Scientific Assessment of Climate Change: Global and Regional Scales

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Overview

A strong consensus among climate scientists has emerged on key aspects of global climate change: humans have unquestionably altered the composition of the atmosphere in significant ways, there has been an increase in global average temperature of 0.4 – 0.8°C (0.7 – 1.5°F) in the past 100 years, and this increase in temperature is probably caused in part by the atmospheric changes wrought by humans. In the future, the accumulation of greenhouse gases is expected to lead to further warming of 1.4 – 5.8°C (2.5 – 10.4°F) by 2100, with moderate (at the low end) to dramatic (at the high end) consequences for humans and global ecosystems. The uncertainty in this wide range of estimates stems about equally from uncertainty about natural feedbacks in the climate system and from estimates of future socioeconomic change.

Climate models are the best tool available for understanding future climate change. CIG has extracted output for the PNW region from eight global climate model simulations, which taken together project a regional warming of 1.7 – 3.5°C (3.1 – 6.3°F) by the 2040s, with modest increases in winter precipitation. **Even with wetter winters, however, the region will likely face reduced summer flows as rising temperatures reduce winter snowpack depth and distribution.** Climate models simulate large-scale temperature much better than other quantities like precipitation; consequently, confidence in the projections of future temperature is higher than for other climate variables. Climate change is expected to continue beyond the 2040s and probably even beyond 2100.

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Introduction

Global climate change[2] has received considerable attention recently owing to international efforts to reduce greenhouse gas emissions and high-profile scientific advancements. In this paper, we review what is known about the science of global climate change and possible regional climate changes. Neither in this paper nor in the July 15-17 workshop will the Climate Impacts Group discuss or advocate any possible courses of action to reduce greenhouse gas emissions; such courses of action are denoted "mitigation" in this context. Rather, our focus is on "adaptation", by which we mean increasing the resilience of human and natural systems to climate change.

The "greenhouse effect" refers to a natural process in which certain gases (water vapor, carbon dioxide, and methane are the most important) allow the sun's radiant energy to pass through the atmosphere, but absorb the radiant energy that Earth gives off at lower wavelengths. This leads to a natural warming of the Earth. Past fluctuations in the composition of the Earth's atmosphere on geologic timescales have produced vastly different climates – 100 million years ago, Earth was so much warmer that alligators lived in what is now Siberia, and the carbon dioxide content of the atmosphere was probably four times present levels (Kump et al., 1999). Throughout Earth's history, the natural warming of the greenhouse effect has kept the planet warm enough to sustain life. What is unusual, however, is the rate at which CO_2 and other greenhouse gases are now increasing.

In the last 150 years or so, humans have enhanced the natural greenhouse effect by increasing the quantities of key greenhouse gases. Carbon dioxide has increased 32% because of burning fossil fuels and reducing forested area, and methane has increased by 151% through agriculture (chiefly cattle and rice paddies) and other human sources (IPCC, 2001).

Two key questions arise from the increase in greenhouse gases: (1) is the planet warming? and (2) can we rule out natural causes for recent climate change? These two questions are answered in the next section using the best available science. First, however, we describe the two-tier process that scientists have used in answering these sweeping questions.

The first tier is the publication of scientific papers in peer-reviewed journals. The process of peer review is a form of quality control in which anonymous reviewers comment on the strengths and weaknesses of an unpublished article; it requires scientists to provide sufficient evidence to back up their claims and hence prevents them

[2] "Climate" refers to the statistics of weather – averages, extremes, and so forth. "Global climate change" in this document, as in the IPCC, refers to changes in global climate without regard to cause (natural or man-made).

from making wild, unsupported claims. Each published paper can be thought of as a "brick" of knowledge. Looking at a pile of bricks, or at a single brick, is an inadequate way of taking in the totality of knowledge.

