Testimony of Jay Gulledge, Ph.D., Pew Center on Global Climate Change to the House Committee on Government Reform, July 20, 2006

Mr. Chairman, Ranking Member, Members of the Committee:

Thank you for this opportunity to speak to you today.

Although I am replacing Dr. James Hansen on this panel, I would like to clarify that I am not representing Dr. Hansen, and I am fully responsible for my testimony.

There has been landmark progress in the science of climate change since the publication of the last IPCC report in 2001 and even in just the past one or two years, as my testimony will show. I would characterize this progress as falling into two general categories: (1) greatly reduced uncertainties and (2) global changes in the climate, many of which were predicted years ago based on the anticipated effects of man-made greenhouse gases, are already being observed. The observed changes, especially changes in global ice cover, are occurring sooner and are more intense than had been expected, indicating that the climate is more sensitive to global warming than had been anticipated.

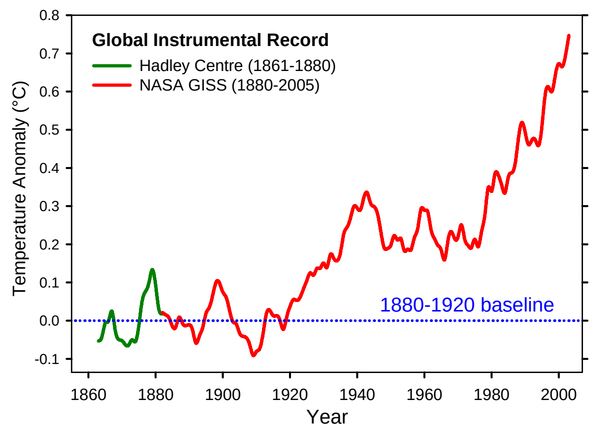


Fig. 1. Global average surface temperature as determined by thermometer readings.

Global Surface Temperature

From 1920 to the present, the earth's surface temperature has increased by 1.4 °F (Fig. 1). The sharpest rise occurred between 1975 and the present, when temperature rose steadily by about 1 °F. The same pattern of warming is apparent in sea-surface temperatures, as illustrated by the tropical North Atlantic (Fig. 2).

The same pattern of warming is also apparent in the Arctic region, which includes all surface area north of 66° North latitude (Fig. 2). Although the Arctic was relatively warm during the mid-twentieth century, it is clearly warmer today than at anytime in the past century. With an increase of 2 to 3 °F over the past century, the Arctic has warmed more than the global average. This amplification of warming over the high latitudes is a fundamental prediction of the enhanced greenhouse effect.

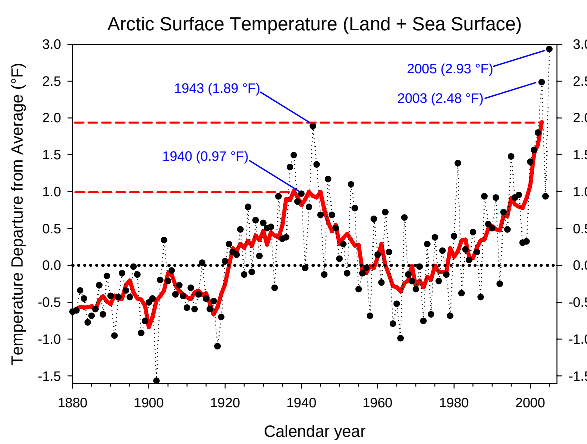


Fig. 2. Average surface temperature for the Arctic region (66° N to 90° N; (Ghcn 2006).

A long-standing uncertainty has been whether the Antarctic is also warming. In 2006, new long-term data were published based on weather-balloon data (Turner, Lachlan-Cope, Colwell et al. 2006). This is now the longest and most geographically comprehensive data set of direct temperature measurements for the Antarctic continent. The results show that the lower atmosphere above Antarctica cooled between the 1950s and 1975, and then increased sharply from 1975 to the present, similar to the global pattern shown in Fig. 1. Moreover, the Antarctic atmosphere has undergone the largest warming trend (1.2 °F per decade) of any spot on the entire globe (Fig. 3). There was also net warming on the ground.

