SIMULATED CHANGES IN VEGETATION DISTRIBUTION, LAND CARBON STORAGE, AND ATMOSPHERIC CO_2 IN RESPONSE TO A COLLAPSE OF THE NORTH ATLANTIC THERMOHALINE CIRCULATION

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ABSTRACT

It is investigated how abrupt changes in the North Atlantic (NA) thermohaline circulation (THC) affect the terrestrial carbon cycle. The Lund-Potsdam-Jena Dynamic Global Vegetation Model is forced with climate perturbations from freshwater experiments with the ECBILT-CLIO ocean-atmosphere model. A reorganization of the marine carbon cycle is not addressed. Modeled NA THC collapsed and recovered after about a millennium in response to prescribed freshwater forcing. The initial cooling of several Kelvin over Eurasia causes a reduction of extant boreal and temperate forests and a decrease in carbon storage in high northern latitudes, whereas improved growing conditions and slower soil decomposition rates lead to enhanced storage in mid-latitudes. The magnitude and evolution of global terrestrial carbon storage in response to abrupt THC changes depends sensitively on the initial climate conditions. These were varied using results from time slice simulations with the Hadley climate model for different periods over the past 21,000 years. Terrestrial storage varies between -67 and +50 PgC for the range of experiments with different initial conditions. Simulated peak-to-peak differences in atmospheric CO_2 and $\delta^{13}C$ are 6 and 18 ppmv for glacial and early Holocene conditions. Simulated changes in $\delta^{13}C$ are between 0.18 and 0.30 permil. The small CO_2 changes modelled for glacial conditions are compatible with available evidence from marine studies and the ice core CO_2 record. The latter shows CO_2 variations of up to 20 ppmv broadly in parallel with the Antarctic warm events A1 to A4.

INTRODUCTION

The paleo record holds important information on the impact of abrupt changes in climate on the carbon cycle. Measurements on air in glacial ice show that atmospheric CO_2 varied by 20 ppmv within several millennia with large iceberg discharges into the NA during Heinrich events 4 to 6. The iceberg discharges have been linked to changes in the NA THC. Here, It is investigated how abrupt changes in the NA THC affect the terrestrial carbon cycle and vegetation cover, complementing earlier studies on changes in the marine C-cycle.

MODEL DESCRIPTION

A version of the Bern Carbon Cycle-Climate Model was applied off-line by forcing it with prescribed temperature, precipitation and cloud cover fields. These fields were derived by combining an observation-based climatology, anomalies from freshwater experiments with the ECBILT-CLIO model, and anomalies from time slice simulations with the Hadley Centre model HadSM3 for different periods during the past 21 kyr. The Bern CC model includes the Lund-Potsdam-Jena Dynamic Global Vegetation Model (LPJ).

RESULTS

The NH cooling after a THC collapse leads to a southward movement of the treeline and a reduction in the extent of boreal and temperate forests, compatible with pollen records. Changes in global terrestrial carbon storage and implied changes in atmospheric CO_2 and $\delta^{13}C$ are small. CO_2 fertilisation operating in LPJ and exchange with the ocean dampen the impact on atmospheric CO_2 of terrestrial carbon release and uptake. The modelled terrestrial response to a THC collapse depends sensitively on initial climatic condition and the associated spatial distribution of vegetation and carbon on land. For glacial conditions, modelled atmospheric CO_2 varies only by 6 ppmv due to terrestrial changes in response to the THC collapse compared to a 12 ppmv peak-to-peak variation under preindustrial climate conditions.

An important result of our study is that not only the magnitude of the peak-to-peak CO_2 variations, but also the specific temporal evolution of carbon uptake and release depends strongly on the initial climate condition and vegetation distribution. For example, terrestrial carbon inventory is reduced during the cold phase and a few centuries thereafter for the run starting at glacial conditions, whereas storage is increased during the entire cold phase for the run starting at 13 kyr conditions. This emphasises the importance of the general setting of the terrestrial response to a THC collapse. The impact of the same climatic perturbation on atmosphere CO_2 can be of opposite sign depending on the initial condition and climatic background.

DISCUSSION AND CONCLUSION

The ice core CO_2 record provides an observational constraint on simulated changes in atmospheric CO_2 in response to a NA THC collapse. However, reconstructed atmospheric CO_2 reflects all changes in the marine and terrestrial carbon cycle, whereas the reorganization of the marine carbon cycle and changes that are not directly related to changes in the NA THC are not considered in our model setup.

For the period from 60 to 20 kyr BP, multi-millennial CO_2 variations of around 20 ppmv were found in ice cores that parallel the Antarctic warm events A1 to A4 which are leading the major D/O events 8, 12, 14, and 17. The simulated CO_2 peak-to-peak variations for a complete THC collapse and recovery are less than 13 ppmv within a period of less than 2000 year in the runs with CO_2 fertilisation for any of the applied initial conditions and less than 7 ppmv for typical glacial conditions. Thus, the model results for atmospheric CO_2 are well within the range of variations and the rate of change found in the ice core record during abrupt glacial events.

Results from ocean modeling and observation-based studies suggest that changes in the marine carbon cycle contributed to the rise in atmospheric CO_2 for each of the A1 to A4 events. Consequently, the contribution of terrestrial changes to the CO_2 increase must have been smaller than found in the ice core record. We conclude that the results of this study are compatible with the ice core record and the available studies of the marine carbon cycle.

REFERENCE

Köhler, P., F. Joos, S. Gerber, and R. Knutti (2005). Simulated changes in vegetation distribution, land carbon storage, and atmospheric CO_2 in response to a collapse of the North Atlantic thermohaline circulation. *Climate Dynamics* , in press.