To assimilate the vast number of studies on a big subject like climate requires a second tier, the process of assessment. On the climate questions, the assessments are a mammoth effort undertaken by the "Intergovernmental Panel on Climate Change", or IPCC. The IPCC was created in 1988 and has issued major reports in 1990, 1996, and 2001 (the First, Second, and Third Assessment Reports). Much of what is presented in the next section comes from the first volume of the IPCC's Third Assessment Report. This comprehensive report was written by over 650 scientists who volunteered considerable time over a period of three years to write the report, and was reviewed by 300 additional scientists (IPCC, 2001). The IPCC assessments constitute the most comprehensive, authoritative statement about the state of the science of climate change, and are, in our judgment, more trustworthy than statements about climate change that one finds in other fora, including the internet, the media, and publications by various interest groups. The interested reader is strongly urged to consult the IPCC "Summary for Policymakers" (see references). Every representation of the state of knowledge of climate science, including this paper, should be viewed as less authoritative than the IPCC report.

President Bush recently asked the U.S. National Academy of Sciences to provide its best judgment on a set of questions concerning the human influence on climate. The Academy panel of 11 scientists, which included two scientists from Joint Institute for the Study of Atmosphere and Oceans (JISAO), reiterated the IPCC findings. This underscores the value of the IPCC process: in summarizing the full body of scientific knowledge, it is difficult to come to any other conclusions than the IPCC did.

Global Climate Change – Past and Present[3]

The IPCC answered affirmatively to both of the questions posed above (is the planet warming? can we rule out natural causes?). The IPCC also, for the first time, provided judgments of the level of confidence of various conclusions (very likely: 90 - 99%, likely: 66 - 90%) as reported below.

Is the Planet Warming?

In answering yes to this question, the IPCC stated that "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system." Evidence marshalled included the following:

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[3] This section is based entirely on the IPCC report (IPCC 2001).

- global average surface temperature has [very likely] increased by 0.4 - 0.8°C (0.7° - 1.5°F) (Figure 1a);
- snow cover has decreased by about 10% since the late 1960s;
- glaciers and sea ice extent have decreased; and
- spring, as marked by blooming or leafing-out dates of various plants, is coming earlier in much of North America.

The warming in the 20th century did not proceed smoothly, but rather in two stages: one from 1910 to 1945 and one since 1976, with temperatures relatively constant at other times.

Can We Rule Out Natural Causes?

Natural causes of climate change include solar variations, volcanic eruptions, and the redistribution of heat by the oceans. In answering this more complicated question about the cause of warming, scientists have taken different approaches. One approach is to examine past climate and determine whether the warming of the late 20th century is unusual. Scientists have carefully reconstructed temperatures in the Northern Hemisphere back to A.D. 1000 (Figure 1b) from tree rings and corals and other "proxy" data, and two things stand out: (1) the 20th century warming is unprecedented in its rate and magnitude of warming and (2) the 1990's are likely the warmest decade in that time.

The second approach is to simulate global temperatures (Figure 2) with a climate model[4] while introducing various forcings, typically solar variations, volcanic eruptions, and human contributions (greenhouse gases and aerosols). When forced by natural causes alone, climate models can generally reproduce the warming from 1910 to 1945, but they cannot reproduce the warming since the mid-1970's. Only when the increase in greenhouse gas concentrations is included can the models reproduce the late-20th century warming.

Another approach is to compare the spatial pattern of warming as observed and as simulated by climate models with the observed increase of greenhouse gases. The pattern early in the century does not resemble the pattern expected from increasing greenhouse gases, and hence was probably natural. By contrast, the pattern of warming late in the century does resemble the pattern expected from increasing greenhouse gases. This underscores the difference between the (probably natural) early-century warming and the (probably unnatural) late-century warming. Taken together, these pieces of evidence support the view that **most of the warming observed over the last 50 years is attributable to human activities** (IPCC, 2001). The National Academy of Sciences panel echoed this

[4] A climate model is an elaborate computer program that simulates the Earth's atmosphere and often its oceans, sea ice, and land processes as well. The goal of a climate model is to simulate correctly the statistics of weather (e.g., average high and low temperature) in some specified window of time (e.g., the decade of the 2020s).

