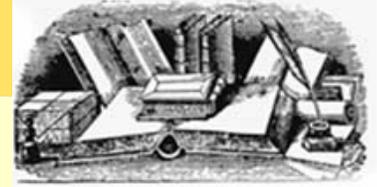


CLIMATE SCIENCE FORUM



Winter 2009



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Large Part of Climate Change Deemed “Irreversible”

Temperatures remain elevated & stable even after carbon dioxide emissions cease

Some people assume that climate will revert to a less harmful state once humans stop putting greenhouse gases into the atmosphere, and that this can happen in our lifetimes or those of our children. Nothing could be further from the truth, says **Susan Solomon**, who [published a paper](#) this month on “Irreversible Climate Change due to Carbon Dioxide Emissions” (see [note 1](#)). Solomon is the coordinating lead author of “[Climate Change 2007: the Physical Science Basis](#)” (2) of the Intergovernmental Panel on Climate Change (IPCC), and discoverer of the ozone hole over Antarctica.

When carbon dioxide (CO₂) emissions stop, she explains, temperatures do not fall to earlier levels, but rather remain elevated and essentially the same for centuries. Solomon maintains that the climate change expected from CO₂ emissions in the first half of the 21st century is largely irreversible for 1000 years after emissions stop. In fact, sea level will continue to rise for many centuries after no more CO₂ is added to the atmosphere. The reason for this unhappy consequence is that the world’s oceans have tremendous mass, and the extra heat in a warming climate and the extra carbon dioxide take a very long time to be mixed into the deep ocean.

The figure at right, from her paper, conveys the point succinctly. If CO₂ emissions grow by 2% per year, as they have since 2000, the concentration of the gas climbs rapidly in the atmosphere. For the sake of argument, she assumes all emissions of CO₂ cease when a “target” concentration is reached (such as 550 parts per million [ppm]). The level is now at 385 ppm, and was at 280 ppm before the industrial era. They want to see how the atmosphere will recover from the buildup of CO₂ from human activities if the activities stop: a “test case.” They explore six different targets for atmospheric CO₂, getting six curves for the rise of CO₂ to a peak level, and a fall-off after emissions stop. Indeed, the level of CO₂ in the atmosphere starts to fall when emissions cease, quickly at first, then quite slowly (top graph). But the temperature of the Earth’s surface, having climbed to a peak at the same time (lower graph),

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Physical and Biological Landscapes Impacted by Warming in Diverse Ways

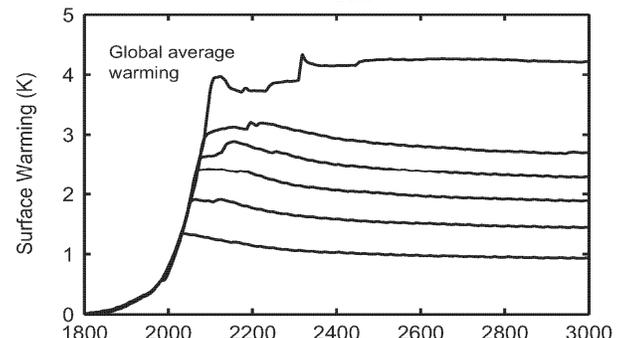
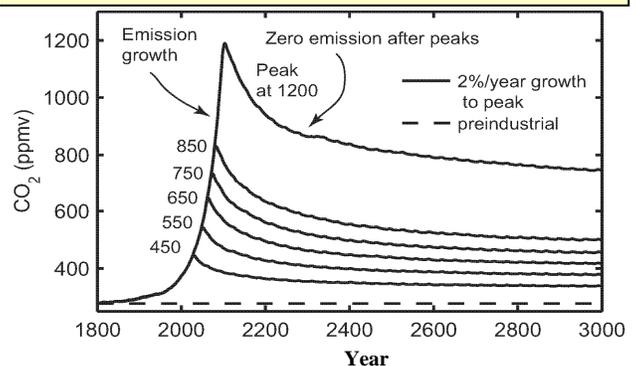
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Global Levels of Methane are Rising Once Again

