CLIMATE CHANGE

Climate Science in Six Well-Documented Findings

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As the science of climate change has been advancing, there is more and more information about what appears to be happening and what is likely to happen in the future — but many aspects about what lies ahead remain only roughly understood. At the same time, as the nation has moved closer and closer to real action on climate change, more and more people are moved to learn about and examine the climate science. With the prospect of changes to the nation's energy system likely to disrupt the status quo, the strengths and weaknesses of scientific understanding are receiving much closer scrutiny, some due to curiosity as a wider array of interested experts build up their knowledge about the issue, some by those seeking to determine how best to prepare and adapt, and some by those working to develop effective and optimal policies — but some by those seeking to have action postponed and some by those misrepresenting the science, or at least obscuring the key findings that have prompted the international conference of the parties in Copenhagen to develop a plan for global action.

With so much information, so many voices and articles, and so many perspectives being offered, it should not be surprising that the public has become a bit overwhelmed, apparently having trouble understanding that the key findings are well understood to justify action by policymakers while at the same time there remain a great many of the details that are under active investigation by the scientific community. This note is intended to summarize the key findings — particularly those that indicate that the risks posed by climate change are so clearly established that emissions reductions must begin immediately.

Background: Because the climate system is extremely complex, and projecting changes out to a hundred years and more into the future is necessarily fraught with difficult questions and uncertainties, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization and the United Nations Environmental Programme in a process that would draw together the understanding of the international scientific community. For the past 20 years, the IPCC has been conducting assessments of the effects of human activities on climate, the resultant impacts on the environment and society, and options for slowing and stopping climate change. These assessments have spurred significant gains in scientific understanding of climate change and, through their wide-ranging and rigorous review process, gained extensive credibility, including the endorsements of the academies of science of many countries and many professional societies.

The assessment reports include detailed and well-referenced chapters on a full range of all the critical scientific topics and carefully reviewed summaries of the detailed science for both policymaker and technical audiences (all of the materials are available here). That the very significant findings in the series of Summary for Policymakers reports have been ***unanimously*** endorsed is a clear indication that the problem is real; the smoothing of the text to gain unanimity, however, also indicates that the reports are not at the cutting edge of science (i.e., IPCC is not some sort of super-green organization as is sometimes charged). A consequence of this caution, which is also a characteristic of the scientific community (its processes tend to prevent jumping to conclusions without strong evidence), is that each of the four IPCC assessments has found reason to consider climate change more imminent and serious than the previous one, and this tendency seems very likely to continue with the Fifth Assessment Report due in 2013.

Summary of the Key Findings: The most important findings on climate change science can be summarized in six statements that are each supported by multiple lines of evidence (and so not put at risk by questions about any one set of data). There are of course many additional details about climate change and expected impacts to be worked out, but the six points alone are so well established and serious that it is clear that action to reduce emissions is needed to moderate the very significant, and quite possibly irreversible, impacts that lie ahead. The six key points, each of which is further elaborated on in a few paragraphs in a succeeding section, can be briefly summarized as follows:

1. Emissions from human activities, particularly the combustion of fossil fuels, are changing atmospheric composition, especially by raising the concentrations of climate-warming gases;
2. These higher concentrations will intensify the natural greenhouse effect, leading to global warming and associated changes in climate that will persist for centuries;
3. Changes in the climate are already evident and consistent with a human influence becoming the dominant influence in the late 20th century;
4. Future climate change is projected to be substantial if emissions continue to increase without restriction;
5. Both the environment and society will be impacted in significant ways as a result of both climate change and the rise in the atmospheric carbon dioxide (CO_2) concentration; and
6. Slowing the ongoing changes in atmospheric composition and climate will require substantial reductions in greenhouse gas (GHG) emissions over coming decades in order to limit anthropogenic interference with the climate system and avoid the most harmful environmental and societal consequences.

