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Modelling the impact of vegetation feedbacks on the minimum extent of the Greenland Ice Sheet during the Last Interglacial

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Outline

- Background
- Feedbacks
- Previous Work
- Experimental design
- Results
- Conclusions

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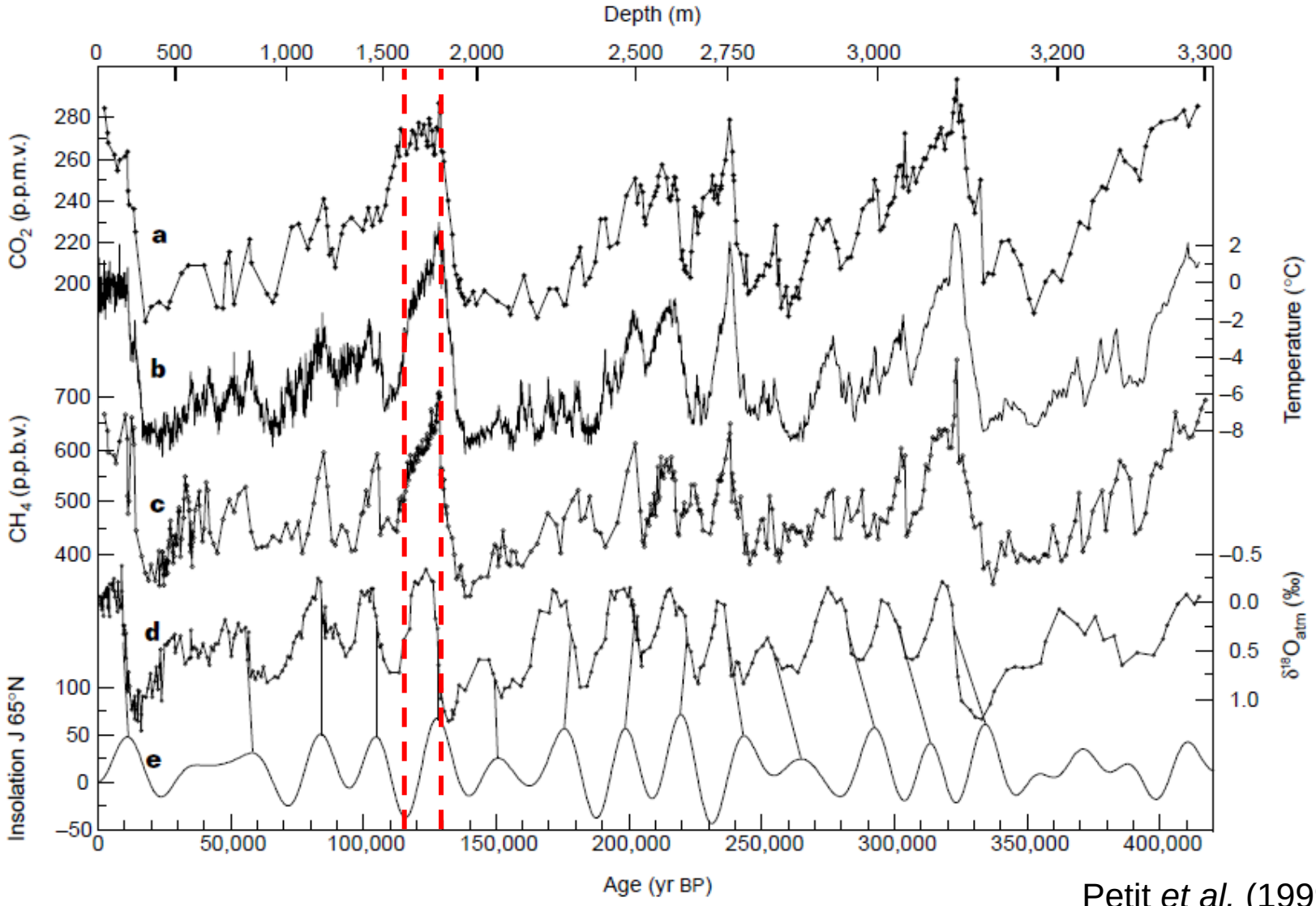
Background: The Last Interglacial (LIG)

