Simulated changes in vegetation distribution, land carbon storage, and atmospheric CO_2 in response to a collapse of the North Atlantic thermohaline circulation

P. Köhler[1], F. Joos[2], S. Gerber[2] & R. Knutti[2]

1: Alfred Wegener Institute for Polar and Marine Research, P.O. Box 12 01 61, D-27515 Bremerhaven, Germany, email: pkoehler@awi-bremerhaven.de

2: Climate and Environmental Physics, Physics Institute, University of Bern, Sidlerstr. 5, 3012 Bern, Switzerland

Alfred Wegener Institute for Polar and Marine Research

Measurements on air enclosed in glacial ice show that atmospheric CO_2 varied by 20 ppmv within several millenia with large iceberg discharges into the North Atlantic (NA) during Heinrich events 4 to 6. The iceberg discharges have been linked to changes in the NA Thermohaline Circulation (THC). Here, we analyse how abrupt changes in the NA THC affect the terrestrial carbon cycle by forcing the Lund-Potsdam-Jena Dynamic Global Vegetation Model with climate perturbations from freshwater experiments with the ECBILT-CLIO ocean-atmosphere model. Changes in the marine carbon cycle are not addressed. Modelled NA THC collapsed and recovered after about a millennium in response to prescribed freshwater forcing perturbing glacial background climate. 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 which are here varied between preindustrial and glacial background climate. Terrestrial storage varies between 67 and +50 PgC for a range of experiments that start at different times during the last 21,000 years. Simulated peak-to-peak differences in atmospheric CO_2 and $\delta^{13}C$ are between 6 and 18 ppmv and 0.18 and 0.30 ‰ and compatible with the ice core records.

Forcing

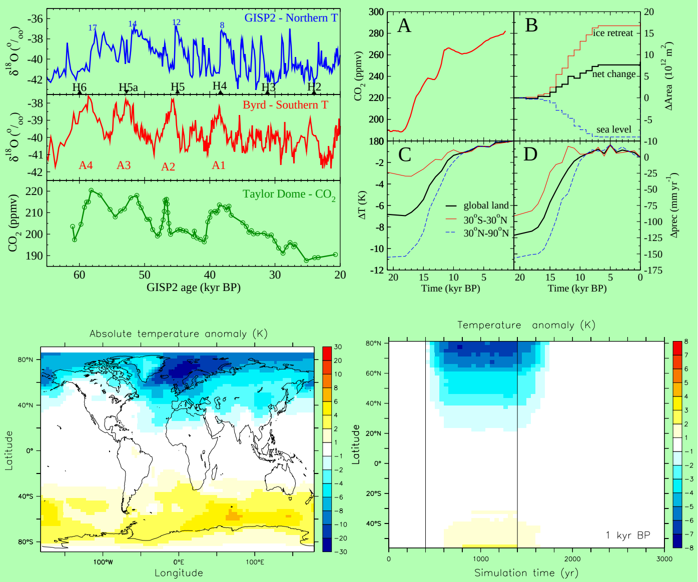

Figure 1: Top Left: (Motivation of this study) Ice core records of fast changes in northern and southern temperature and CO_2. D/O events, Heinrich events and Antarctic warm events are labelled.

Top right: Different initial conditions for last 21 kyr. LPJ was forced by anomalies calculated with the HadSM3 climate model for conditions during the last 21 kyr BP.

Bottom: Temperature and precipitation (not shown) anomalies from ECBILT-CLIO were used as climate anomalies in LPJ-DGVM.