The first two findings are very well established; the second two findings are becoming increasingly well established; and the last two findings address the challenge society faces in dealing with the issue. The supporting evidence for these findings is presented briefly in the following sections, both to help in your understanding, and so that you can help explain climate change and its importance to others—not by assertion, but by reasoning.

Finding 1: Human Activities Are Changing Atmospheric Composition.

In 2008, the atmospheric CO_2 concentration measured at the Mauna Loa Observatory in Hawaii was ~385 parts per million by volume (ppmv). This concentration, which closely tracks the concentration at other stations around the globe, is ~22% higher than the value of ~315 ppmv observed when the station was established in 1957 and ~37% above the pre-industrial value of ~280 ppmv. The concentrations of other GHGs, such as methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and other halocarbons, are also well above their preindustrial level and still rising. Because the removal processes are slow relative to the emissions, the increased concentrations, except for CH_4, will persist for centuries or longer, transforming the problem into an intergenerational issue

These increases in atmospheric concentrations are being driven by a range of human activities. Initial emissions of CO_2 resulted from plowing of land for agriculture and deforestation. Emissions from these sources are estimated to have been contributing ~1.5 ± 0.5 PgC/yr (1 PgC = 1 petagram of carbon = 10^{15} grams of carbon) for the past 50 years. [Note that those in the policy community work with emissions of CO_2 rather than of carbon, and so these numbers have to be multiplied by 3.67 to account for the mass of the two oxygen atoms.]

The combustion of coal, oil, and natural gas, which transfers geologically stored carbon into the atmosphere, was about equivalent to the land use contribution in 1950, but has grown dramatically since then. Annual fossil-fuel emissions totaled ~7 PgC/yr in 2000 and have been over 8 PgC/yr the past few years. This acceleration in emissions is occurring primarily as a result of the rapid growth in the global economy (until 2009), especially due to the increase in the number of coal-fired power plants being constructed in China and southern and eastern Asia to alleviate the poverty of people in those regions. While approaches are available to limit the emissions of many of the non-CO_2 GHGs, most projections suggest continuing rapid increases in CO_2 emissions unless strong policy actions are taken.

Finding 2: The Increasing CO_2 Concentration Will Warm the Planet.

The Earth's climate is different than that of the Moon largely because of the presence of the Earth's atmosphere. Rather than incoming solar radiation directly striking the surface, the atmosphere intervenes, reflecting and absorbing some of the incoming solar radiation and letting only about half reach the surface. This energy warms the surface until the incoming flow of energy is balanced by emission of infrared (IR) radiation. Most of the IR radiation emitted upward is absorbed by the GHGs and radiated back toward the surface, causing further energy gain by the surface that must be balanced by warming and emission of more upward-directed IR radiation. This absorption of upward IR radiation, with much radiated back toward the surface, tends to impede the natural cooling of the planet, having an effect like that of a greenhouse, although because of a different physical mechanism. As a result, the Earth's surface temperature is, on average, ~33 °C (about 59°F) higher than it would be if there were no greenhouse effect.

Mars and Venus provide excellent tests of scientific understanding that GHGs cause this warming to occur. The surface temperature of Venus is much higher than that of Earth, but not because Venus is closer to the Sun. On a per-unit-area basis, the very bright clouds that make Venus so visible in the night sky limit the absorption of solar radiation to less than the amount absorbed by the Earth. Instead, Venus's very high atmospheric concentrations of GHGs allow some solar energy to pass through, but then recycle the IR radiation over and over to pump up the surface temperature. Although the Martian atmosphere is mainly CO_2, it is farther from the Sun; lacking water vapor, its surface temperature is only slightly elevated by its GHGs and so is well below the surface temperature of the Earth.

Once adjustments are made for the very different compositions and pressures of the atmospheres of these planets, the same radiation models used to simulate solar and IR radiation fluxes in the Earth's atmosphere explain the conditions observed on the Earth's sister planets. Without doubt, increasing the concentrations of GHGs will amplify the warming by a significant amount, leading to climate change and sea-level rise.

