The Bern3D-LPX climate-carbon cycle model: Recent developments and applications

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UNIVERSITÄT BERN

OESCHGER CENTRE
CLIMATE CHANGE RESEARCH

outline

Part 1: Introduction

- What is the Bern3D-LPX model?
- Who are the people working with it? And how?

Part 2: Recent examples of application

- Paleo: Reconstruction of past ^{14}C production
- Present/Future: Terrestrial GHG feedbacks
- Future: Multi-target study

Part 3: Outlook

- Bern3D variable grid

Part 4: Summary

The history of the Bern carbon-cycle model

model name	IPCC	model components: atm	sea ice	ocean	land
Bern	SAR	0D		multi-box (HILDA)	4-box biosphere
BernCC-LPJ	TAR	0D		multi-box (HILDA)	DGVM (LPJ)
Bern2.5D-LPJ	AR4	1D EBM	1D	zonally averaged (3 basins)	DGVM (LPJ)
Bern3D-LPX	AR5	2D EBM	2D	3D (GOLDSTEIN)	DGVM (LPX)

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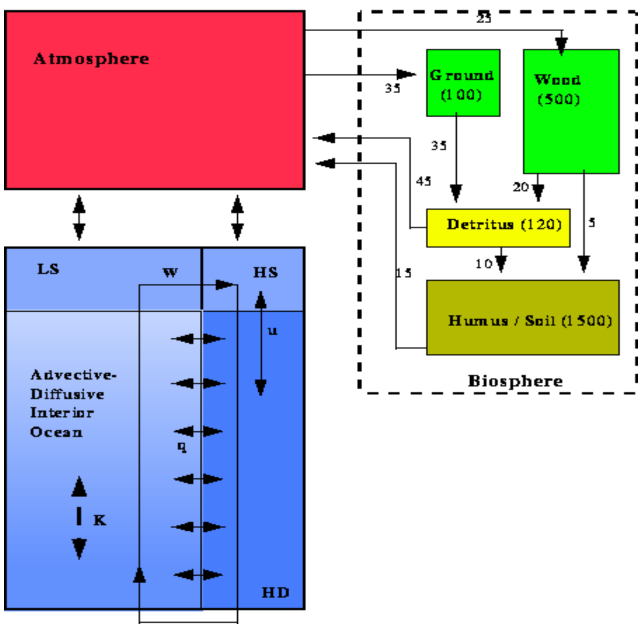
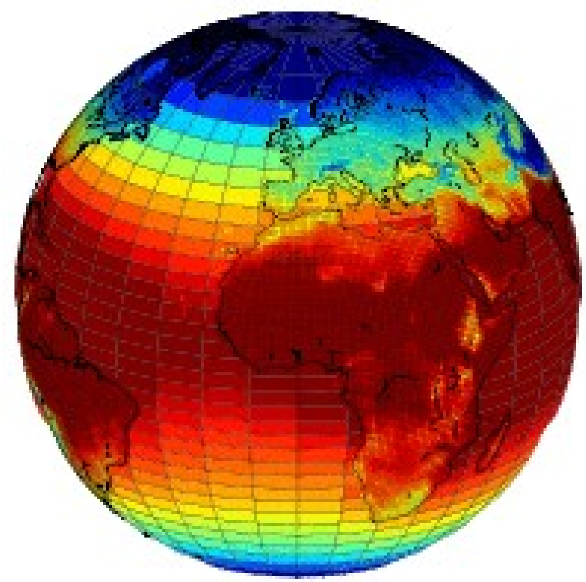
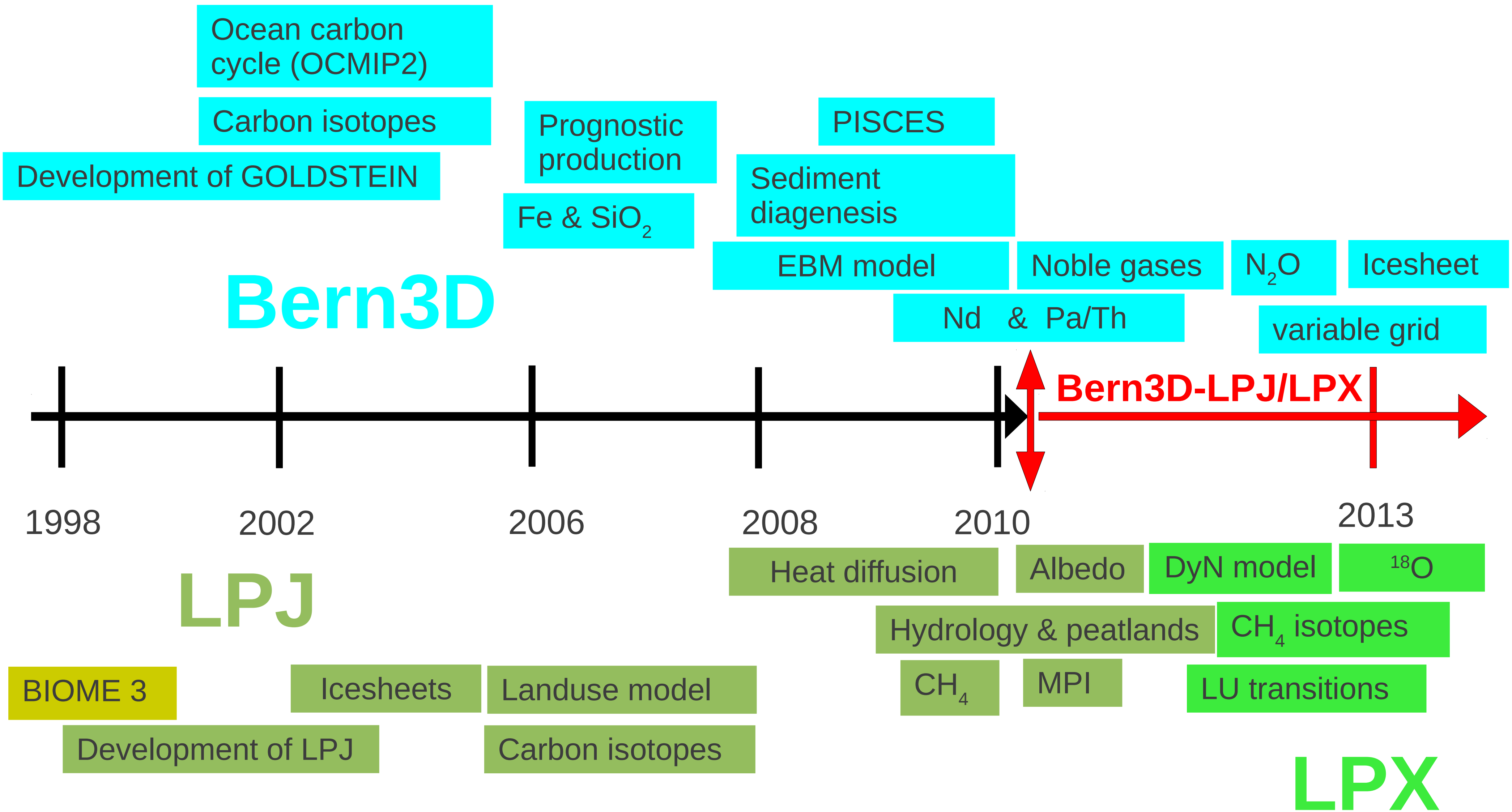
original Bern model (~1995)



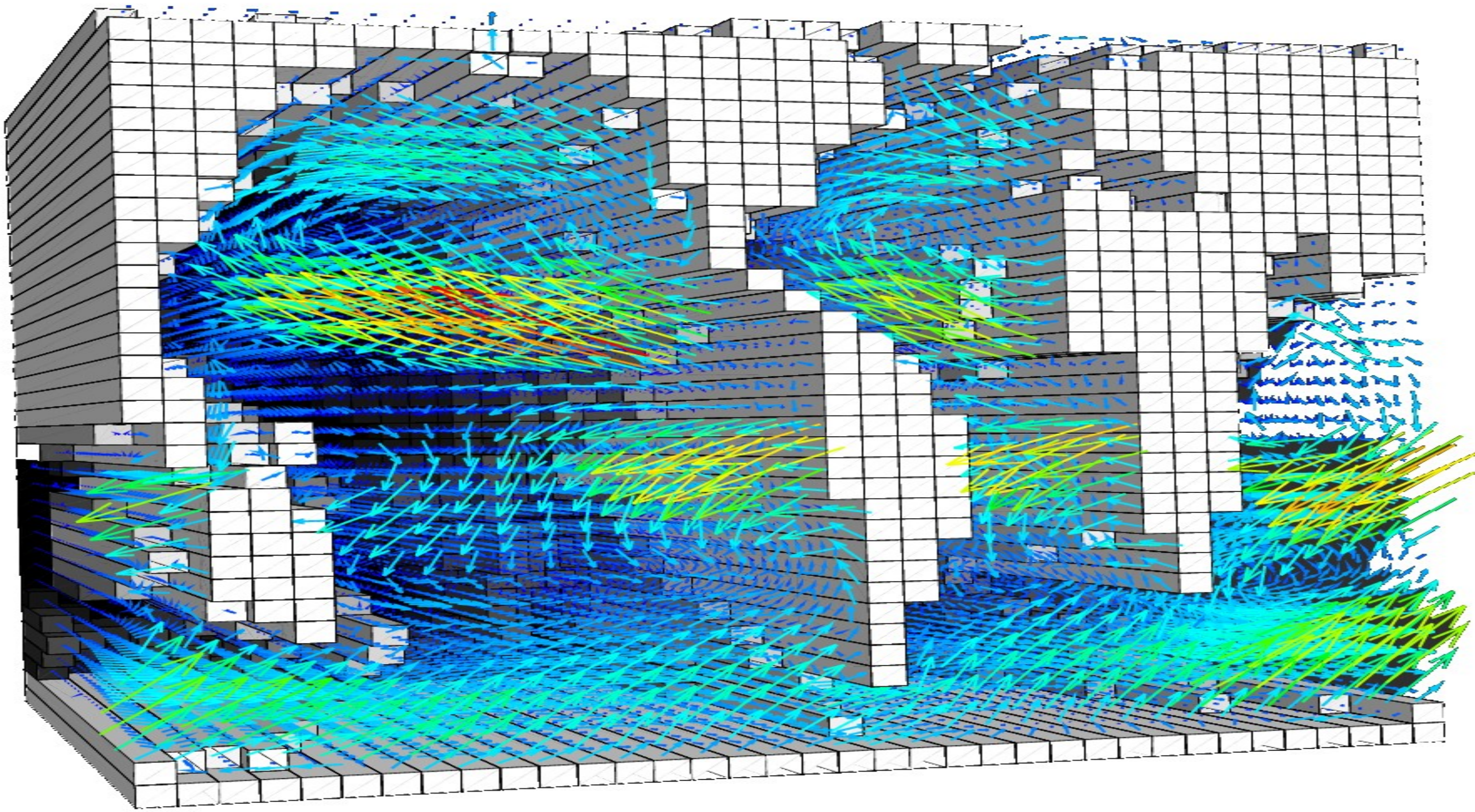
Bern3D-LPX (~2012)



What is the Bern3D-LPX model?