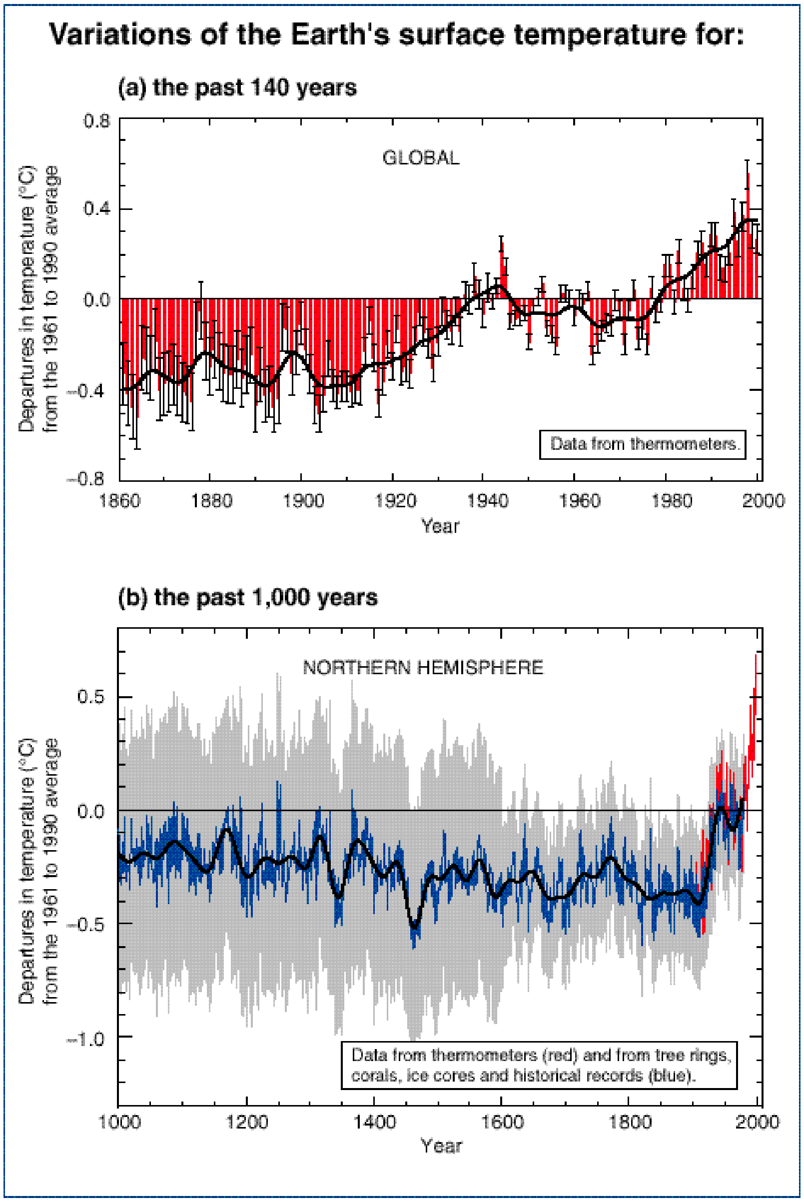

Figure 1: Variations of the Earth's surface temperature over the last 140 years and the last millennium.

(a) The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (black line, a filtered annual curve suppressing fluctuations below near decadal time-scales). There are uncertainties in the annual data (thin black whisker bars represent the 95% confidence range) due to data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data and also in adjustments for urbanisation over the land. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by 0.6 ± 0.2°C.

(b) Additionally, the year by year (blue curve) and 50 year average (black curve) variations of the average surface temperature of the Northern Hemisphere for the past 1000 years have been reconstructed from "proxy" data calibrated against thermometer data (see list of the main proxy data in the diagram). The 95% confidence range in the annual data is represented by the grey region. These uncertainties increase in more distant times and are always much larger than in the instrumental record due to the use of relatively sparse proxy data. Nevertheless the rate and duration of warming of the 20th century has been much greater than in any of the previous nine centuries. Similarly, it is likely[7] that the 1990s have been the warmest decade and 1998 the warmest year of the millennium.

[Based upon (a) Chapter 2, Figure 2.7c and (b) Chapter 2, Figure 2.20]

Figure taken from IPCC, 2001

statement, saying: "Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities…" (NAS, 2001).