Finding 3: Human Activities Are Already Changing the Earth's Climate.

The increasing upturn in global average temperature since the start of the Industrial Revolution is one indication the global climate is changing. Overall warming since the mid-19th century totals ~0.8°C (almost 1.5°F), with most of the increase occurring since 1970. For years before the thermometer network was established, proxy indicators (e.g., histories of tree ring characteristics, pollen types, coral growth, etc.) suggest that current global average surface temperatures are higher than at any time in the past thousand years, and likely much, much longer (the Northern Hemisphere was apparently a degree or so warmer for a several thousand year period centered on a period perhaps 4,000 years ago as a result of changes in the timing and shape of the Earth's orbit around the Sun).

Increases in ocean temperatures and in sea level (because ocean warming causes thermal expansion); reductions in sea ice, mountain glaciers, snow cover, and, increasingly, in ice sheet mass; and poleward and upward shifts in the ranges of temperature-sensitive species all provide reinforcing evidence that change is already underway.

To evaluate the relative contributions to recent climate change of natural influences (e.g., changes in solar radiation and volcanic activity) and human-induced influences (e.g., increases in GHG concentrations, changes in aerosol loadings, changes in stratospheric ozone), global atmosphere-ocean models have been used to determine their individual and combined signs and patterns of change. The newest model results match changes in temperature since the start of the 20th century on not only a global basis, but also on a continental-scale basis. Changes in the early 20th century appear to have been mainly due to natural influences, with the warming influence of GHG increases being offset by the cooling influence of sulfate aerosols. For the past several decades, however, natural factors have likely played a very small role (solar radiation has actually been slightly decreasing) and the observed warming can only be explained by the rising concentrations of GHGs. Because the net atmospheric lifetimes of most GHGs is decades to centuries (depending on species), their emissions keep accumulating in the atmosphere and will exert a strong warming influence for many centuries.

Finding 4: Much Greater Climate Change Lies Ahead

IPCC's 2007 assessment presents projections of changes in climate from an international set of comprehensive atmosphere-ocean-land-cryosphere models for three scenarios of how international society and its sources of energy (and therefore GHG emissions) might evolve in the absence of specific policy actions to limit GHG emissions. For the 21st century, the models project the global average temperature will increase to ~2.5–4.5°C (~4.5-8°F) above its pre-industrial level. While this may seem like a modest increase compared to the change in average temperature from winter to summer or as a result of moving from New York to Arizona, this shift will be affecting everyone and the entire environment in all seasons. As another comparison, the increase is equivalent to approximately half of the global warming since the peak of the last glacial about 20,000 years ago when 2 km of ice covered northern North America, and will increase the global average temperature to well above the last interglacial period about 125,000 years ago, when sea level was 4–6 m (~13-20 feet) higher than at present, likely due mainly to substantial melting of the Greenland ice sheet.

For the next few decades, the global average temperature is projected to increase 0.2–0.3°C (~0.35 to 0.55°F) per decade. This rate of warming is initially not strongly dependent on the emissions scenario, in part, because the mix of energy technologies will change only slowly and, in part, because much of the warming over the next couple of decades will be a result of the continuing warming influence of past emissions. Beyond 2050, however, how our energy choices evolve over coming decades, with or without policy, will make an increasing difference.

Warming is not all that will occur. Storm tracks will shift in response to the changes in temperature gradients and airflows, leaving some regions drier and high latitudes likely wetter. Precipitation tends to become more intense, continuing recent trends, leading to more drenching rains and flooding. Away from the storm tracks, higher temperatures increase evaporation, decreasing soil moisture and causing faster transition to drought conditions.

The warming of the oceans and melting glaciers alone are projected to contribute to sea-level rise of ~0.3–0.5 m (~1-2 feet) by 2100, which is roughly double the rise that occurred due to climate change during the 20th century. Based on what happened 125,000 years ago when orbital variations caused the world to be slightly warmer, loss of ice from the Greenland and Antarctic ice sheets could double to triple this amount, and cause substantial additional rise in sea level thereafter.