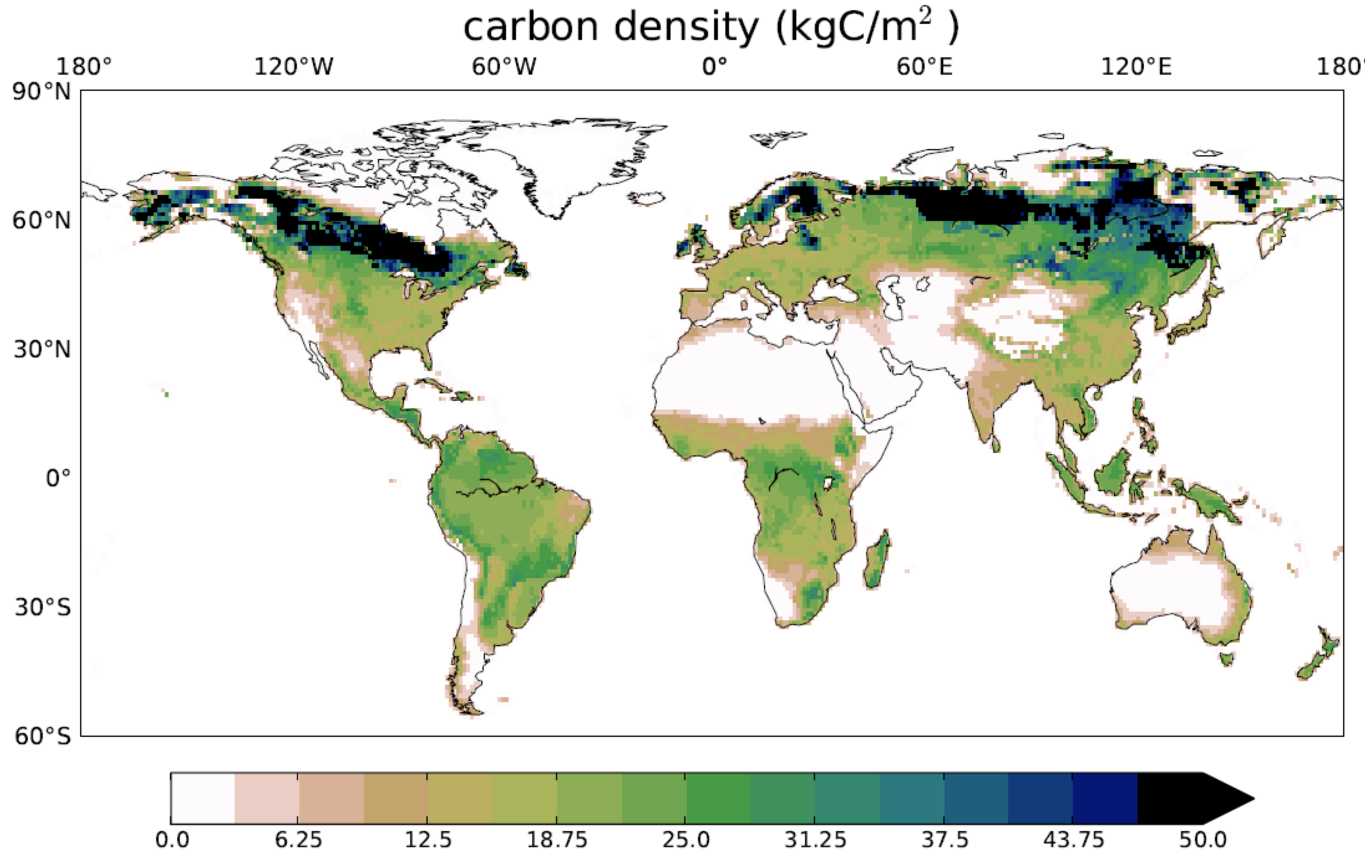


The Bern3D ocean/atmosphere model



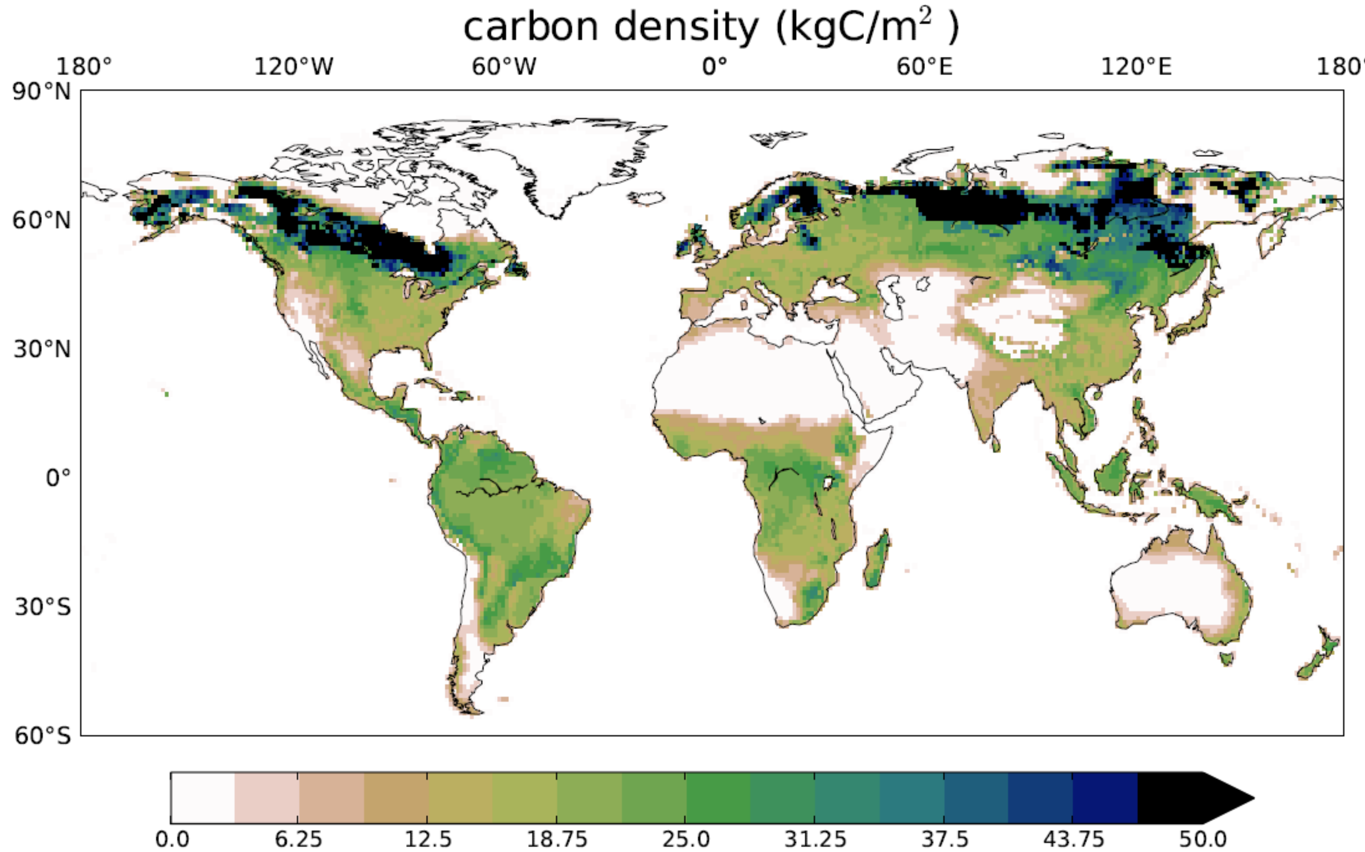
- 36x36x32 boxes → focus on large scale response (i.e. basin-scale)
- Frictional-geostrophic balance with velocity relaxation → not an OGCM
- OCMIP2-type foodweb model, extended with Fe and SiO cycle
- Sediment diagenesis model
- 2D EBM atmosphere → no dynamics, prescribed winds etc

The LPJ/LPX global dynamic vegetation model



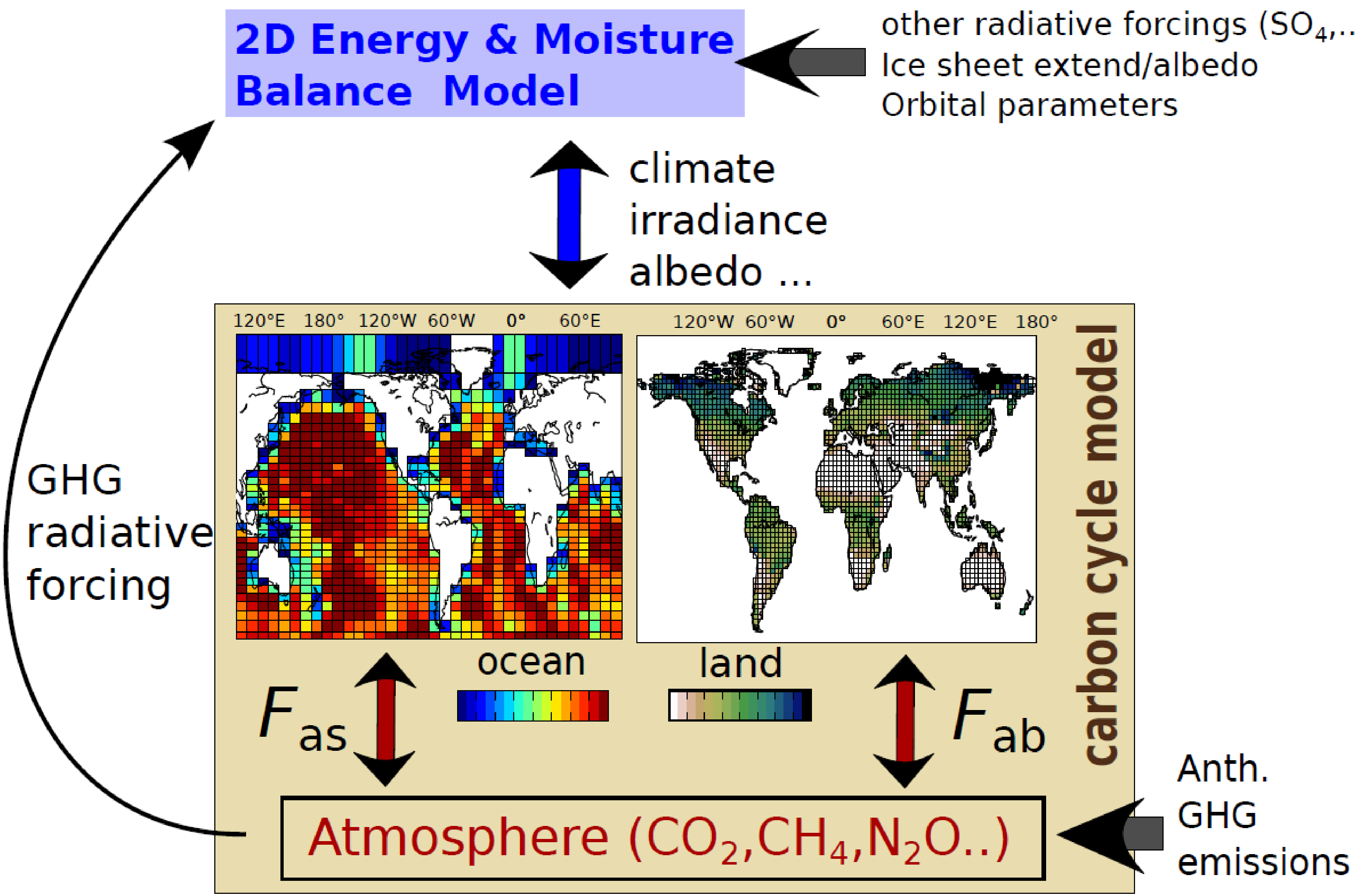
- Independent cells → no need to simulate global domain
- Land-classes : natural, wetland, cropland, buried...
- Plant functional types (PFTs)
- C & N pools : Vegetation, litter, soil, products...
- Variable resolution: 2.5° x 3.75°, 1° x 1°, 0.5° x 0.5° depending on application

The LPJ/LPX global dynamic vegetation model



“**input:** climate, $p\mathrm{CO_2}$ → **output:** NEP, $\mathrm{eN_2O}$, $\mathrm{eCH_4}$, albedo”

Coupled setup



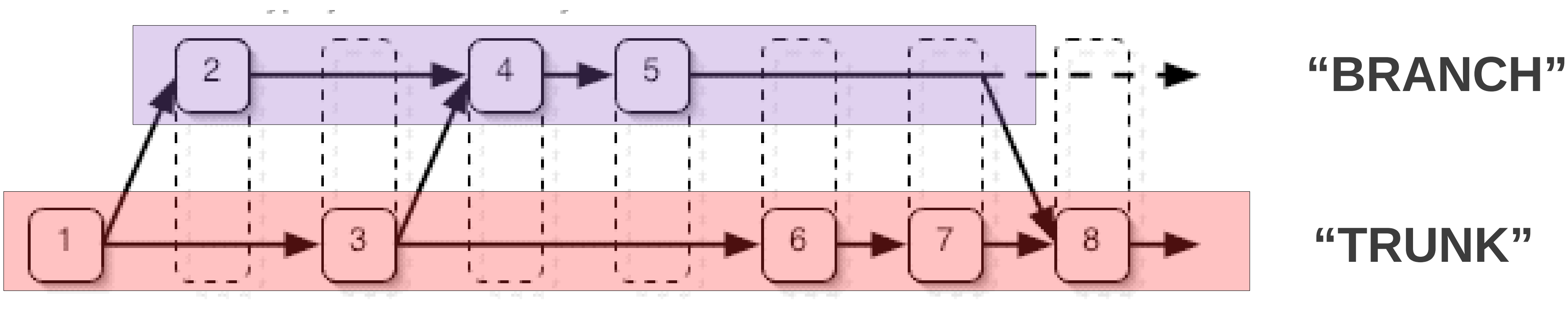
The Bern3D-LPX code

*Fortran code incl. comments and empty lines

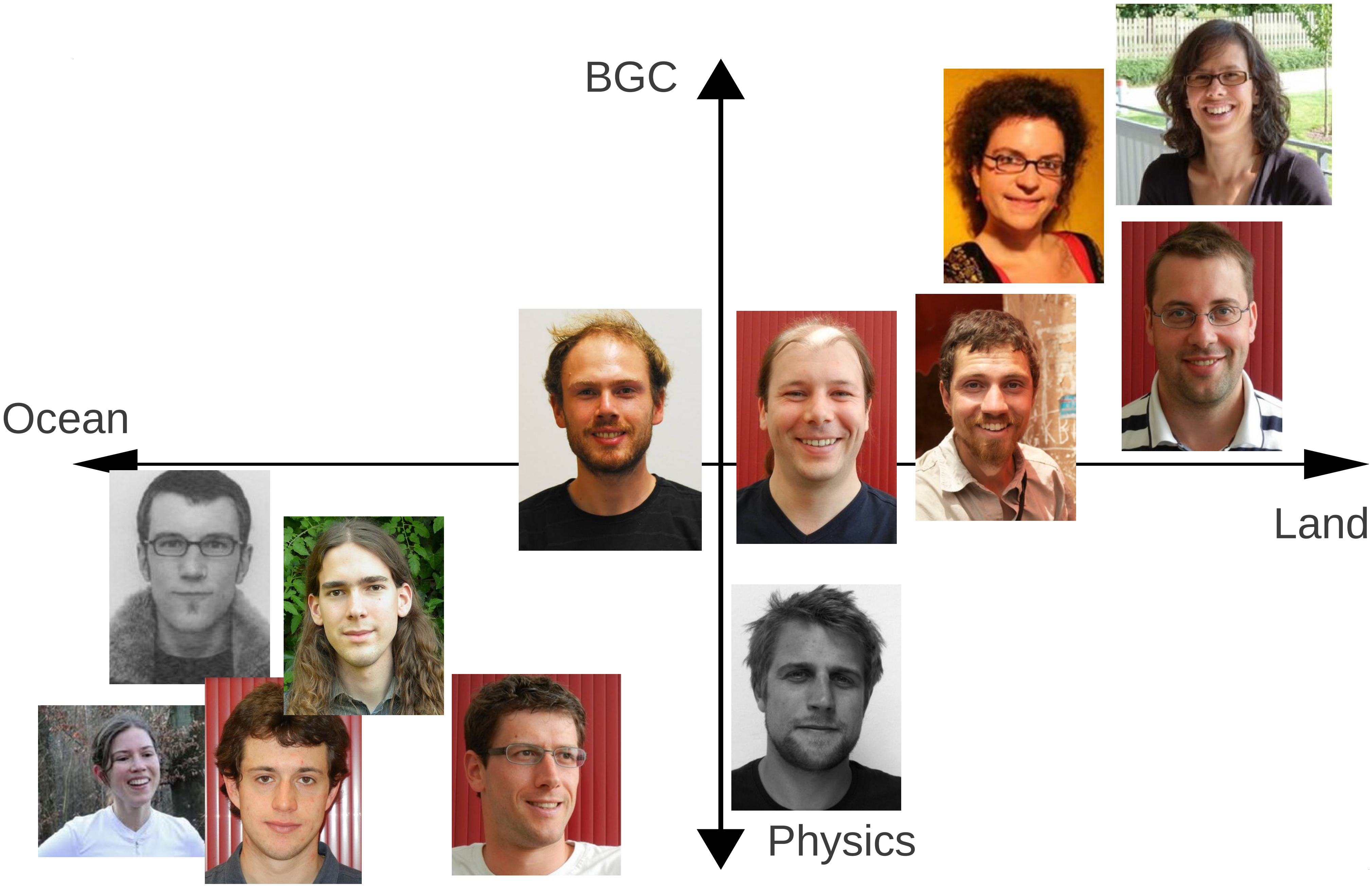
Component	Kilo lines of code (KLOC)*
Bern3D (OCN+BGC+EBM)	48
Sediment	35
LPX	41
TOTAL	**124**

→ version control needed

IPSL:	~340
CESM:	~850
Linux Kernel:	~16'000
Windows XP:	~45'000



The Bern3D-LPX group: Who is who?



