Testimony

of

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Climate Change: Are Greenhouse Gas Emissions from Human Activities Contributing to a Warming of the Planet?

Summary

My name is Michael Oppenheimer, professor of Geosciences and International Affairs at Princeton University. This testimony responds to three questions asked by this committee about global warming, its causes and its likely future course, based on the findings of the recent report of the Intergovernmental Panel on Climate Change, the peer-reviewed literature, and my own research.

1. *Global temperatures are certainly increasing, the warming and associated sea level rise have accelerated, and a pervasive global climate change is well underway.*

2. *It is very likely that most of the recent climate change is attributable to human activities, particularly emissions of greenhouse gases and aerosol particles. Natural climate variability and changes in the sun and volcanic emissions have played a lesser role.*

3. *During this century, global mean temperatures are expected to increase by amounts that are larger and occur faster than any in the history of civilization and reach levels perhaps not seen in tens of millions of years when ice sheets were much reduced and sea level was much higher than today. The temperature change would be largest on land and at high latitudes, broadly affecting key aspects of the climate system and remaking the face of the Earth.*

Sea level was likely 13 to 20 feet higher about 125,000 years ago, mainly due to the retreat of polar ice when polar temperatures were 5 to 9 degrees Fahrenheit higher. Additional global warming of only 3-4 degrees Fahrenheit may bring a return of such polar warmth. Prompt, substantial global emissions reductions, lead by US implementation of an economy-wide cap, is a prerequisite for avoiding such an outcome.

Introduction

My name is Michael Oppenheimer. I am the Albert G. Milbank Professor of Geosciences and International Affairs at Princeton University, where my affiliations include the Department of Geosciences, the Woodrow Wilson School of Public and International Affairs, and the Princeton Environmental Institute. I have authored over 90 articles in peer-reviewed journals including papers on Earth's atmosphere and ice sheets, climate change and its impacts on the environment, and policies for responding to climate change, in addition to basic atomic and molecular physics and astrophysics. I recently served on the National Research Council's Panel on Climate Variability and Change. I am a lead author and contributing author to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and was a lead author or contributing author to various chapters of the Second and Third Assessment Reports of IPCC. Before assuming my current position at Princeton University, I was chief scientist for Environmental Defense. I am currently a science advisor to this group. Earlier, I held the position of atomic and molecular astrophysicist at the Harvard-Smithsonian Center for Astrophysics.

I am grateful for the opportunity to testify before this committee on the subject of climate change. My testimony will address three questions posed by this committee, and my responses will be based on the Working Group I section of the Fourth Assessment Report of the IPCC, *Climate Change 2007: The Physical Science Basis*, as well as my own research and review of the literature. In addition, I will address the subject of ice sheets

and sea level rise which received considerable attention in the wake of the publication of the Summary for Policy Makers of the IPCC report. Finally, I will report some recent findings from the literature on the question of the time remaining to avoid levels of climate change that some research has characterized as "dangerous".

I want to emphasize that I am testifying in my capacity as an individual scientist, and not as an official representative of the IPCC or Princeton University. While I largely base my testimony on, and specifically cite, the recent IPCC report and other relevant literature, the conclusions drawn here are my own.

Question 1: Are global temperatures increasing?

The Fourth Assessment uses unusually definitive language in stating, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level". It is noteworthy that evidence for a pervasive global warming since the mid-19th century comes not only from surface temperature measurements but also from temperatures inferred from measurements aloft, temperatures at and beneath the ocean surface, and temperature trends on six of the seven continents (excluding Antarctica). Furthermore, IPCC points to the broad response of the Earth system as a whole as evidence of the warming, most particularly the decline of

snow and ice cover including the shrinkage of glaciers, and global sea level rise of 5 to 9 inches over the 20th century.

(To put the rate of sea level rise in perspective, I would like to point to estimates that along typical sandy stretches of the US east coast, a one-foot sea level rise leads to about 100 feet of land loss by erosion and submergence [1]).

Most striking is the finding that rates of warming and sea level rise have both accelerated. The warming trend over the last 50 years, about a quarter of a degree Fahrenheit per decade, is nearly twice that for the last 100 years. Furthermore, the report notes, "There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century". The rate of rise from 1993 to 2003 is about 70% greater than that from 1961 to 2003, although there is uncertainty over whether the rapid rate of rise will persist, decrease, or increase.

