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Climate
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Discussions

Interactive comment on “The importance of Northern Peatlands in global carbon systems during the Holocene” *by* Y. Wang et al.

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The origin of the ~20-ppm or larger rise in atmospheric CO_2 during the last 7000 years has remained elusive. A shift of that size, about one quarter of the typical glacial-interglacial range, indicates that an enormous amount of carbon (at least ~42 billion tons) was added to the atmosphere, but that far more (several hundred billion tons) was moving among the rapidly exchanging reservoirs in the atmosphere, surface ocean, and continents. Yet Earth's climate was not changing in any major way during this interval, so why was such an enormous amount of carbon on the move? The last scattered remnants of the North American sheet melted by 6000 years ago, and no major volumes of ice have grown or melted since then. Global temperature is thought to have changed by less than 1^{o}C during this interval. This paper by Wang and colleagues helps to move the discussion of this elusive issue a step forward by narrowing the range of possible explanations.

Despite the absence of obvious large-scale changes in natural forcing, many attempted explanations have sought natural origins for this CO_2 increase. As Wang and colleagues summarize, interactive carbon-climate models have investigated various combinations of: natural losses of vegetation from the continents, a warming of the ocean (which would lower CO_2 solubility in sea water), and a build-up of coral reefs (Ridgwell et al, 2003).

Joos et al (2004) added a useful insight to this issue by applying a mass-balance analysis of late-Holocene changes based on changes in atmospheric CO_2 values and the carbon-isotopic composition of atmospheric CO_2 ($\delta^{13}CO_2$). They concluded that most of the carbon added to the atmosphere during the last 8000 years must have come from oceanic carbon carrying an isotopic value far less negative than that from the continents. Joos and colleagues favored the ocean-chemistry hypothesis of Broecker et al. (2001), who proposed that this massive late-Holocene transfer was the result of a delayed adjustment in ocean chemistry to imbalances imposed during the immediately preceding millennia. Prior to 8000 years ago, forests were reoccupying land left open behind melting ice sheets. Broecker's hypothesis suggested that the carbon sequestered in those growing forests would have extracted CO_2 carbon from the atmosphere and ocean and thrown the carbonate chemistry of the ocean out of balance, which was then gradually restored through the pre-industrial interval.

Until now, no carbon/climate model has allowed for the enormous amounts of carbon that were buried in boreal peat lands during the middle and late Holocene. Wang and colleagues use a wide range of field data to estimate that total carbon burial in northern peat lands over the last 8000 years was in the range 160-280 billion tons (160-280 pgC). Their well-reasoned analysis notes that this estimate is subject to caveats tied to still-uncertain assumptions about the precise quantitative link between the spread of northern peat lands and the amount of carbon buried in each regions.

Their analysis throws new light on the possible source of the $\sim$42 (or 280) billion tons of carbon needed to account for the $\sim$20-ppm CO_2 increase. Results from their model agree with previous simulations (and abundant ground-truth evidence), that regions like the Sahel that were becoming drier during the middle/late Holocene would have released carbon to the atmosphere over the last 8000 years. Despite this trend, the huge amount of carbon that was buried in northern peat lands during the same interval makes it very unlikely that the continents would have been a net natural carbon source.

The analysis from the "Green" McGill model by Wang and colleagues further suggests that the $\sim$20-ppm increase in CO_2 would have warmed climate by just 0.2^{o}C, with a small resulting effect on carbon emissions from the ocean due to reduced CO_2 solubility. Like Joos et al. (2004), Wang and colleagues use process-of-elimination reasoning to conclude that the deep ocean is left as the only possible major natural source of carbon that can explain the CO_2 rise since 7000 years ago. By process of elimination, their reasoning leads to the chemical-imbalance mechanism proposed by Broecker et al. (2001).