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Climate Warming Impacted Physical Landscape, Plant & Animal Communities in Numerous, Diverse Ways

Fourteen scientists led by Cynthia Rosenzweig of the NASA Goddard Institute for Space Studies [documented \(note 1\)](#) a wide variety of physical and biological changes now underway on every continent except Antarctica, and found the changes are consistent with locally warming temperatures. The scientists also attribute the cause of most of the documented changes to human influence. Rosenzweig is author of a recent book on climate variations and agricultural harvests (*note 2*).

They examined some 80 papers in the scientific literature that reported changes over 20 years or more sometime from 1970 to 2004. Examples include earlier snow melt and associated flooding of rivers in spring, less snow pack in the Western states, melting of permafrost, shrinking glaciers, more wildfires, warming of lakes and rivers, and more erosion of coasts by storms. Biological changes were very diverse, from earlier blooming of flowers, unfolding of leaves, and migration of birds in spring, to an altered distribution of diatoms, krill, and many other species in the ocean, or a decline in productivity of marine ecosystems. Cold-adapted communities of plants and animals were replaced by warm-adapted ones, and interactions between species were altered.

The authors noted whether each change was “in the direction of” warming temperatures or not. They also compared the geographic patterns of these changes with the mapped pattern of temperature change. Then they counted the number of changes “consistent with warming” and the number not consistent with warming.

Most of the changes (90%) are consistent with warmer temperatures, and 95% of physical changes (such as the loss of glaciers or the timing of river flow) are consistent with warming.

Rosenzweig points to human influences on climate for the cause of most of the changes noted on Earth as a whole, because [the Intergovernmental Panel on Climate Change \(IPCC\) \(note 3\)](#) had already attributed the causes of the temperature change to human influence. For North America, Asia, and perhaps Europe, they also attributed the cause of most changes to regional warming, and to the influence of mankind on that warming.

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On other continents and in the tropics, observations of changes in biological and physical systems were too sparse for the group to confidently identify them as impacts of climate change.

Their conclusion: even now, warming has significantly impacted animal and plant communities and physical systems on at least three continents and on the Earth as a whole.

CITATIONS

1. “[Attributing physical and biological impacts to anthropogenic climate change](#)” by Cynthia Rosenzweig and 13 other authors, *Nature*, vol. 453, 353-357, May 15, 2008. [http://www.nature.com/nature/journal/v453/n7193/full/nature06937.html]
2. “Climate Variability and the Global Harvest” by Cynthia Rosenzweig and Daniel Hillel (2008). Oxford Univ. Press, London.
3. [Climate Change 2007: Impacts, Adaptation and Vulnerability.](#) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Editors, M.L. Parry and four others, Cambridge Univ. Press, Cambridge, UK, 2007. [http://www.ipcc.ch/ipccreports/ar4-wg2.htm]

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Global Methane Levels Rising Once Again

Suspect melting permafrost in tundra or under the sea floor

Global methane levels have remained flat for eight years since 1999 while levels of the more predominant carbon dioxide (CO₂) have increased 5%. Methane is generated both by nature and by human activities, just like CO₂, and its abundance has more than doubled since pre-industrial times, according to the World Meteorological Organization. So it is unwelcome news that the concentrations of methane are once again on the rise, at least since the start of 2007.

In [reporting observations from Australia \(footnote 1\)](#), Professors M. Rigby and R. Prinn explored what may be driving the increase, and consider it likely that the source is in the Northern Hemisphere. Two distinct sources in the Arctic, one on land and the other under the sea, may be responsible for the new emissions of this greenhouse gas, and both are related to Arctic warming.