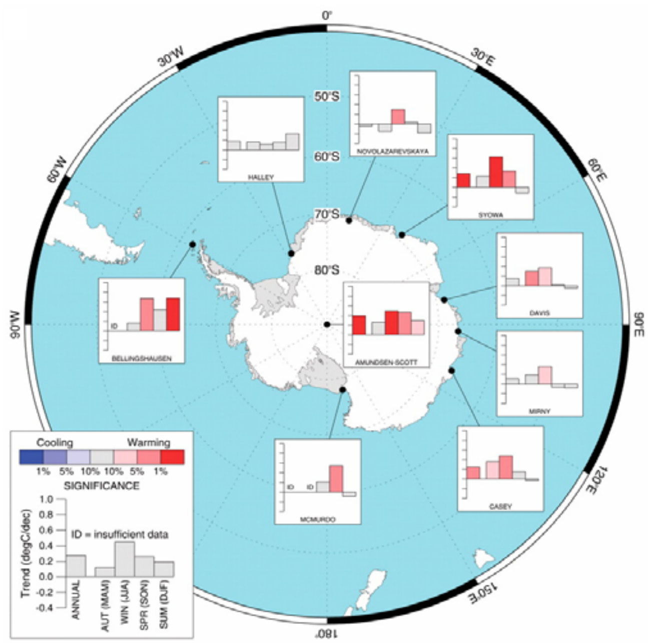


Fig. 3. Annual and seasonal warming in the Antarctic atmosphere over the past three decades (Turner et al. 2006).

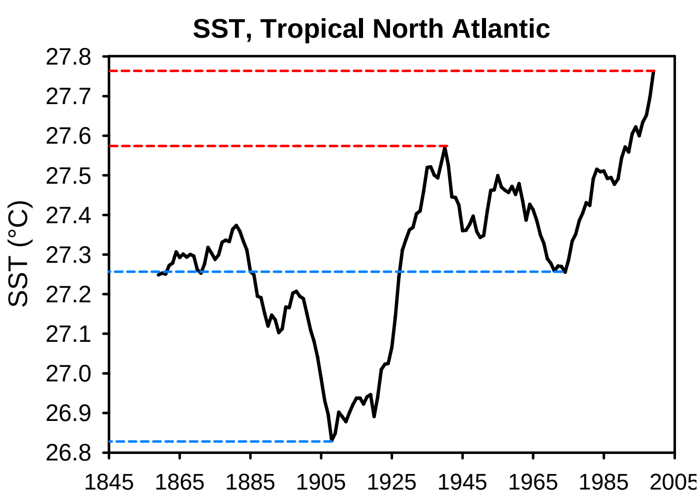


Fig. 4. Sea-surface temperature for 1860-2005 in the tropical North Atlantic Ocean (see (Webster et al. 2005)

Tropical sea-surface temperatures show a warming pattern similar to the global average and Arctic warming trends. Again, the present is considerably warmer than the mid-twentieth century warm period, as illustrated for the tropical North Atlantic (Fig. 4).

Not only is the current global temperature higher than at any time in the past century, recent research on past global climate indicates that the late 20th century is warmer than at any time in the past 1,000 years or more. One area of research that illustrates this finding is the reconstruction of past surface temperature from multiple proxies (ancient biological or geological structures that store information on the contemporary temperature at the time the structure was formed). Several reconstructions have been produced, none of which find evidence for any time in the past millennium when global surface temperatures approached those that have occurred since 1990 (National Research Council 2006); Fig. 5). Proxy reconstructions provide only one of several lines of evidence that support this conclusion.

