The Importance of Northern Peatlands in Global Carbon Systems During the Holocene

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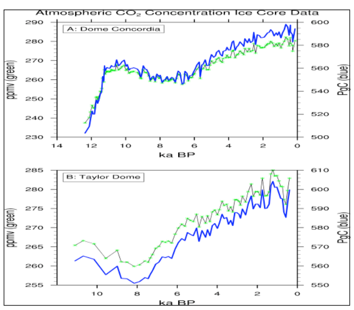
Abstract. We applied an inverse model to simulate global carbon (C) cycle dynamics during the Holocene using atmospheric carbon dioxide (CO_2) concentrations reconstructed from Antarctic ice cores and prescribed C accumulation rates of Northern Peatland (**NP**) as inputs. Previous studies indicated that different sources could contribute to the 20 parts per million by volume (ppmv) atmospheric CO_2 increase over the past 8000 years. These sources of C include terrestrial release of 40-200 petagram C (PgC, 1 petagram = 10^{15} gram), deep oceanic adjustment to a 500 PgC terrestrial biomass buildup early in this interglacial period, and anthropogenic land-use and land-cover changes of unknown magnitudes. Our study shows that the prescribed peatland C accumulation significantly modifies our previous understanding of Holocene C cycle dynamics. If the buildup of the NP is considered, the terrestrial pool becomes the **"sole"** C sink of about 180-300 PgC over the past 8000 years, and the only C source for the terrestrial and atmospheric C increases is presumably from the deep ocean due to calcium carbonate compensation. Future studies need to be conducted to constrain the basal ages and growth rates of the NP in the Holocene. Overall our results also suggest that the huge reservoir of deep ocean C explains the major variability of the glacial-interglacial C cycle dynamics without considering the anthropogenic C perturbation.

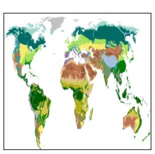
Motivation

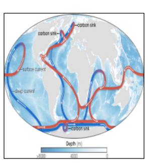


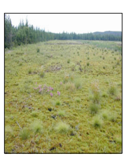
Atmospheric CO_2 concentrations from Antarctic Ice Cores (Indermühle et al., 1999; Luthi et al., 2008).

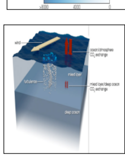
A few hypotheses were proposed to explain the 20-ppmv atmospheric CO_2 increase from 8000 years before present (8 ka BP): 1) a terrestrial C release of 40-200 PgC, 2) a deep oceanic adjustment to the 500-PgC terrestrial biomass buildup early in this interglacial, 3) a buildup of coral reefs, and 4) anthropogenic land-use and land-cover changes of unknown magnitudes with potential strong feedbacks from the ocean.

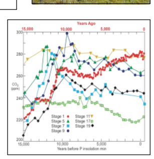
Previous modeling studies all neglected the slow, but persistent development of the NP, which is initiated from 12-13 ka BP with a present-day store of about 250-450 PgC.



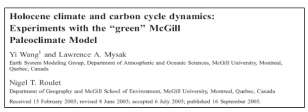








Model Description, Experiment Design, Methodology, and Results



Holocene climate and carbon cycle dynamics: Experiments with the "green" McGill Paleoclimate Model

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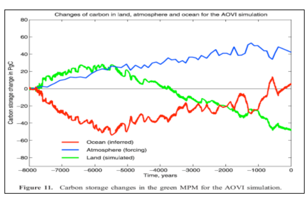
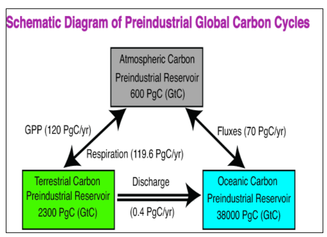


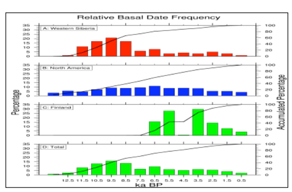
Figure 11. Carbon storage changes in the green MPM for the AOVI simulation.

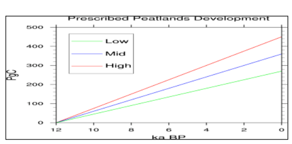
The "Green" McGill Paleoclimate Model (MPM) is a 6-component (atmosphere-ocean-sea ice-land surface-ice sheet-vegetation) Earth system Model of Intermediate Complexity (EMIC, Claussen et al., 2002).

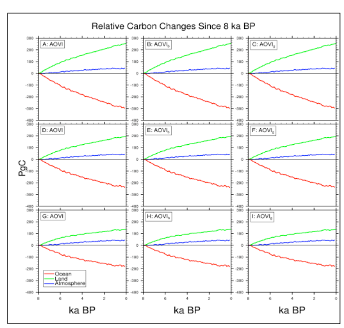
The atmosphere module is a sectorially averaged energy-moisture balance model. The 2.5-D ocean module is based on Wright and Stocker (1991). The MPM was developed to include the biogeophysical feedbacks (Wang et al., 2005a, b,c). The MPM was used in studies of Holocene climate changes and C cycle dynamics with a retreating Laurentide Ice Sheet (LIS), the last glacial inception (Z. Wang et al., 2005; Mysak, 2008), glacial abrupt climate changes and Dansgarrd-Oeschger Oscillation (Wang and Mysak, 2006), and the next glacial inception (Mysak, 2008).



An inverse method is used to derive the relative C changes in the ocean in order to conserve the global C. If both atmospheric and land (including NP) C increase during the Holocene, we can infer that the only source of this atmospheric C increase must come from the ocean. However, if atmospheric C increases, while the land C decreases during the Holocene, we cannot uniquely determine the source of the atmospheric C increase. We designed three types of runs, in two of which we considered the compensation of the NP buildup on the net primary productivity of our vegetation module proportionally based on the land area in the model (boreal or global).







Summary and Future Work

Previous studies showed that terrestrial C could be a sink (8-6 ka BP) and source (6-0 ka BP) during the Holocene. Because of the slow, but persistent NP development, the terrestrial C become the sole sink since about 12 ka BP. Without considering the anthropogenic land use and land cover changes (Ruddiman, 2007), we conclude that the deep ocean is the "sole" C source for the atmospheric CO_2 increase of about 20 ppmv.

There are a few uncertainties in our study. First, our prescribed NP development is highly idealized, and is based on the present-day estimates of total peat C. Some large portions of the NP are still not well constrained by basal dates. Second, the C accumulation rates may be varying with climatic and biogeographic conditions (Yu et al., 2003), although Gorham et al (2003) indicated a relative constant C accumulation rate. Third, we neglect the radiative forcing of methane emitted from the NP, which was estimated at roughly 0.05-0.1 W/m² through the Holocene (Frolking and Roulet, 2007). Finally, we also neglect the fresh water forcing from the melting of the LIS. We believe that the freshwater has limited impacts on the ocean circulation and terrestrial C cycle dynamics after the 8.2 ka BP "cold" event (Wang and Mysak, 2005).

Although we rely on the clear, robust ice-core-reconstructed atmospheric CO_2, we believe that the $\delta^{13}C$ signal derived from ice core during the Holocene is not well constrained (Broecker et al., 2001).

We do not include the anthropogenic land-use and/or land cove changes during the Holocene. We believe that the magnitude of these unknown changes and their biogeophysical and biogeochemical consequences are not well-constrained.

A marine C cycle module in the MPM is under intensive development and testing. With this module, we will further illustrate whether the biological (biological pump), geochemical (solubility pump), or geological ($CaCO_3$ compensation) pathway has contributed to the 20 ppmv atmospheric CO_2 increase in the Holocene.

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