Another striking finding is that, unexpectedly, the major ice sheets in Greenland and Antarctica (particularly the West Antarctic ice sheet) are both shrinking. The report notes that losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003 (about 15% of the total sea level rise observed over that period, but with a large uncertainty). More recent research than that included in the IPCC report suggests the rate of ice sheet loss has continued to accelerate [2].

It is particularly noteworthy that the report firmly dispensed with some earlier assertions which have sometimes been misused in the public debate on global warming. Among these were the attribution of the global warming trend to the heat island effect; an apparent discrepancy between temperatures inferred from balloon-borne and satellite measurements of the lower- and mid-troposphere and the surface temperature record; doubts that water vapor, a key amplifier of warming, is indeed building up in the atmosphere; and the notion that the rate of sea level rise has been constant for many centuries.

To summarize in my own words: Global temperatures are certainly increasing, the warming and associated sea level rise have accelerated, and a pervasive global climate change is well underway.

Question 2: If global temperatures are increasing, to what extent is the increase attributable to greenhouse gas emissions from human activity, as opposed to natural variability or other causes?

IPCC also reached a very strong conclusion on this point: "Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations". The IPCC report emphasizes that the human influence now has been discerned in specific aspects of climate, including ocean temperatures, continental-average temperatures, temperature extremes and wind patterns. A significant human influence over temperatures has *likely*

been discerned for all continents but Antarctica. “Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves”.

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These findings come from two sources. Most important are statistical comparisons of the geographic pattern of temperature and other climate changes, and their evolution over time, with patterns produced by computer models. Such models estimate changes in the climate system that should have occurred as greenhouse gas levels increased over time. These are compared with modeled estimates of the effect of natural climate variability, and the effects of changes in the sun and volcanic emissions, that is, temperature changes that might have occurred absent the greenhouse-gas increase. Such comparison allows the effect of natural variability, the sun, and volcanoes to be separated from the effect of the greenhouse gases.

Another source of information is analysis of so-called paleo-climate proxies, indirect indicators of climate that are used to infer temperature changes for periods before a reliable thermometer record is available. These include data retrieved from ice and sediment cores, tree rings, and pollen. Temperatures inferred using such methods have greater uncertainty than direct measurements. Nevertheless, IPCC reached certain key conclusions with increased confidence since its last assessment. Among these, I cite two verbatim:

- Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years.

- The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres (about 13 to 20 feet) of sea level rise.

I shall return to discuss the broad implications of the second point later in this testimony.

IPCC's judgments on likelihood take into account uncertainties inherent in both methods. For example, it is not possible at this time to ascribe small-scale climate changes, i.e., those taking place over distances smaller than a continent, to the greenhouse gas buildup.

Once again, the IPCC sought to put to rest two issues that have clouded the public discussion of climate change. It has often been asked why warming occurred in the early 20th century before the bulk of human emissions of the greenhouse gases occurred. IPCC states that "it is likely that anthropogenic forcing (i.e., the human-made climate-changing effect of greenhouse gases) contributed to the early 20th century warming evident in these records". Changes in volcanic emissions and solar radiation also made significant contributions to the earlier warming. Second, IPCC notes that between 1750 and today, changes in the sun contributed less than 10% of the climate forcing due to human activities.

To summarize in my own words: *It is very likely that most of the recent climate change is attributable to human activities, particularly emissions of greenhouse gases and aerosol particles. Natural climate variability and changes in the sun and volcanic emissions have played a lesser role.*

Question 3: How do you expect future global temperatures to be affected by greenhouse gas emissions from human activity?

Obviously, answers to questions about the future are attended by much greater uncertainty than those about the past. Projections of future global temperatures depend on the sensitivity of the climate and the amount of greenhouse gases emitted. The Fourth Assessment provides improved guidance on the question of climate sensitivity, which is defined as the response of global average temperature to a doubling of carbon dioxide levels in the atmosphere:

- Climate sensitivity is *likely* to be in the range 3.6 to 8.1 degrees Fahrenheit with a best estimate of about 5.4 degrees, and is *very unlikely* to be less than 2.7 degrees.