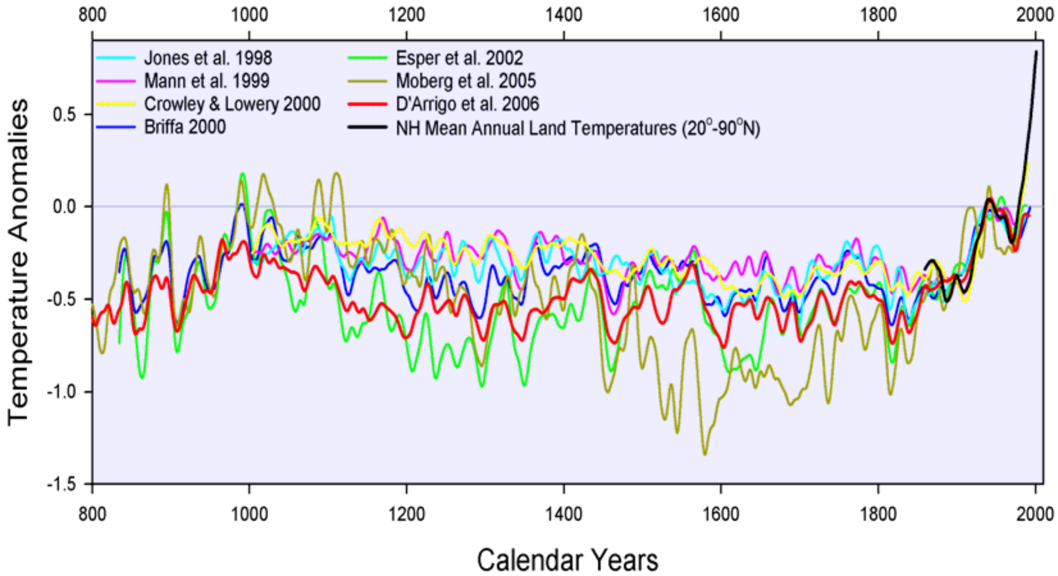


Fig. 5. Temperature of the past 1,200 years, based on paleoclimate proxies (D'Arrigo et al. 2006).

The discussion above confirms that the observed pattern of global surface warming extends to the high latitudes in both the north and the south, and that the warming at high latitudes is larger than the warming at low latitudes, as predicted by the enhanced greenhouse theory. Moreover, the degree of warming since 1990 is of historic proportions, both for the twentieth century and the past millennium.

Ocean Heat Uptake

In 2005 a major breakthrough was made in understanding global warming when a large dataset was published showing that the global ocean had been absorbing more heat than it was releasing since at least 1955 (Fig. 6; Levitus, Antonov and Boyer 2005). Over this period, the heat content of the global ocean increased by an amount equivalent to 10,000 times the amount of energy produced for electricity in the U.S. in 2005. This amount of heat is far too large to have been transferred to the ocean from anywhere else within the climate system, and requires the accumulation of new energy from outside the earth system, such as from increased solar radiation or from the trapping of more outgoing infrared heat, as occurs from increased greenhouse gas concentrations in the atmosphere. The sun's intensity has not changed appreciably over the past 5 decades, but this period coincides with the most intense increase in man-made greenhouse gases.

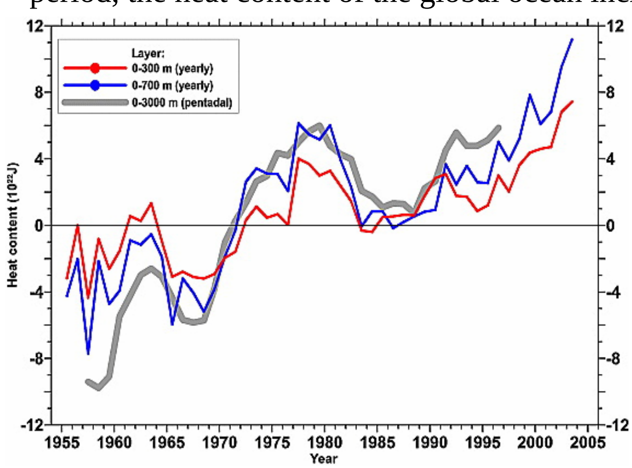


Fig. 6. Ocean heat uptake over the past 50 years. (Levitus et al. 2005)

