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Eidgenössische Technische Hochschule Zürich
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Land–atmosphere carbon exchange during abrupt climate change

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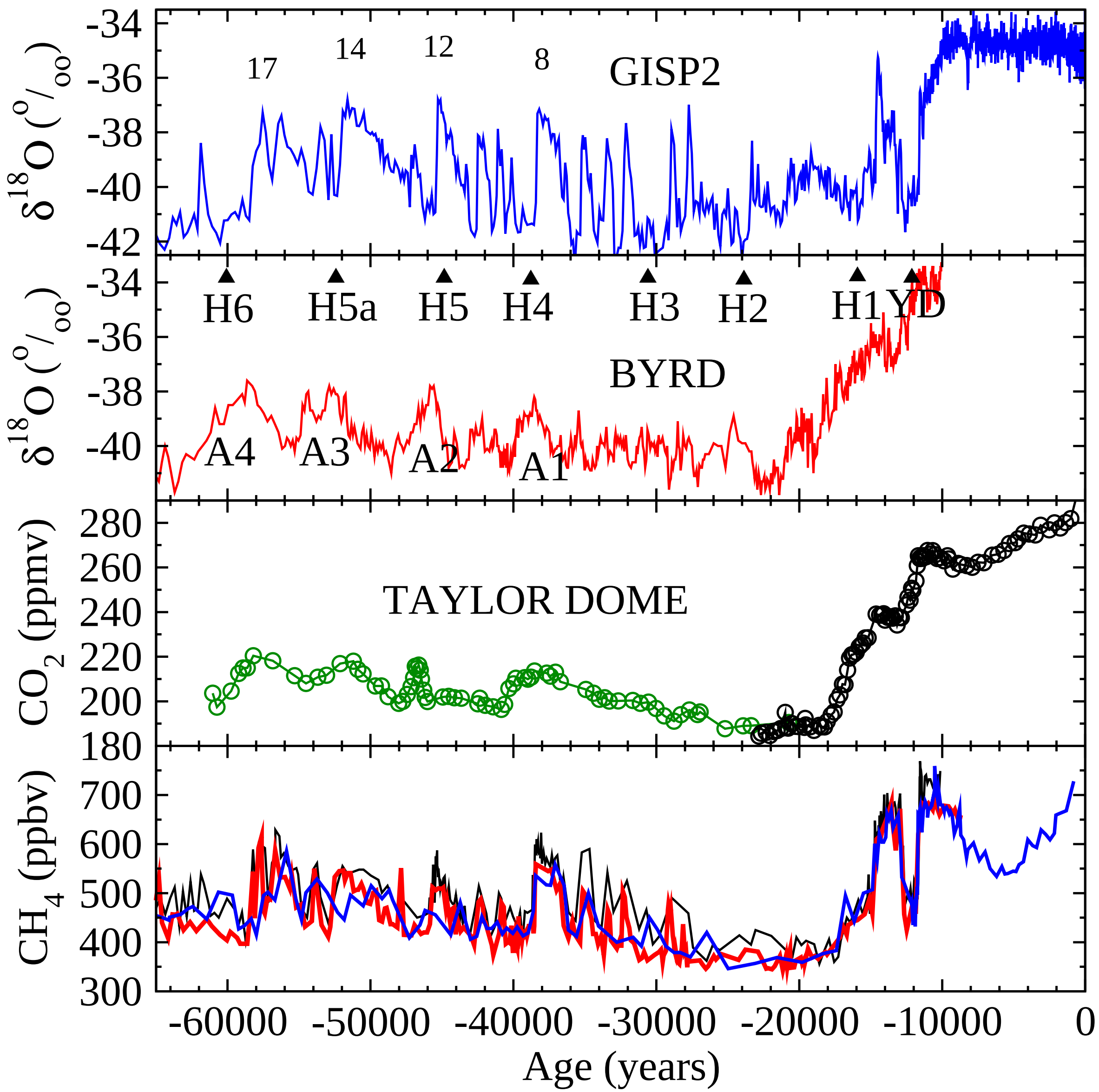
Fortunat Joos[Bern], **Stefan Gerber**[Bern,PEI], **Reto Knutti**[Bern,ETH]

ESF Conference OCEAN CONTROLS IN ABRUPT CLIMATE CHANGE, Obergurgl 05/2007

Climate Dynamics (2005), 25: 689-708

Data constraints on abrupt climate changes during past 60 kyr
Modelled bipolar seesaw (ECBILT-CLIO)
Terrestrial carbon storage in LPJ-DGVM
Case study for preindustrial times (1 kyr BP)
Importance of the background climate

Data constraints on abrupt climate changes in the past 60 kyr



Dansgaard/Oeschger events (e.g. 17, 14, 12, 8)

Heinrich events (H1–H6)

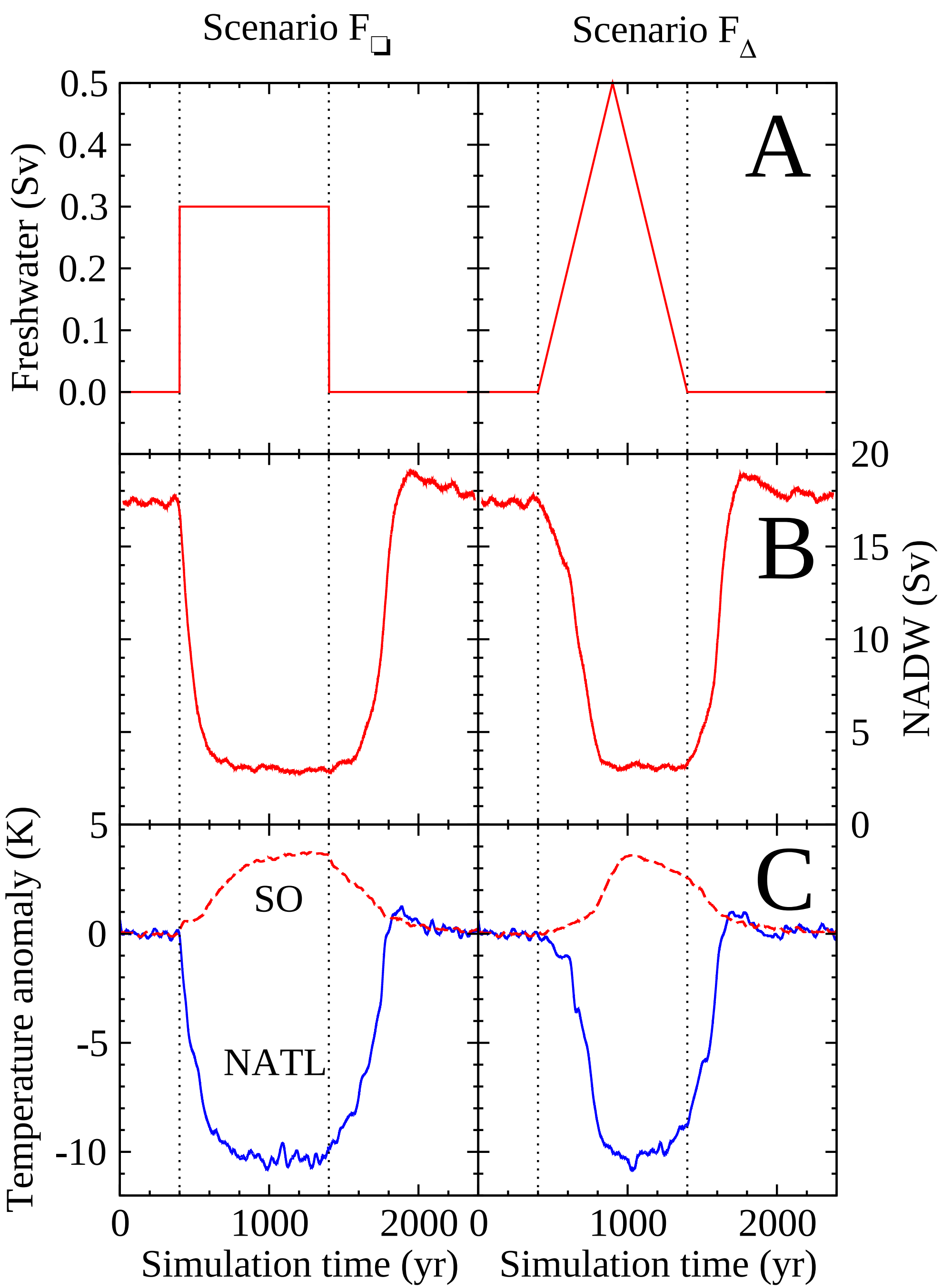
Antarctic warming events (A1–A4)

atmospheric CO_2 (±20 ppmv)

atmospheric CH_4 (±200 ppbv)

Grootes and Stuiver, 1997; Johnsen et al.,1972; Indermühle et al., 1999, 2000; Blunier et al., 1998, Brook et al., 1996, 2000, Blunier and Brook, 2001

Modelled bipolar seesaw (ECBILT-CLIO)



Bipolar seesaw in ECBILT-CLIO

Knutti et al., 2004.

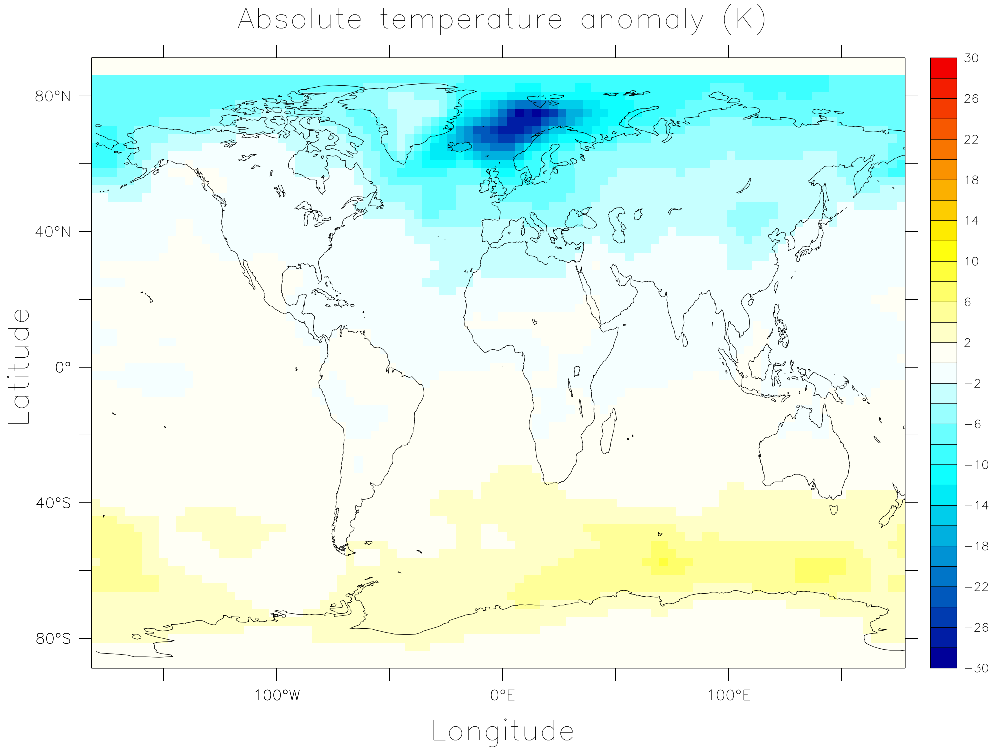
Mimicking the bipolar seesaw by freshwater discharge into the North Atlantic (50°– 70°N).

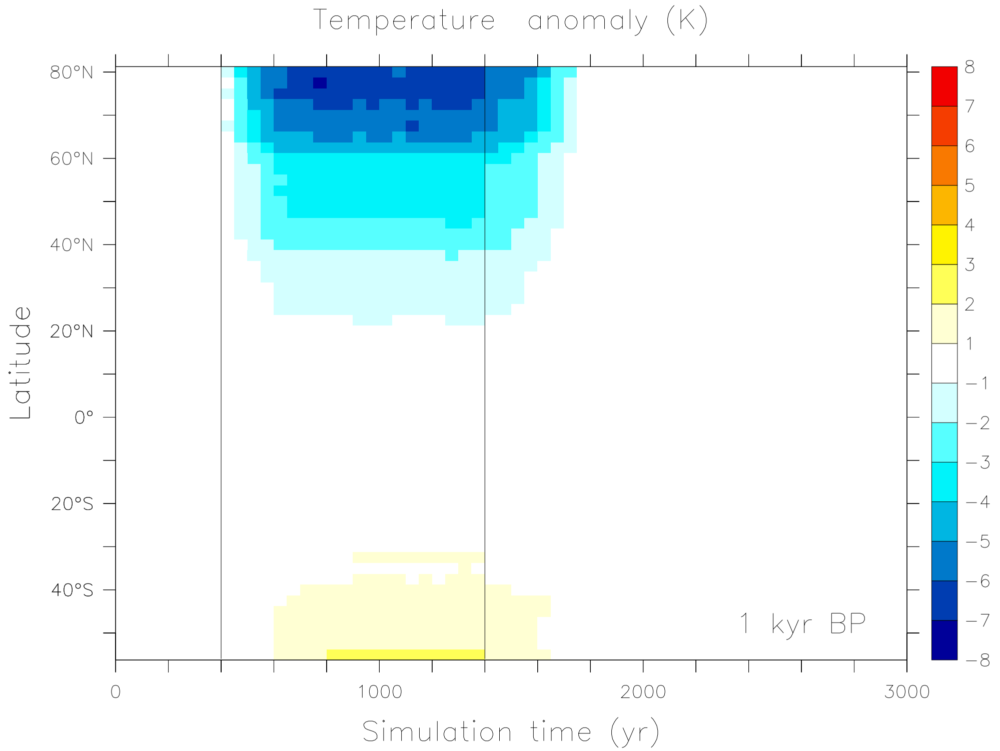
Global coupled atmosphere–ocean–sea ice model

ECBILT2: T21 atmosphere (Opsteegh et al., 1998)

CLIO: OGCM + sea ice (Goose and Fichefet, 1999)

ECBILT-CLIO — Temperature



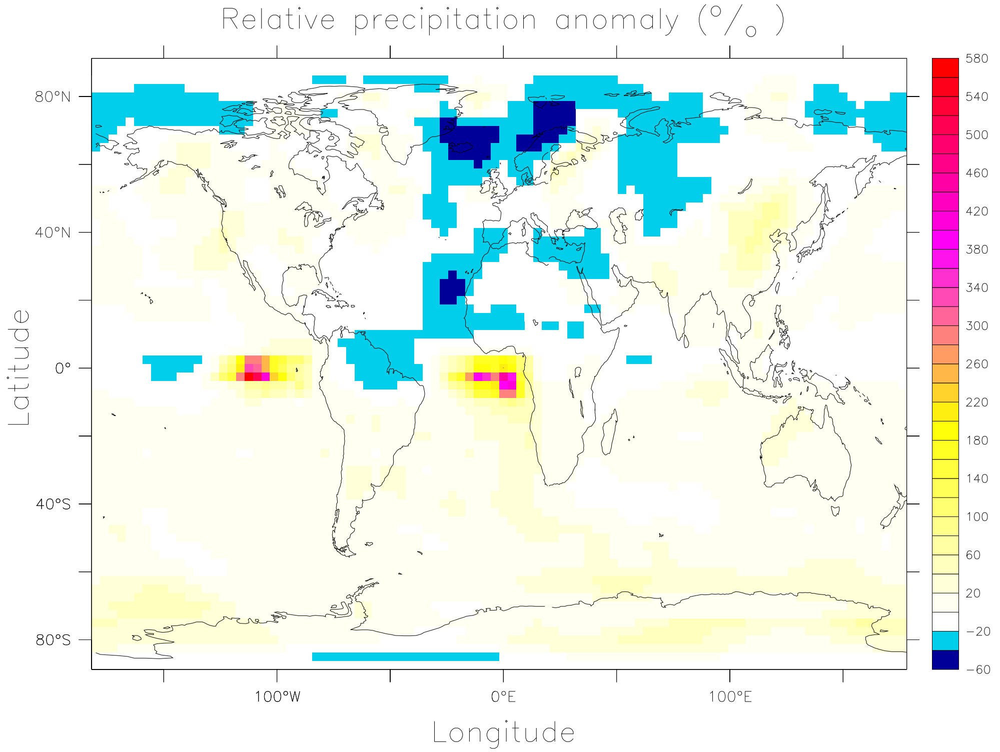


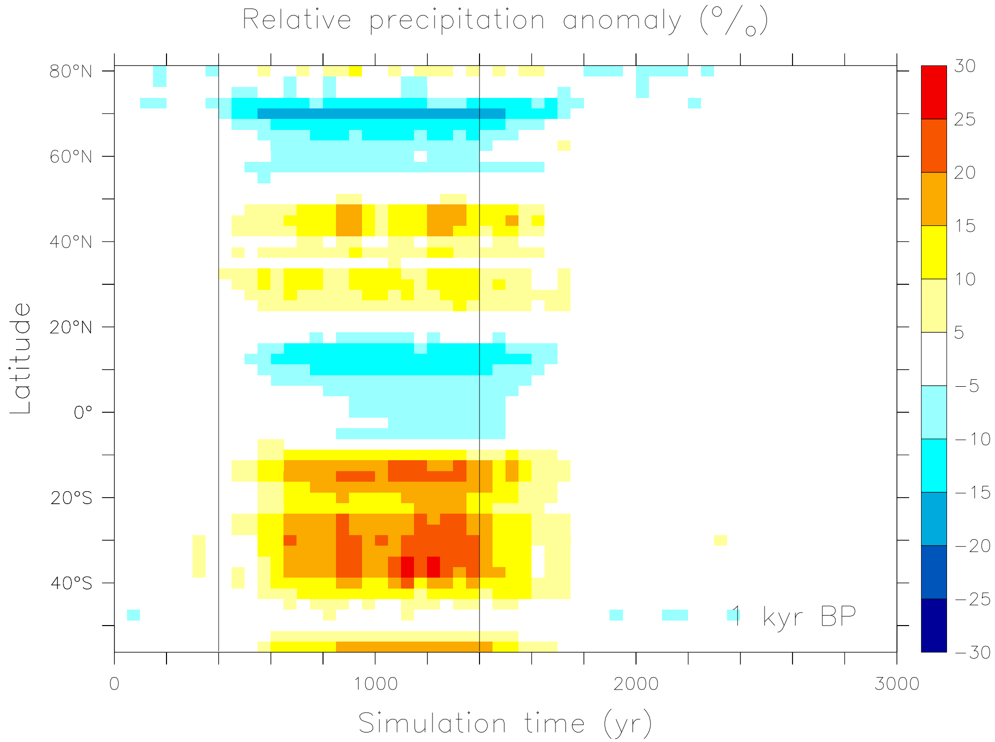
Zonally averaged ΔT over ice free land area:

North (70°N): cooling by 7K

South (50°S): warming by 2K.

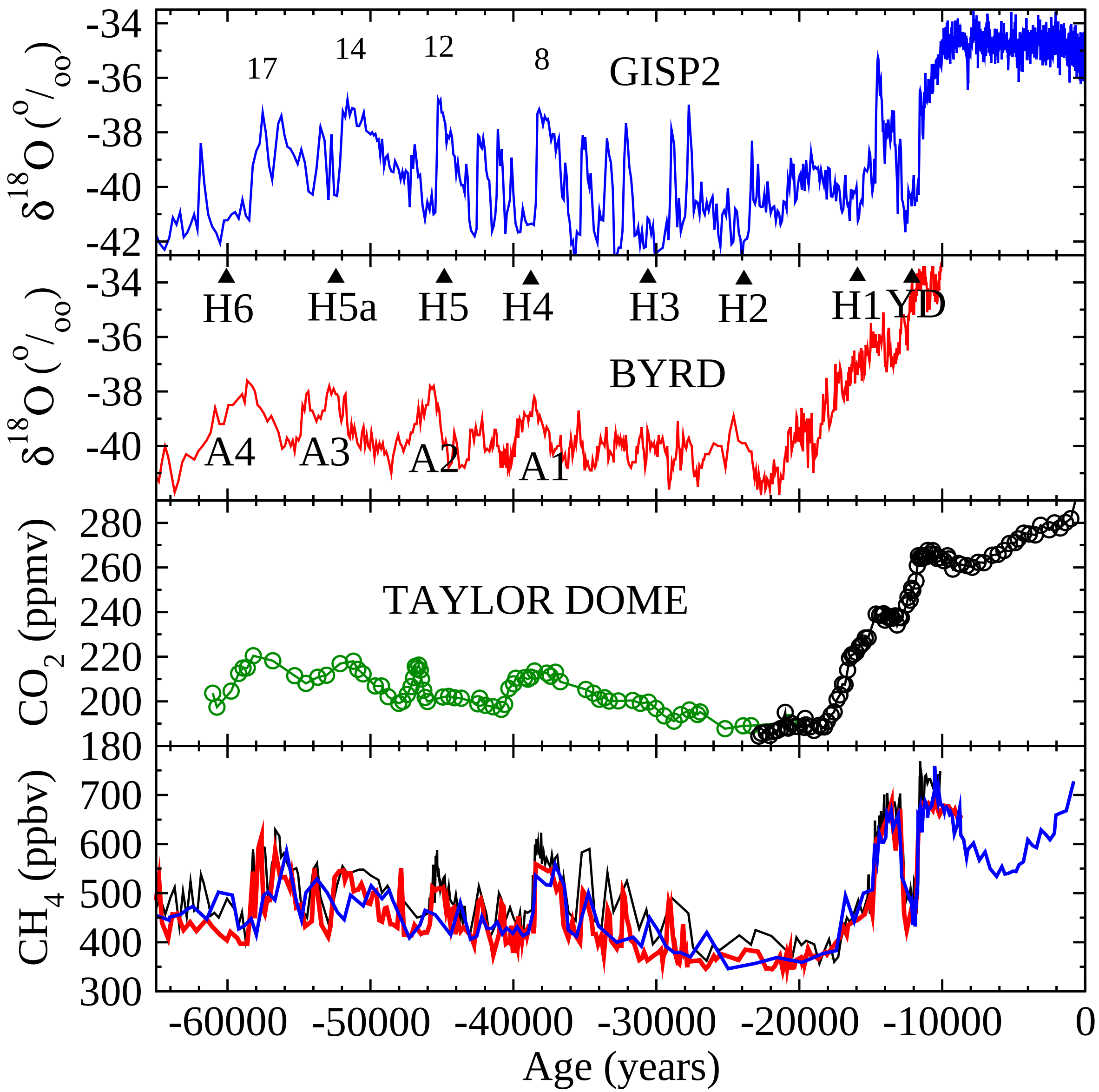
ECBILT-CLIO — Precipitation





Zonally averaged Δprec over ice free land area:

Drier conditions in the tropics — wetter conditions in the subtropics



Data constraints on abrupt climate changes in the past 60 kyr

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atmospheric CO_2 ($\pm$20 ppmv)

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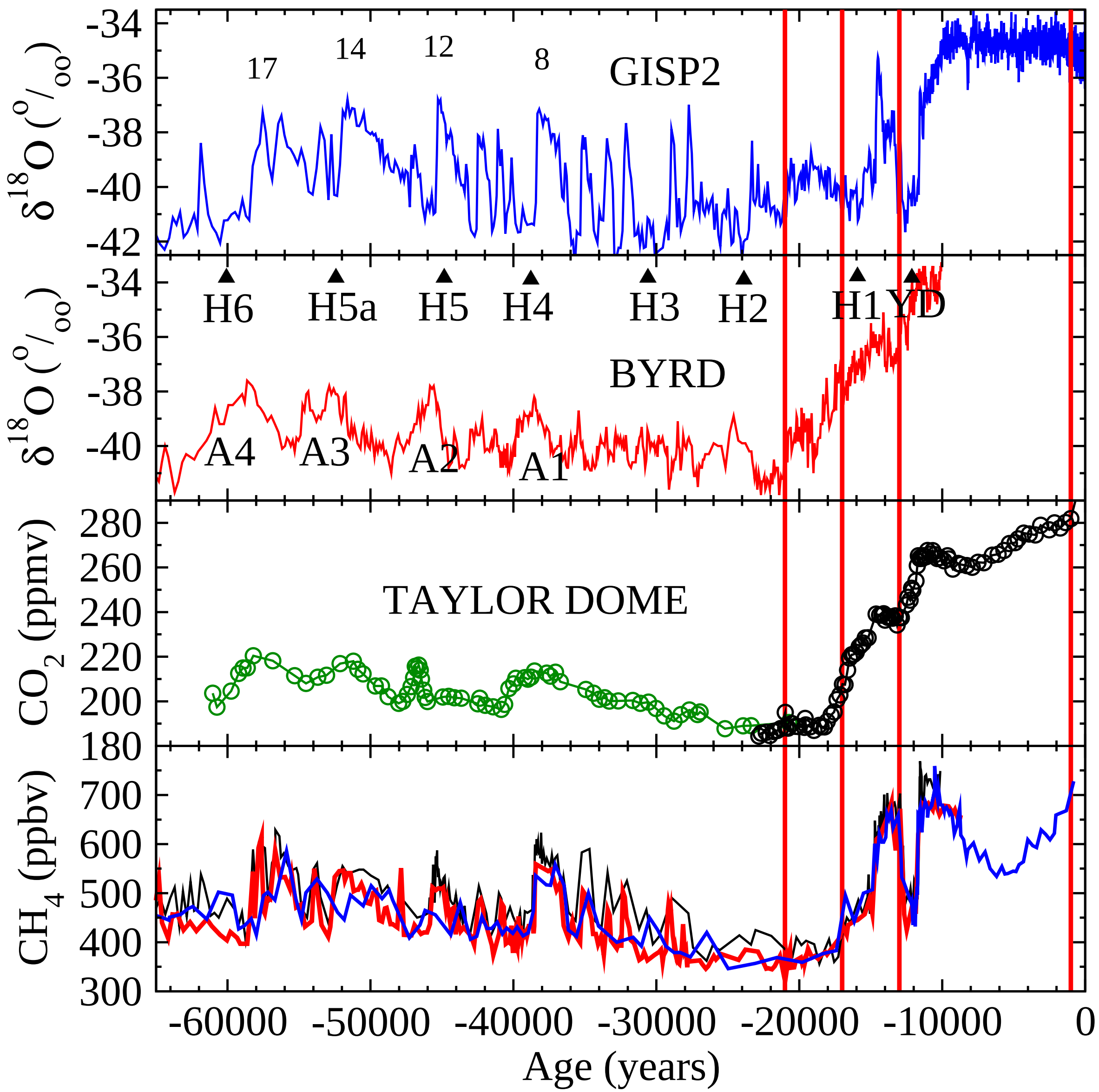

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Case studies for 4 time slices:

1, 13, 17, 21 kyr BP

PRE, YD, H1, LGM

Terrestrial carbon storage in LPJ-DGVM

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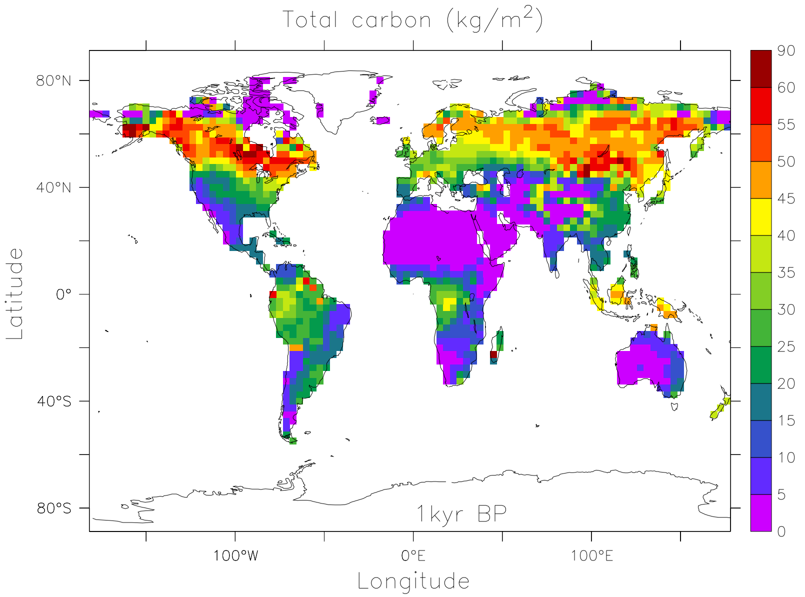
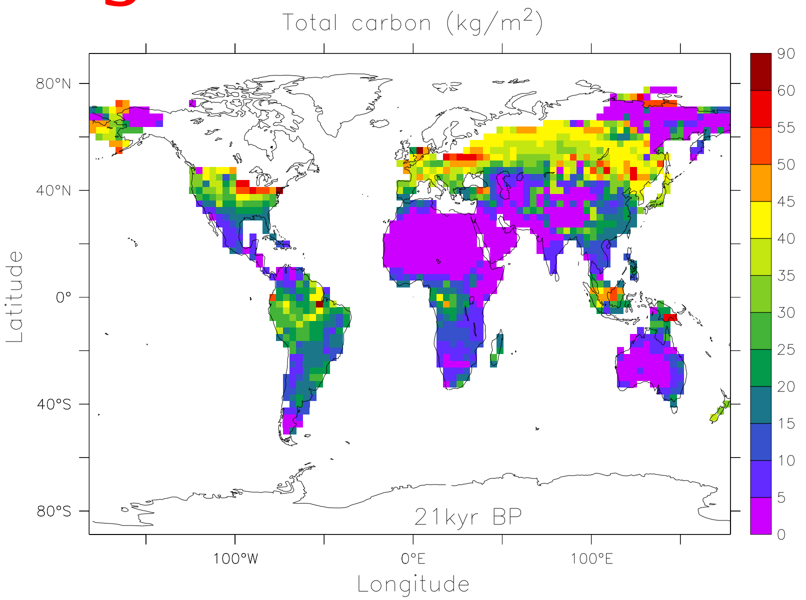
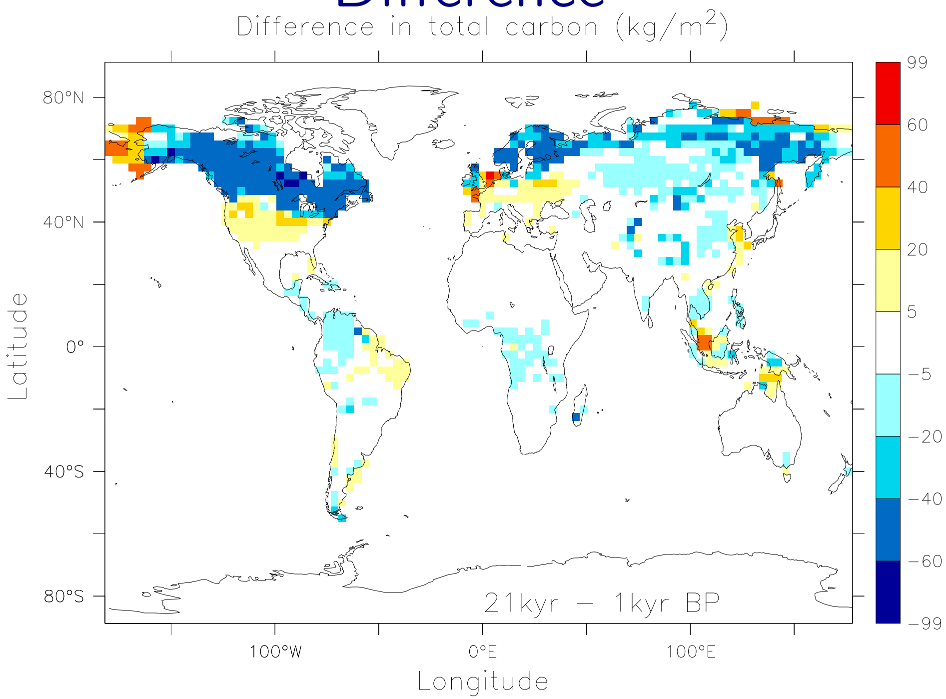
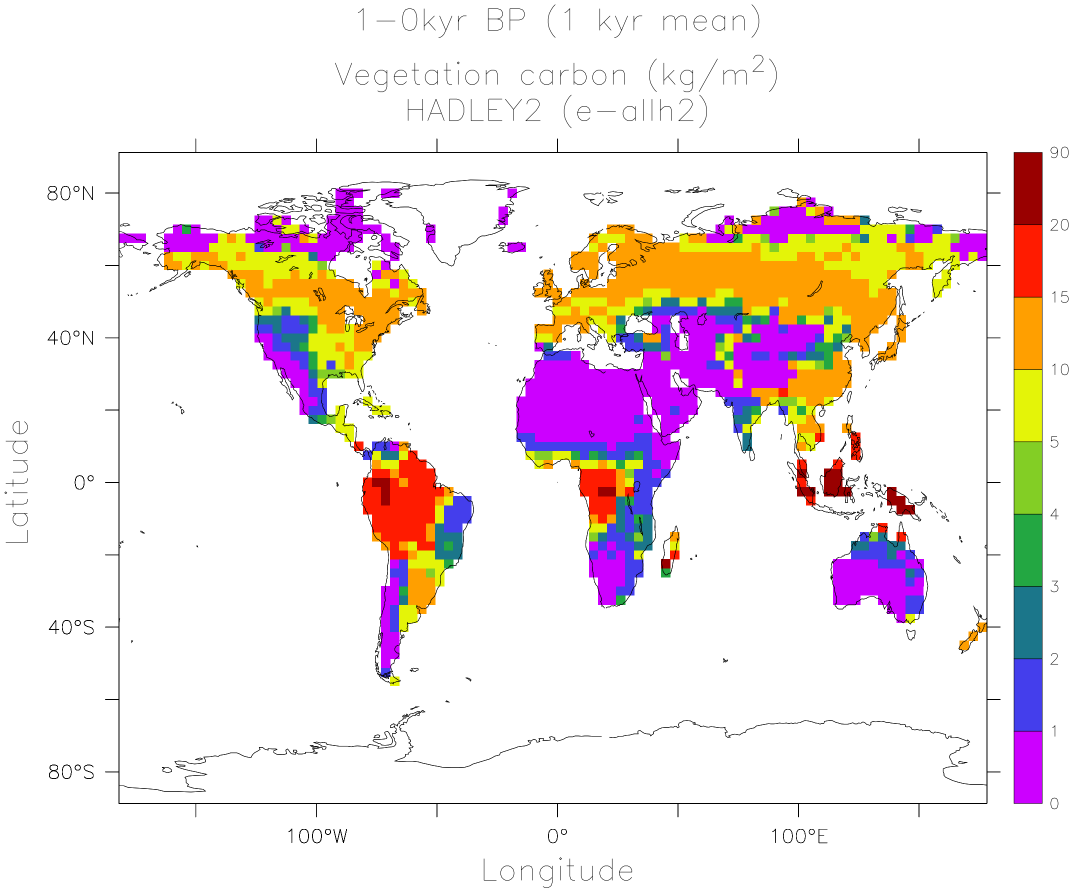


