World to be even hotter by century's end

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If Earth's past cycles of warming and cooling are any indication, temperatures by the end of the century will be even hotter than current climate models predict, according to a report by University of California, Berkeley, researchers.

The scientists based their conclusion on a study of Antarctic ice cores containing a 360,000-year record of global temperature and levels of carbon dioxide and methane - two of the major greenhouse gases implicated in global warming. They found that during periods of warming, greenhouse gas levels rose and created significantly higher temperatures than would be expected solely from the increased intensity of sunlight that triggered these warm periods.

Though the ice core data do not point to specific processes that amplify the warming, the researchers suspect that it is due to warmer soils and oceans giving off more CO_2 and methane, which add to the greenhouse effect of CO_2 from fossil fuel burning and other human activities.

Thus, while current models predict temperature increases of 1.5 to 4.5 degrees Celsius (2.7 to 8.1 degrees Fahrenheit) from a doubling of atmospheric carbon dioxide levels, the natural processes injecting more CO_2 into the atmosphere will lead to temperature increases of 1.6 to 6 degrees Celsius (2.9 to 10.8 degrees Fahrenheit), with the higher temperatures more likely, the researchers said.

"We are underestimating the magnitude of warming because we are ignoring the extra carbon dioxide dumped into the atmosphere because of warming," said John Harte, UC Berkeley professor of energy and resources. "Warming gets an extra kick from CO_2 feedback."

"The warming caused by our release of CO_2 triggers changes in the Earth system that lead to release of more CO_2 to the atmosphere," added co-author Margaret Torn, a UC Berkeley adjunct associate professor of energy and resources and staff scientist at Lawrence Berkeley National Laboratory. "If that is the case, then every bit of CO_2 release now is actually committing us to a larger CO_2 change in the atmosphere."

The result, Harte and Torn conclude in their paper, is "that the upper value of warming that is projected for the end of the 21st century, 5.8ºC [10.4ºF], could be increased to 7.7ºC [13.9ºF], or nearly 2ºC additional warming."

The report is scheduled for publication in the May 26 issue of Geophysical Research Letters. That issue also will contain an article that looks at the same effect over a shorter time scale, confirming the amplification reported by Harte and Torn and suggesting that it may be even greater.

Current climate models, called General Circulation Models, start from fundamental physical processes to calculate a probable temperature increase based on likely atmospheric carbon dioxide levels, typically a doubling of today's CO_2 concentration. These models also include feedback mechanisms that boost or moderate warming, such as the increased heat absorption expected when highly reflective ice sheets and glaciers melt; or the effect of more atmospheric water vapor on the formation of clouds, which both reflect sunlight and insulate the Earth.

But models are only now beginning to take into account the extra carbon dioxide and methane injected into the atmosphere as global temperatures increase. Though this is expected because warmer soils decompose faster, releasing more CO_2, and because warmer oceans outgas more CO_2, scientists have yet to quantify the full impact of these processes.

"Without a mechanism, people feel uncomfortable putting these processes in a model. I think that's a big mistake," Harte said.

Luckily, it's possible to estimate the effect of CO_2 feedback by looking at how the Earth responded to past cycles of warming and cooling, which were caused by natural variations in the strength of sunlight hitting Earth, rather than by human production of greenhouse gases. Ice cores drilled in the Vostok ice sheet in 1998 and 1999 by Russia, France and the United States span nearly 420,000 years and carry information about four major climate cycles and many smaller temperature swings. In 1999, scientists measured CO_2 and methane levels from gas trapped in bubbles in the ice, and have estimated global temperature based on oxygen isotope and deuterium ratios. UC Berkeley's Kurt Cuffey, professor of geography and earth and planetary science, updated these measurements in 2001.

Climate scientists immediately saw that the ice core data imply a strong positive feedback to global CO_2 and methane levels, but how much this impacted warming trends was unclear.

Harte, a physicist by training, and Torn devised a way to use these data and current global climate models to estimate the effect of increased CO_2 entering the atmosphere as a result of warming, called the "gain," analogous to the gain of an electronic amplifier - the factor by which output power increases. From Cuffey's data, Harte and Torn were able to extract the effect of temperature on CO_2 and methane levels. They calculated the reverse - the effect of CO2 and methane levels on temperature, or the so-called climate sensitivity - from climate models, using a number consistent with a new estimate published in the April 20 issue of *Nature*.

Harte and Torn added the resultant gains from CO_2 and methane to the gain already known for other climate feedbacks, in particular the largest source, increased atmospheric water vapor, to get a total gain that they used to calculate the temperature increase that would result from a doubling of current CO_2 levels.

Both researchers emphasize that the large temperature range they predict - 1.6 to 6 degrees Celsius - does not mean that we have an equal chance of ending up with less warming as with greater warming. In other words, it doesn't mean that the uncertainties are symmetric about an average increase of 3.8ºC.

"People see this uncertainty and think that we have an equal probability of dodging a bullet as catching it. That is a fallacy," Torn said.

"By giving the appearance of symmetric feedback, people have an excuse to say, 'Maybe we don't have to worry so much,'" Harte said. "But while there are uncertainties in the feedbacks, all the major feedbacks are positive, meaning they would increase warming, and we know of no significant negative feedbacks that would slow warming."

While Harte acknowledges that the future may not look like past periods of global warming, "in the absence of contradictory evidence, we have to assume the future will respond like the past."

"Whatever the mechanisms that cause temperature to create a change in CO_2 and methane, they are repeatable again and again and again over many cooling and warming cycles. So, although the world is different today than it was then, we don't have a basis for ignoring them," Torn added.

Harte has been conducting studies on experimental plots in the Rocky Mountains that would quantify the effect of warmer temperatures on soil carbon. He and his colleagues found that artificially heated plots lost significant soil carbon to the atmosphere as CO_2, compared to control plots. Thus, he said, the effect of heating on the carbon cycle in his plots is to generate a positive feedback, though he noted that this might be a short-term effect. The long term effect, however, is unknown, as is the effect of warming in other habitats.

"We need to know the effect of warmer temperatures in all different habitats, not just temperate Rocky Mountain forests but also the tropics and European boreal forests and Eastern U.S. deciduous forests and savanna and prairie. There are huge data gaps," he said.

Torn noted, however, that humans are the biggest unknown.

"To predict the future, you have to guess how much CO_2 levels will go up. That depends on the biggest uncertainty of all - what humans decide to do. Do we get smart and prevent CO_2 emissions? Do we continue with business as usual? Or will we end up somewhere in between?"

Source: UC Berkeley, By Robert Sanders