Using the ocean heat content data described above, another recent study demonstrated that the enhanced greenhouse effect explains the ocean's heat gain over the past 5 decades (Barnett, Pierce, Achutarao et al. 2005). Observations show that the oceans have been warming from the surface downward, which indicates heat transfer from the atmosphere (red dots in Fig. 7). The vertical pattern of heat penetration with depth varies from ocean to ocean as a result of currents transporting heat from one ocean to another (Fig. 7a). Modeling of natural variability from solar and volcanic forcings did not produce temperature profiles that matched this fingerprint (Fig. 7a). However, the combined influence of anthropogenic greenhouse gases, natural forcings, and internal variability matched the unique fingerprint of heat penetration for each ocean (Fig. 7b). Of the three elements, anthropogenic greenhouse gases strongly dominated the overall forcing.

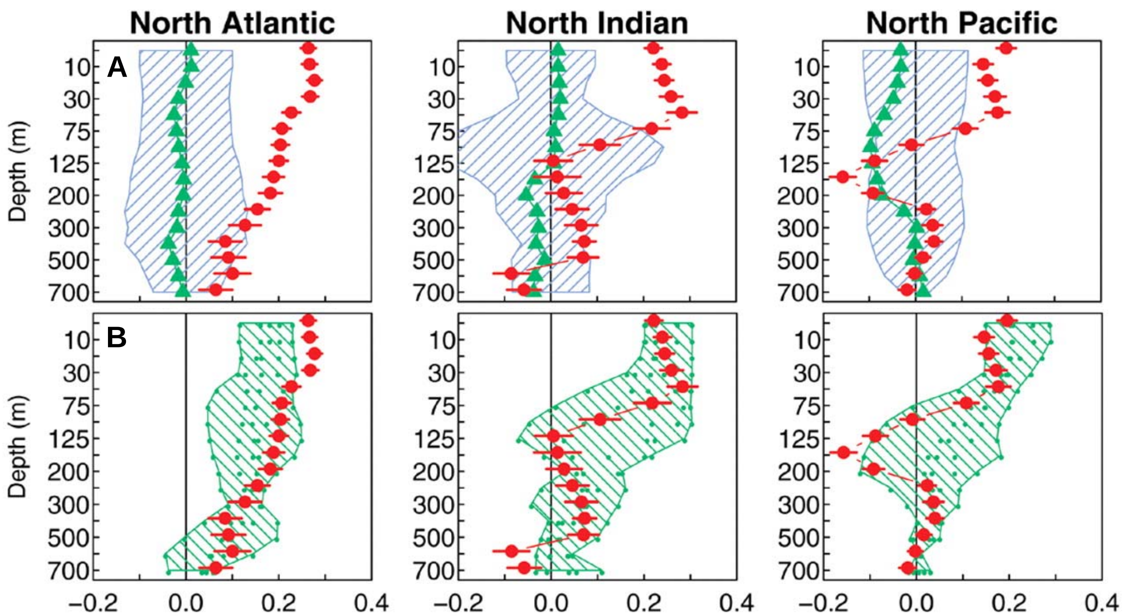


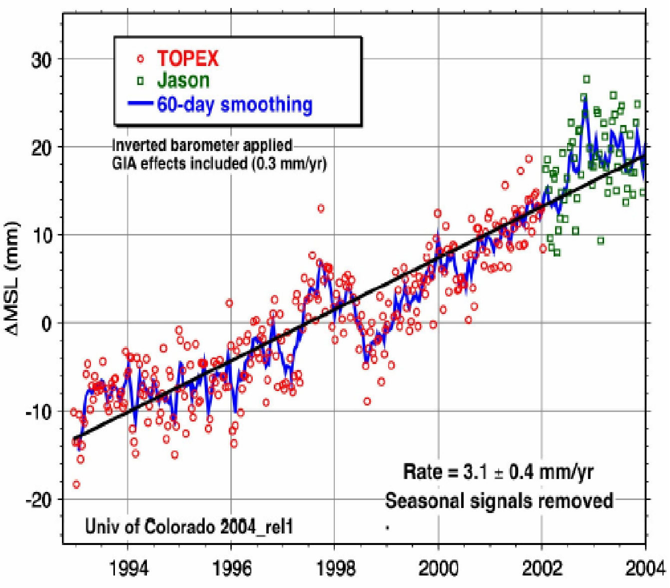
Fig. 7. Observed ocean heat content with (A) natural factors only and (B) natural + human factors. The results shown in Fig. 7B show that man-made greenhouse gases are responsible for warming the global ocean over the past 50 years (Barnett et al. 2005).