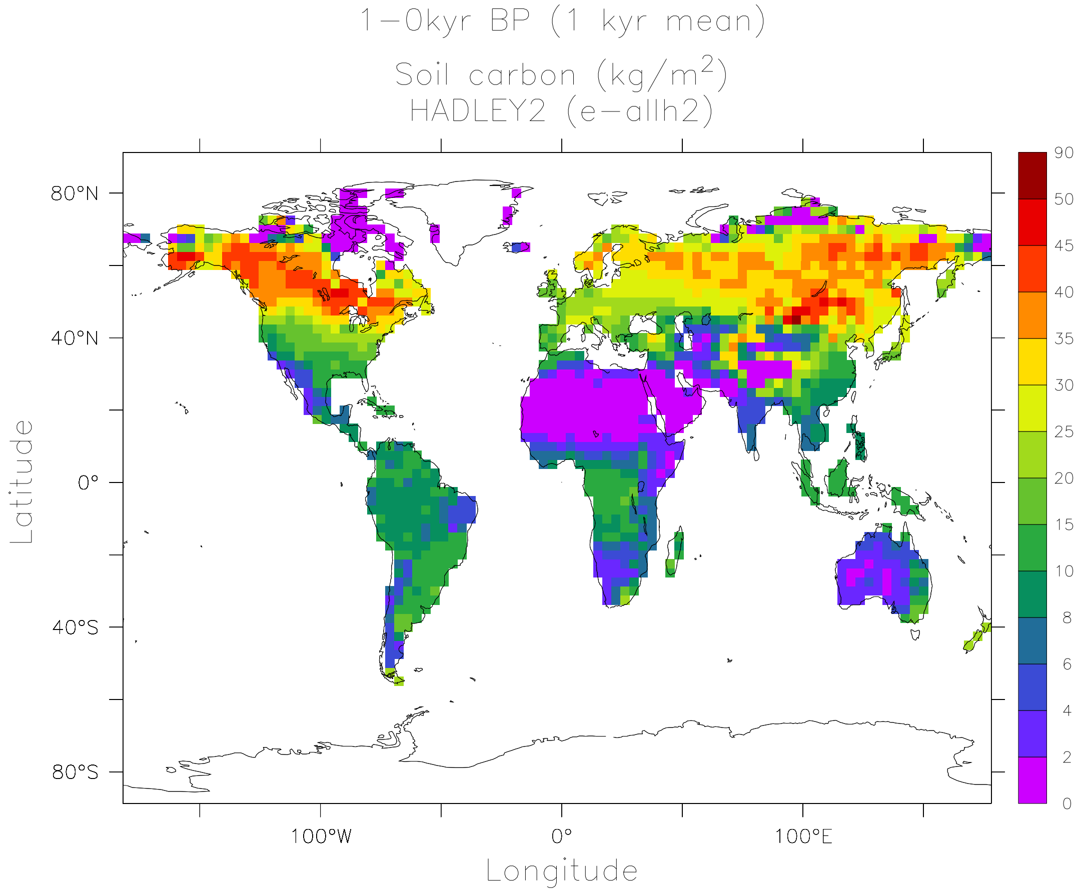


PRE   Difference   LGM



Vegetation versus soil carbon





Vegetation

Soil

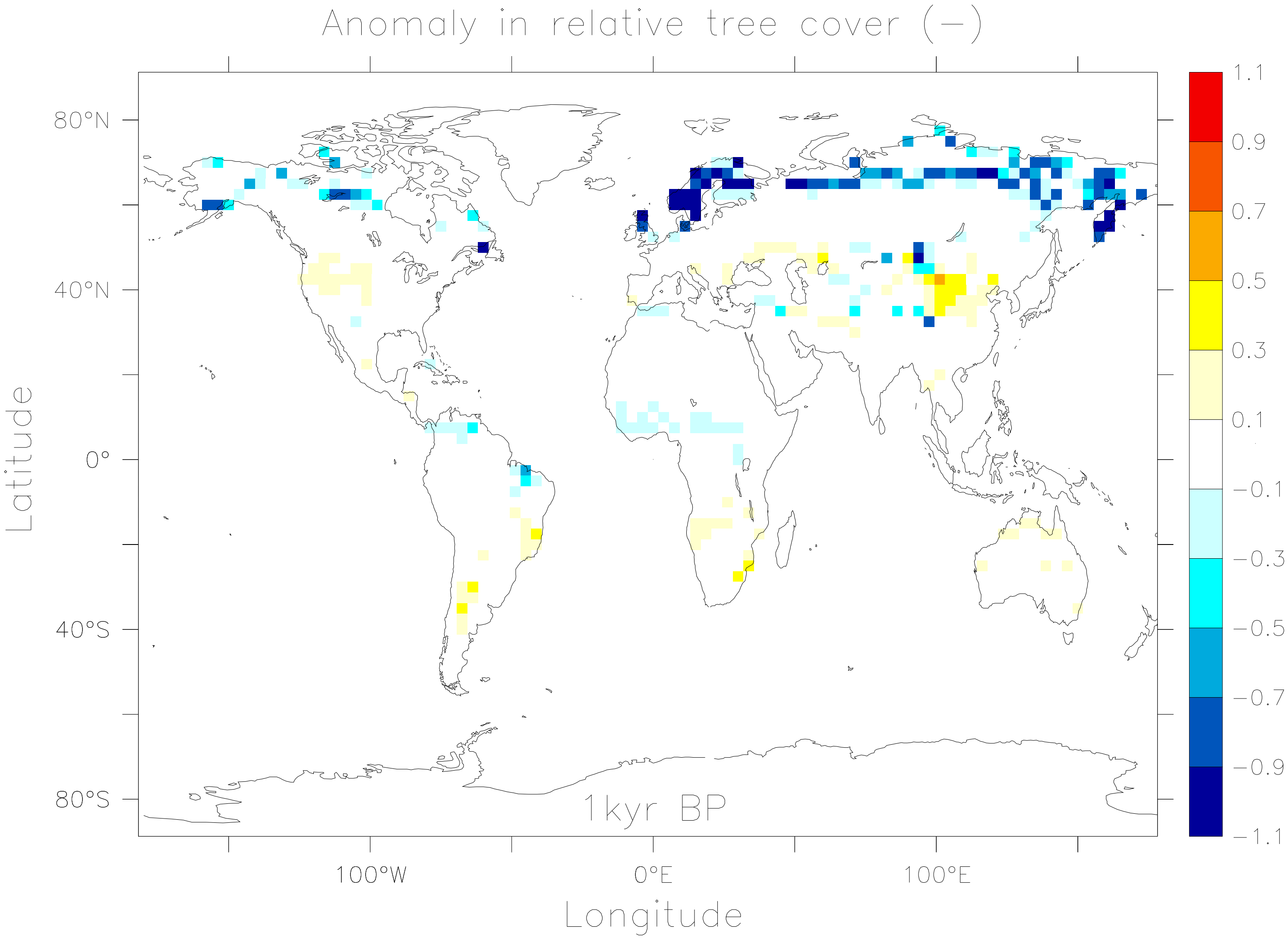
Rule of thumb:

Tropics: more than 2/3 of carbon in the vegetation

Boreal areas: more than 2/3 of carbon in the soil

Case study for preindustrial times (1 kyr BP)

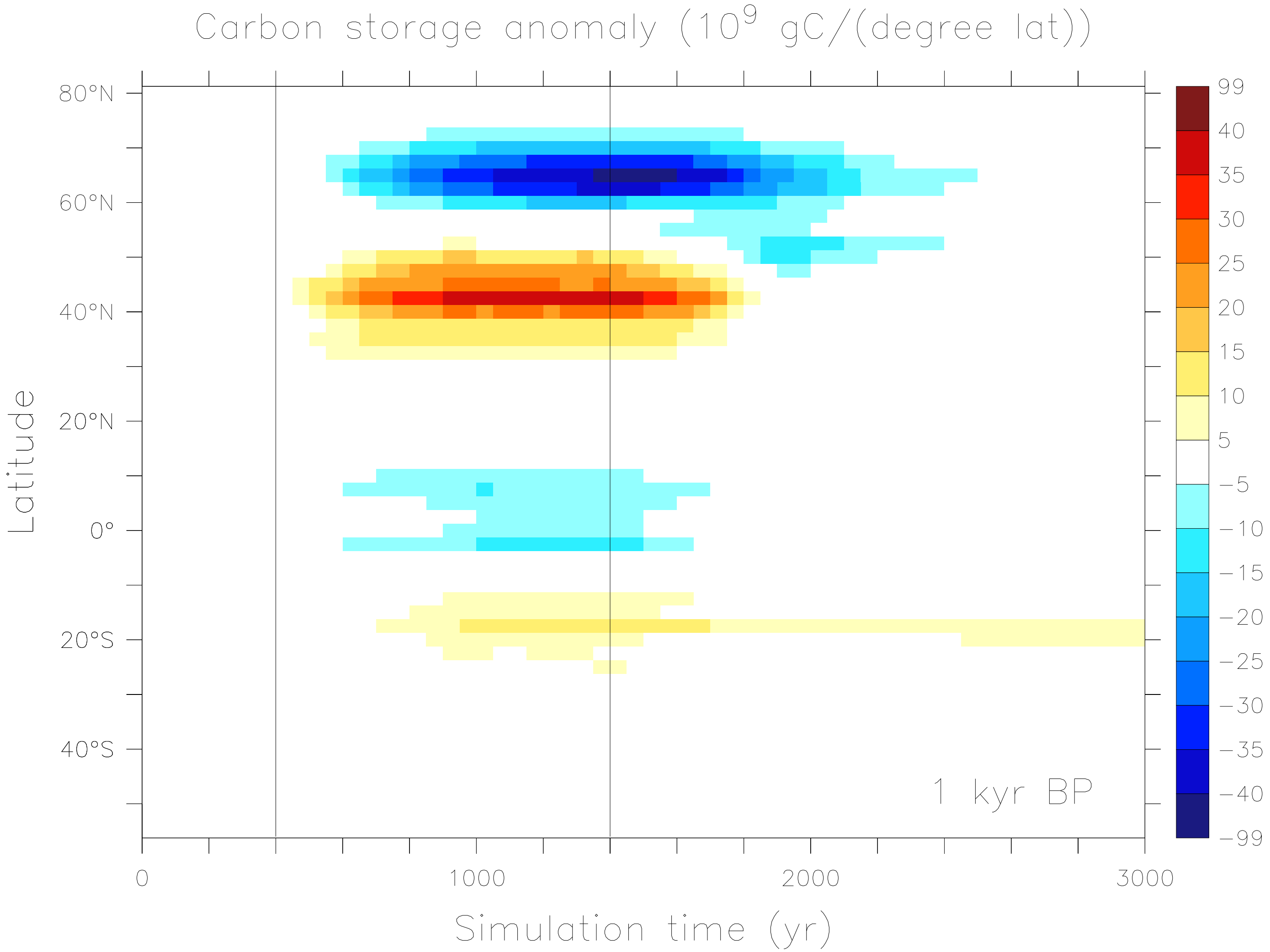
Vegetation — Tree Cover



Southward shift of the northern treeline = f(temperature)

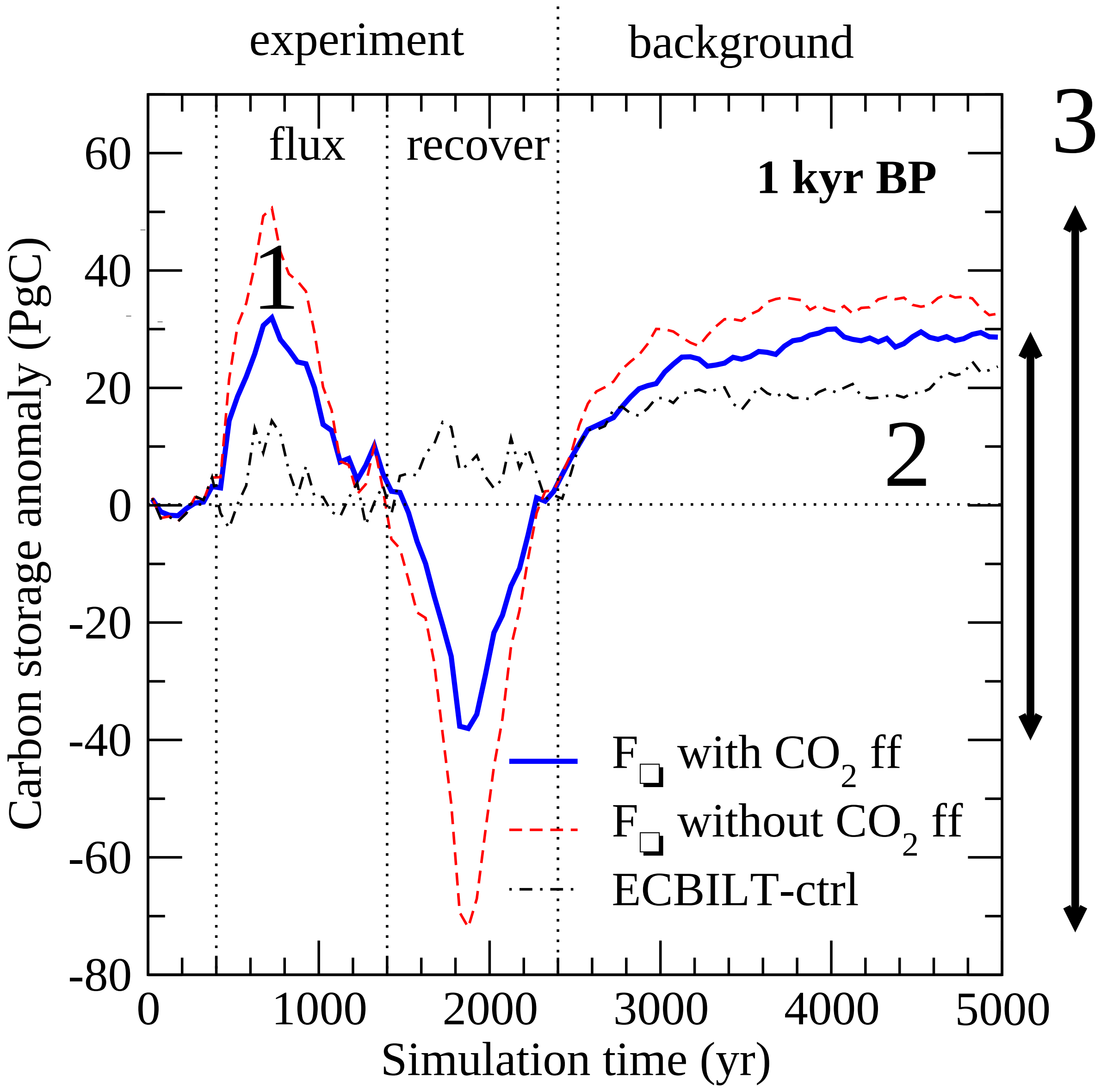
Less trees in Sahel area (Mulitza et al.) = f(precipitation)

