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Interactive comment on “Ice-driven CO_2 feedback on ice volume” *by* W. F. Ruddiman

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Remark: I submit this comment on behalf of myself and Hubertus Fischer (hufischer@awi-bremerhaven.de), both Alfred Wegener Institute for Polar and Marine Research Bremerhaven, Germany.

This article is an interesting contribution towards the “chicken-egg” discussion, what was first on glacial/interglacial timescales: the rise in atmospheric CO_2 or in temperature respectively land ice sheets. The author divides the component of the CO_2 variations into three different frequency bands known to be important from variation in orbital forcing. According to the author CO_2 is driven by ice sheet growth in two of the frequency bands ((41 kyr)$^{-1}$, (100 kyr)$^{-1}$), while it is leading ice sheet growth in the third band ((23 kyr)$^{-1}$). The author recognizes in his manuscript the limitations of traditional spectral analysis in resolving leads and lags in data which obviously is not just a sum of sine functions but a nonlinear response to an external forcing. It is worth noting that for the most dramatic change in ice volume and CO_2, i.e. during glacial/interglacial transitions, where phasing can be unabiguously determined, CO_2 significantly leads ice volume. In addition to methodological limitations of a spectral analysis approach any statistical (lagged) correlation of ice volume and CO_2 changes does not necessarily imply causality. Accordingly, any hypothesis of ice sheet forcing of CO_2 and vice versa has to be tested against results from climate and carbon cycle models. Accordingly, here we will not comment on any methodological aspects but want to comment on Ruddiman's hypothesis in the light of our model results on changes in the global carbon cycle over the last 740 000 years and to add some points to the question what kind of processes might have caused the observed variations in CO_2 and their ability to be controlled by ice sheet growth.

Recently, we tried for the first time to reconstruct the observed transient variations in atmospheric CO_2 during Termination I by using a box model of the global carbon cycle in a forward simulation mode [Köhler et al. (2005)]. The model was forced by various proxy records derived from ice and marine sediment cores and was also applied for the longer time interval of the last 740 000 years [Köhler and Fischer (2006)]. The analysis performed in these two studies identified the contribution of various processes to the variations in CO_2, which were partly mentioned by Ruddiman. Changes in ocean circulation and $CaCO_3$ fluxes between deep ocean and sediments were identified as main contributors in our model, followed by iron fertilised changes in marine export production and variations in ocean temperature. While the size in carbon storage in the terrestrial biosphere and the direct effects of sea level change were increasing the observed glacial/interglacial amplitudes in CO_2, the contribution of an increased glacial sea ice cover and thus reduced gas exchange rate on CO_2 were uncertain due to the resolution of the used model.

In the sequence of events hypothesised for Termination I [Köhler et al. (2005)] a reduced marine export production caused by less iron input together with a breakdown of

Southern Ocean stratification start the rise in CO_2. Especially the observed reduction in aeolion dust and iron input in the Antarctic region [EPICA community members (2004)] happens prior to 17 kyr BP, at times when sea level rose by less than 10 m [Fairbanks (1990)]. The assumption on Southern Ocean stratification was based on δ^{13}C data measured on benthic forminifera in marine sediments [Hodell et al. (2003)] and on δ^{13}C of CO_2 found in ice cores [Smith et al. (1999)]. This makes the ice sheet driven control of CO_2 by these two processes unlikely.

The ocean temperature in the Antarctic region seemed to be in phase with atmospheric CO_2 over the last 650 kyr [Petit et al. (1999)], [Siegenthaler et al. (2005)]. It certainly takes as long as the turn-over time of the ocean until the deep ocean temperature changes, and thus deep ocean temperature and ice sheet growth may have happened in phase [Bintanja et al. (2005)]. However, for atmospheric CO_2 the PCO_2 in the surface ocean is of main interest. There might be a component of deep ocean temperature on the carbon cycle through its impact on the $CaCO_3$ chemistry and its dissolution rates, which may be in phase with the ice sheet growth. But even the origin of this process would be the temperature fluctuations in the atmosphere which propagated through the water column and which was triggered prior to the ice sheet variability.

The effect of gas exchange caused by sea ice variations in the North will lead to opposing effects than in the South, because the North Atlantic is a sink to CO_2 while the Southern Ocean is is source. This implies that an increased glacial sea ice cover in the North would increase glacial CO_2 and thus the amplitude which has to be explained by other processes. In the Southern Ocean the timing of a sea ice retreat during terminations is still a matter of debate [Röthlisberger et al. (2002)], [Shemesh et al. (2002)]. But as stated already by Ruddiman it seems difficult to find a convincing link between the sea ice variability in the South and northern hemisphere ice sheet growth.

Changes in the Atlantic ocean circulation might be caused by varying freshwater inputs in the surface ocean of the North Atlantic and thus be of controlled by the ice sheet growth.