The ocean absorbs more than 80% of the heat that is initially trapped by greenhouse gases. This heat does not affect the atmosphere right away, but ocean temperature gradually equilibrates with the atmosphere. As a result, the new heat that is currently stored in the ocean will come back out over the next several decades, further warming the earth's surface. This warming, about 1 °F, is already with us and will occur later even if we were to stabilize greenhouse gas emissions today. Hence, we are already committed to an additional warming approximately equivalent to the warming that occurred during the late 20th century (Meehl et al. 2005).

Sea Level Rise

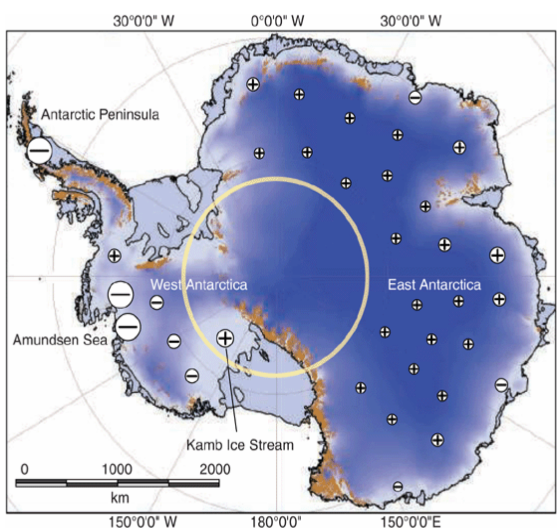
Based on tide-gauge records, the average rate of sea level rise (SLR) over the twentieth century was about 0.7 inches per decade (Houghton et al. 2001; Church and White 2006). Satellite altimeter measurements taken since 1993, by contrast, indicate that the rate of

SLR at the end of the twentieth century was about 1.2 inches per decade (Fig. 8; (Cazenave and Nerem 2004). This result alone indicates that the rate of SLR is higher now than it was earlier in the twentieth century and implies a minimum acceleration rate of 0.05 inches per decade. This exact estimate of acceleration over the twentieth century was obtained using a more sophisticated statistical method from reconstructed tide gauge records (Church and White 2006).



So it is now apparent that SLR has accelerated over the twentieth century. If the current rate of acceleration were to continue through the year 2100, global sea level would rise by about one foot during the twenty-first century, which is consistent with predictions of the IPCC Third Assessment Report (Houghton, Ding, Griggs et al. 2001; Church and White 2006). However, with continued global warming, it is reasonable to expect the rate of acceleration to continue to increase, leading to greater than one foot of sea level rise.

Fig. 8. Global sea level rise during 1993-2004 as measured by satellite-born altimeters (Cazenave and Nerem 2004). The measured rate is 70% higher than the average rate of sea level rise over the 20th century.



Glacier Water Cycle Intensification

Decades ago, glaciologists predicted that the enhanced greenhouse effect would cause the water cycle of glaciers to become intensified (Oerlemans 1982; Huybrechts et al. 1991). Glaciers gain ice by snowfall at high elevations and they lose ice by melting at low elevations. The amount of snowfall and melting have both increased in mountain glaciers from the tropics to the high latitudes (Dyurgerov 2003), as well as in the large polar ice sheets of Greenland (Johannessen et al. 2005) and Antarctica (Fig. 9; (Vaughan 2005).