Zonally averaged land carbon storage anomalies



Increase (soil respiration) & decrease (northern treeline) in C storage

Persisting anomaly 20°S (model artefact)



Land carbon anomaly

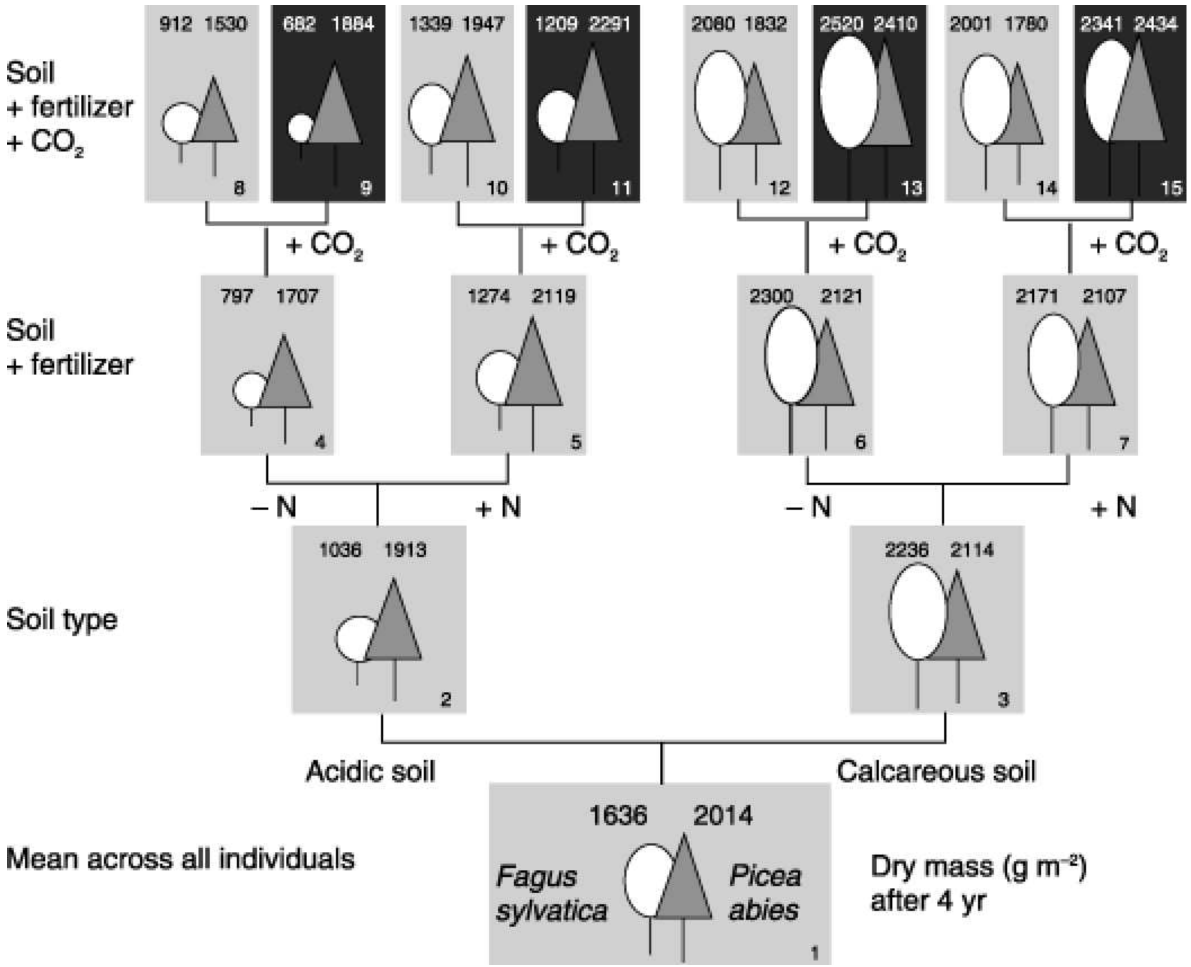
1. CO_2 fertilization (NPP $= f(CO_2)$) is dampening the amplitude by factor of two

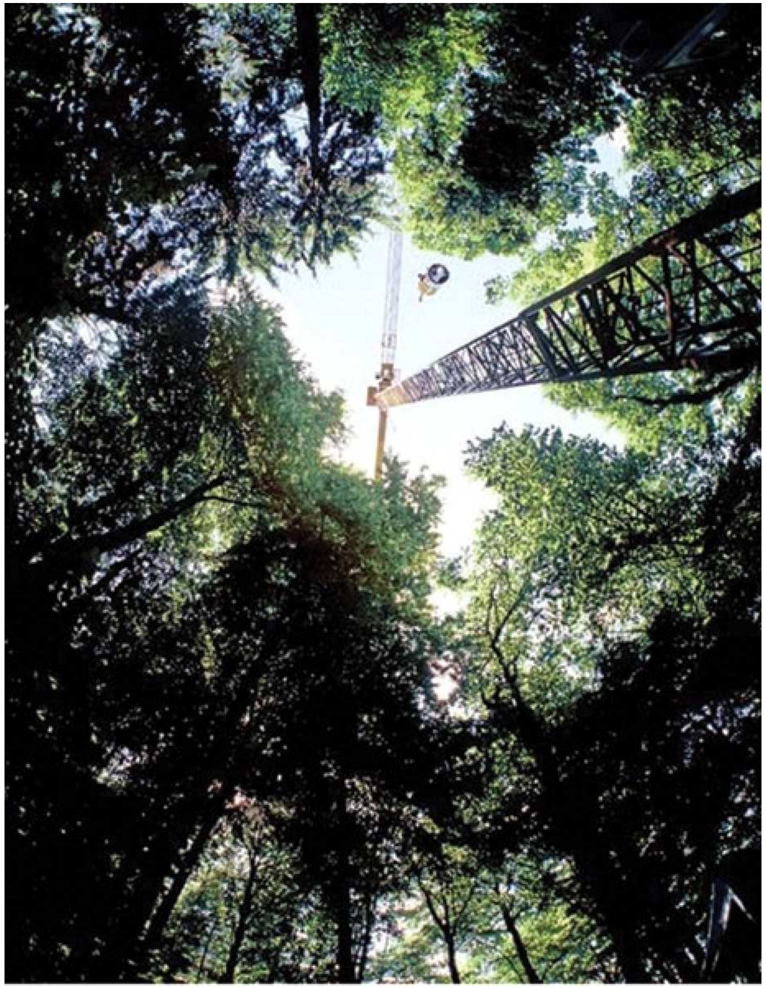
2. Final offset (20–30 PgC) due to single PFT reorganisation (precipitation) in a few grid cells in the tropics

3. Peak-to-peak-amplitude: $\Delta C(\text{terrestrial}) = 70$ and 120 PgC

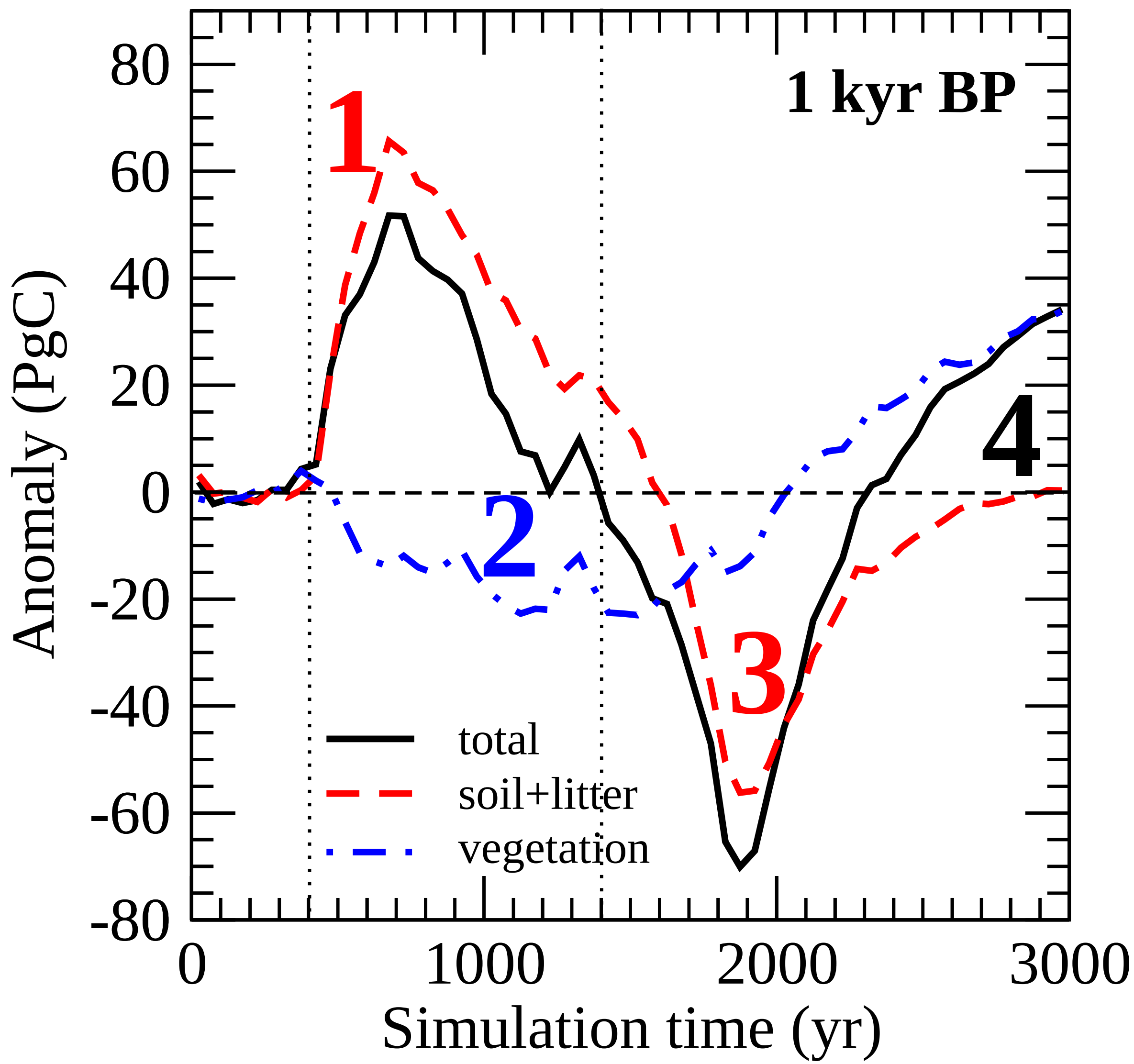
But...

Evidence for CO_2 fertilisation effect on vegetation growth is still poor





Körner 2006



Soil versus vegetation

1. Soil respiration is reduced during cold times
$\Rightarrow$ carbon gain

2. Treeline shifts to South
$\Rightarrow$ carbon loss

3. Warming at the end of the experiment leads to increased soil respiration
$\Rightarrow$ carbon loss

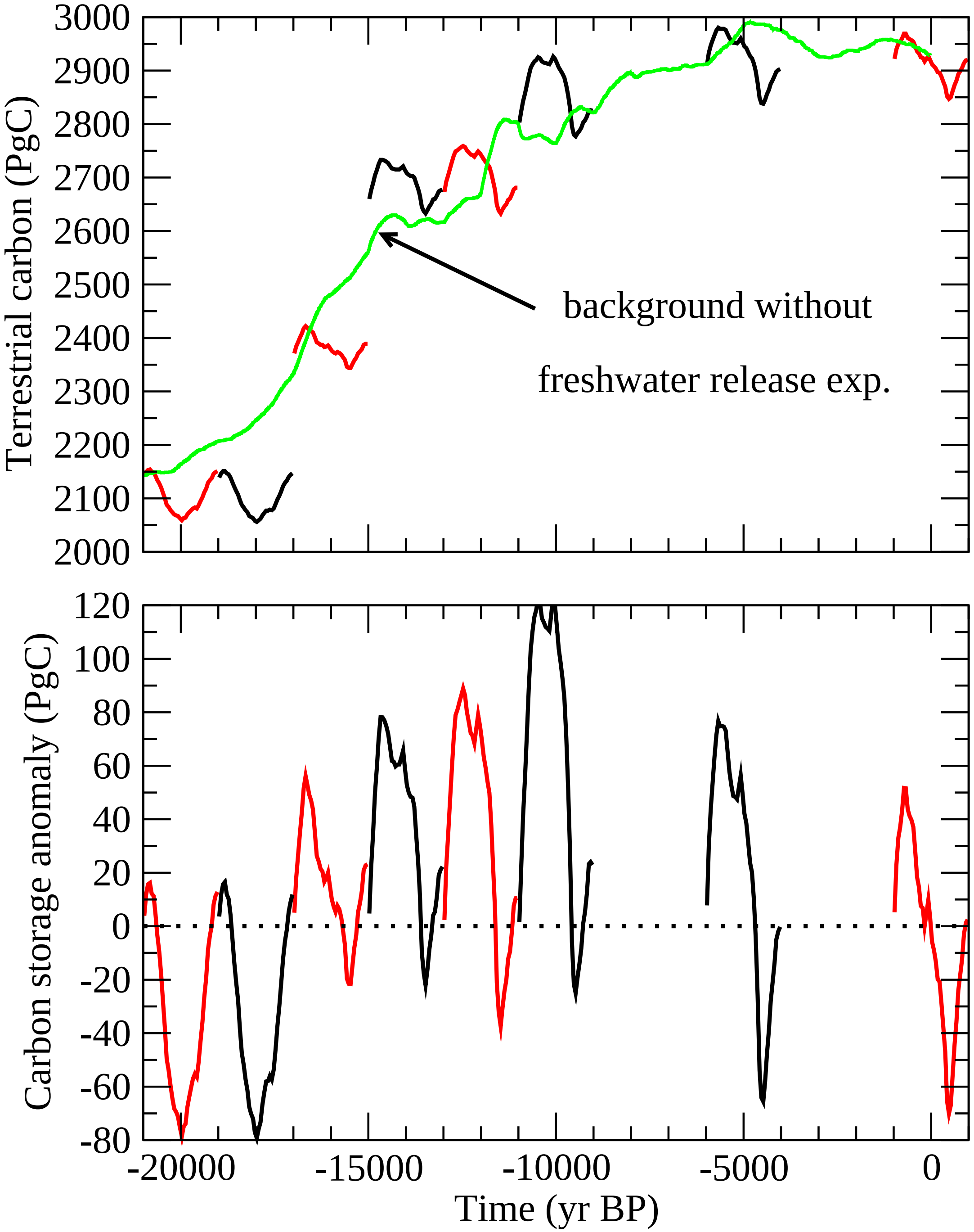
4. Treeline back North / delayed recovery
$\Rightarrow$ carbon gain

Importance of the background climate

Atmospheric CO_2 concentration (ice cores)

Land ice sheet extent / sea level (ICE–4G)