Applications of the Bern3D-LPX model

PALEO

Pre-Quaternary experiments
Glacial cycles
Holocene
Last Millennium

PRESENT

Understanding the Earth system
Ocean tracer assimilation
Novel tracers

FUTURE

Global warming scenarios
Allowable emissions
GHG feedbacks

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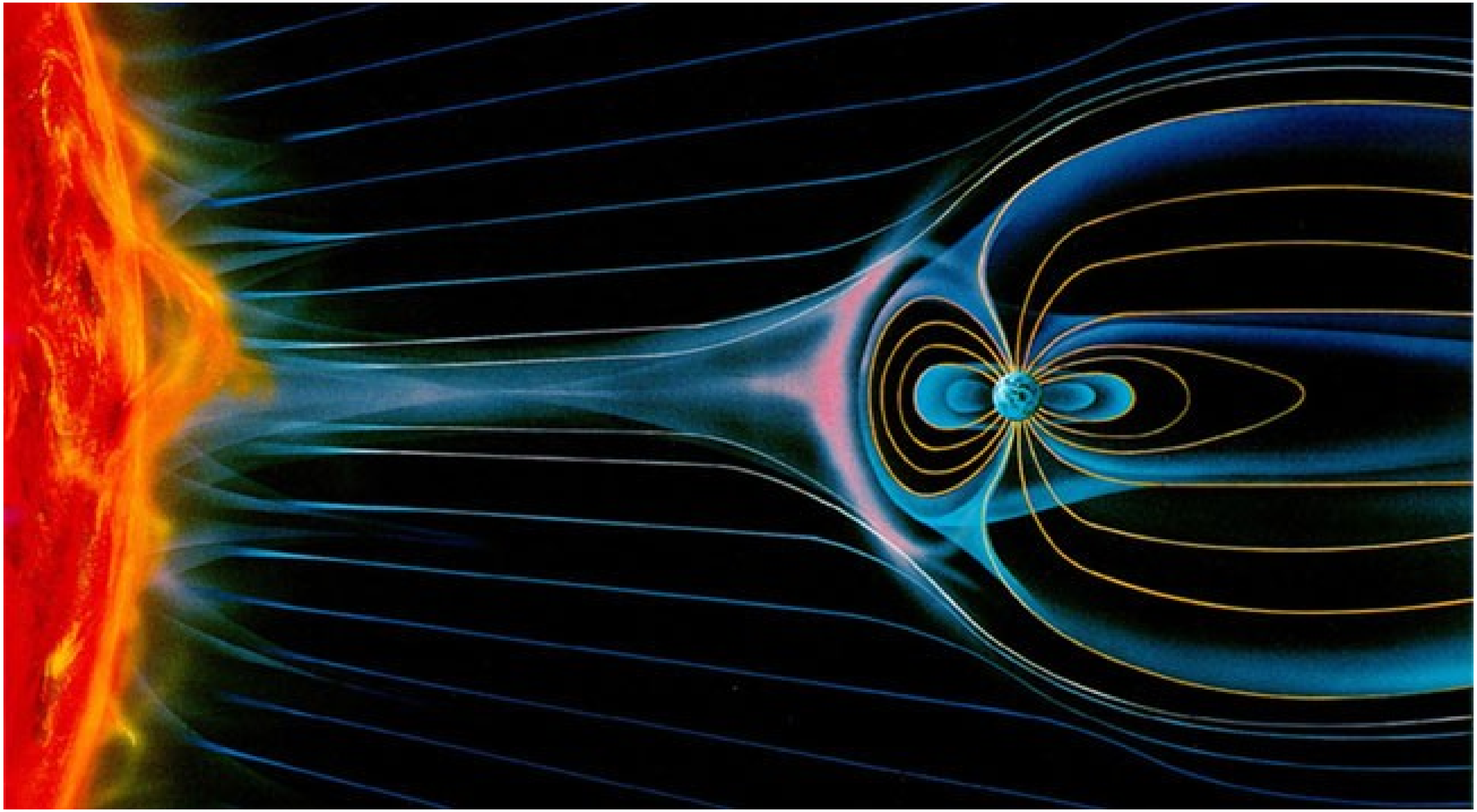
Examples of application

1) Radiocarbon production
Roth and Joos, 2013, CPD

2) Terrestrial GHG feedbacks
Stocker *et al., 2013, Nature CC*

3) Multi-target study
Steinacher et al., 2013, Nature (accepted)

Example 1: ^{14}C production rate

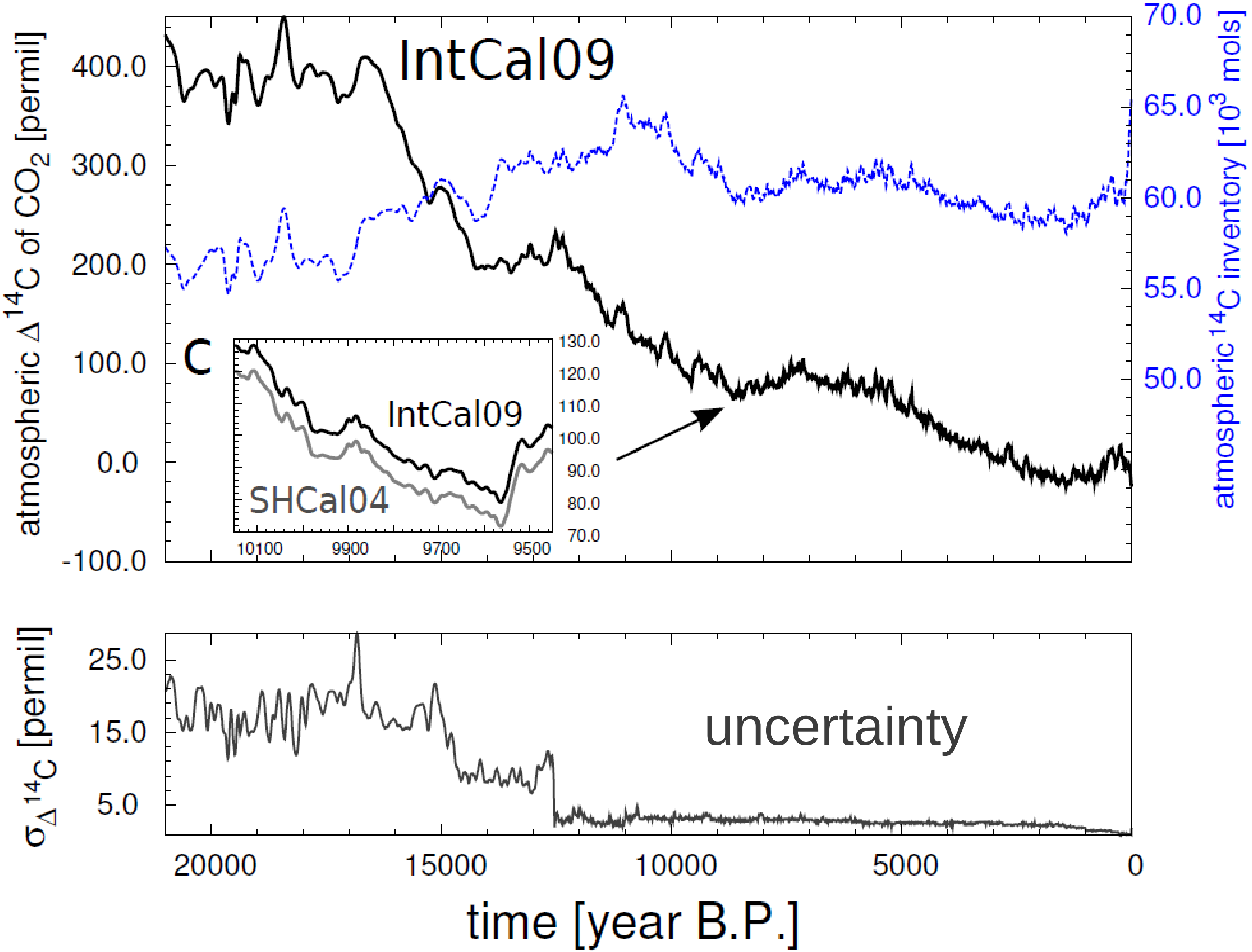


Goal:

Reconstruct the Holocene ^{14}C production rate and compare to earlier box-model reconstructions. Use it as a solar activity proxy.

Example 1: ^{14}C production rate

Graphics in this section are from
Roth and Joos, CPD, 2013



Example 1: ^{14}C production rate

the atmospheric budget equation for radiocarbon:

assumption: well mixed atmosphere!

change in atmospheric ^{14}C

decay of atmospheric ^{14}C

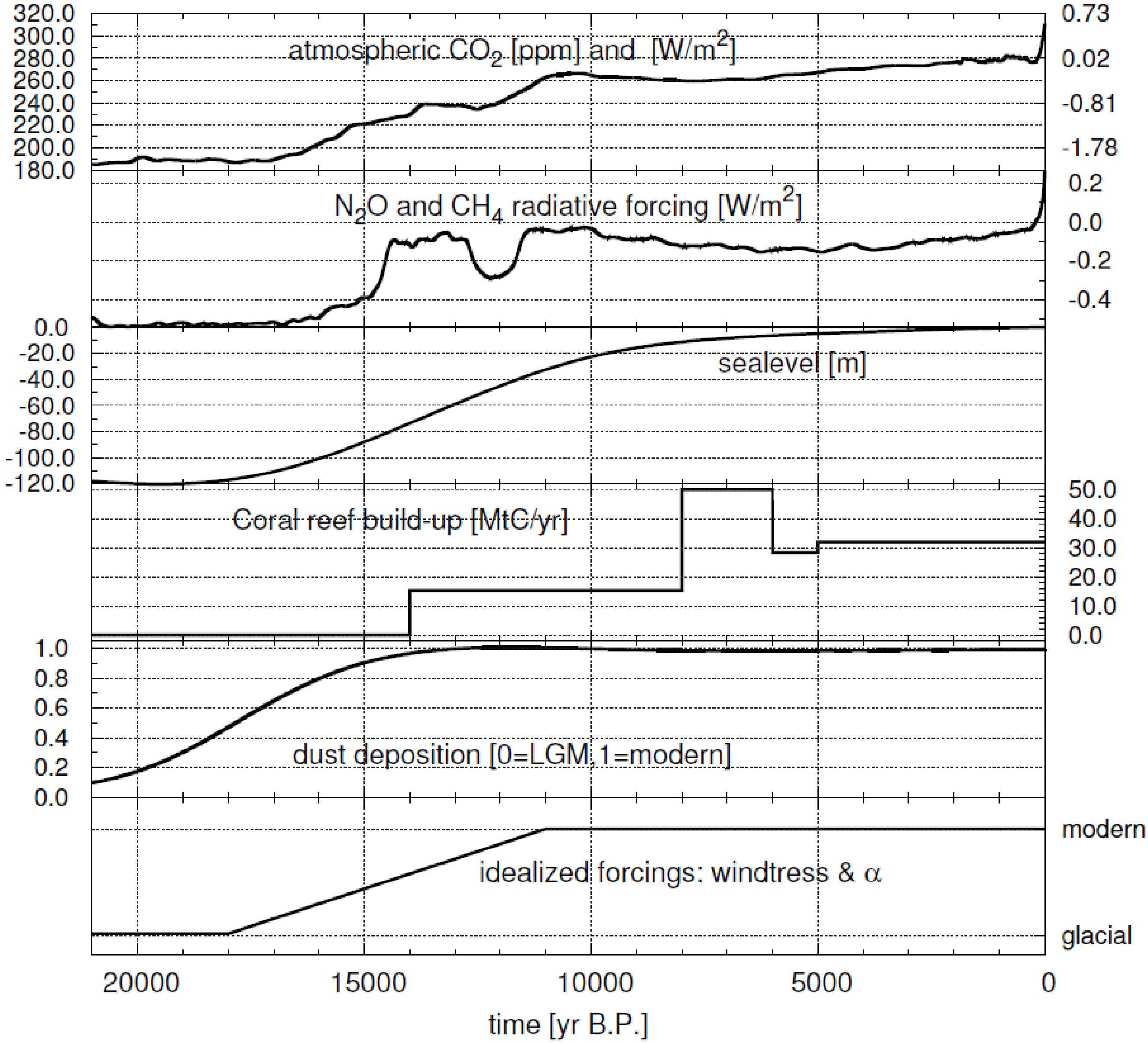
$$Q = {}^{14}F_{as} + {}^{14}F_{ab} + \lambda\, {}^{14}N_a + {}^{14}\dot{N}_a + \ldots$$