Global Climate Change – Future

The match between past climate as observed and as simulated with climate models (Figure 2), along with other evidence presented in the IPCC report, underscores the utility of climate models in estimating future climate. Two factors influence the model-generated estimation of future climate: (1) future concentrations of major

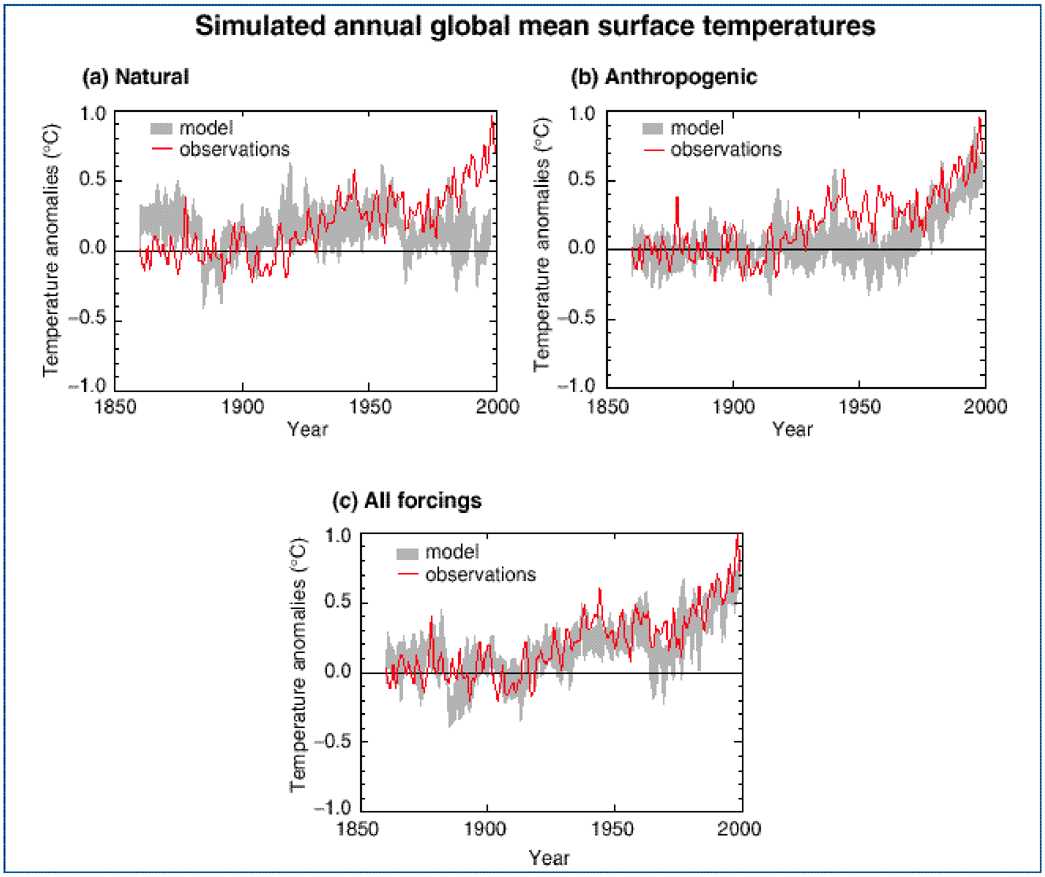

Figure 2 – Simulations (shading) of Earth's average temperature using (a) natural forcings (solar variation and volcanic activity); (b) anthropogenic forcings (greenhouse gases and an estimate of sulfate aerosols); and (c) both natural and anthropogenic forcings. The later simulation produces a faithful reconstruction of observed temperature changes (solid line) (Figure taken from IPCC, 2001).

greenhouse gases and sulfate aerosols[5] and (2) the response of the climate system to a given concentration of greenhouse gases and sulfate aerosols. The first factor is provided by socioeconomic scenarios, which yield a variety of possible future development paths, each of which produce a different mix of greenhouse gases and aerosols. For example, IPCC scenarios for future CO_2 concentrations give values in 2100 ranging from twice the pre-industrial concentration to 3½ times the pre-industrial concentration. The second factor – the response of the climate system to a given concentration of greenhouse gases – is a property of the models themselves.