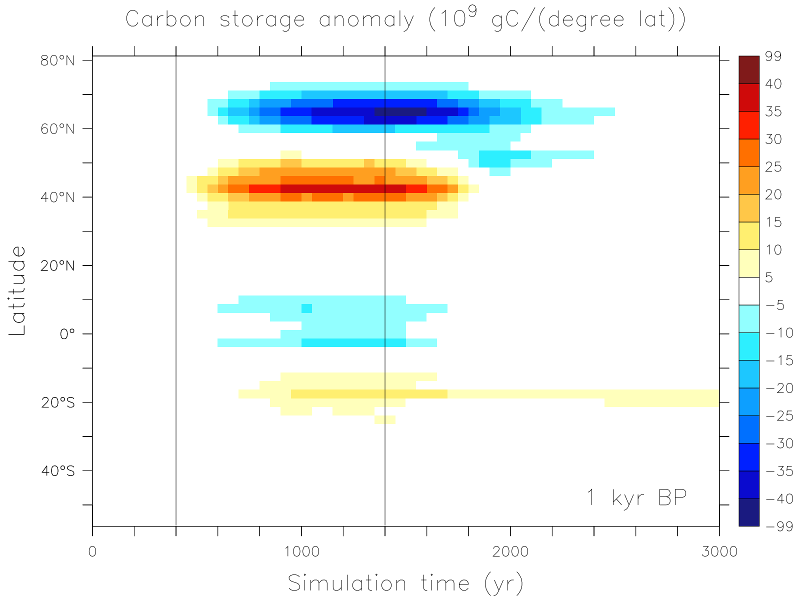
Global temperature / precipitation fields (HadSM3 model output)



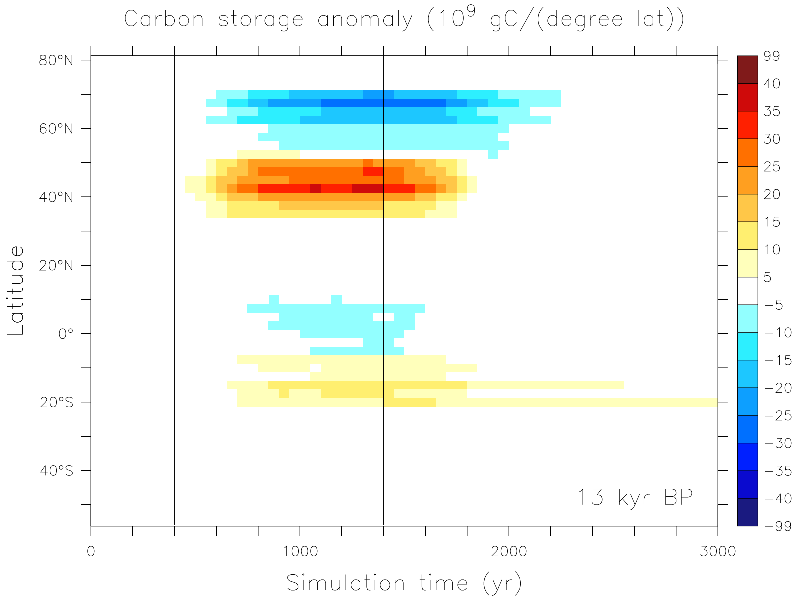
Impact of climate change during Termination I

Size and direction of carbon storage anomaly depends on background climate, mainly background temperature.

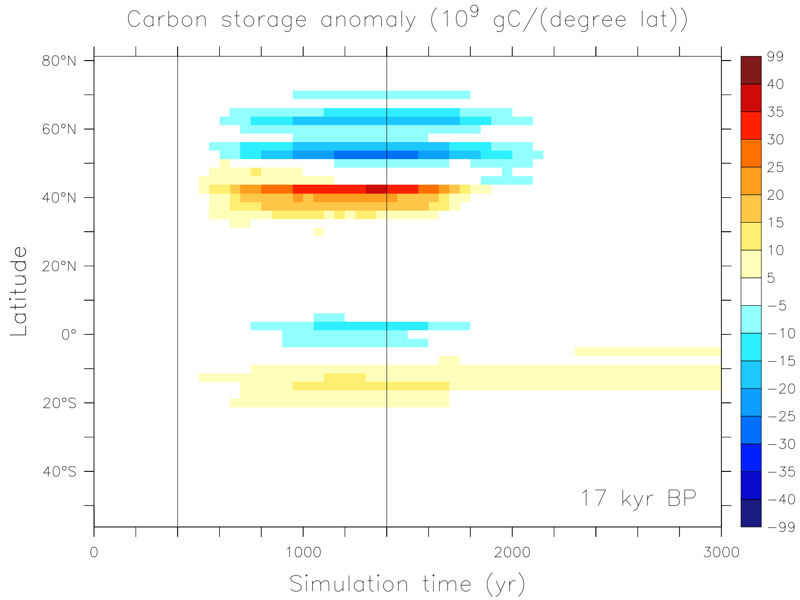
Zonally averaged land carbon storage anomalies



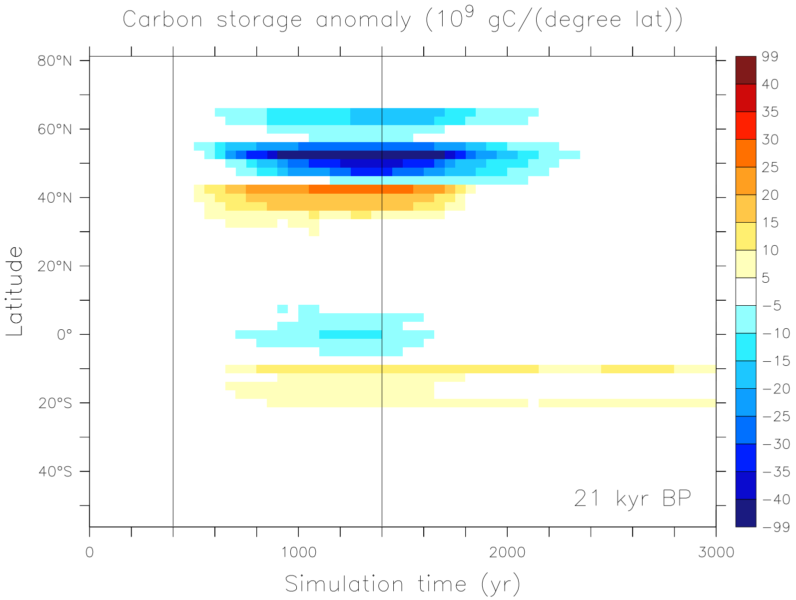
1 kyr BP



13 kyr BP

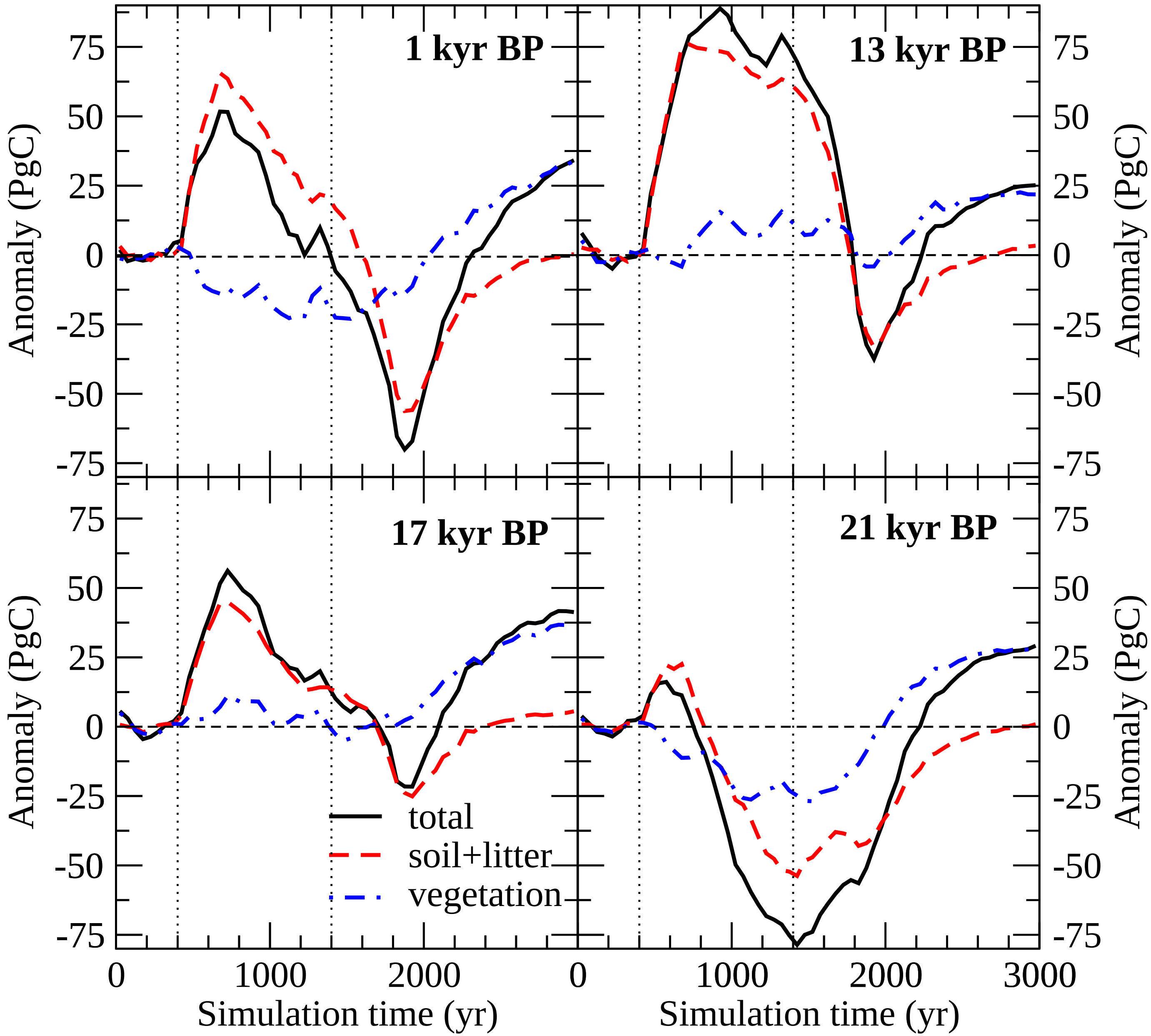


17 kyr BP



21 kyr BP

Increase / decrease in terrestrial carbon storage



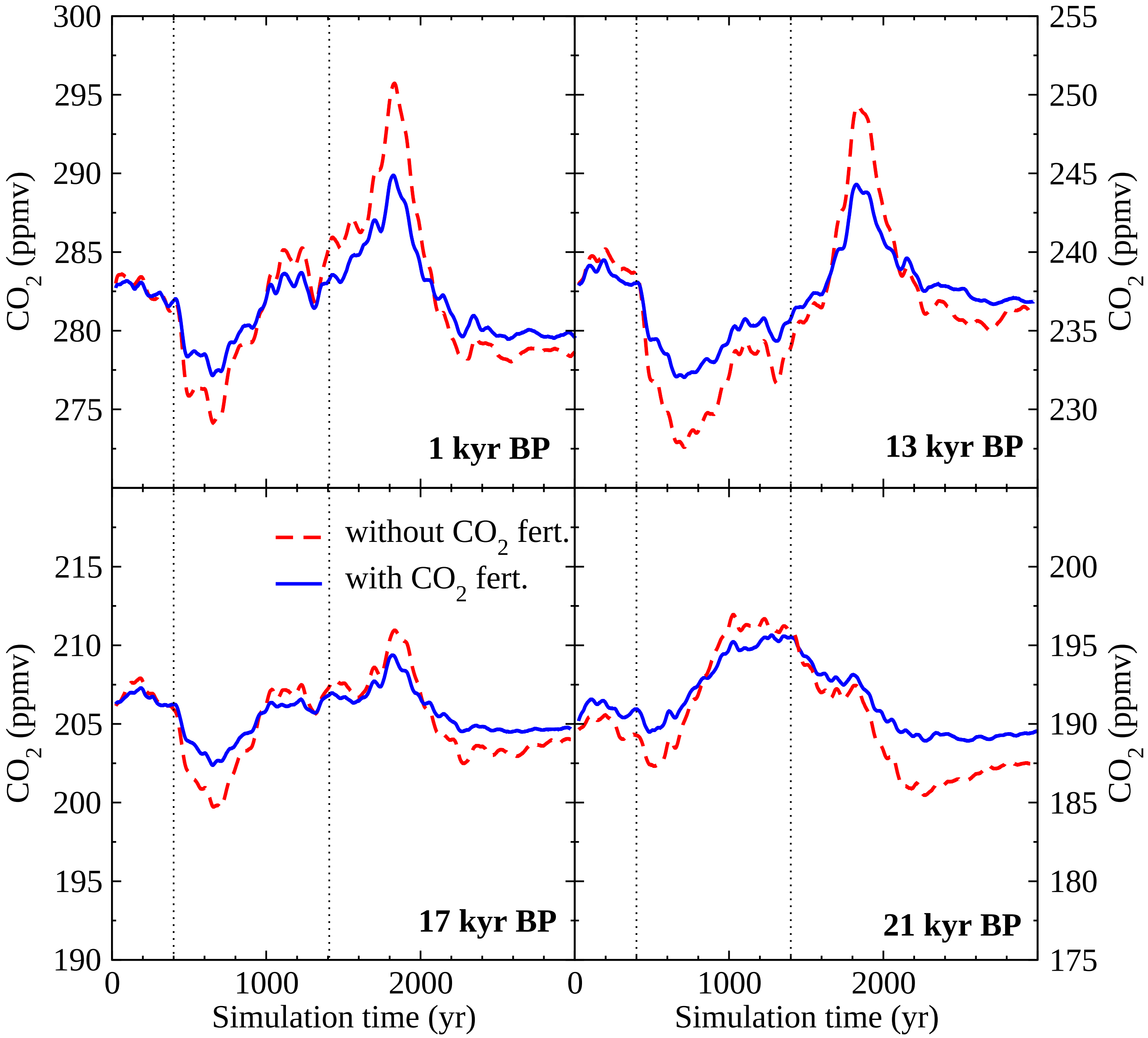
Impact of climate change for different times

without CO_2 fertilization

13 kyr BP: Younger Dryas cold event

17 kyr BP: Heinrich event during partly glaciation

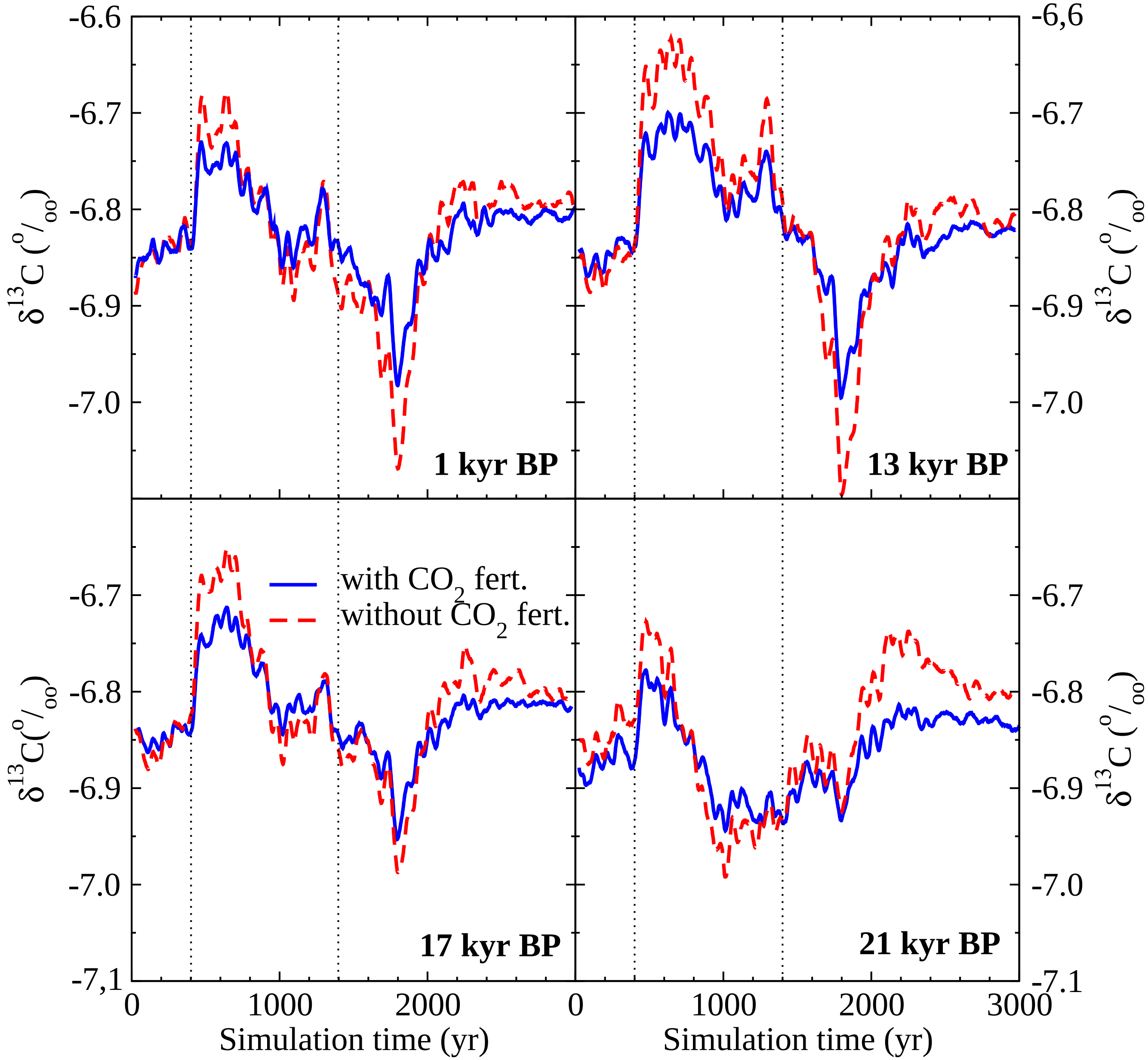
21 kyr BP: Heinrich event during full glaciation



Impacts on atmospheric CO_2

LGM amplitude: ∼7–12 ppmv

To be consistent with the ice core record the marine carbon cycle needs to contribute about the same magnitude.