air-sea flux

air-biosphere flux

corrections terms

Example 1: ^{14}C production rate



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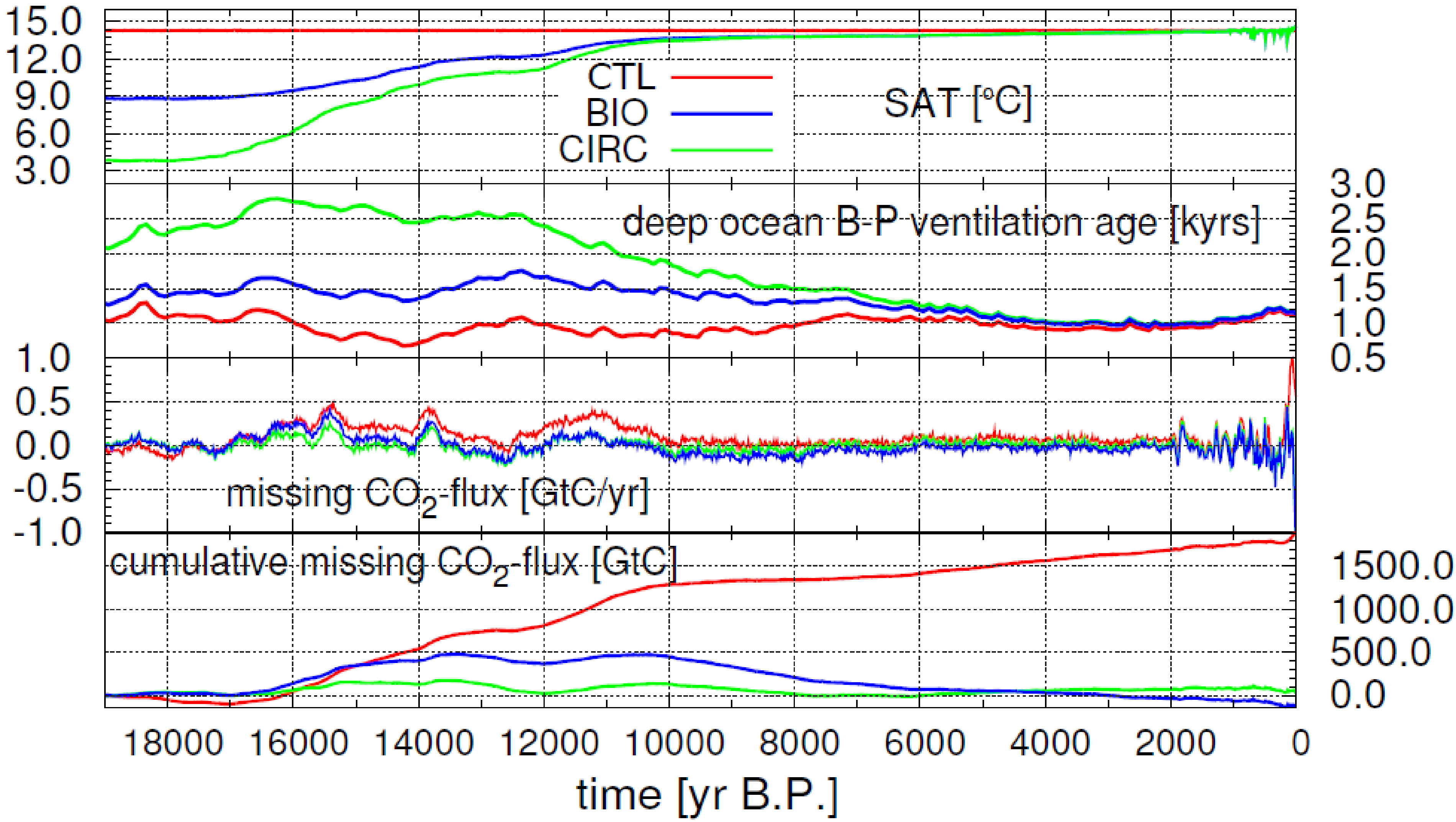

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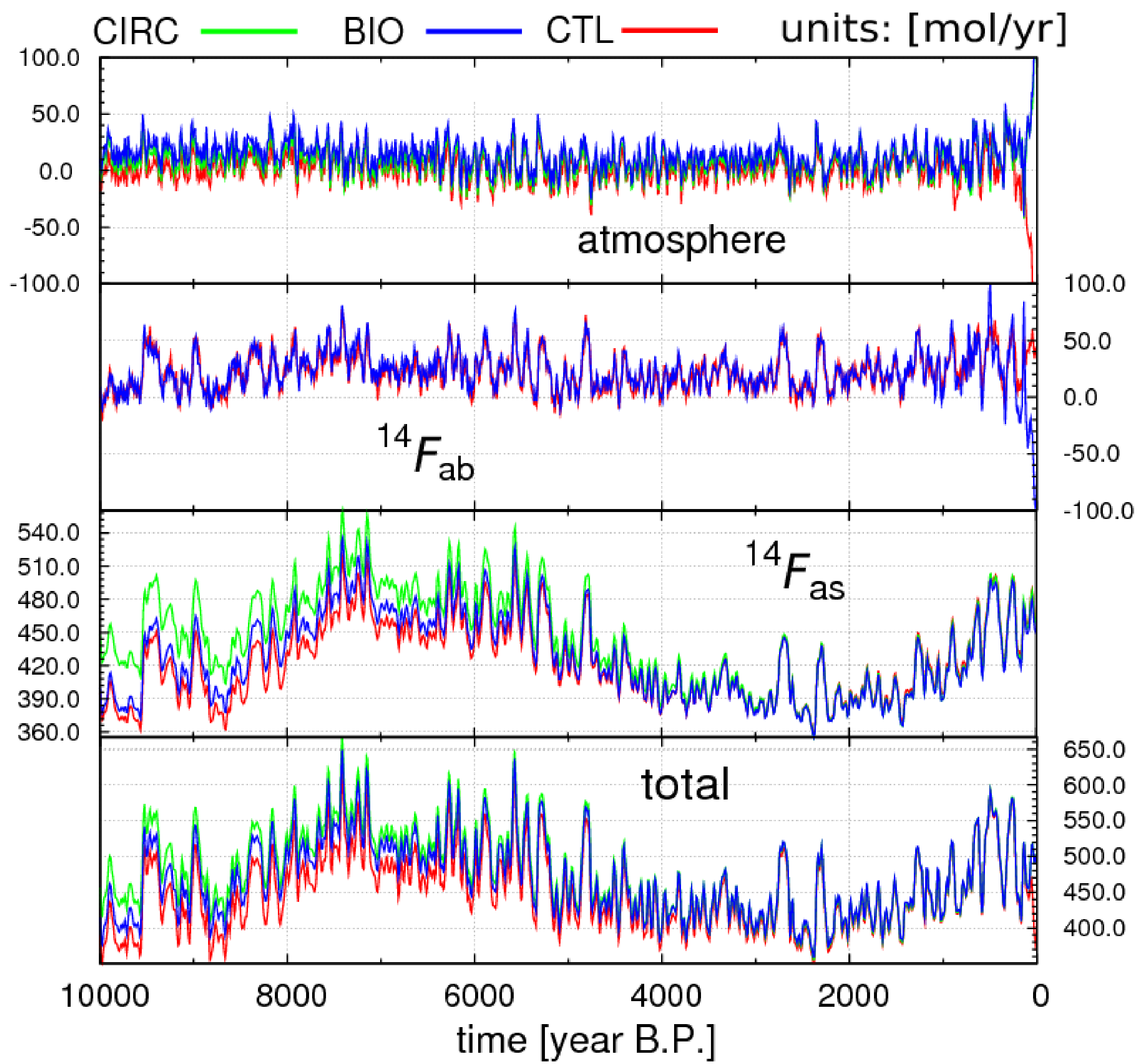

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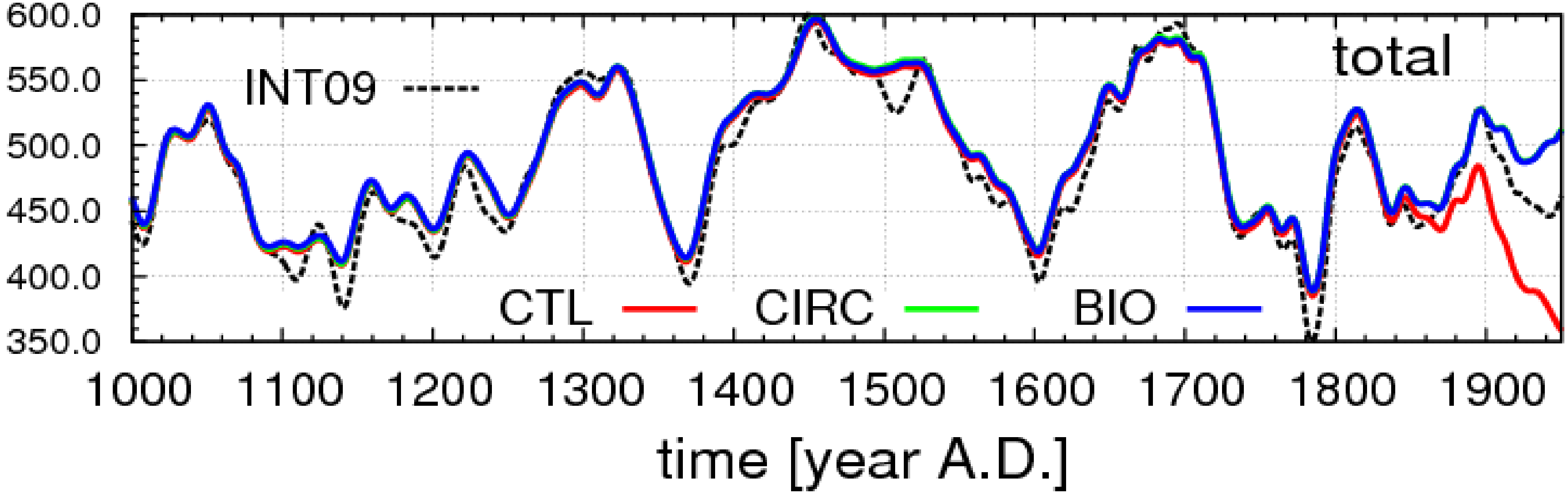

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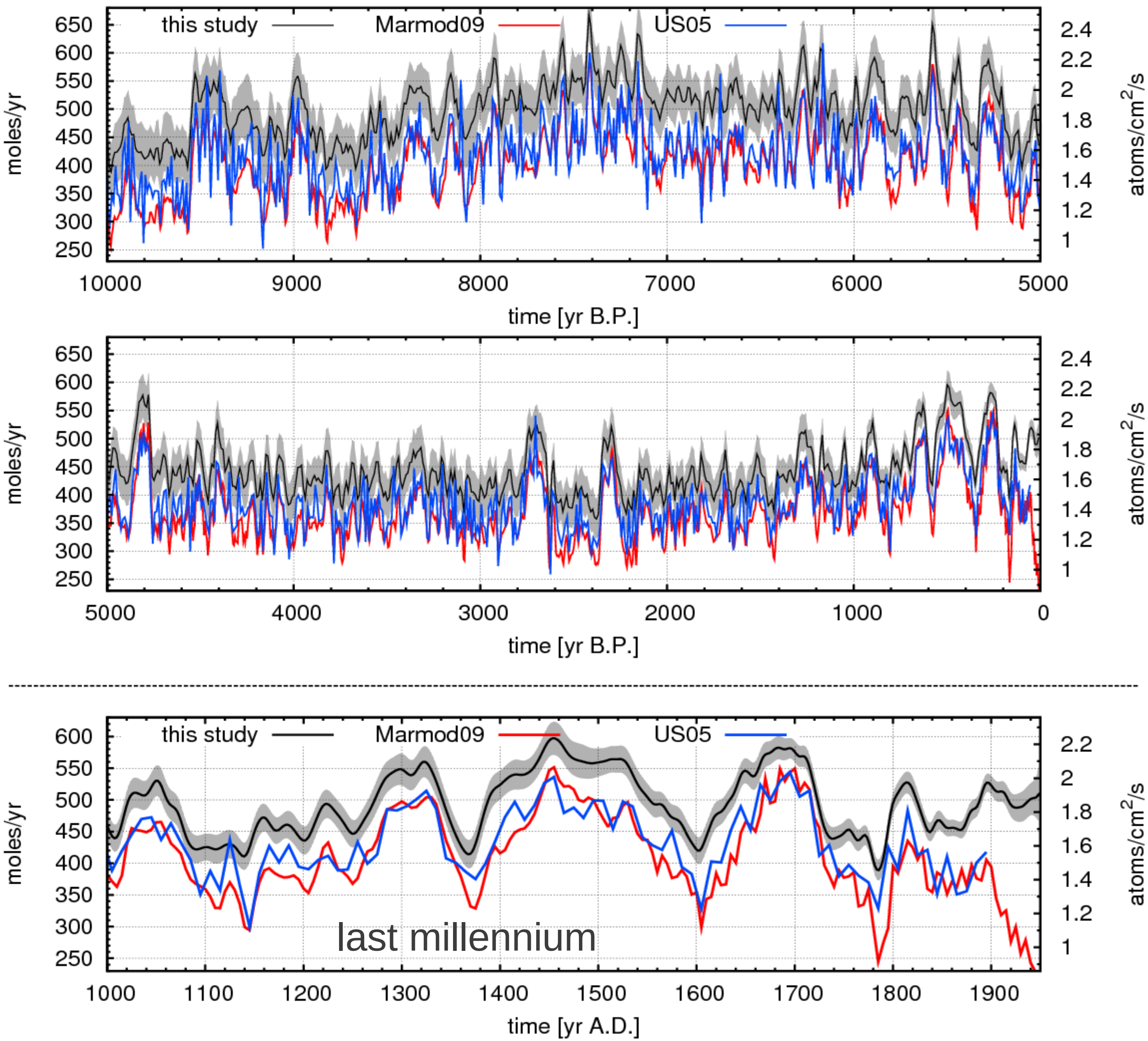


Example 1: ^{14}C production rate

Conclusions:

- Influence of climate on Q is rather small except for the early Holocene
- Q is higher than in previous studies (~1.7 atoms/cm^2/s)
- Interhemispheric ^{14}C gradient does makes a difference

Example 1: ^{14}C production rate

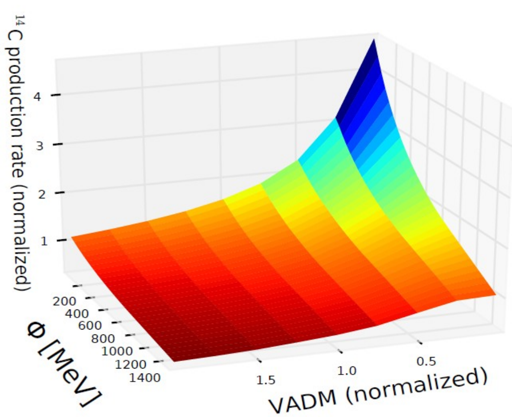
Conclusions:

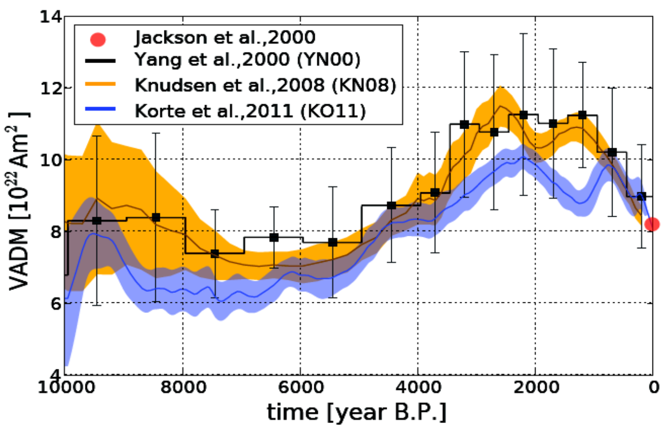
•Influence of climate on Q is rather small except for the early Holocene

•Q is higher than in previous studies (~1.7 atoms/cm^2/s)

•Interhemispheric ^{14}C gradient does makes a difference

Q is then used as a proxy for solar activity → different story



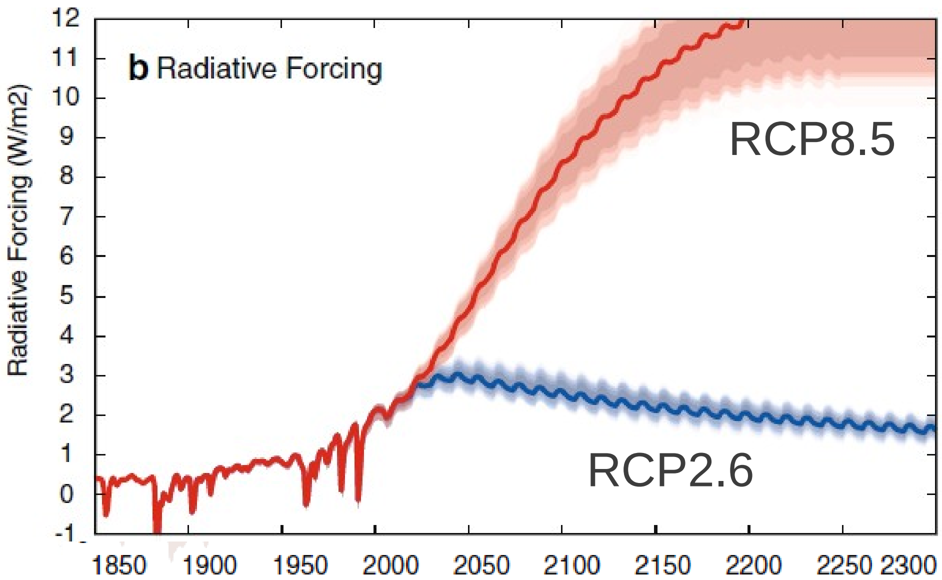


Example 2: Terrestrial GHG feedbacks

Question:

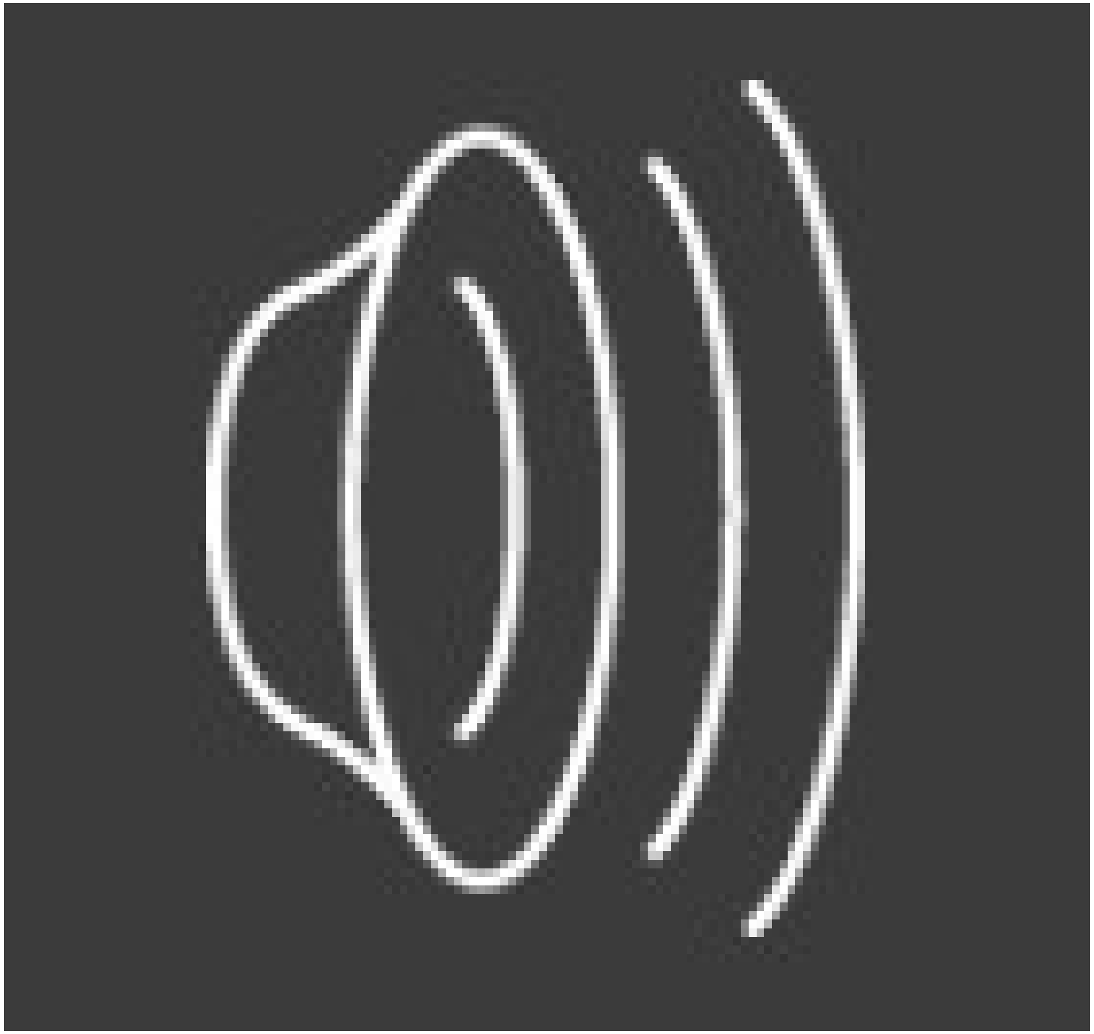
- What is the magnitude of the land feedback, how will it evolve in future scenarios?

- What is the contribution of changing N_2O and CH_4 emissions from the land-biosphere to the total feedback.



Meinshausen et al., 2011, Climatic Change

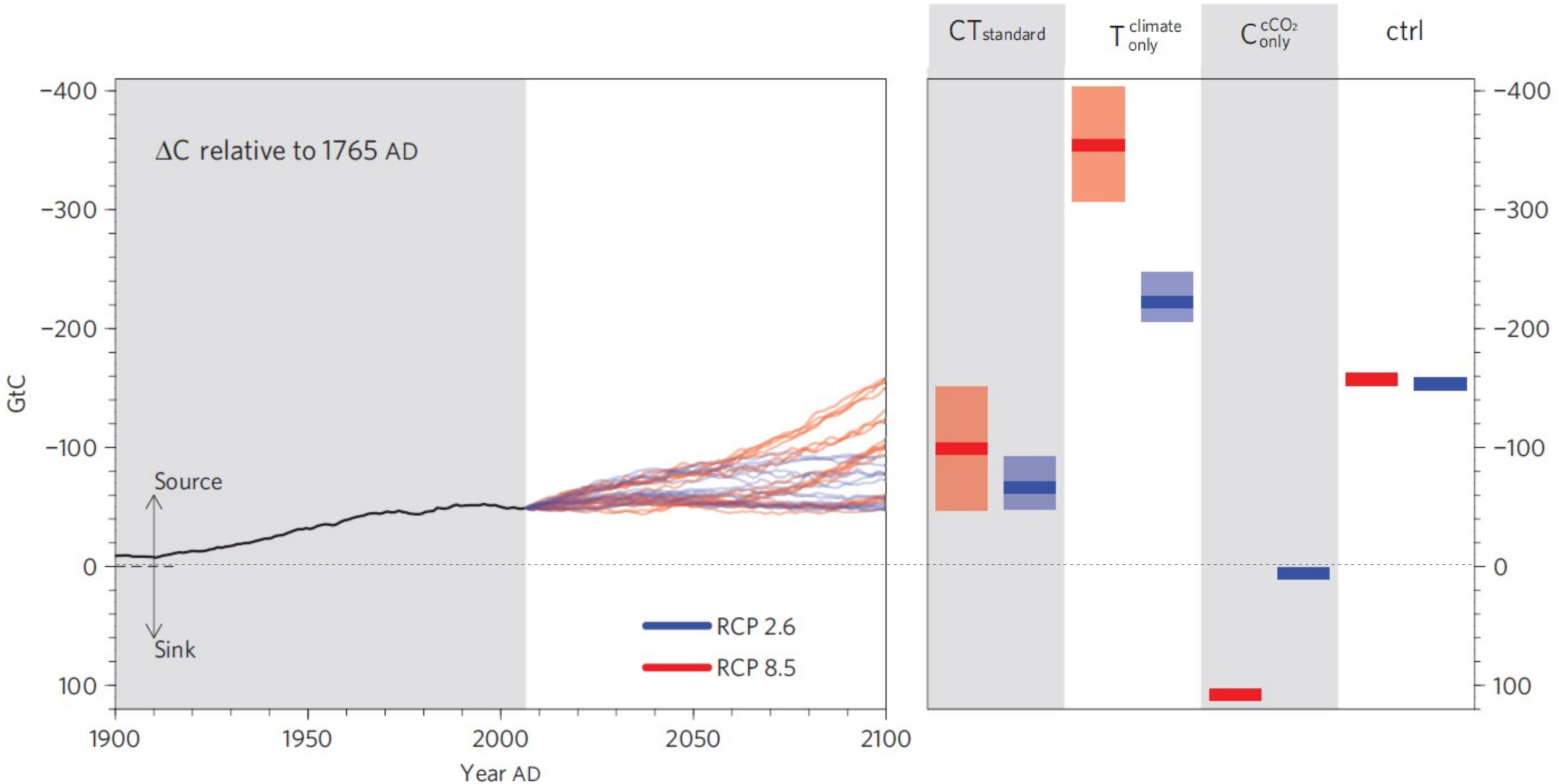
Example 2: Terrestrial GHG feedbacks



Change in carbon density w.r.t. 1765 AD

Example 2: Terrestrial GHG feedbacks

All graphics in this section are from
Stocker et al., 2013, Nature Climate Change



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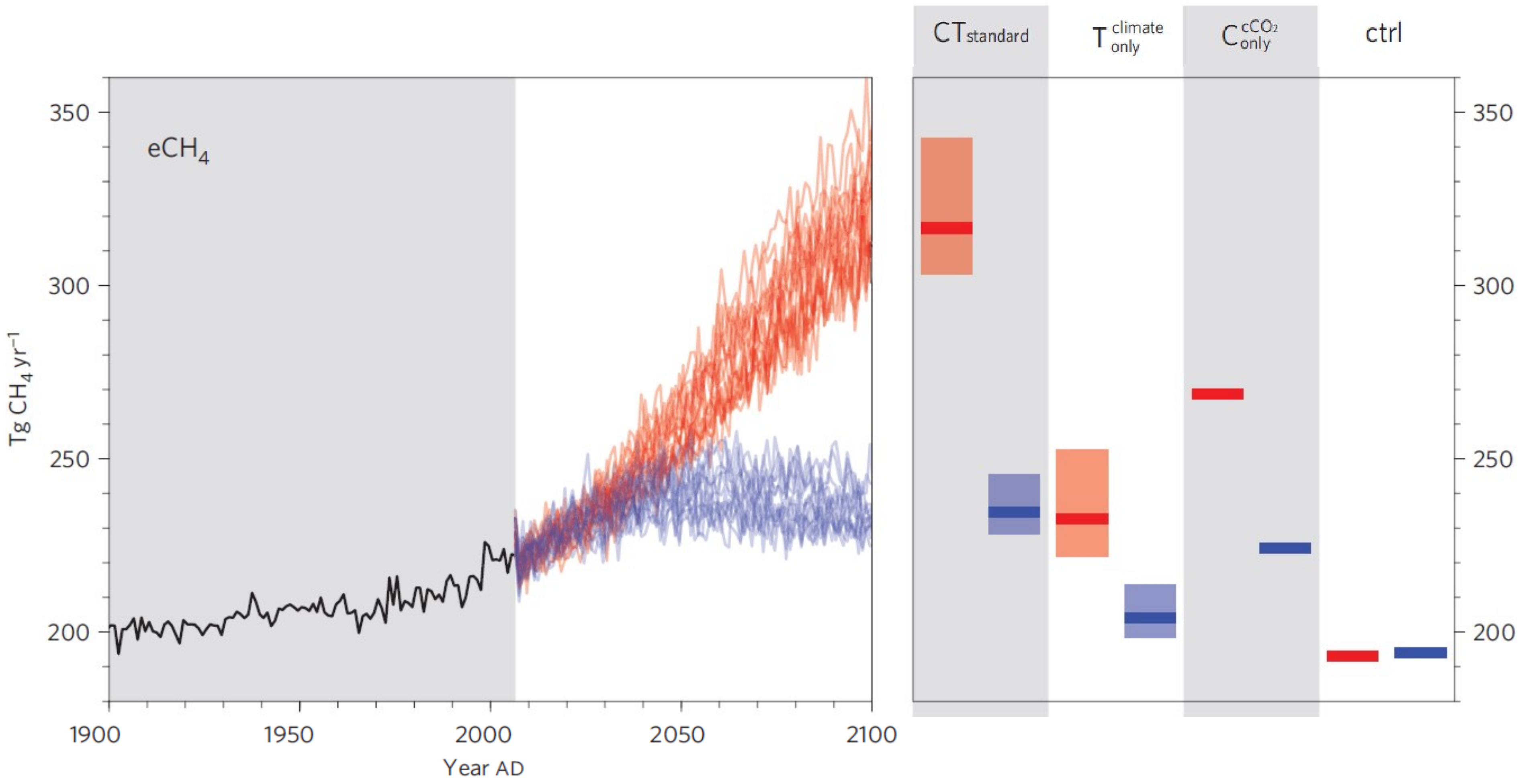