- Values substantially higher than 8.1 degrees Fahrenheit cannot be excluded.

Future emissions depend on the size of Earth's population, the state of economic development, and technologies employed and lifestyles pursued. What sort of motor

vehicles, if any, will be dominant a century from now? How many will be owned by a typical family in the US? In China? What sorts of engines and fuels will power them? How efficient in their use of fuels will they be? How far will they be driven in a typical year? This is only one set of questions that must be answered to project futures emissions. Obviously, there is a range of plausible responses, and these are captured by IPCC in emissions scenarios reported in its Special Report on Emissions Scenarios.

These scenarios indicate that the carbon dioxide concentration in the atmosphere will approach or exceed a doubling in this century absent policies to limit emissions. Furthermore, Earth's warming is delayed by the slow heating of the oceans. Accounting for these factors, models project a warming of 2 to 11.5 degrees Fahrenheit during the 21st century. If emissions are low (which is more likely to occur with explicit global policies to reduce emissions) a warming of 2-5.2 degrees Fahrenheit is expected. If very fast and sustained emissions growth occurs with no restrictions, warming of 4.3-11.5 degrees Fahrenheit is expected. Many intermediate scenarios are plausible, producing intermediate ranges.

Let me emphasize two points:

- A larger warming than these global mean values is expected over land and at high northern latitudes, such as the upper plains and upper Midwest regions of the US.

- Some additional warming above today's temperatures is inevitable both due to gases already emitted and because an overnight turn-around in emissions is not possible.

Combined with the findings of others studies, the IPCC projections indicate that the warming would likely be larger and occur faster than any global temperature change in the history of civilization, and this is potentially the case even if emissions are reduced promptly. If instead emissions occur at the high end of projections and climate sensitivity is high, the scale and scope of change would be unprecedented in millions and perhaps tens of millions of year, and, in my personal view, would be disastrous.

Global climate change accompanying projected warming will be sweeping. Among the changes projected by IPCC are:

- It is *very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent.

- It is likely that future tropical cyclones (typhoons and hurricanes) will become more intense.

- Sea level would continue to rise for centuries.

<u>To summarize in my own words:</u> During this century, global mean temperatures are expected to increase by amounts that are larger and occur faster than any in the history of civilization and reach levels perhaps not seen in tens of millions of years when ice sheets were much reduced and sea level was much higher than today. The temperature change would be largest on land and at high latitudes, broadly affecting key aspects of the climate system and remaking the face of the Earth.

Sea Level Change and the Ice Sheets

The greatest impact of warming to the US and many other areas may come from rising seas, but estimating future sea level rise has proven difficult for both the 21st century and for the longer term. The key uncertainty lies in how the ice sheets in Greenland and Antarctica will behave as Earth warms. The Greenland ice sheet contains an equivalent of about 23 feet of sea level rise and the West Antarctic section of the Antarctic ice sheet, the part of the larger ice sheet thought most vulnerable to warming, alone contains an equivalent of about 17 feet of sea level rise.

Rapid collapse of small, floating ice shelves in West Antarctica has been followed by unexpected acceleration into the sea of the land-based ice in back of the ice shelves, adding to sea level rise. The Greenland ice sheet has also experienced unexpected dynamical changes as "outlet" glaciers terminating in the sea, as well as other parts of the ice sheet have accelerated, doubling the contribution to sea level rise since the early 1990s due to melting alone.

The unfortunate truth of the matter is that, in contrast to success of projections of atmospheric warming, no computer models exist that can reproduce the recent changes in the ice sheets, called "dynamical" because they involve ice flowing into the sea rather than merely ice melting away. Consequently no reliable basis exists for projecting the future of the ice sheets. The failure of models is particularly stark for Antarctica because there the models had projected a significant *growth* in the ice sheet due to increased precipitation from the warming global atmosphere. Instead, the Antarctic ice sheet as a whole probably has lost rather than gained ice recently largely due to rapid losses in the Amundsen Sea region of West Antarctica.