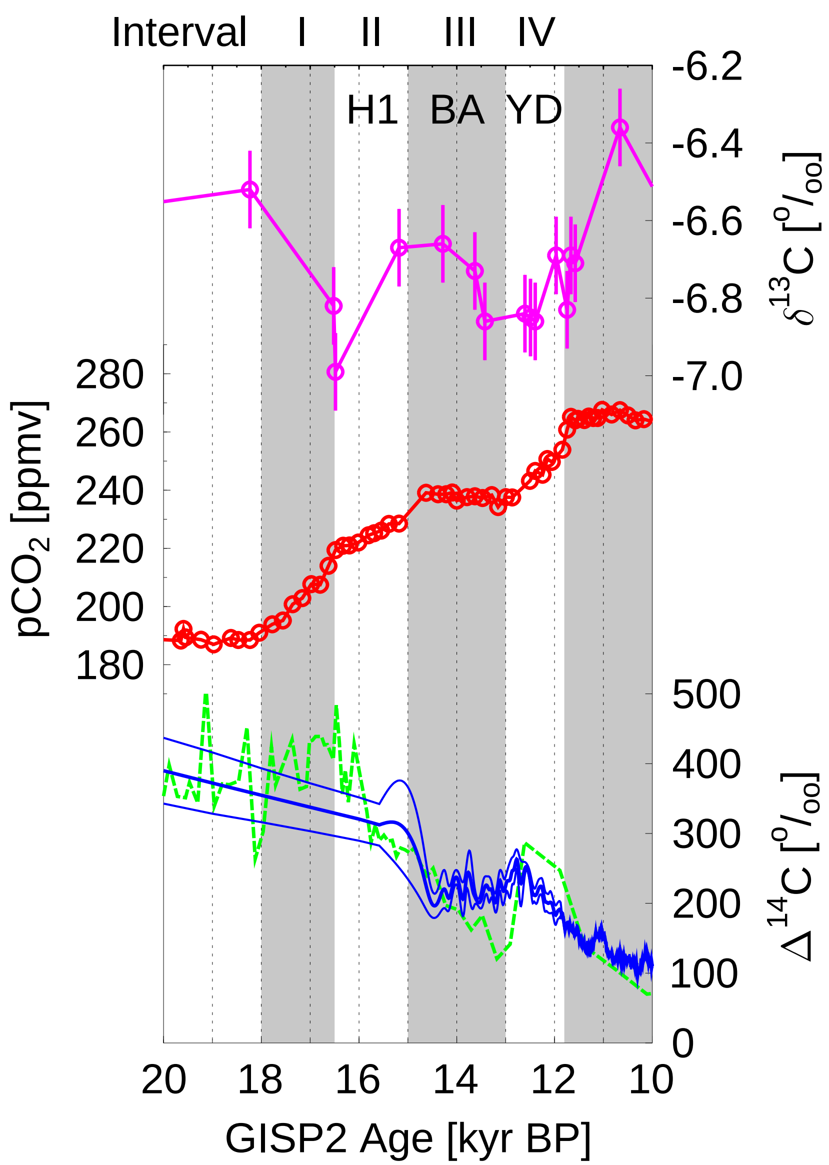
Impacts on atmospheric δ^{13}C

LGM amplitude:
~ -0.2 to -0.3‰

Ice core record not clear on δ^{13}C:

H1 & YD:
$-$ 0.2 to -0.4‰ excursion

but both events occur during the last glacial/ interglacial transition



Data constraints on $\delta^{13}C$

Taylor Dome (Smith et al., 1999)

EPICA Dome C (Monnin et al., 2001)

INTCAL98 (Stuiver et al., 1998)
Cariaco basin (Hughen et al., 2004)

Conclusions

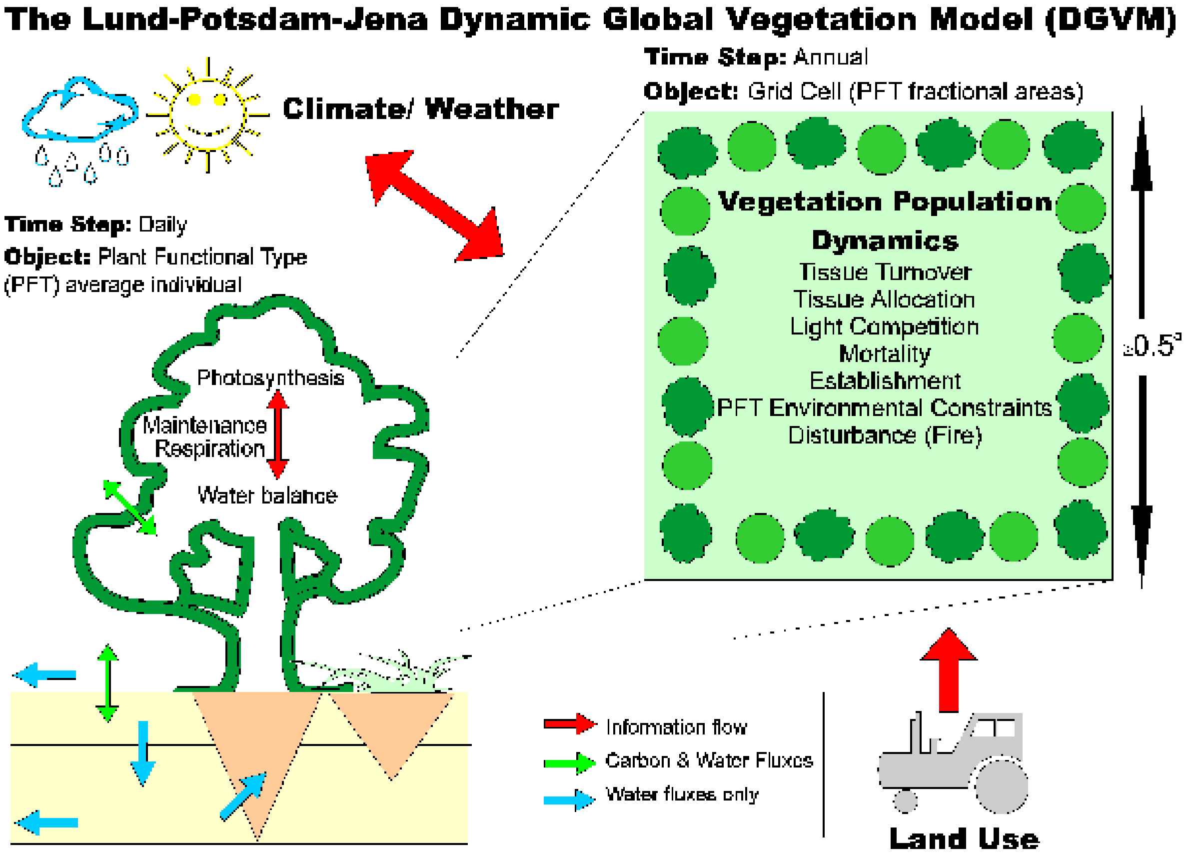
- Abrupt climate changes caused by the bipolar seesaw lead to opposing trends in terrestrial carbon storage: a southward shift of the northern treeline (carbon loss) and a reduction in soil respiration in mid latitudes (carbon gain).
- The overall net effect on carbon storage depends on the global balance of losses and gains and is highly sensitive to the applied background climatology.
- Be careful about the magnitude because of the unknowns in the CO_2 fertilisation feedback.
- The increase of 20 ppmv in atmospheric CO_2 during the Antarctic warming events A1–A4 might by ~50% caused terrestrial carbon release.
- **OUTLOOK** Impact of same ECBILT-CLIO scenarios on CH_4 cycle in LPJ-DGVM: see poster by Jed Kaplan and Joe Melton.

LPJ-DGVM

Sitch et al., 2003 GCB.

LPJ Dynamic Global Vegetation Model

Lund-Potsdam-Jena

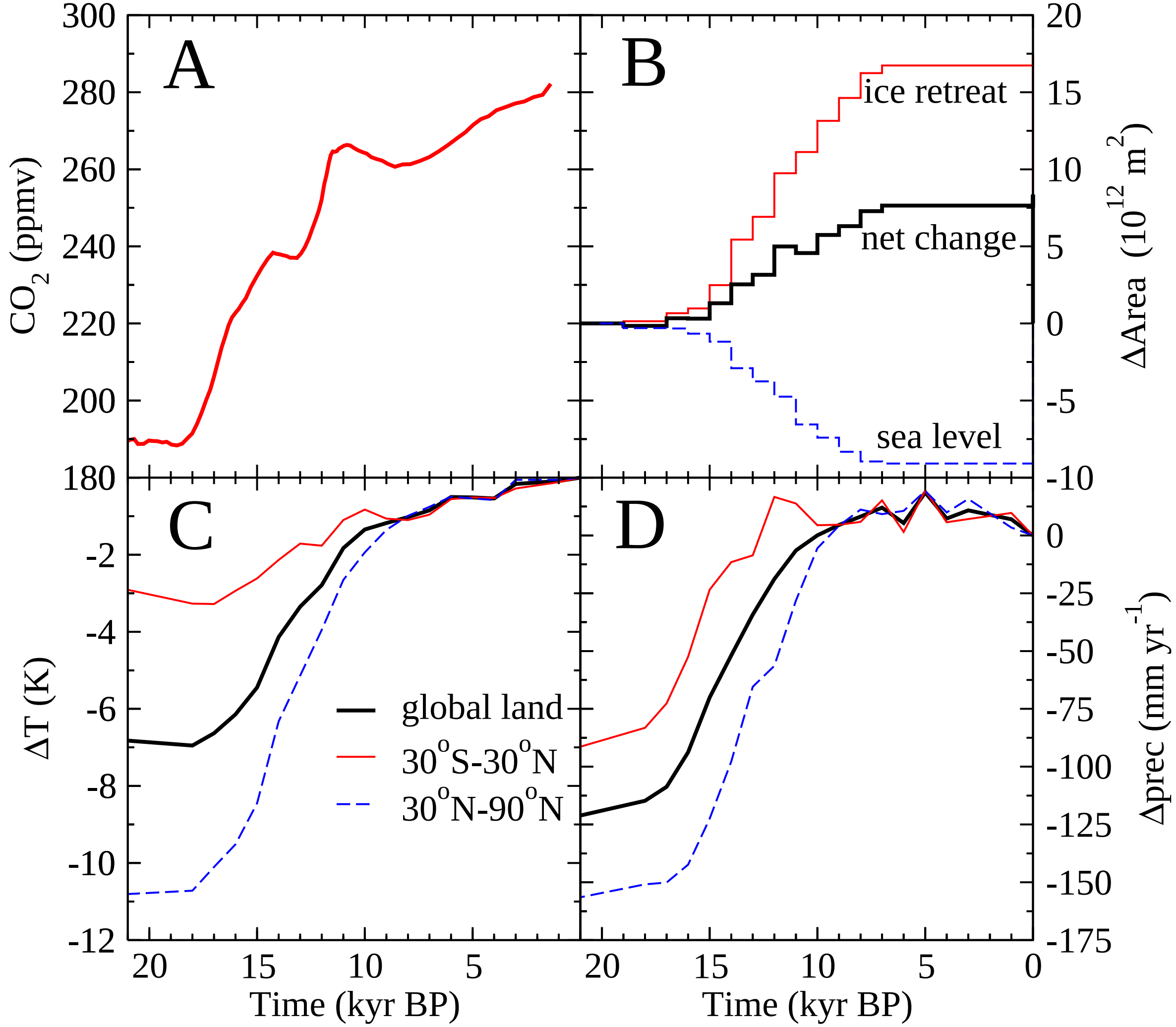


Drivers:
– monthly mean temperature, precipitation and insolation fields
– CO_2
– terrestrial ice free land area

Spatial resolution: 3.75°× 2.5°

Plant functional types (PFT)

Tropical broadleaved evergreen tree
Tropical broadleaved raingreen tree
Temperate needle-leaved evergreen tree
Temperate broadleaved evergreen tree
Temperate broadleaved summergreen tree
Boreal needle-leaved evergreen tree
Boreal summergreen tree
C3 grass
C4 grass



Background forcing of LPJ-DGVM

same as in Joos et al., 2004 GBC.

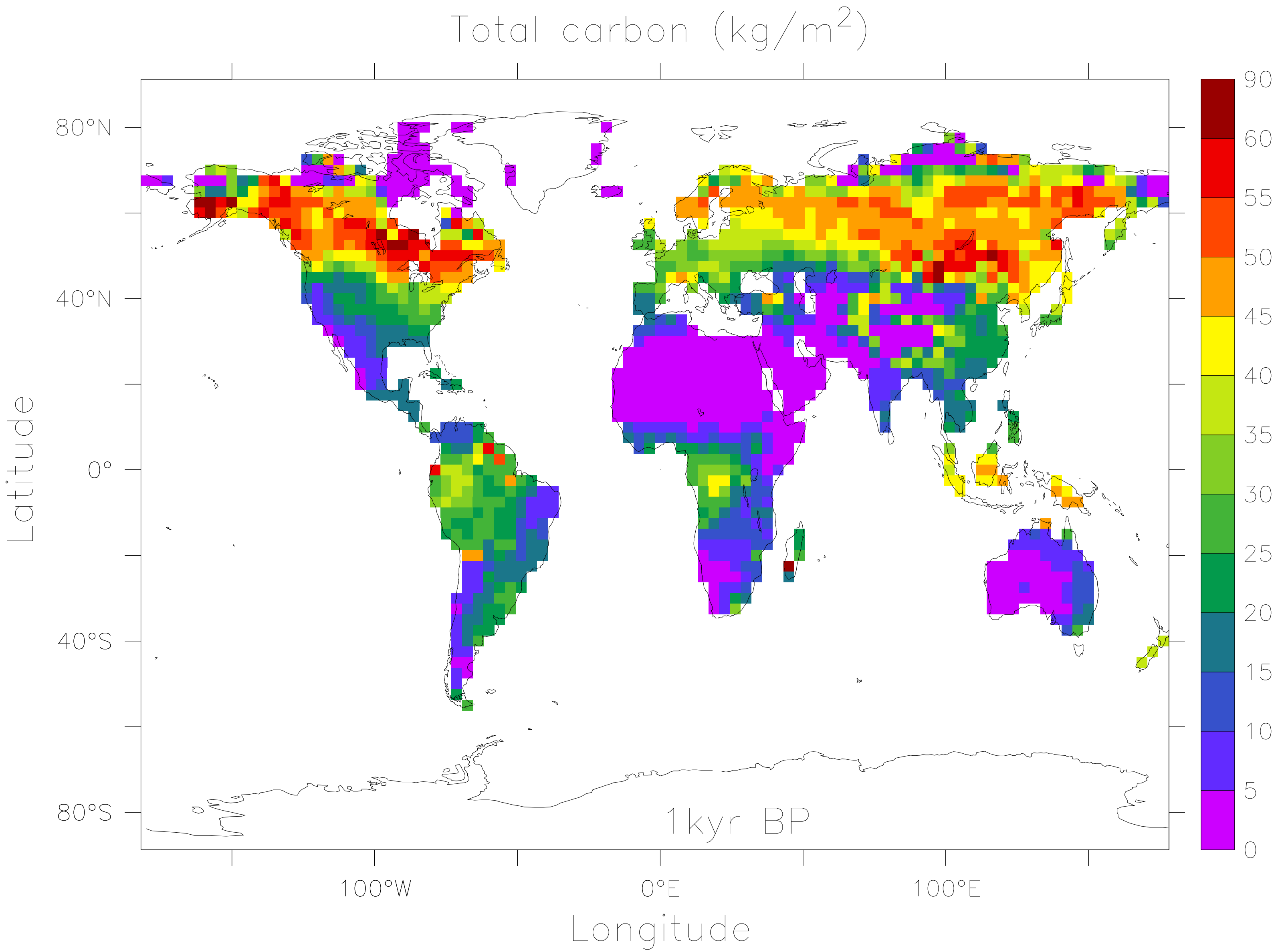
Present day mean climatology (Leemans and Cramer 1991) with following pertubations:

A: CO_2 (EPICA Dome C, Monnin et al., 2001) GISP2 age scale

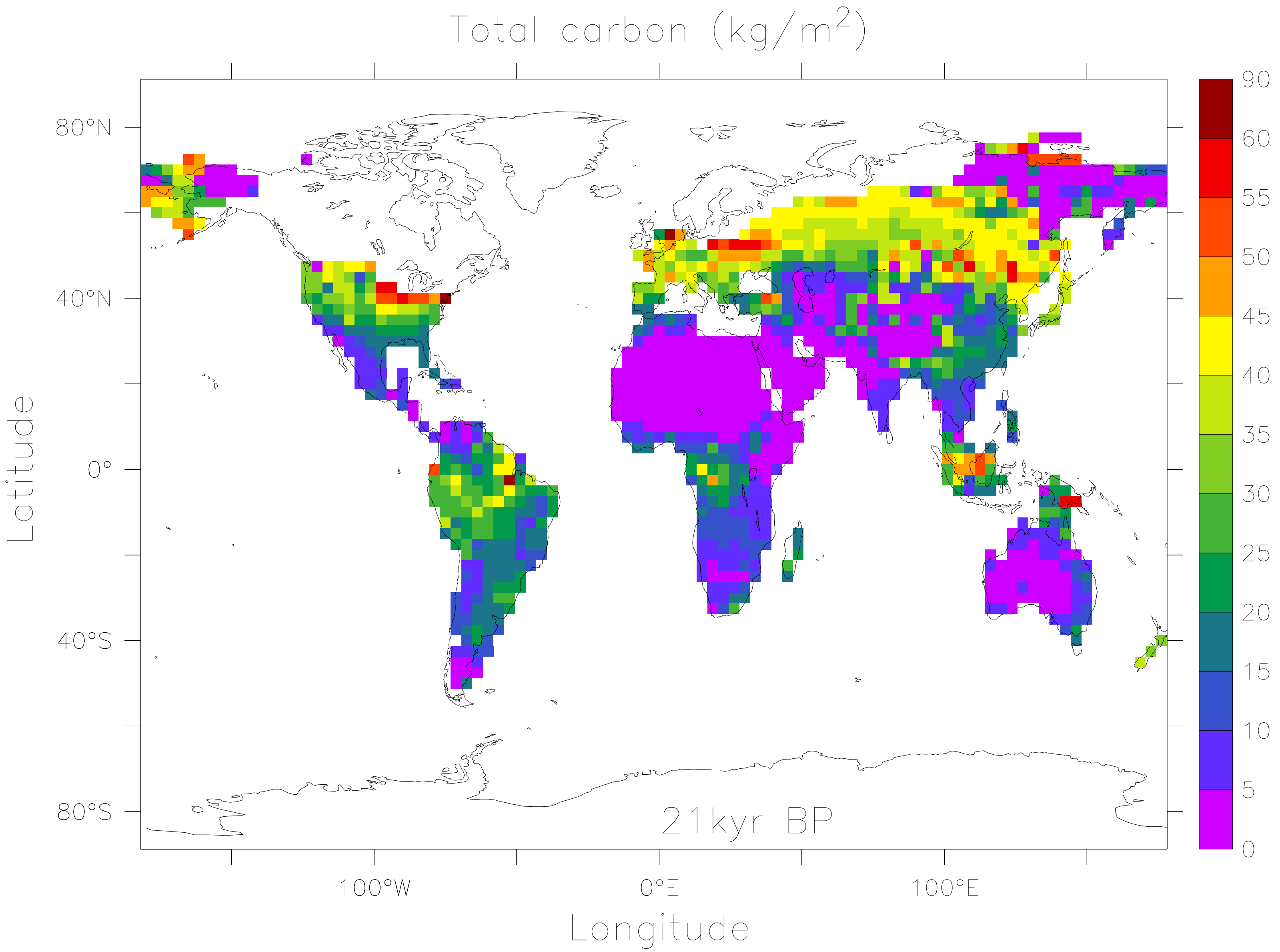
B: land area from Peltier 1994

C,D: ΔT and Δprec from Hadley Centre Unified Model

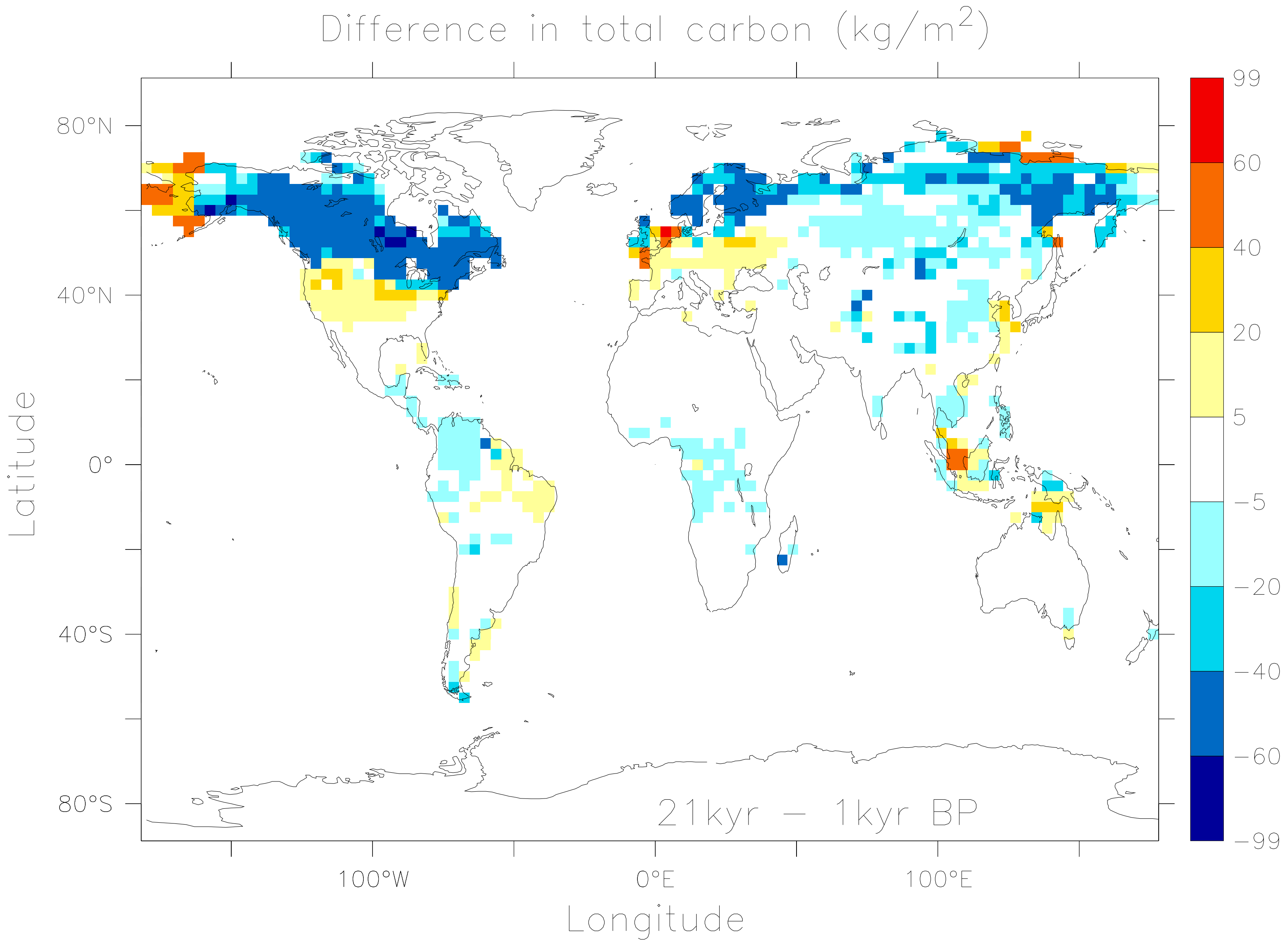
Preindustrial carbon storage LPJ-DGVM



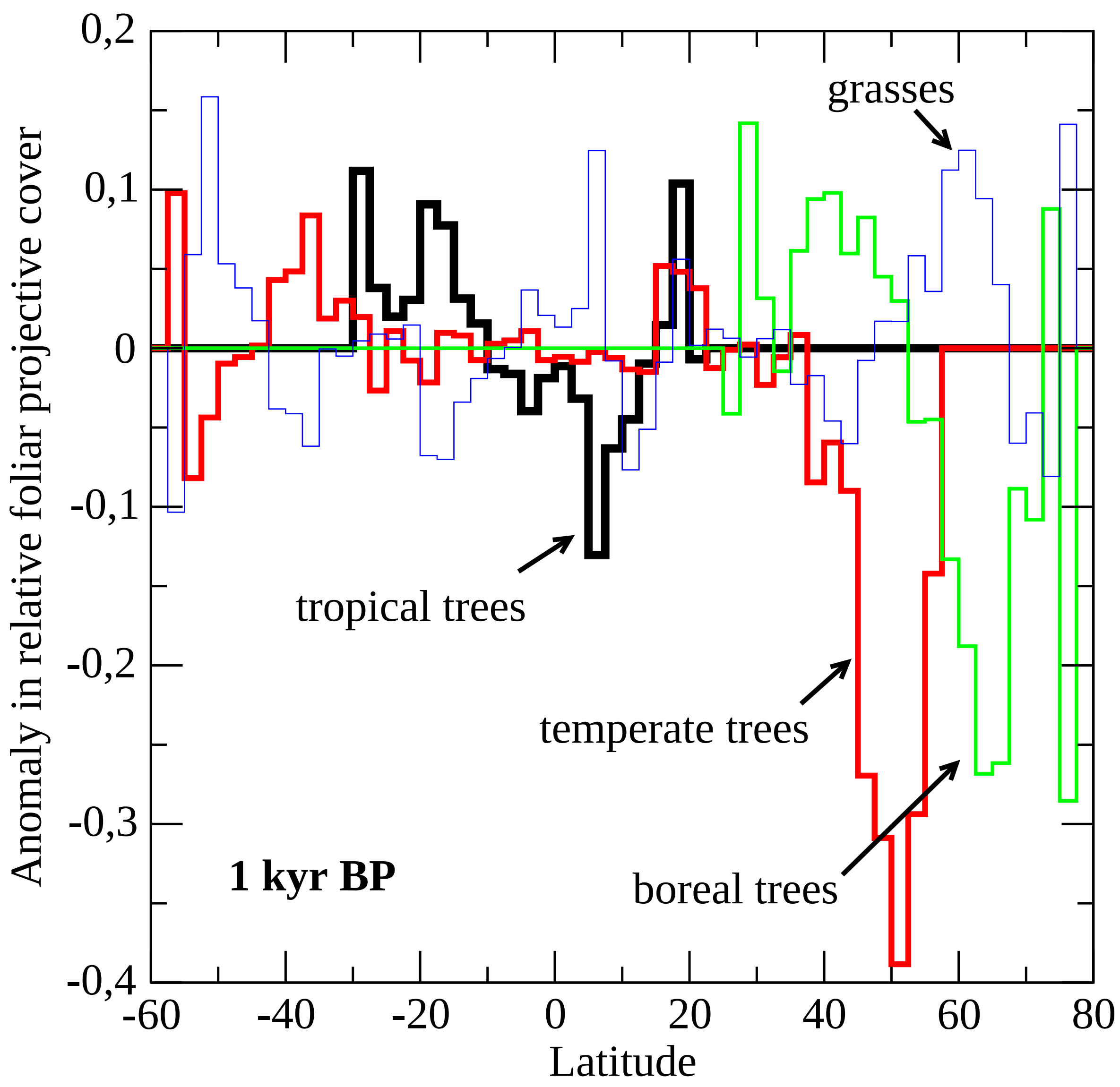
Glacial carbon storage LPJ-DGVM



Difference in carbon storage LPJ-DGVM (21 – 1 kyr BP)