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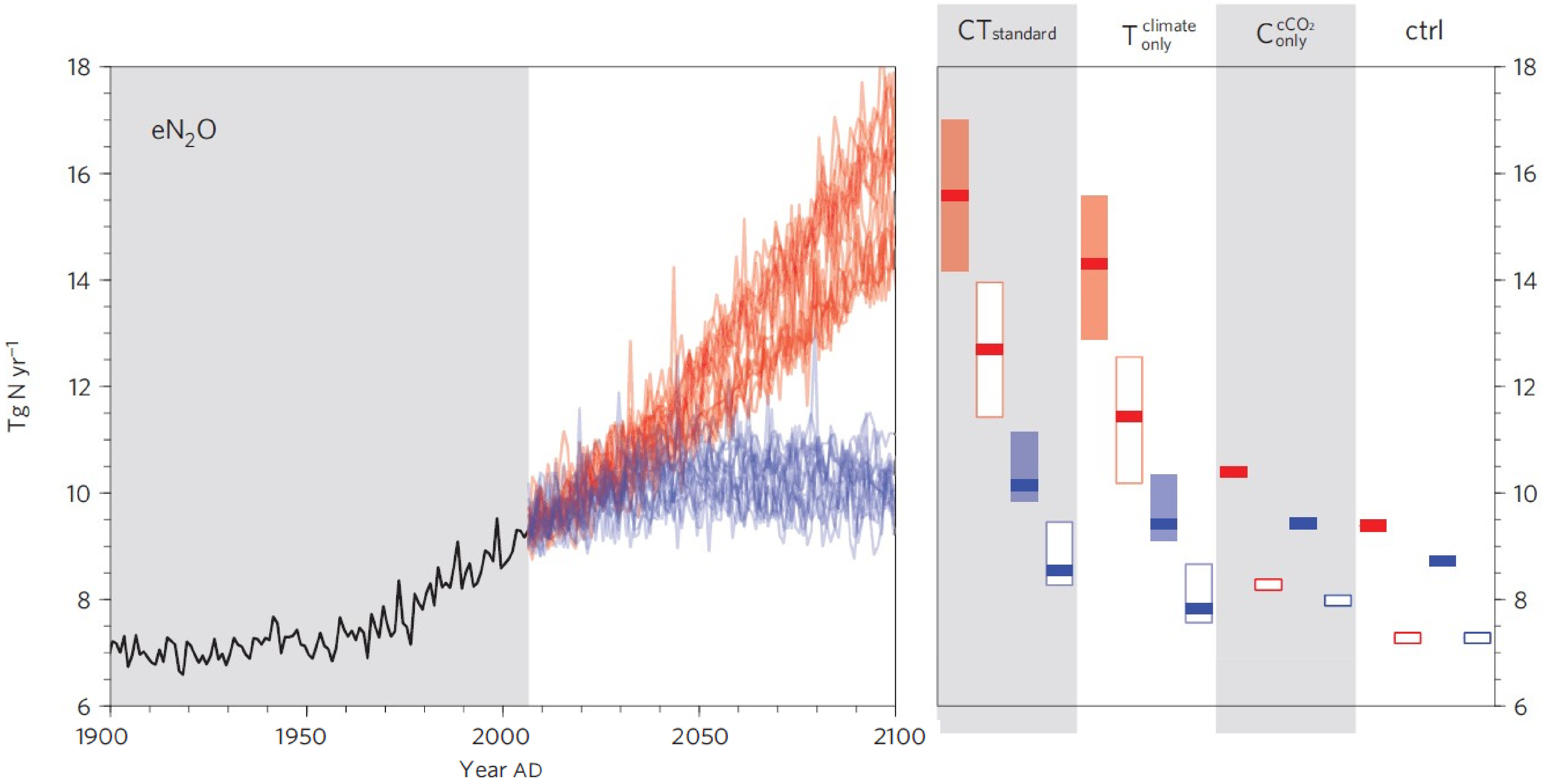

Example 2: Terrestrial GHG feedbacks

Control: Landbiosphere sees neither changes in climate nor pCO_2

$\rightarrow \Delta C, eN_2O, eCH_4, \text{albedo} \rightarrow RF_{ctrl} \rightarrow T_{ctrl}$

Then coupled runs, e.g.

CT : Landbiosphere sees changes in climate & pCO_2

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CT : Landbiosphere sees changes in climate & pCO_2

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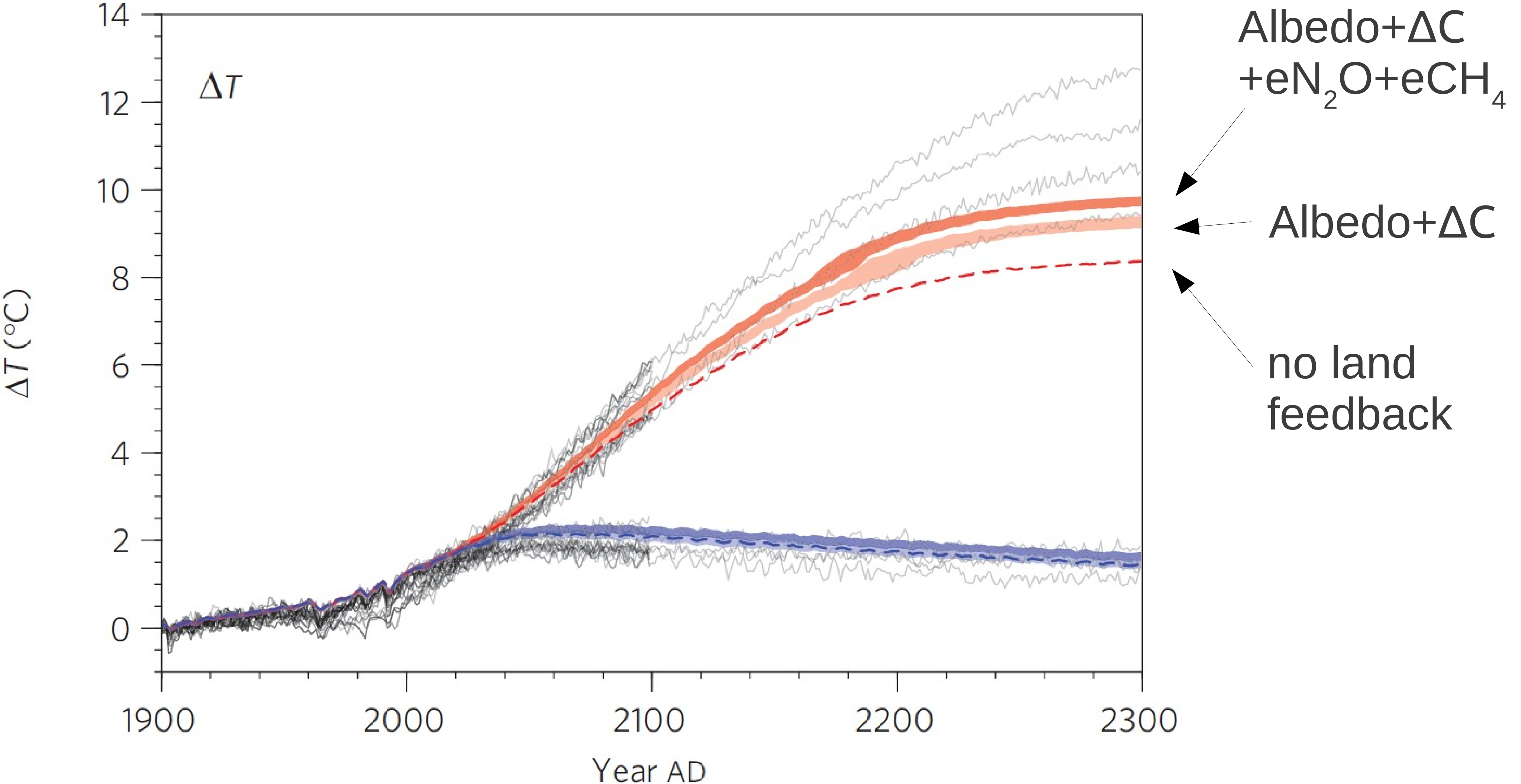
Feedback:
Given an <u>external</u> forcing, what is the response of the climate with and without a certain component.

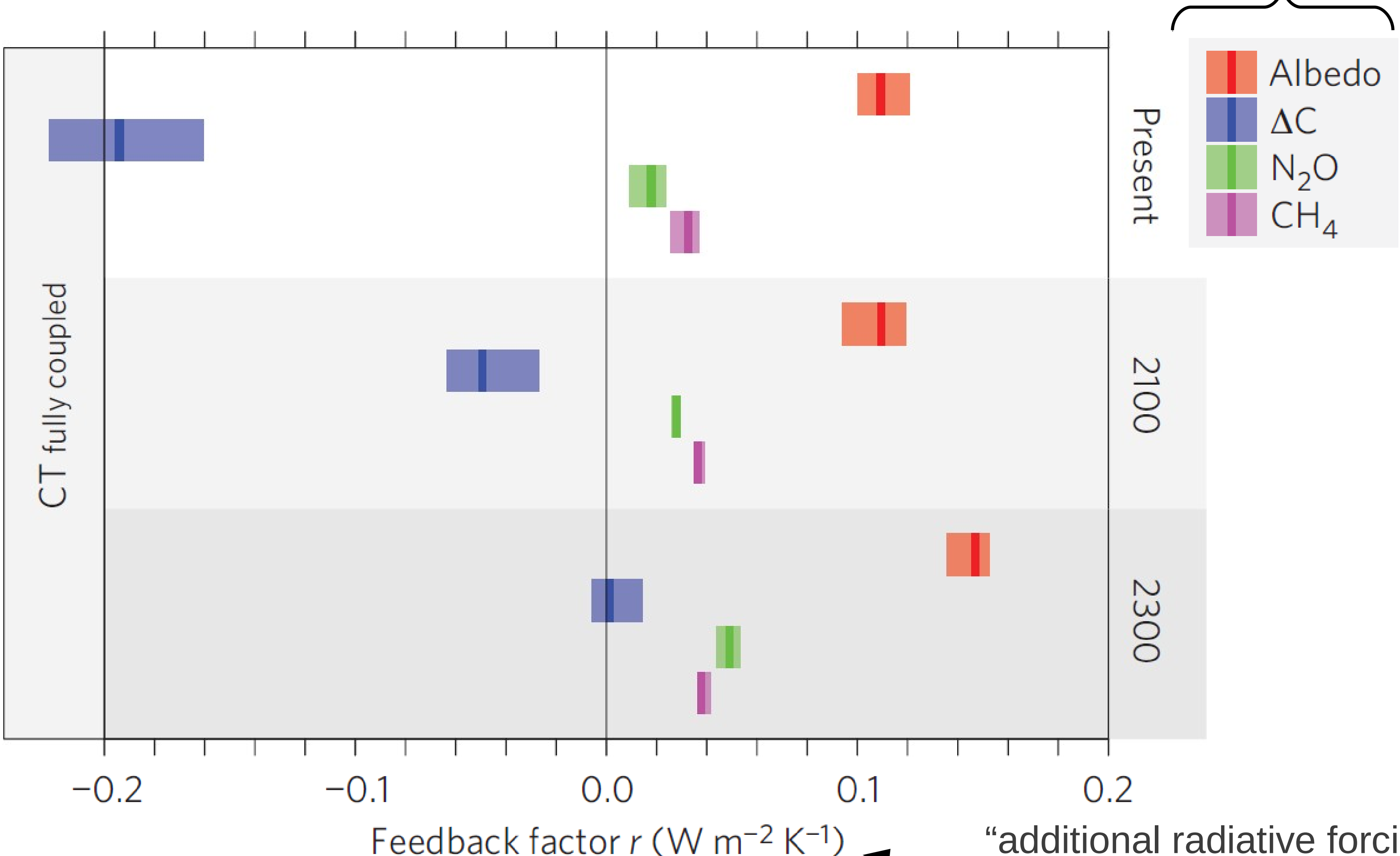
Example 2: Terrestrial GHG feedbacks



Example 2: Terrestrial GHG feedbacks

Land “**sees**” both CO_2 and climate changes:

What the climate model “sees”



“additional radiative forcing per 1K global warming”

Example 2: Terrestrial GHG feedbacks

Conclusions:

- The efficiency of the Bern3D-LPX allows to perform an extensive sensitivity analysis with 200+ simulations
- Total terrestrial feedback currently ~0, but increases in the future
- N_2O and CH_4 feedbacks are rather small, but always positive.
- The representation of the biogeochemical effect of CO_2 (i.e. fertilization) is crucial (→ talk last monday)

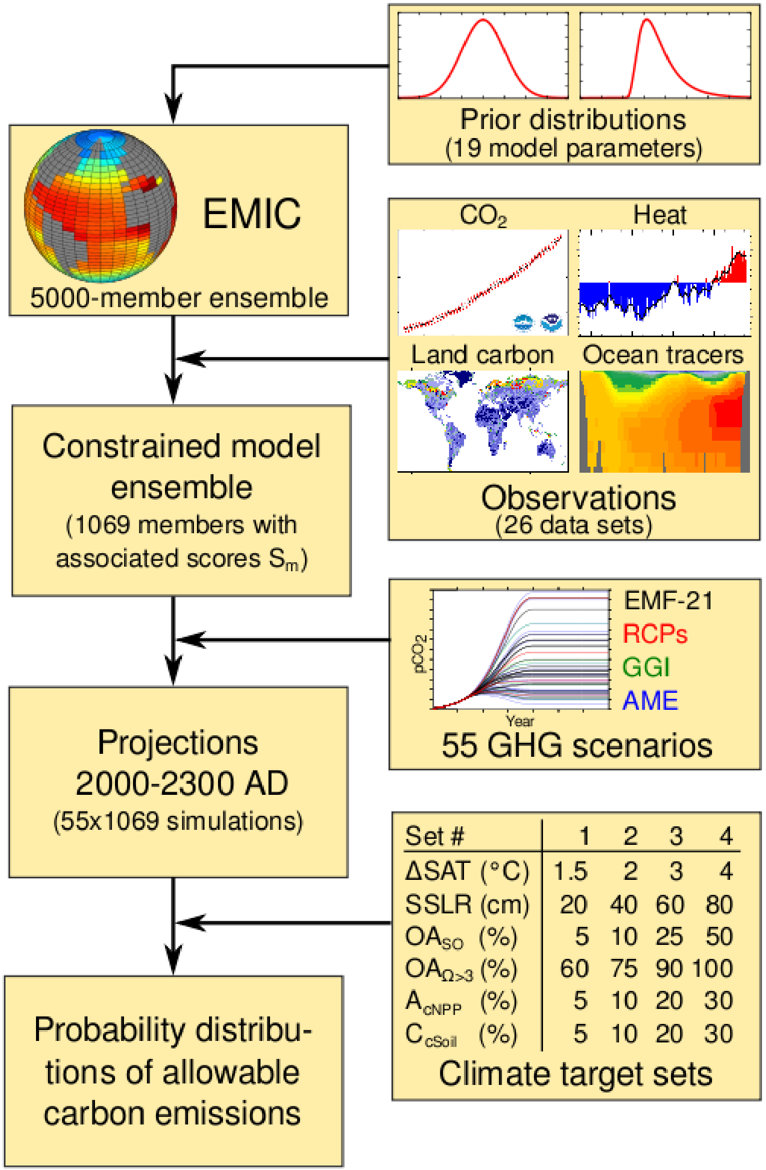
Example 3: Multi-target study

All graphics in this section are from
Steinacher et al., 2013, Nature (accepted)

Question:

- How do the allowable CO_2 emission change when considering multiple targets (instead of only temperature targets)

Target	Target Set Number				Units
	1	2	3	4	
ΔSAT	1.5	2	3	4	$°C$
SSLR	20	40	60	80	cm
OA_{SO}	5	10	25	50	% of area $> 50°$S
$OA_{\Omega>3}$	60	75	90	100	% of area in 1800
A_{cNPP}	5	10	20	30	% of crop area in 2005
C_{cSoil}	5	10	20	30	% of soil carbon in 2005



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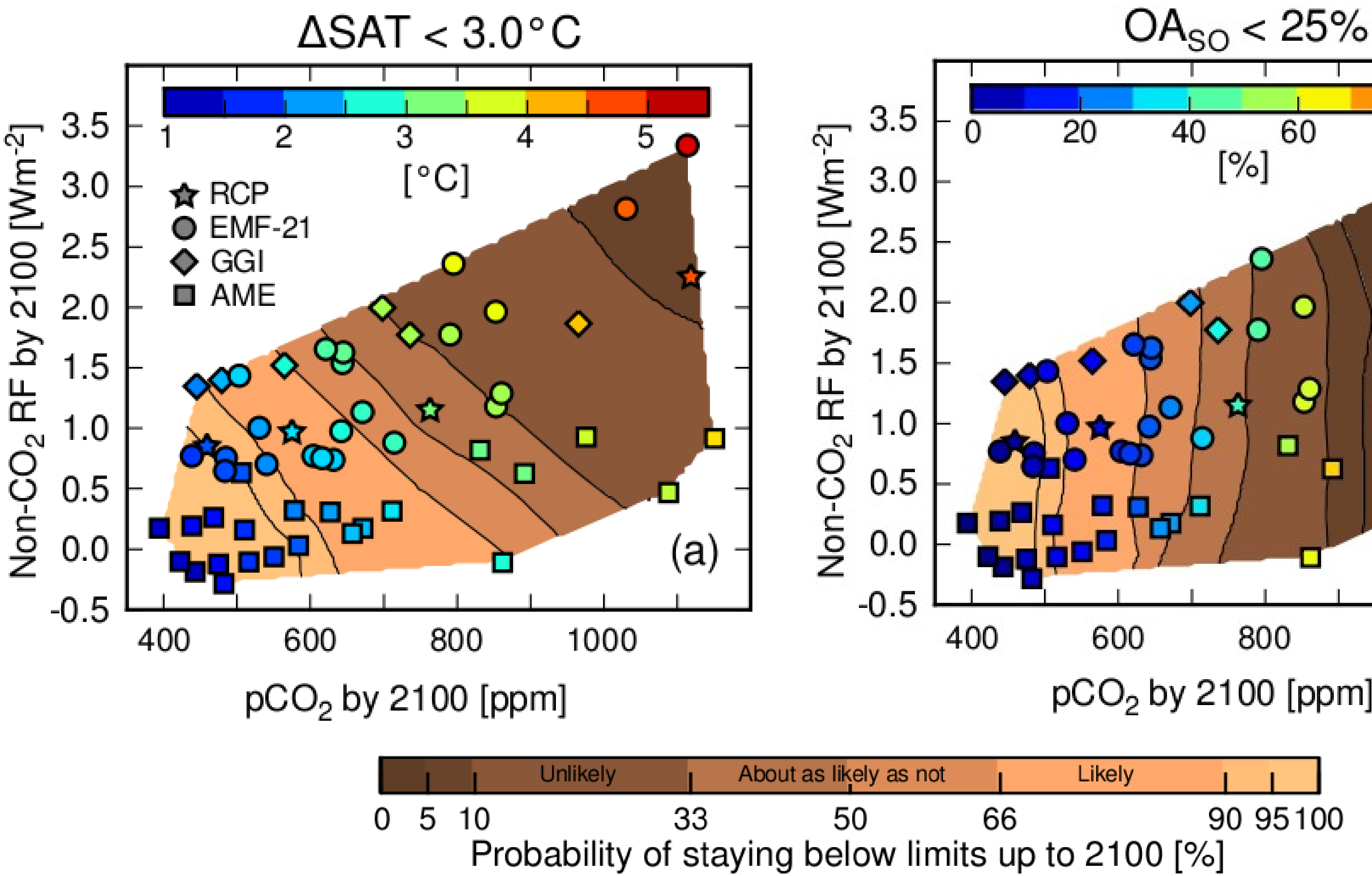

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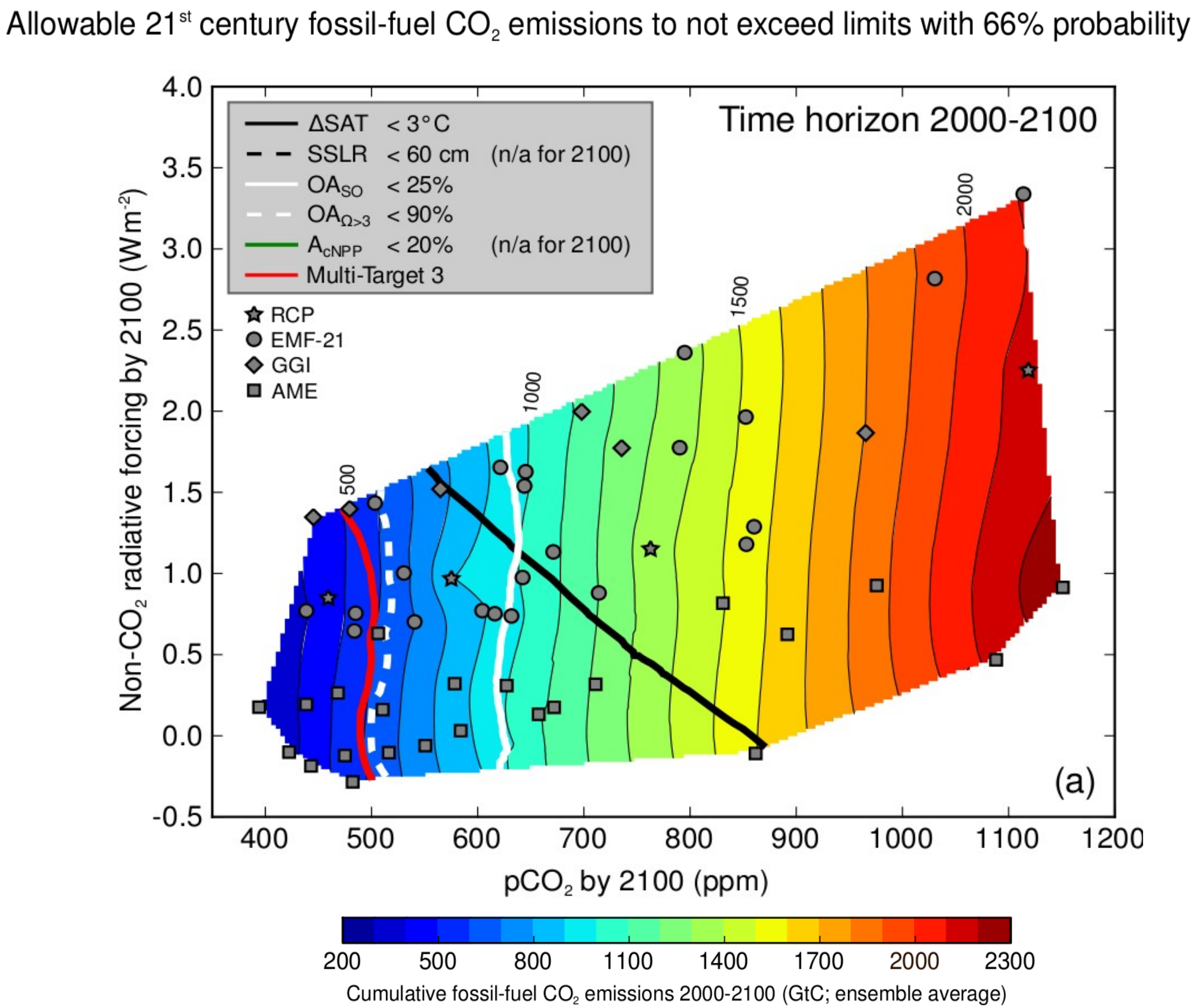