But this line of reasoning does not fully resolve the issue. Wang et al. note that their approach does not directly evaluate the possibility posed by Ruddiman (2003) that the CO_2 increase could have been anthropogenic. They point to the recent conclusion from Ruddiman (2007) that direct anthropogenic emissions can probably account for only $\sim$9-10 ppm of the CO_2 increase, but they neglect to mention key evidence cited in that paper that suggests that the large amount of carbon that came from the ocean could have been an anthreopogenic response.

One such line of evidence is the multi-core benthic marine δ^{18}O stack of Lisiecki and Raymo (2005), which shows a drift toward lighter (warmer) values during the last 7000 years. In contrast, the comparable portions of previous interglaciations all trend toward heavier (cooler) values. The fact that the warming Holocene trend is anomalous compared to the earlier cooling trends is suggestive of an anthropogenic origin. The δ^{18}O decrease of $\sim$0.2$^o/_{oo}$would equate to a deep-ocean warming of $\sim$0.84^{o}C which would

reduce whole-ocean CO_2 solubility and drive atmospheric CO_2 values higher.

A recent simulation with a version of the CCSM3 model that included a dynamical ocean provides a similar but slightly smaller ($\sim$0.5^{o}C) estimate of the anomalous warmth for the Holocene ocean caused by early anthropogenic forcing (Kutzbach et al., in revision). Observations and modeling thus both support the argument that at least 5-6 ppm of the 20-ppm Holocene CO_2 rise resulted from an unusual warming of the ocean caused by anthropogenic forcing. This 5-6 ppm contribution adds to the 9-10 ppm from direct anthropogenic emissions caused mainly by deforestation.

Ruddiman (2007) also pointed to evidence of a possible role for the Southern Ocean, which many climate scientists view as a major 'player' in glacial-interglacial CO_2 changes. Deuterium data from Dome C (Jouzel et al., 2007) show a Holocene trend that drifted toward slightly more positive (warmer) values after 7000 years ago, before eventually ending up at values close to those 7000 years ago. These δD trends contrast with persistent downward trends toward more negative (colder) values early in previous interglaciations. This contrast suggests that anthropogenic greenhouse-gas emissions during the Holocene kept the Antarctic region anomalously warm, thereby potentially adding more CO_2 feedback from the Southern Ocean to the atmosphere.

In summary, both observations and modeling studies provide evidence that the deep ocean and the Southern Ocean could have added a considerable amount of indirect (feedback) amplification to the direct anthropogenic CO_2 signal of 9-10 ppm. They did so as the ocean became warmer (or remained anomalously warm) compared to previous cooling trends.

At this point, the evidence seems clear that the ocean was the source of much of the carbon needed to explain the CO_2 rise since 7000 years ago. The ocean-chemistry hypothesis of Broecker et al. (2001) calls on a (natural) delay in the adjustment of ocean chemistry as the mechanism, but no such increase has been found during similar intervals during previous interglaciations (Ruddiman, 2007). In contrast, the early-anthropogenic hypothesis calls on a unique intervention by agricultural humans in the operation of climate system, with the oceans playing a major feedback role.

I add two minor comments/suggestions:

—Dating of the Taylor Dome record is uncertain because it was not aligned to well-dated layers of volcanogenic origin. The high-resolution CO_2 record at Dome C published in Luthi et al. (2008) has been updated to the recent EDC3 time scale of Parennin et al. (2007) and would seem to be a better choice.

—Wang and colleagues note that the radiative effect of methane released from northern peatlands during the Holocene was small, but the radiative effect of the global methane changes measured in ice cores was not trivial. The pre-industrial CH_4 increase after the $\sim$560-ppb minimum value reached 5000 years ago was $\sim$160 ppb, equivalent in radiative terms to a $\sim$7-8 ppm increase in CO_2. The additional indirect effects of methane on stratospheric H_2O and tropospheric ozone could have enhanced this direct effect by 30-40% to an equivalent radiative effect of $\sim$10-11 ppm, or half that from the CO_2 increase.

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