Faced with this uncertainty, IPCC projects 7 to 15 inches of sea level rise for this century if emissions are low, and 10 to 24 inches if emissions are high, *excluding future rapid dynamical changes in ice flow* (emphasis mine). In other words, these estimates assume that the rates of loss of ice from Greenland and Antarctica will not continue to accelerate. Surely this is an optimistic assumption [3], and IPCC recognized as much in providing some additional scenarios (from among many plausible ones) of additional dynamical change that produce higher sea level rise.

These problems make the projection of long term changes beyond the 21st century even more complex. But IPCC did provide important information relevant to this question:

- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 13 to 20 feet higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 5 to 9 degrees Fahrenheit higher than present…

I would like to point out that a future global warming of only 3- 4 degrees Fahrenheit may be sufficient to cause 5 degrees of polar warming. Disintegration of much of the Greenland and part of the West Antarctic ice sheet may follow. Paleo-climate studies reported in the literature provide little guidance on the possible rate of sea level rise for such warming. One study does suggest that rates could have approached 3 feet per century as sea level rose to 13-20 feet above the current level [4], a point not noted in the IPCC Summary for Policy Makers. Such rates could reasonably be characterized as catastrophic for many regions if they occurred again in the future.

To address this point further, I paraphrase IPCC:

- Current models suggest that a global warming of 2.2 to 7 degrees Fahrenheit from present, if sustained for millennia, would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m.

It is interesting that the conclusions from the models and the conclusions from paleo-climate data are similar in foreseeing large scale polar ice loss with temperature changes that are less than or comparable to what may occur over this century. The nub of the

problem is whether we can trust the models in their claim that it would take millennia for the Greenland ice sheet to disintegrate once the process begins. Based on the fact that these very same models are not capable of reproducing recent dynamical ice loss, and that dynamical processes are an important control on the rate of disintegration, I conclude that we cannot trust the model estimate of a millennial timescale. It is entirely plausible that loss of large parts of the polar ice sheets, and a very large sea level rise over the course of several hundred years, rather than over millennia, would occur once the world warms as little as 3-4 degrees Fahrenheit above the present global mean temperature.

The models also assign little role to the West Antarctic ice sheet in the sea level rise for such modest warming. But the paleo-climate data indicate Antarctica likely played a role along with Greenland in causing the 13 to 20 foot rise of the distant past [4]. Accordingly, based on both recent observations and the distant past, the models have little credibility in their projections of the rate of ice loss from Antarctica, particularly the West Antarctic ice sheet.

Implications for Policy

Given that a warming of 3-4 degrees Fahrenheit above the present global mean may represent a plausible limit for avoiding "dangerous" climate changes [5], what does such a limit imply for actions to reduce emissions? This issue goes beyond the remit of IPCC Working Group I, so I will draw on the peer reviewed literature directly. The answer is

that the chances of avoiding such a warming appear to be less than 50-50 if atmospheric concentrations of carbon dioxide are permitted to exceed 450ppm [6].

Unless the growth in global emissions is reduced soon, first through reductions in emissions in developed countries like the United States, later by measures in developing countries, global temperature is likely eventually to climb above the 3-4 degree Fahrenheit limit. Then the ice sheets may gradually shrink, causing sea level to rise 13 to 20 feet, possibly over as brief a period as several centuries. And if the warming were allowed to continue, that would be only the beginning of a process that would eventually lead to total loss of both the Greenland and West Antarctic ice sheets, and a much larger sea level rise.

Only prompt and sizable reductions in global emissions, hopefully carried out with the leadership of the United States, and in collaboration with other large emitters such as the EU, Japan, China, and India, would avoid such an eventuality. I point to the five-, ten-, and fifteen-year mandatory emission reduction targets embodied in the proposal from USCAP [7] as plausible initial steps to meeting this challenge.

There are many areas of scientific research where additional federal support is sorely needed, even while emissions reductions are being implemented. Clearly, one of the highest priorities ought to be developing a new generation of computer models of Earth's ice sheets.

It is apparent to me, and I hope to everyone else, that the US and all other countries ought to prepare to deal with a warmer world in any event. It is even more important to note that the window of opportunity to avoid potentially disastrous outcomes may be closing fast.

Thank you.

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