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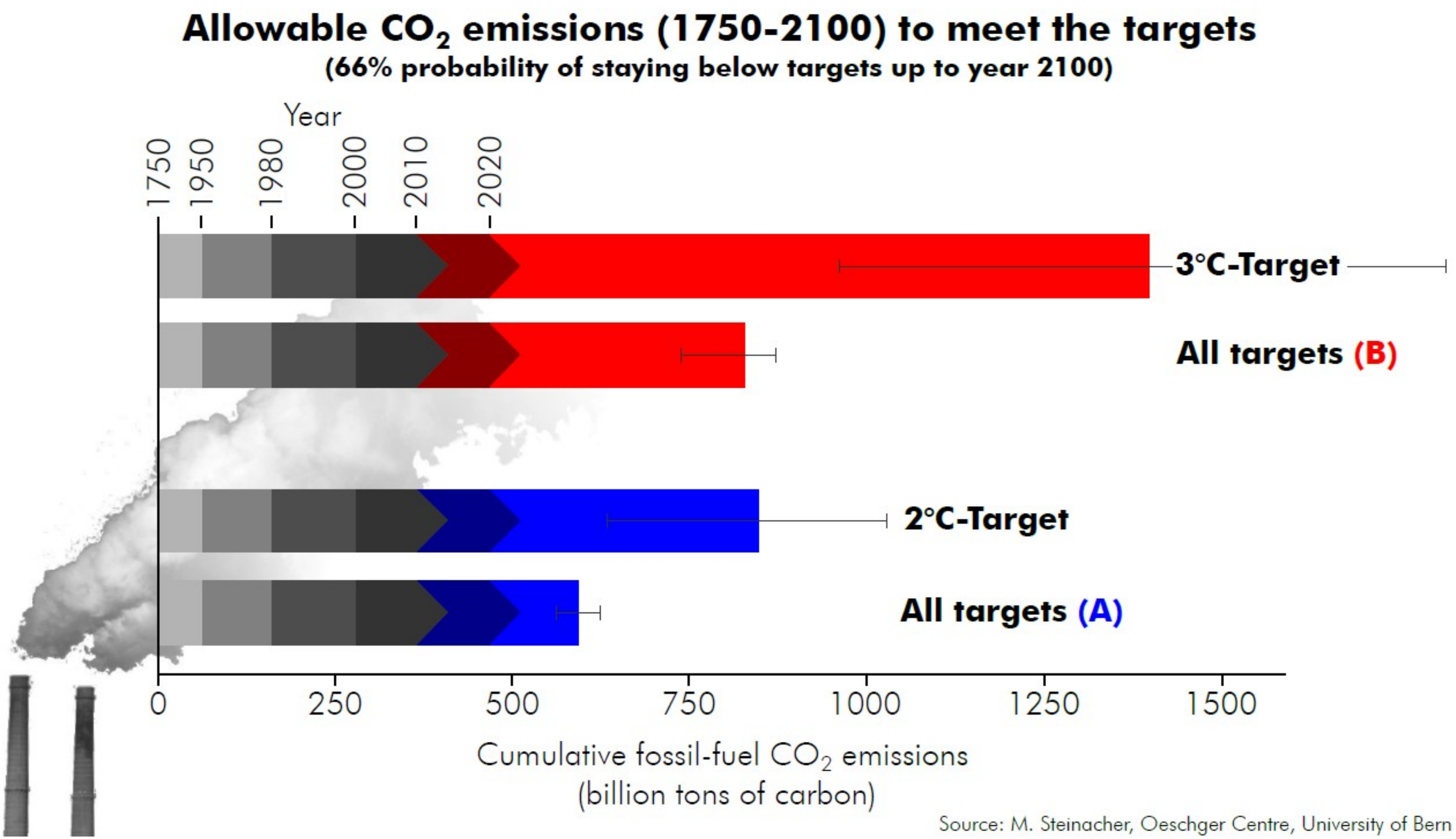
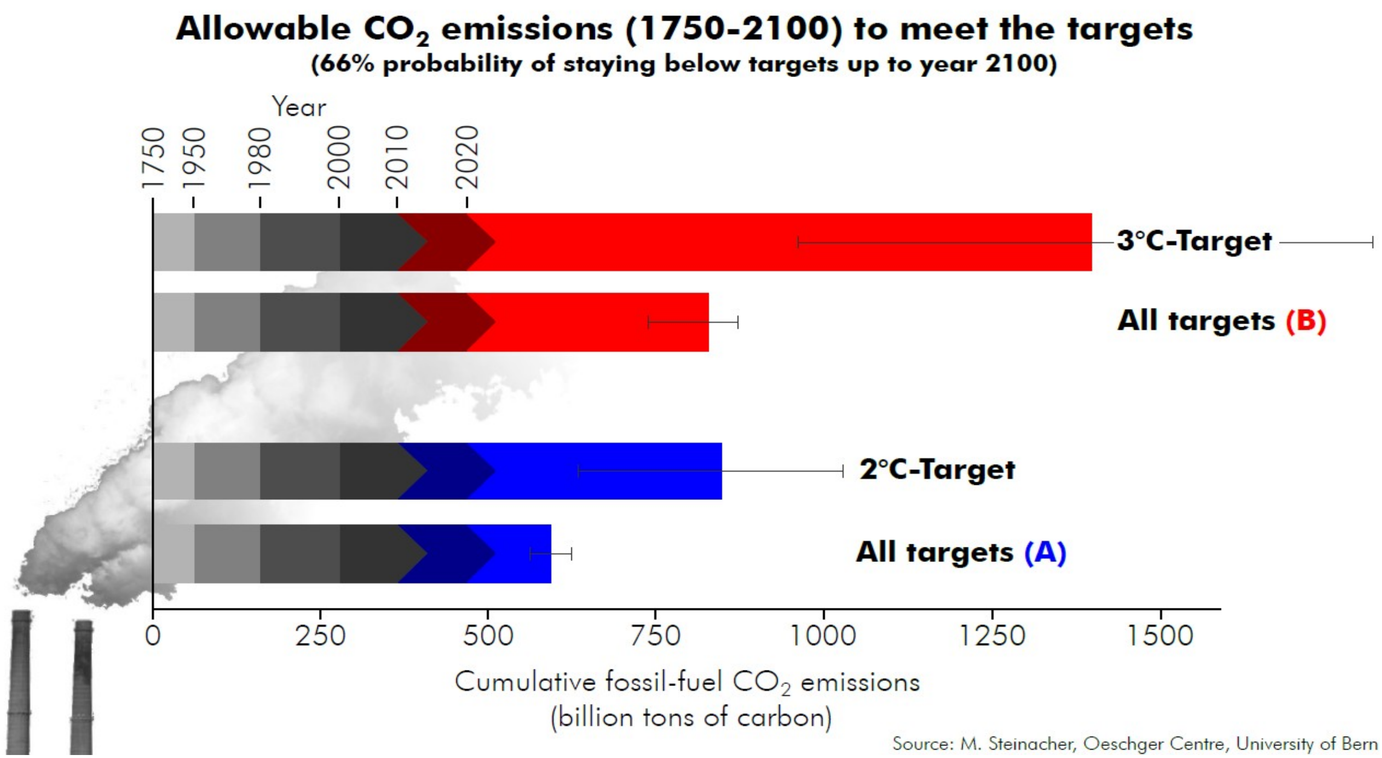


Emissions up to 2011: 347 GtC

Example 3: Multi-target study



Conclusions

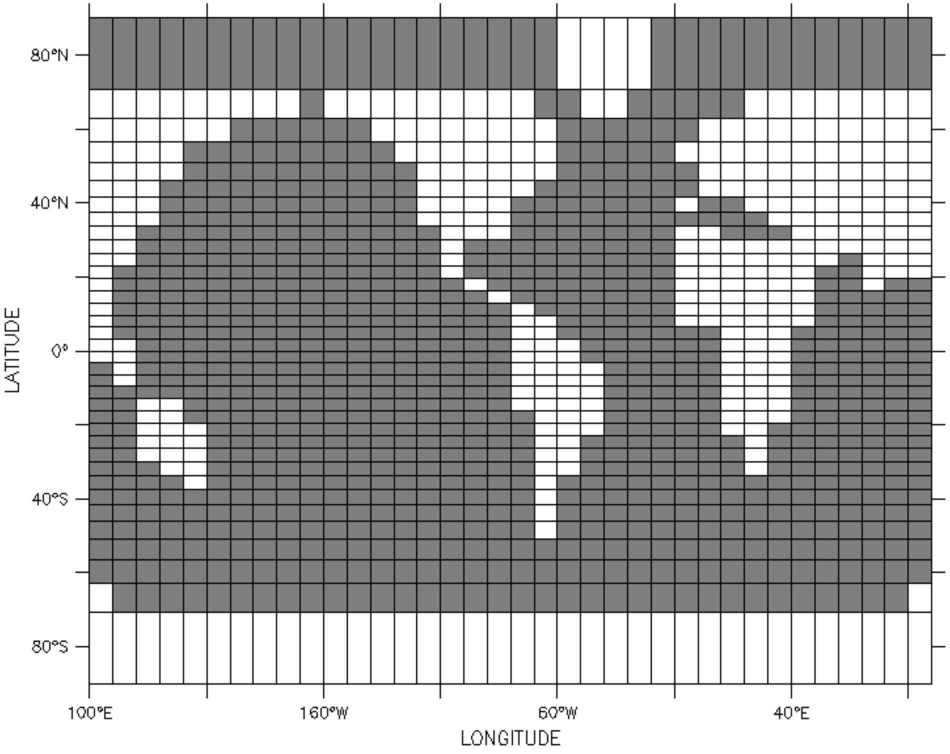
- Including additional targets along with the conventional global temperature limits can considerably reduce the allowable CO_2 emissions

- CO_2 targets should be treated separately from other greenhouse gases in policy frameworks.

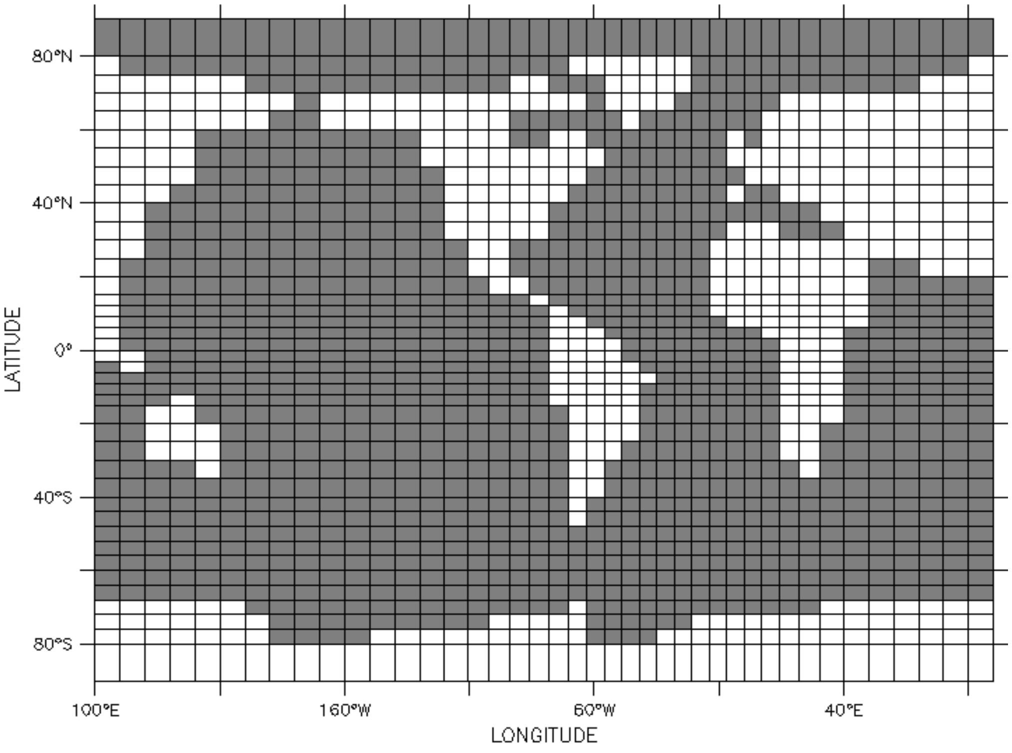
Outlook

Bern3D ocean model with variable horizontal resolution

old



new



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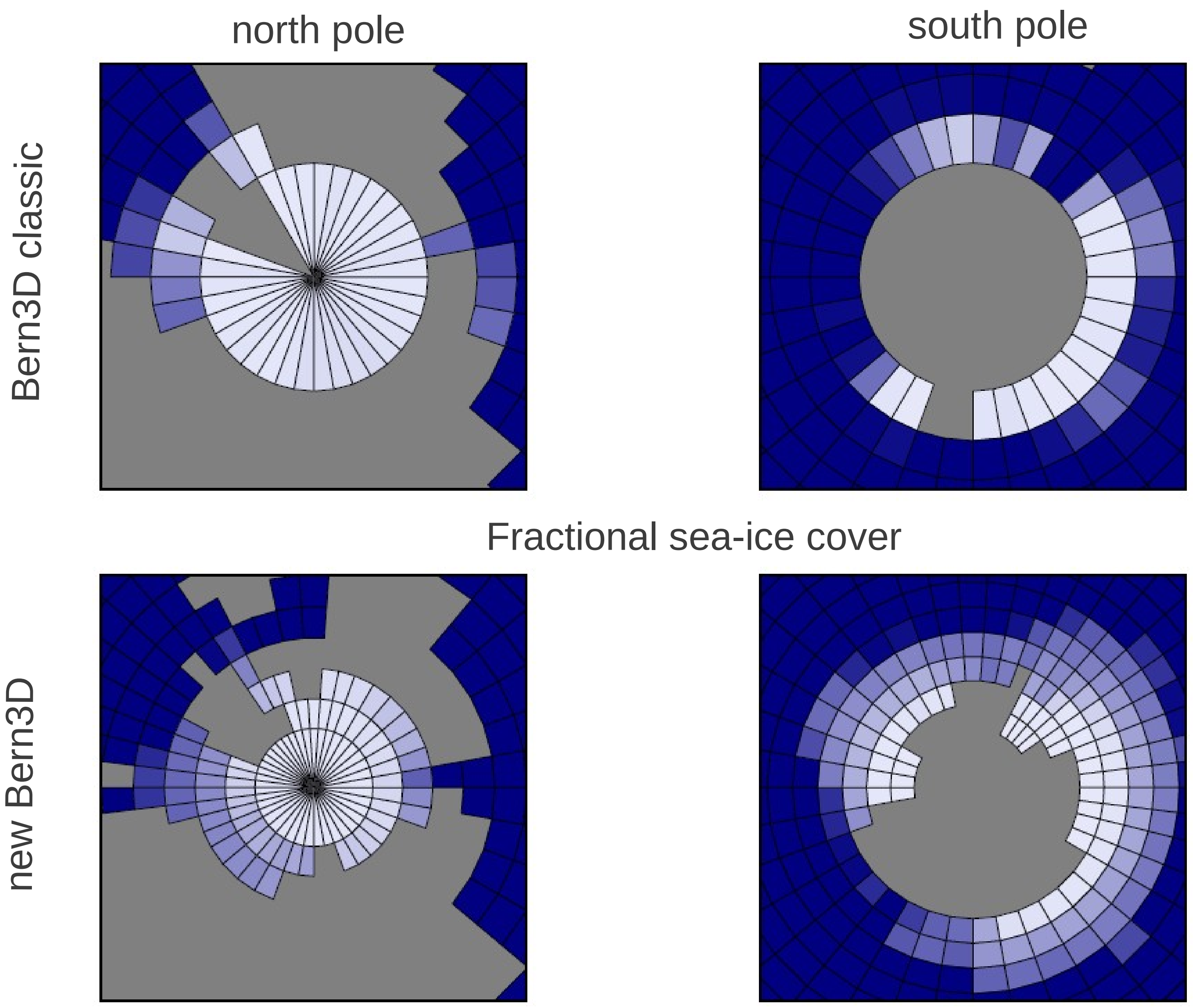
north pole
south pole
Bern3D classic
Fractional sea-ice cover
new Bern3D

Summary

• ~ 20 years of evolution from the original “Bern” - model to Bern3D-LPX

• The (ocean) model is still a coarse-resolution model → large-scale response is of interest.

• Model development and application goes in parallel by the same people.

• Bern3D-LPX is an ideal tool both for science and education (e.g. Master thesis) to asses all kind of questions both in the past and the future.

• The development of the model is ongoing.