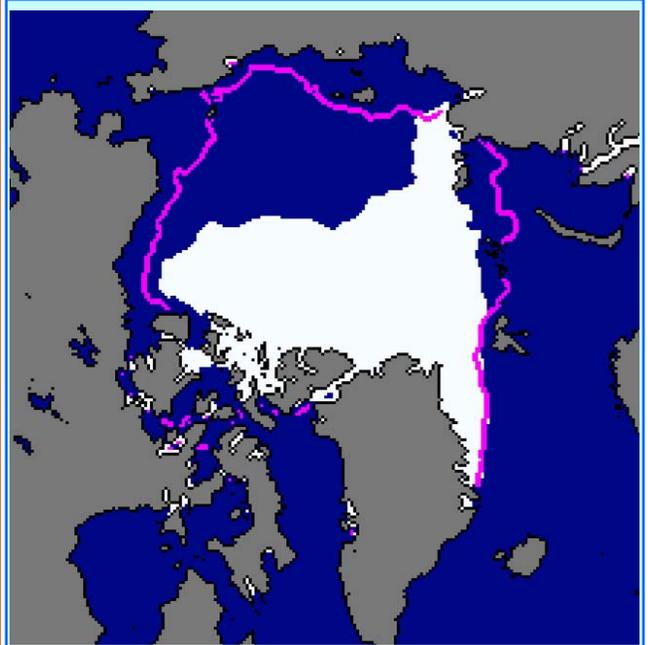
It is known that wetlands release more methane to the atmosphere than any other source of the gas. Mikhail Mastepanov and colleagues were monitoring the emission of methane and CO₂ from tundra soils in far northern Greenland.

Usually they go home in early September, but funding in the International Polar Year of 2007-08 allowed them to stay many weeks longer. Their prolonged stay led to a discovery that in permafrost soils on land, wet tundra may be releasing a burst of methane when it freezes in the late autumn. Mastepanov and colleagues [report \(2\)](#) that tundra soil released as much methane when it was freezing as it did during the entire growing season.

Large expanses of the continental shelf underneath the shallow margins of the Arctic Ocean just north of Siberia contain permafrost in the sediments. These sediments were once above sea level, during the glacial climate of the Ice Ages when sea level was lower. Like most freshwater wetlands, the ancient tundra also generated methane, some of which became trapped in the permafrost as the soil froze. As the sea rose, it covered the former wetlands, but the permafrost remained frozen as long as the mean annual temperature of the sediments in the shallow Arctic seas remained below 0°C. (The sea water overlying the sediments can remain unfrozen at temperatures below 0°C because the salt content of the water lowers the freezing point.)

Russian investigator Igor Semiletov reported that some of these shallow Siberian seas have extremely high concentrations of methane. He speculated that undersea sediments were warmed during the recent ice-free summers to the point that long-trapped methane was released into the water. He added that 80% of the sub-sea permafrost now was between -1°C and 0°C and susceptible to releasing methane. He reported the news at the meeting of the American Geophysical Union (AGU) last December.

(continues at the right >>→)



The Arctic coast of Siberia (*top edge of map*) is unfrozen in most years by September. Above, the average edge of sea ice on the Arctic Ocean in September is marked by the purple line. The white area shows the actual extent of sea ice in September 2007 when the ice area reached an all-time low.

(Map from National Snow and Ice Data Center, Boulder, Colorado, 2007)

Both mechanisms, if confirmed, can lead to a positive feedback cycle, in which newly released methane drives further warming in the Arctic through the greenhouse effect, which then leads to more thawing of permafrost or sub-sea sediments that contain “prehistoric” methane. The Russian scientists exhibited concern, saying they saw the first signs of methane release from the sea floor, and that sub-sea sediments are “the most fragile part of the cryosphere.”

CITATIONS

1. “[Renewed growth of atmospheric methane](#)” by M. Rigby and R. G. Prinn et al, *Geophysical Research Letters*, Vol. 35, L22805, doi:10.1029/2008GL036037, 2008.
2. “[Large Tundra methane burst during onset of freezing](#)” by Mikhail Mastepanov et al, *Nature*, vol. 456, 628-630, 4 December 2008.

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(Irreversible Climate Changes—Continued from [page 1](#))

remains essentially near the peak temperature, falling much less than one degree C for hundreds of years after emissions stop.

