

DRAFT AMS Statement on Climate Change

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How is climate changing?

Climate is changing in many ways, and there is strong observational and scientific evidence that, at least over the last 50 years, human activities are the major contributor to climate change. Global mean temperatures have been rising steadily over the last 40 years, with the six warmest years occurring in the last decade. Regionally, the warming trend is greatest in northern latitudes and over land. Projected decreases in sea ice are already being observed, and ice loss has recently accelerated in Greenland. In the U.S. most of the observed warming has occurred in the West and in Alaska. Temperature rises have significant hydrologic effects by themselves. Freezing levels rise in elevation, rain occurs instead of snow at mid-elevations, spring maximum snow-pack decreases, snowmelt occurs earlier, and the spring runoff that supplies over two-thirds of the western U.S. stream-flow is reduced.

However, there are regional anomalies in the signature of climate change, with little or no annual temperature change in the southeast U.S. in recent decades. The east-west difference in U.S. temperature trends may be tied to analogous asymmetry in the spatial patterns of global ocean warming, or to differences in aerosol distribution and effects, or to other unknown factors that affect atmospheric circulation, cloudiness, and precipitation within the nation. An important research goal is to understand the relation of climate at the state and regional level to the patterns of global climate.

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

Sea levels are steadily rising around the world and glaciers are in retreat. These rises are expected to accelerate in the coming century as the oceans absorb more heat and the melting of land ice-sheets increases. The impacts of even small rises in sea level on coastal cities are expected to be severe, particularly in conjunction with stronger storm surges associated with more 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 the Earth arising from slow orbital changes, or changes in the sun's energy reaching the Earth's surface due to volcanic eruptions. In recent decades, humans have begun to affect 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

The most 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

the earth and its atmosphere. The atmosphere therefore warms 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 greenhouse gas contribution to warming since the late 1800s, with increases in the other greenhouse gases accounting for the rest; slight changes in solar output may have provided a small augmentation to warming in recent decades.

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 fifty years atmospheric CO₂ concentration has been increasing at a rate much faster than any rates observed in the geological record for several thousand years. As a result, global annual-mean surface temperatures are rising at an extremely rapid rate to values higher than at any time in the last four hundred and probably one thousand 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 while further increases in greenhouse gas 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 the 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 and redirect the incoming solar energy. Humans alter land surface characteristics through irrigation practices, removal and re-introduction of forests, agricultural changes to vegetative cover, reduction of soil water recharge by soil compaction, modification of heat storage by cities and reservoirs, and 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. Accurate characterization of each of the greenhouse gas, aerosol and land-surface influences, and of their combined net affect, is a high priority of the climate science research community.

How can climate change be projected in the future?

Climate will continue to change for natural and man-made reasons. 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 fundamental physical laws of motion, thermodynamics and radiative transfer. The physical laws 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 the 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 infra-red radiation.

Climate models are essentially extensions of weather forecast models, but unlike daily weather forecasts, there is a 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 pre-historic paleoclimate evidence, and careful process-study observations of the causal chain between energy flow changes, and climate pattern responses. A strong test of the validity of current climate models is their ability to reproduce the global mean temperature changes of the past century when (and only when) they include all natural and man-made climate forcings.

Since the weather is chaotic, weather predictions beyond a few days are nowadays based around ensembles of simulations that indicate 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. The emission scenarios used to drive the climate model projections are uncertain since they depend on socio-economic responses to climate change; these 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 system. Their effect is delayed to some extent because the thermal inertia of the oceans ensures the warming lags behind the driving forcing. For the next several decades there is a clear consensus on projected warming rates among different models and different emission scenarios.

Many of the trends observed in recent decades are projected to continue. The model projections all show more and earlier warming in 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, small vertical rises translate into large inland horizontal encroachment of salt water where coastal elevations are low. 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, ice sheet modeling and paleoclimatic observations indicate that the melting of the Greenland Ice Sheet will likely cause global sea level to rise meters if warming continues at its present rate through the 21st century.

Confidence in projections is higher for temperature than other elements, especially 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.

In terms of water resource management, global warming also implies a reduction of winter snow accumulations (in favor of rain), a reduced spring snow-pack and gradual glacier retreat, with consequently deficient dry season river 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, leading to complications in the interpretation of observed trends of both phenomena.

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. Longer-term variation such as El Niño and La Niña will also continue to occur but the intensity and frequency of occurrence will also likely change. Thus, 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.

In a warmer climate, the water vapor content of the air increases exponentially with temperature, leading to more intense precipitation (i.e. proportionately more precipitation will fall over a given duration), with implications for water resource management and flooding. More intense precipitation leads to more energetic storms, so the incidence of damaging weather is likely to increase. Although a growing body of recent scientific work suggests that hurricanes are intensifying, and that they should continue to intensify with future sea surface temperature increases, significant uncertainty remains as to how other future influences on hurricane strength will change in the future.

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. 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.

Conclusions

Despite the uncertainties noted above, there is adequate evidence from observations and climate models to conclude that climate is changing; that humans have significantly contributed to this change; that further climate change will continue to have serious impacts on human societies, on economies, on ecosystems and on wildlife through the 21st century and beyond.

Policy choices in the near future will determine the extent of these impacts. Policy decisions are seldom made in a context of absolute certainty. Prudence dictates extreme care in managing our relationship with the only planet known to be capable of sustaining human life.