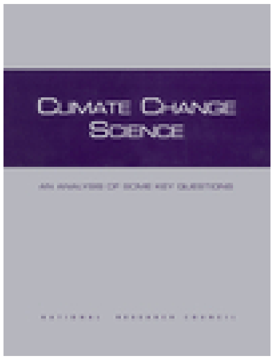

Climate Change Science: An Analysis of Some Key Questions

Committee on the Science of Climate Change, National Research Council

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Climate, Climate Forcings, Climate Sensitivity, and Transient Climate Change

CLIMATE

Climate is the average state of the atmosphere and the underlying land or water, on time scales of seasons and longer. Climate is typically described by the statistics of a set of atmospheric and surface variables, such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature, and the concentration and thickness of sea ice. The statistics may be in terms of the long-term average, as well as other measures such as daily minimum temperature, length of the growing season, or frequency of floods. Although climate and climate change are usually presented in global mean terms, there may be large local and regional departures from these global means. These can either mitigate or exaggerate the impact of climate change in different parts of the world.

A number of factors contribute to climate and climate change, and it is useful to define the terms climate forcings, climate sensitivity, and transient climate change for discussion below.

CLIMATE FORCINGS

A climate forcing can be defined as an imposed perturbation of Earth's energy balance. Energy flows in from the sun, much of it in the visible wavelengths, and back out again as long-wave infrared (heat) radiation. An increase in the luminosity of the sun, for example, is a positive forcing that tends to make Earth warmer. A very large volcanic eruption, on the other hand, can increase the aerosols (fine particles) in the lower stratosphere (altitudes of 10-15 miles) that reflect sunlight to space and thus reduce the solar energy delivered to Earth's surface. These examples are natural forcings. Human-made forcings result from, for example, the gases and aerosols produced by fossil fuel burning, and alterations of Earth's surface from various changes in land use, such as the conversion of forests into agricultural land. Those gases that absorb infrared radiation, i.e., the "greenhouse" gases, tend to prevent this heat radiation from escaping to space, leading eventually to a warming of Earth's surface. The observations of human-induced forcings underlie the current concerns about climate change.

The common unit of measure for climatic forcing agents is the energy perturbation that they introduce into the climate system, measured in units of watts per square meter (W/m^2). The consequences from such forcings are often then expressed as the change in average global temperature, and the conversion factor from forcing to temperature change is the sensitivity of Earth's climate system. Although some forcings—volcanic plumes, for example—are not global in nature and temperature change may also not be uniform, comparisons of the strengths of individual forcings, over comparable areas, are useful for estimating the relative importance of the various processes that may cause climate change.

CLIMATE SENSITIVITY

The sensitivity of the climate system to a forcing is commonly expressed in terms of the global mean temperature change that would be expected after a time sufficiently long for both the atmosphere and ocean to come to equilibrium with the change in climate forcing. If there were no climate feedbacks, the response of Earth's mean temperature to a forcing of 4 W/m^2 (the forcing for a doubled atmospheric CO_2) would be an increase of about 1.2°C (about 2.2°F). However, the total climate change is affected not only by the immediate direct forcing, but also by climate "feedbacks" that come into play in response to the forcing. For example, a climate forcing that causes warming may melt some of the sea ice. This is a positive feedback because the darker ocean absorbs more sunlight than the sea ice it replaced. The responses of atmospheric water vapor amount and clouds probably generate the most important global climate feedbacks. The nature and magnitude of these hydrologic feedbacks give rise to the largest source of uncertainty about climate sensitivity, and they are an area of continuing research.

As just mentioned, a doubling of the concentration of carbon dioxide (from the pre-Industrial value of 280 parts per million) in the global atmosphere causes a forcing of 4 W/m^2. The central value of the climate sensitivity to this change is a global average temperature increase of 3°C (5.4°F), but with a range from 1.5°C to 4.5°C (2.7 to 8.1°F) (based on climate system models: see section 4). The central value of 3°C is an amplification by a factor of 2.5 over the direct effect of 1.2°C (2.2°F). Well-documented climate changes during the history of Earth, especially the changes between the last major ice age (20,000 years ago) and the current warm period, imply that the climate sensitivity is near the 3°C value. However, the true climate sensitivity remains uncertain, in part because it is difficult to model the effect of cloud feedback. In particular, the magnitude and even the sign of the feedback can differ according to the composition, thickness, and altitude of the clouds, and some studies have suggested a lesser climate sensitivity. On the other hand, evidence from paleoclimate variations indicates that climate sensitivity could be higher than the above range, although perhaps only on longer time scales.

TRANSIENT CLIMATE CHANGE

Climate fluctuates in the absence of any change in forcing, just as weather fluctuates from day to day. Climate also responds in a systematic way to climate forcings, but the response can be slow because the ocean requires time to warm (or cool) in response to the forcing. The response time depends upon the rapidity with which the ocean circulation transmits changes in surface temperature into the deep ocean. If the climate sensitivity is as high as the 3°C mid-range, then a few decades are required for just half of the full climate response to be realized, and at least several centuries for the full response.[1]

Such a long climate response time complicates the climate change issue for policy makers because it means that a discovered undesirable climate change is likely to require many decades to halt or reverse.

Increases in the temperature of the ocean that are initiated in the next few decades will continue to raise sea level by ocean thermal expansion over the next several centuries. Although society might conclude that it is practical to live with substantial climate change in the coming decades, it is also important to consider further consequences that may occur in later centuries. The climate sensitivity and the dynamics of large ice sheets become increasingly relevant on such longer time scales.

It is also possible that climate could undergo a sudden large change in response to accumulated climate forcing. The paleoclimate record contains examples of sudden large climate changes, at least on regional scales. Understanding these rapid changes is a current research challenge that is relevant to the analysis of possible anthropogenic climate effects.

[1]The time required for the full response to be realized depends, in part, on the rate of heat transfer from the ocean mixed layer to the deeper ocean. Slower transfer leads to shorter response times on Earth's surface.