Using their knowledge of atmospheric chemistry, they calculated whether and [how fast the level of CO₂ would drop](#) as the ocean absorbs the gas from the air, and how fast temperatures would fall as a result.

Sea level would rise at least 0.4 to 1 meter if CO₂ concentrations are allowed to reach a fairly modest level of 600 ppm in this century. The seas could rise twice as much if the melting of ice sheets on land is considered.

Solomon and co-authors write, “It is sometimes imagined that slow processes such as climate changes pose small risks, on . . . the assumption that a choice can be made to quickly reduce emissions and thereby reverse any harm within a few years or decades. This . . . is incorrect for carbon dioxide emissions, because of the longevity of atmospheric CO₂. . . and ocean warming.”

How is this possible? First, CO₂ levels will **not fall** to pre-industrial levels. Because of the chemistry and the slow rate of mixing in the ocean, the levels fall and then plateau; in the long term the increase of CO₂ in the atmosphere above the pre-industrial level will stabilize at about 40% of the peak increase that will have occurred when emissions stop. This is shown in the top panel of the [Figure on page 1](#). The CO₂ level in the atmosphere never falls to pre-industrial values, and it *never even falls to today’s level*.

Then, why do temperatures not fall in the atmosphere while CO₂ concentrations are falling, after the magic day when emissions stop? As the ocean warms (at first) then cools, there is a lot of inertia. The Ocean is still warming while the atmosphere is cooling, so the rate that heat flows from the air to water drops off. As the atmosphere passes less and less heat to the ocean, CO₂ is still warming the atmosphere, but this warming by CO₂ decreases as the amount of the gas falls. The two effects are almost in balance, and the atmosphere remains warm, within ½°C of the peak temperature that was reached.

What does this portend for patterns of rainfall or drought? A “robust characteristic” of climate change in atmospheric models is an expansion of the so-called “Hadley cell,” the predominant circulation in the tropics and subtropics. That implies that the belt of dry climates now running through the latitude of Mexico and the Sahara will shift north, which means the American Southwest and the Mediterranean basin can expect drier conditions. More frequent drought has already been documented in these regions. Solomon presents a map indicating many regions (North Africa, southern Europe, west Australia) can expect 10% less rainfall in the dry season *per degree of warming* – and many expect 2°C of warming by the year 2050. She reminds us, “The American dust bowl was associated with

an average rainfall decrease of 10% over 10 to 20 years.”

Rising sea level is an irrevocable result of carbon dioxide emitted in the past, even if the emissions are totally stopped, according to the paper. The next figure, illustrates a calculation of the lower limit to possible sea level rise, depending on the peak “target” CO₂ concentration. This shows the “lower limit” of sea level rise because melting of ice is not considered here. A one meter rise in sea level is a possible consequence of a target CO₂ level of 550 ppm (we are now at 385 ppm); a rise of 2 meters is possible from a target of 1000 ppm.

Solomon concludes that changes in the geography of the Earth’s coastlines are irreversible as many coasts and islands will be submerged. The take-home message: if CO₂ emissions are stopped today, further warming and sea level rise are inevitable and irreversible. The CO₂ has already been released.

CITATIONS

1. “[Irreversible climate change due to carbon dioxide emissions](#)” by Susan Solomon, G.K. Plattner, R. Knutti, and P. Friedlingstein (2009). *Proceedings of the Nat. Academy of Sciences*, vol. 186, no. 6, 1704-1709, February 10, 2009. [<http://www.pnas.org/cgi/doi/10.1073/pnas.0812721106>]
2. “[Climate Change 2007: the Physical Science Basis](#),” Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Edited by S. Solomon *et al* (2007). Cambridge Univ. Press, Cambridge, UK, and New York, NY. [<http://www.ipcc.ch/ipccreports/ar4-wg1.htm>]

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[RELATED STORY: How warming has impacted ecological communities and the physical landscape on six continents - Full story](#)

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