Finding 5: Substantial Societal and Environmental Impacts Will Result.

Even in the absence of temperature change, the rise in the CO2 concentration alone will affect the biosphere. On land, the increase will tend to help plants grow faster and use available soil moisture more efficiently. To the extent that crops can out-compete the weeds and pests that will also benefit, this can increase agricultural yields, especially in the most productive areas. In the oceans, however, the rising CO2 concentration will increase the ocean acidity (i.e., make the pH less basic). This effect is already reducing the depth at which calcium carbonate sediments dissolve. By mid-century, further ocean acidification will very likely threaten shell-forming organisms at the base of the marine food web, the skeletons of fish, and the world's coral atolls, which provide homes to significant numbers of species. The potential seriousness of this issue is only just emerging.

Climate change itself will have a wide range of dramatic consequences. In many cases, the effects will more rapidly and intensely impact the poor and indigenous peoples because they have fewer resources for proactive adaptation. Warming will force the relocation of many species. As high latitude species are crowded out by species from lower latitudes, they will be pushed toward extinction, leading to significant loss of global biodiversity.

For food and fiber production, increases are likely in mid-latitudes for small warming, but larger warming will lead to very hot and dry periods during the growing season; in addition, pressure from pests and weeds will increase significantly. In some regions, pest outbreaks are already killing off key tree species, increasing the likelihood and intensity of wildfire under the increasing hotter and drier weather conditions caused by global warming. Human health is likely to be most impacted by more frequent and intense heat waves, greater threats of insect and other vector-borne diseases, and challenges posed by more extreme weather. Of most long-term concern are the disruptions of coastal habitats and the dislocations of people and infrastructure that are expected from significant sea-level rise, with the effects initially felt in low-lying river deltas. By late in the century, however, effects will have much more extensive impacts, especially in regions exposed to higher storm surges from more intense tropical cyclones.

Finding 6: Significant Emission Reductions Are Required to Stabilize the Climate

To limit the projected impacts, the nations of the world, including the United States, adopted the United Nations' Framework Convention on Climate Change (UNFCCC) in the early 1990s. Its objective is to stabilize "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system," doing so in a manner that would protect ecosystems and food production while enabling "economic development to proceed in a sustainable manner." Achieving stabilization will only be possible by reducing emissions of GHGs to match their removal rates by physical, chemical, and biological processes. Stabilizing at near the present CO2 concentration, which is the primary cause of the global warming observed today, would require cutting emissions to ~80% below present levels. Because such a sharp reduction would take time, the CO2 concentration seems likely to rise to well above its present level of ~385 ppmv unless very aggressive policy actions are taken—and taken quickly.

Unfortunately, even the most optimistic of IPCC's emissions scenarios result in the CO2 concentration rising to more than 500 ppmv (and effectively even higher due to the warming contributions of increases in the concentrations of other GHGs). Less ambitious efforts to control emissions are projected to lead to a CO2 concentration of 700–1000 ppmv. As a result, returning atmospheric composition to a state compatible with the present climate will essentially require going to very near zero emissions for CO2 and other long-lived gases, with much of the reduction achieved by 2050 and the rest by 2100.

Fortunately, in getting started on the path to sharp reductions in emissions, significant reductions can be achieved through increases in efficiency, and experience has taught us that such "low-hanging fruit" tends to regrow as innovation proceeds. If we pursue a portfolio approach of matching the most appropriate technologies to needs and environmental conditions, aggressive research also seems very likely to provide an array of cost-effective sources of energy that do not release CO2. There are also many available and inexpensive approaches to reducing emissions of non-CO2 warming influences. In particular, sharp reductions in the species with relatively short atmospheric lifetimes, (methane, precursors to tropospheric ozone, and black carbon) would cause their warming influence to quickly go down, likely relatively rapidly reducing the rate of climate change.

References to Recent Papers

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