice caps and sea level rise. Important goals for future work include the need to understand the relation of climate at the state and regional level to the patterns of global climate and to reverse the decline in observational networks that are so critical to accurate climate monitoring and prediction.

Policy choices in the near future will determine the extent of the impacts of climate change. Policy decisions are seldom made in a context of absolute certainty. Some continued climate change is inevitable, and the policy debate should also consider the best ways to adapt to climate change. Prudence dictates extreme care in managing our relationship with the only planet known to be capable of sustaining human life.

[This statement is considered in force until February 2012 unless superseded by a new statement issued by the AMS Council before this date.]