Putting together these two factors, the IPCC came up with a wide range of warming rates: 0.8 – 2.6°C (1.4° – 4.7°F) warmer than 1990 by 2050, and 1.4 – 5.8°C (2.5 – 10.4°F) warmer by 2100. In our judgment, the lower and upper bounds are unlikely to occur, though the upper bound was the chief focus of media attention on the IPCC

[5] It should be noted that the influence of aerosols on climate is not well known, though it is generally accepted that they provide some regional cooling.

report. The low bound results from a low estimate of climate sensitivity and a scenario in which global population peaks in mid-century and then declines, and a rapid transformation of the global economy from manufacturing to service and information, with clean and resource-efficient technology. The upper bound results from a high estimate of climate sensitivity and a scenario with rapid global economic growth fueled by rapidly rising consumption of fossil fuels. Whatever the rate of warming, it is very likely that land areas will warm more than the oceans, especially at high latitudes in the Northern Hemisphere.

Other important aspects of global climate are likely to change as well. Precipitation is expected to increase at high latitudes, with extreme precipitation events becoming more common, hurricanes are expected to become more intense (though not more widespread), and sea level is expected to rise by between 9 and 88 cm (4" and 35") by 2100. Changes in the behavior of El Nino and other facets of the climate are possible. Furthermore, although projections tend to focus on the next 100 years, the long lifetime of CO_2 molecules in the atmosphere means **that even after CO_2 concentrations are stabilized** (a situation that occurs only in the lowest IPCC scenarios, and then not until 2100) **climate will continue to change and sea level will continue to rise**. A warmer climate will persist for centuries, even long after any successful effort to reverse the changes.

Pacific Northwest Climate Change

Past

Using quality-controlled data from weather stations with records beginning no later than 1920, we calculate that the average temperature in the U.S. Pacific Northwest has increased 0.8°C (1.5°F) in the past 100 years, a rate slightly higher than the global average; temperature trends in southern BC are about 0.5°C (0.9°F) in the coastal region and 1.1°C (2.0°F) over the period 1895-1995 (ELP web site). Few stations in the three states show cooling, but Idaho stations have the lowest average warming. Changes in precipitation have occurred as well, with most stations showing an increase; the increase is greater than 30% per century at about a dozen stations, mostly in eastern Washington, eastern Oregon, and western and northern Idaho. The changes in regional precipitation are unevenly distributed over the year. The warmest year in most of the PNW (especially east of the Cascades) was 1934, but the warmest decade was the 1990s – warmer than any other decade by 0.5°C (0.9°F). Although the IPCC attributed continental-scale warming over the last 50 years to human activities, no such attribution can yet be made to warming on the scale of the Pacific Northwest, in part because of the capacity of the atmosphere and ocean to redistribute heat. Future climate changes may also be partly masked or accentuated by such redistribution, within the larger framework of a global increase in temperature.

Future

We have extracted changes in temperature and precipitation in the PNW from a subset of the climate models used by the IPCC (Mote et al., 1999, with updates in Mote et al., 2001). These model simulations used a simpler projection of future greenhouse gases (1%/year CO_2 equivalent) than the IPCC projections, but there is little difference in CO_2 concentrations before 2050. The average warming from these eight scenarios is 2.8°C (5°F) from the 20th century to the 2040s (Figure 3), with a range of 1.7 – 3.5°C (3.1 – 6.3°F). The models project changes in precipitation of roughly –5% to +20% in most months between November and May, with an average of about +10%, so the wet season is projected to get a bit wetter. Between June and October, some models show slight increases in precipitation and some show slight decreases; the average change is near zero. In summary, then, future PNW climate is very likely to be warmer, with somewhat enhanced precipitation in the wet season. On the basis of models' skill at simulating 20th century global climate variables, as summarized by the IPCC, we have more confidence in the temperature projections than in the projections of winter precipitation or (less still) summer precipitation.