Fig. 9. Antarctic glacier water cycle. Dark shading with (+) sign shows areas of ice thickening (increased snowfall) and light shading with (-) sign shows ice thinning (Vaughan 2005).

These new observations reduce uncertainty about the cause of global climate change because glaciers all around the globe are responding as originally predicted based on the enhanced greenhouse theory; the response is no longer merely a prediction. Also, the observed change in the glacier water cycle reveals the sensitivity of the climate system to a relatively small amount of warming compared to what is projected for the future as a result of continued greenhouse gas emissions. It is safe to say that glaciologists have been surprised by how quickly and sensitively glaciers around the world, and especially the large polar ice sheets, have responded to late 20th century warming.

Fig. 10. Decline of Arctic sea ice extent from 1979-200. The magenta line shows the average extent for 1979-2001.

Glaciers began retreating around 1850 at the end of the Little Ice Age, but accelerated during the 20th century, followed by a short period of advance, then a rapid retreat in the late 20th century. By comparing this pattern to the global surface temperature in Fig. 1, it is clear that mountain glaciers are extremely sensitive to temperature changes on the order of those currently caused by human activities.

New Signs of Climate Sensitivity

Unfortunately, the global climate is already responding to global warming in a sensitive fashion, even though the amount of warming so far is relatively small compared to the projections of future warming. For instance, Arctic sea ice reached the lowest extent ever recorded in September of 2005 and is being lost at current rate of about 8% per year (Fig. 10). Some climatologists predict that the Arctic Ocean will be ice-free during the summer by the year 2100, a condition that has not existed for at least one million years (Overpeck et al. 2005).

Mountain glaciers from the tropics to the mid-latitudes are losing ice vary rapidly. The relationship between glacier retreat and surface temperature is so tight that it is a simple matter to infer global surface temperature from historic glacier length records, using a simply physical relationship (Oerlemans 2005). There was no change in glacier lengths during the Little Ice Age that lasted from about 1500 to about 1850 (Fig. 11).

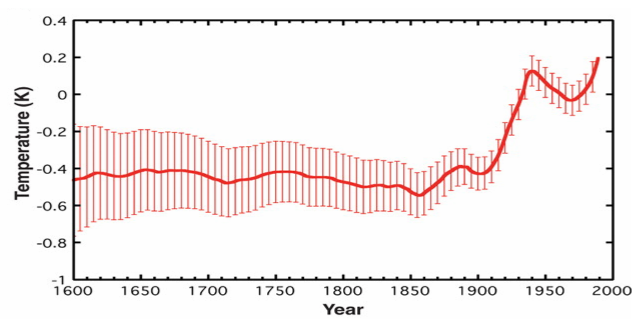


Fig. 11. Surface temperature reconstruction based on glacier length records determined by the physical relationship between change in glacier length and surface temperature (Oerlemans 2005).

The changes in glacier length reflected in Fig. 11 correspond to a relatively small amount of warming compared to projections for the future, and there is already another 1 °F of warming stored in the ocean, as explained above. Because billions of people around the world rely exclusively or primarily on mountain glaciers for their water supplies, the sensitivity of these glaciers to warming is of vital policy importance. Western Canada and the Western USA rely heavily on snow pack and glacier water. More critical is the sole reliance of a large population in South America that relies entirely on Andean glaciers for water (Bradley et al. 2006). Some of these glaciers are already gone, and others are perilously close to disintegrating. There is a similarly critical condition in Central Asia, where more than a billion people rely on glaciers for water. These regions are primarily economically underdeveloped and lack the financial resources to adapt to a dwindling water supply.