Glacial – Interglacial

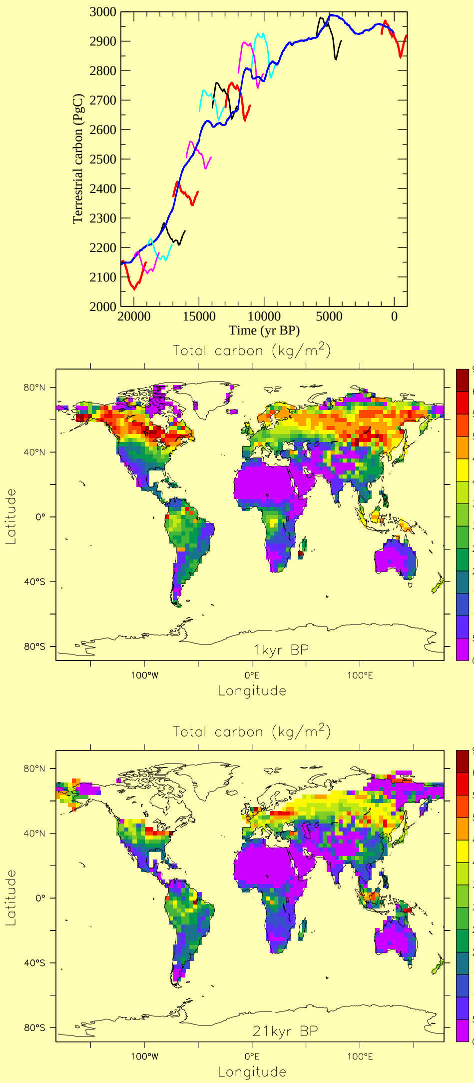

Figure 2: Top: Glacial/interglacial carbon storage during the last 21 kyr (blue). Carbon storage anomalies during collapse of THC at different initial conditions (red, black, cyan, magenta). Conditions (1, 13, 17, 21 kyr BP) in red were analysed in detail (see CO_2 in Figure 4). Middle, bottom: Terrestrial carbon storage at 1 and 21 kyr BP, respectively.

Preindustrial reference

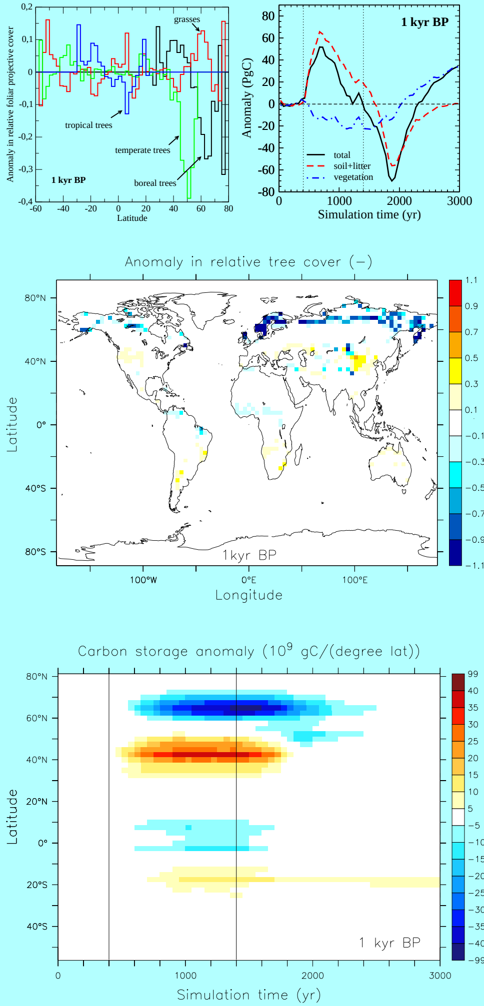

Figure 3: Top left: Changes in vegetation cover for aggregated PFTs.

Top right: Carbon storage anomaly (total, soil, vegetation).

Middle: Relative change in tree cover (peak THC shutdown compared with initial cond.).

Bottom: Carbon storage anomaly over time. Principal response is similar for different initial conditions, but main changes in the northern hemisphere are due to land ice sheets shifting further south during glacial conditions.

Atmospheric CO_2

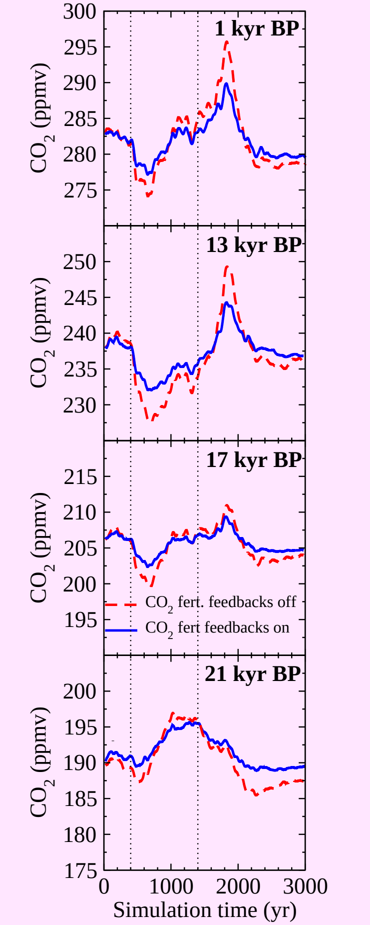

Figure 4: Final results for changes in atmospheric CO_2 induced through changes in terrestrial carbon storage for different initial conditions.

LPJ Dynamic Global Vegetation Model

Lund-Potsdam-Jena

DEKLIM