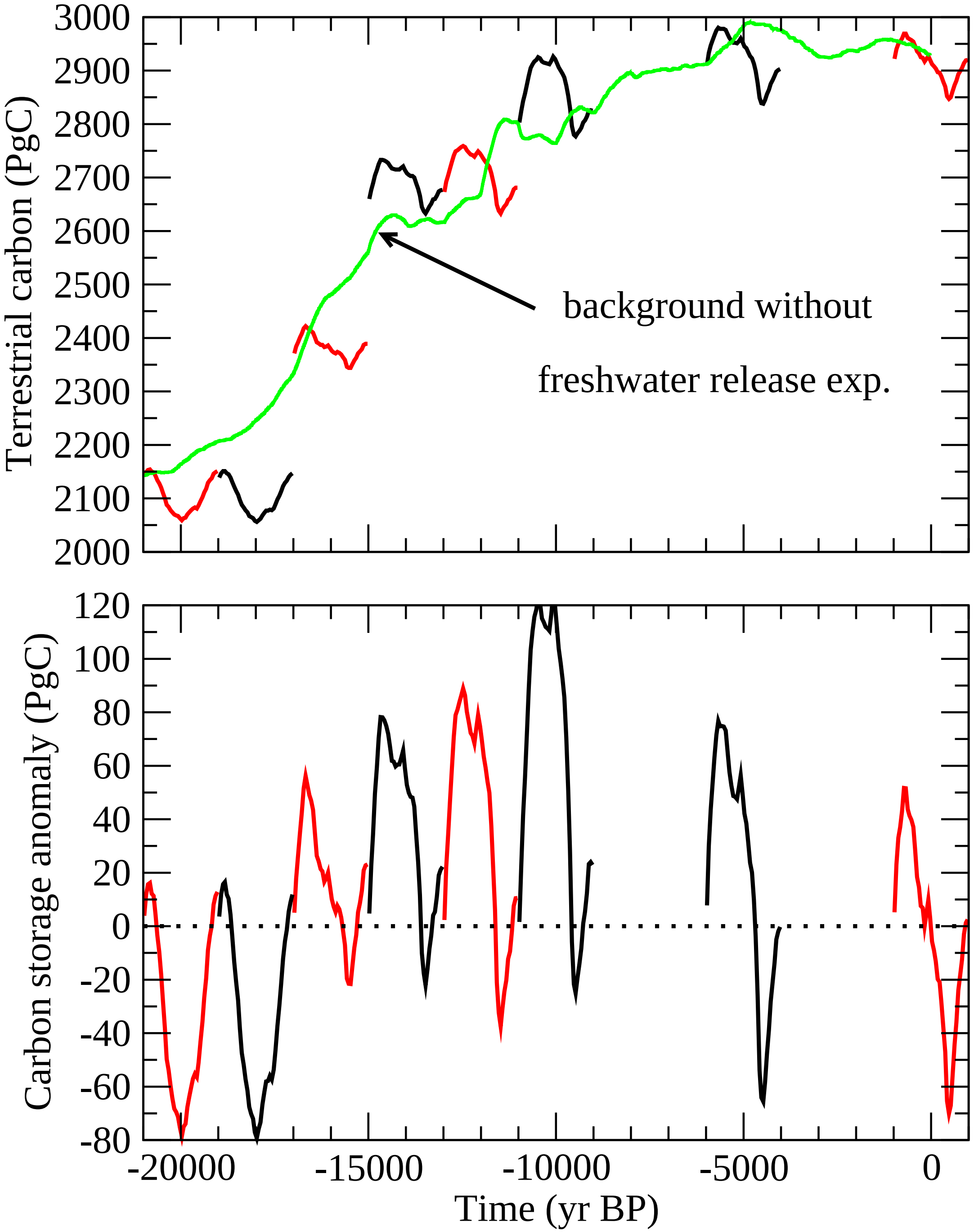
Impact of climate change on vegetation



Grasses replace boreal trees north of 50°N

Boreal trees replace temperate trees in mid high latitudes

Small reduction in tropical tree cover



Impact of climate change during Termination I

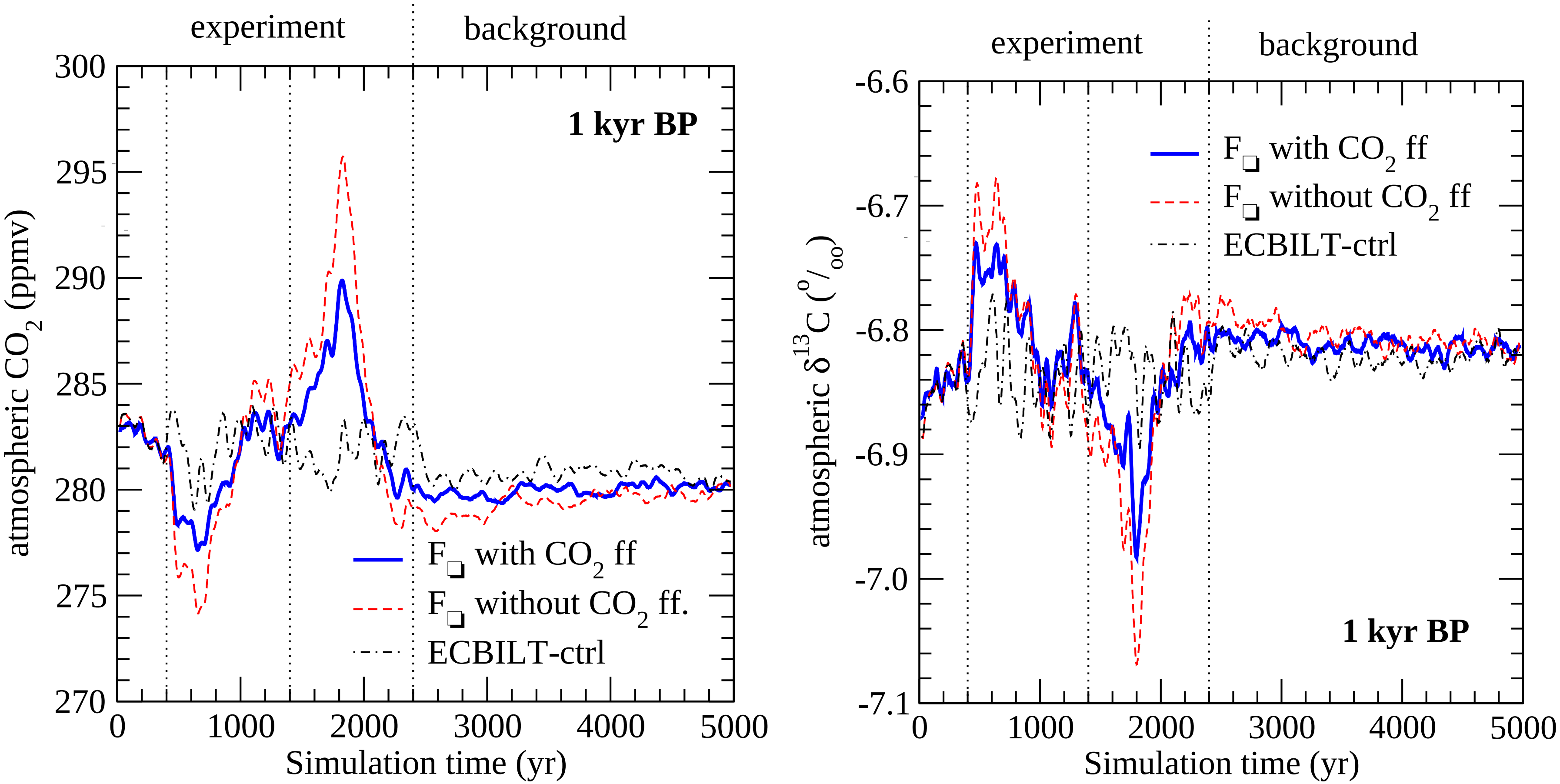
Background terrestrial carbon:

ice retreat:	+ 610 PgC
sea level rise:	− 190 PgC
CO_2 fertilization:	+ 650 PgC
climate change:	− 250 PgC
total:	+ 820 PgC

Size and direction of carbon storage anomaly depends on background climate.

Atmospheric carbon records

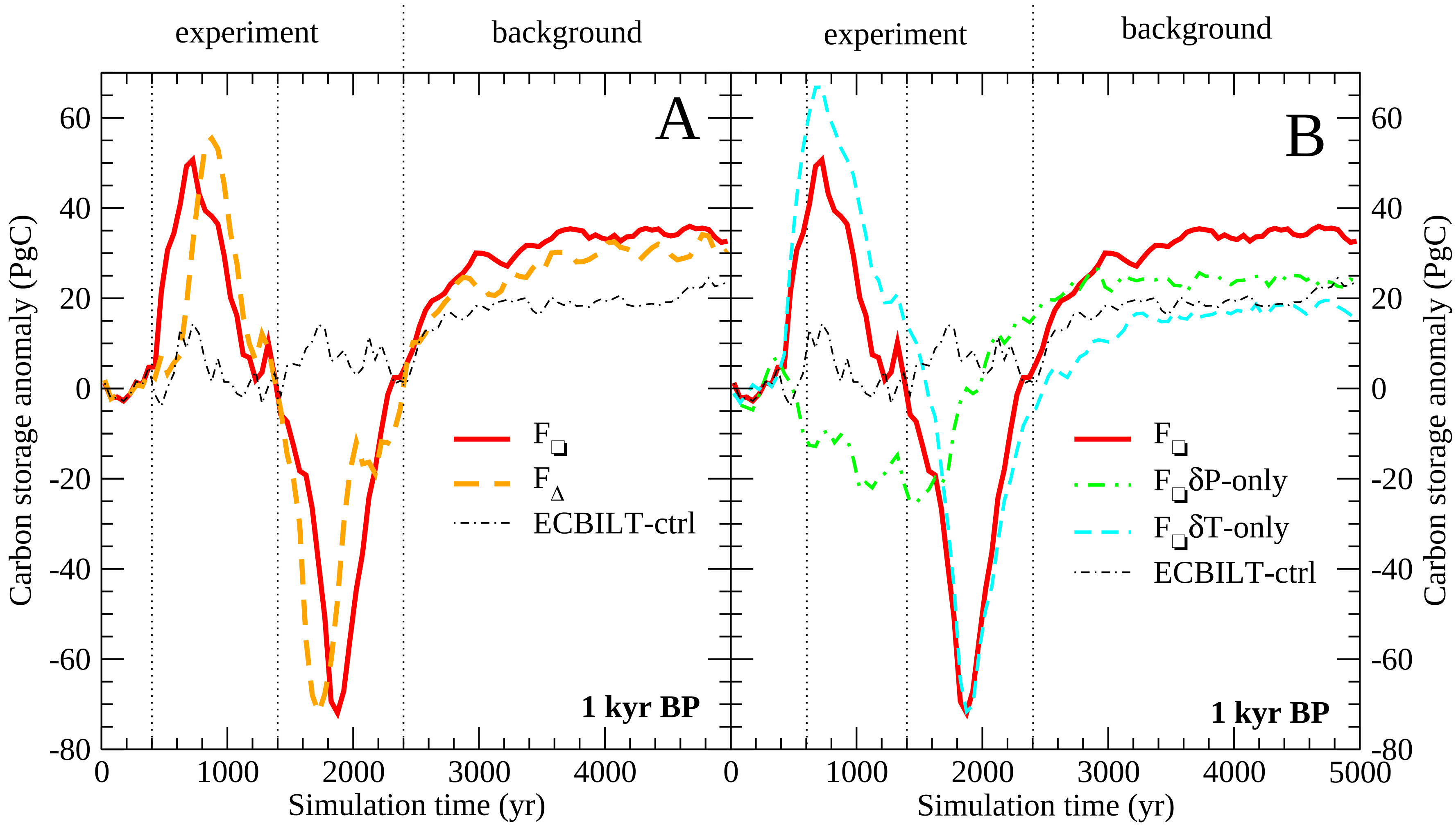
LPJ anomalies coupled to the HILDA carbon cycle model



Peak-to-peak-amplitudes:

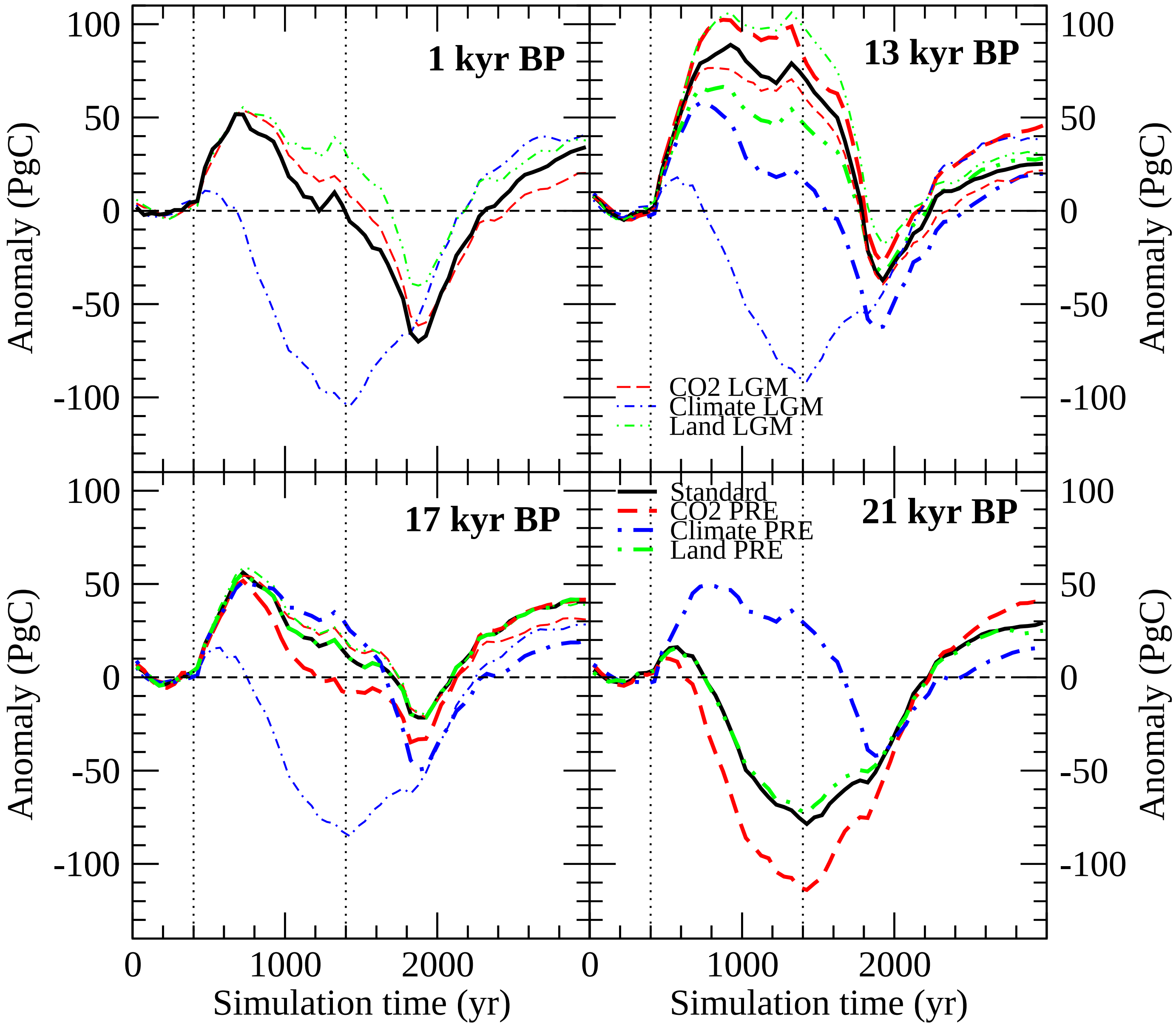
$\Delta CO_2 = 13$ and 21 ppmv $\qquad \Delta\delta^{13}C = 0.24$ and 0.40 ‰

Sensitivity studies



Shape of freshwater discharge

Temperature vs. Precipitation

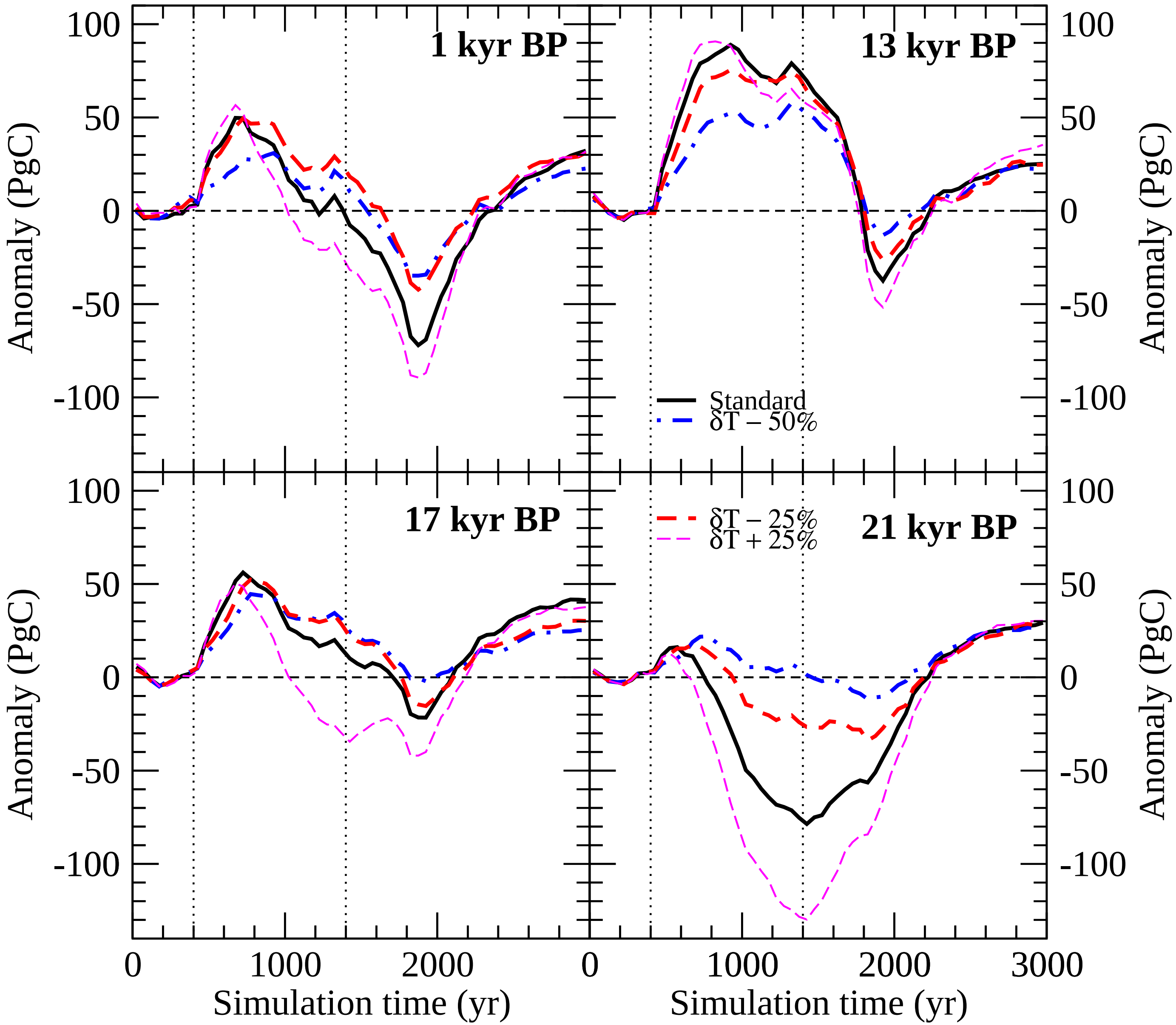


Sensitivity analysis on boundary conditions

without CO_2 fertilization

vary CO_2
vary climate
vary land area

LPJ is most sensitive to climate variations



Sensitivity analysis on the magnitude of the temperature anomaly (ΔT)

without CO_2 fertilization

ΔT − 50%
ΔT − 25%
ΔT + 25%

Especially during full glaciation the magnitude of ΔT constitutes the response