Terrestrial carbon storage depends on various conditions: CO_2 itself, climate, and the land area available for vegetation. CO_2 fertilisation has a negative feedback mechanism on atmospheric CO_2: A rise in CO_2 will foster terrestrial photosynthesis and thus reduce the CO_2 increase. However, as the turnover time of the terrestrial pools is of the order of years to centuries this feedback will only delay the atmospheric CO_2 dynamics. The available land area is directly determined by the ice sheets and the sea level. The opposing effects of increased availability through retreating land ice sheets and sea level rise have to be considered here. According to a modelling study using a dynamic global vegetation model the increased carbon storage in the area gained by ice retreat was more than twice as much as the carbon lost due to sea level rise [Joos et al. (2004)]. However, this net effect driven directly by the ice sheet dynamics was only about half of the glacial/interglacial rise in the terrestrial carbon and will actually reduce the increase in atmospheric CO_2.

The most direct effect of a waxing and waning of the land ice sheets is the change in sea level. As a result the ocean volume is changed. In a larger ocean volume dissolved species such as dissolved inorganic carbon are diluted. Furthermore, the input of freshwater from the land ice sheets in the ocean is reducing ocean salinity by about 3% during Termination I. Taken together these direct effects of changes in ice sheets / sea level on CO_2 lead to a glacial rise in CO_2 by about 15 ppmv, the opposite direction of the observation found in the ice core records.

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The last of the mentioned processes, the $CaCO_3$ chemistry, is a response process to changes in the deep ocean CO_3^{2-} concentration called carbonate compensation [Broecker and Peng (1987)]. This process will react on all global changes in the carbon cycle, but especially on the input of terrestrial carbon in the ocean reservoirs. As argued previously half of the glacial/interglacial amplitude in terrestrial carbon storage can be accounted for as driven by ice sheets. The amplification of this ice sheet driven terrestrial change by the deep ocean/sediment interaction might again be accounted for as caused by the ice sheet change. However, as mentioned already for the ocean temperature changes it might take as long as the turn-over time of the ocean (~ 1000 years) until the signals from the atmosphere reach the deep ocean and a couple thousand years until a new equilibrium is reached [Joos et al. (2004)]. Therefore, non ice sheet driven changes in terrestrial carbon storage (driven by climate and CO_2) might be amplified by the $CaCO_3$ chemistry at times when the ice sheets themselves change and thus might suggest an in-phase or cause-and-effect relationship, which does not exist.

All-together we see little evidence that ice sheets controlled large parts of the observed glacial/interglacial rise in atmospheric CO_2. The processes which from our point of view might be driven by ice sheet variations sum up to a neutral contribution and thus to no change in atmospheric CO_2 during Termination I (ocean circulation in the Atlantic: $+15$ ppmv; northern sea ice: -12 ppmv; half of the terrestrial carbon storage: -20 ppmv; sea level: -15 ppmv; $CaCO_3$ chemistry: $+20-30$ ppmv) [Köhler and Fischer (2006)]. Unless there are no strong other arguments which might support the postulated link between land ice sheets and atmospheric CO_2 the hypothesis of Ruddiman sits on shaky ground.

References

[Bintanja et al. (2005)] Modelled atmospheric temperatures and global sea levels over the past million years, Nature, 437, 125–128; doi: 10.1038/nature03975.

[Broecker and Peng (1987)] The role of $CaCO_3$ compensation in the glacial to interglacial atmospheric CO_2 change, Global Biogeochemical Cycles, 1, 15–29.

[EPICA community members (2004)] Eight glacial cycles from an Antarctic ice core, Nature, 429, 623–628.

[Fairbanks (1990)] The age and origin of the Younger Dryas climate event in Greenland ice cores, Paleoceanography, 5, 937–948.

[Hodell et al. (2003)] Pleistocene vertical carbon isotope and carbonate gradients in the South Atlantic sector of the Southern Ocean, Geochemistry, Geophysics, Geosystems, 4, 1004, doi: 10.1029/2002GC000367.

[Joos et al. (2004)] Transient simulations of Holocenic atmospheric carbon dioxide and terrestrial carbon since the Last Glacial Maximum, Global Biogeochemical Cycles, 18, GB2002, doi: 10.1029/2003GB002156.

[Köhler and Fischer (2006)] Proposing a mechanistic understanding of changes in atmospheric CO_2 during the last 740 000 years, Climate of the Past Discussions, 2, 1–42, SRef–ID: 1814–9359/cpd/2006–2–1.

[Köhler et al. (2005)] Quantitative interpretation of atmospheric carbon records over the last glacial termination, Global Biogeochemical Cycles, 19, GB4020, doi: 10.1029/2004GB002345.

[Petit et al. (1999)] Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, Nature, 399, 429–436.

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[Röthlisberger et al. (2002)] Dust and sea salt variability in central East Antarctica (Dome C) over the last 45 kyrs and its implications for southern high-latitude climate, Geophysical Research Letters, 29, 1963, 10.1029/GL015186.

[Shemesh et al. (2002)] Sequence of events during the last deglaciation in Southern Ocean sediments and Antarctic ice cores, Paleoceanography, 17, 1056, doi: 10.1029/2000PA000599.

[Siegenthaler et al. (2005)] Stable carbon cycle-climate relationship during the late Pleistocene, Science, 310, 1313–1317; doi: 10.1126/science.1120130.

[Smith et al. (1999)] Dual modes of the carbon cycle since the Last Glacial Maximum, Nature, 400, 248–250.

Interactive comment on Climate of the Past Discussions, 2, 43, 2006.