Mountain glaciers are relatively small and easy to melt compared to the enormous continental ice sheets covering Greenland in the north and Antarctica in the south. For this reason, glaciologists have been surprised in recent years to find these large ice sheets responding sensitively to global warming. The ice sheet covering the Greenland continent contains enough water to raise global sea level by more than 20 feet if completely melted. Until recent months, however, estimates of continental ice loss were biased low because they assumed that the rate of glacier flow was unchanging, and only accounted for mass loss through ice melt (Alley et al. 2005; Rignot and Kanagaratnam 2006). Glaciers are rivers of ice that flow slowly from the high-elevations of the continent to the low-lying coasts and into the sea. New satellite measurements indicate that the flow of Greenland's glaciers has accelerated dramatically over the past decade. Accounting for the combined effects of accelerating ice melt and flow rates, the most recent study of the Greenland ice mass estimated a net loss of ice twice as high as the previous IPCC estimate (Rignot and Kanagaratnam 2006).

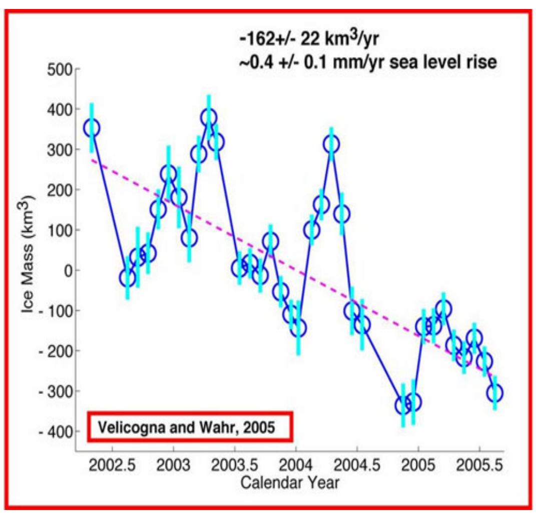


Fig. 12. Ice loss from the Antarctic ice sheet determined by gravity sensing satellites (Velicogna and Wahr 2006).

The largest ice sheet on earth covers Antarctica and stores enough water to raise global sea level by 230 feet. Although scientists do not think that anthropogenic climate change could cause a complete meltdown of Antarctica, a loss of just 10 percent of its ice would release more water than a total loss of the Greenland ice sheet. The Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton, Ding, Griggs et al. 2001) estimated that Antarctic ice was more or less in balance (no net ice gain or loss), but the report estimated that the Western Antarctic ice sheet (WAIS) was losing ice, while the larger Eastern Antarctic ice sheet (EAIS) was gaining ice at a rate that balanced the ice lost from the WAIS. The most recent results paint a different picture. New gravity-sensing satellites, the first instruments to cover the entire Antarctic continent, indicate that the entire ice sheet is now in negative balance as a result of large losses of ice from the WAIS and no net changes in the EAIS (Velicogna and Wahr 2006). According to these measurements, Antarctica lost about 450 km^3 of ice—roughly the volume of Lake Erie—between 2003 and 2005. Like Greenland, much of the ice loss from the WAIS results from ice flow into the sea, which had been neglected in previous estimates of mass balance (Alley, Clark, Huybrechts et al. 2005; Velicogna and Wahr 2006).

Global ice cover is an important indicator of climate sensitivity. Not only are small mountain glaciers responding, but enormous continental polar ice sheets are also responding. The fact that changes have surprised glaciologists represents a lack of appreciation for how sensitive the climate system is to a relatively small amount of warming. Scientists are currently struggling to reassess the true sensitivity of the climate to the enhanced greenhouse effect, as it appears to have been underestimated.

Conclusions

Together, the recent observations described above have dramatically strengthened the scientific consensus that global climate change is underway and that on a global scale it is caused mostly by man-made greenhouse gases accumulating in the atmosphere. Direct observations of climate change also confirm that the climate system is more sensitive than scientists have previously assumed, as illustrated by the fact that the most recent IPCC report, published in 2001, did not project that the large polar ice sheets would be experiencing net ice loss as a result of the relatively small amount of warming that has occurred so far. Other new evidence also suggests that the amount of greenhouse gases required to warm the earth by a certain amount is smaller than previously thought. These are two critical aspects of climate sensitivity that appear to have been underestimated.

It is now clear from direct observations of climate changes currently underway that the amount of climate change to which we are already committed will have significant impacts on the climate system. Continued emissions of greenhouse gases will add further to these impacts.

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