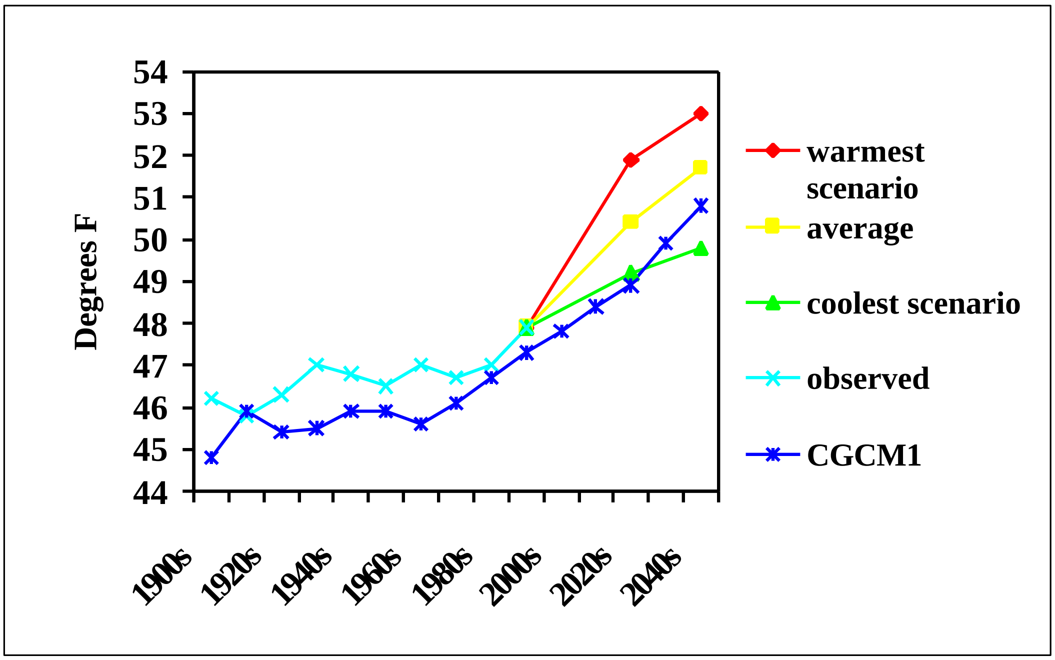

Figure 3 – Decadal average temperatures in the Northwest as observed (crosses) and as simulated to the 2040s by the CGCM1 climate model (stars). Also shown are the average and the warmest/coolest scenarios for the 2020s and 2040s from eight climate models.

Although an increase in precipitation can be expected for the PNW's wet season, climate change will significantly impact the availability of water resources in the region, particularly during summer months. Most of the PNW – its ecosystems and human endeavors – relies on snowpack to transfer water from the wet season (when water is provided) to the dry season (when it is most needed). Modest changes in temperature dramatically affect snowpack depth and areas of accumulation as more precipitation falls as rain rather than snow during critical winter months. Consequently, the water supply in the PNW is uniquely vulnerable to a warming climate. With these climate scenarios, the modest increases in wet-season precipitation do little to ameliorate a reduction in snow-covered area, and our hydrological modeling simulations indicate significant reductions in summer streamflow in most of the region's rivers. Reductions in water available for irrigation, hydropower, fish flow, and urban uses therefore seem likely. The effects of climate change on the hydrologic regime are detailed further in White Paper #2 ("Effects of Climate Change on Water Resources in the Pacific Northwest: Impacts and Policy Implications").

Conclusions

An increase in Earth's average temperature of at least 1.4°C (2.5°F) by 2100 is, in the judgment of the world's climate scientists, virtually certain. Regional projections are somewhat less reliable, but the best available science points to a warming for the Northwest of about 0.5°C (0.9°F) per decade, resulting in a gradual reduction in snow cover and summer streamflow. These projections are by no means proven, but are sufficiently well grounded to warrant serious consideration in long-range plans. In our judgment, it is virtually certain that 21st century climate in the Pacific Northwest will be warmer than 20th century climate, and that notions of climate as "constant" (e.g., the 1971-2000 period currently used to define "normal climate") – what statisticians define as "stationary statistics" – will become obsolete. Consequently, definitions of "normal climate" based on the past should be used only with great caution in guiding future natural resource decisions.

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