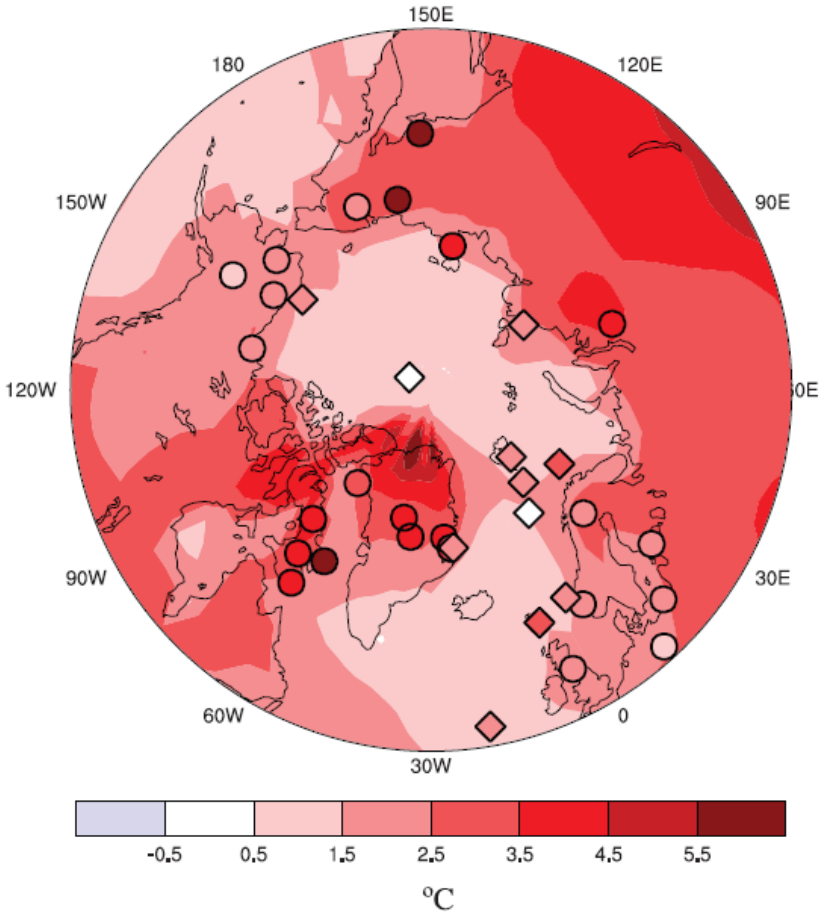


Petit *et al.* (1999)

- LIG: ~130 to 116 thousand years ago (ka)

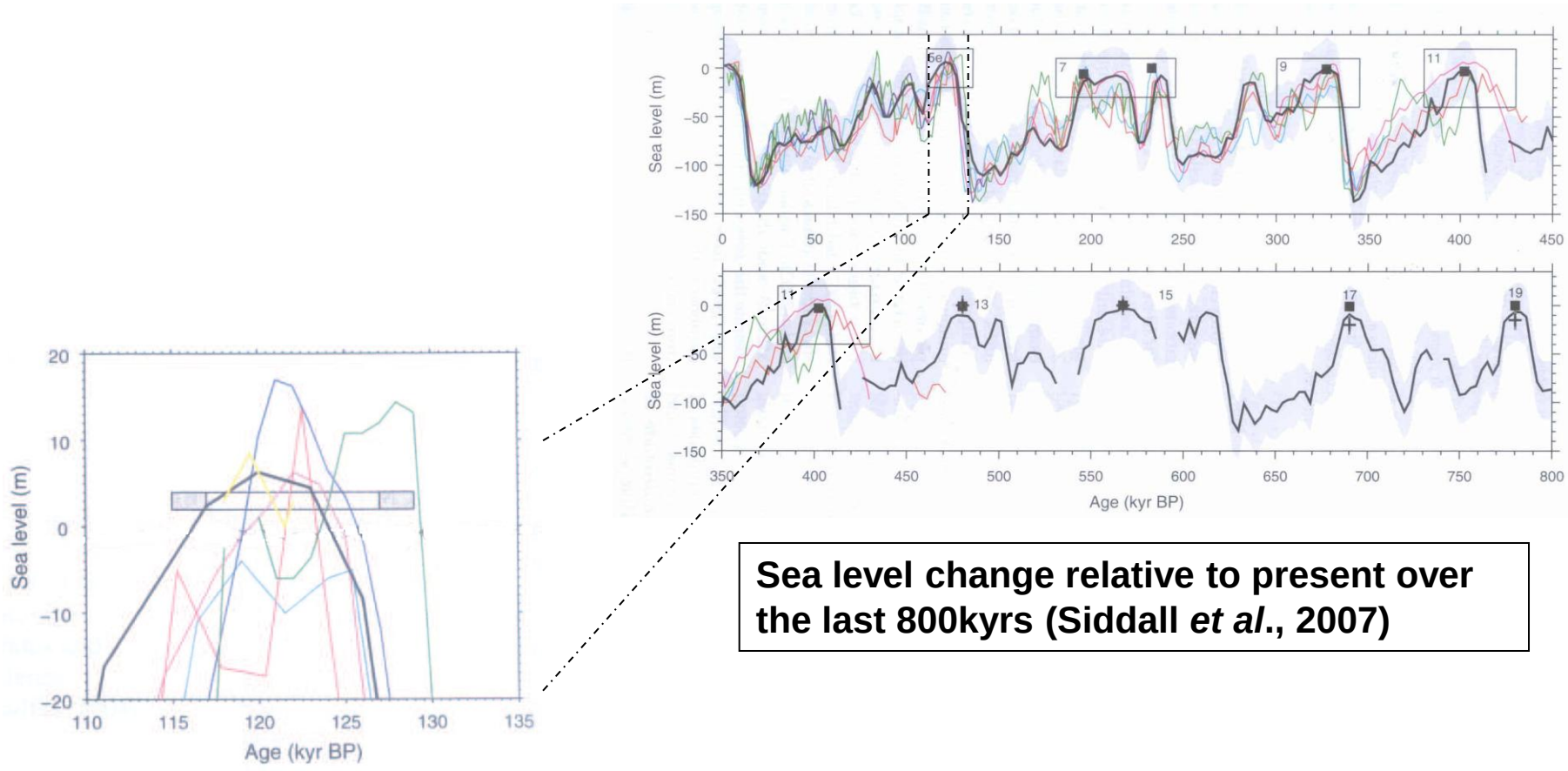
Background: Greenland during the LIG

- Palaeodata and AOGCMs indicate summer warming of ~2 - 5 C
- Annual temperatures similar to today
- Migration of boreal forest into regions now occupied by tundra in the Arctic



Summer surface air temperature change relative to present day (IPCC, 2007)

Background: Greenland during the LIG



Sea level change relative to present over the last 800kyrs (Siddall *et al*., 2007)

- Sea level highstand of ~ 4 to 6m
  - reduction in the size of the Greenland ice sheet (GrIS)
  - possible reduction in the Antarctic ice sheet

What caused the warming during the LIG?

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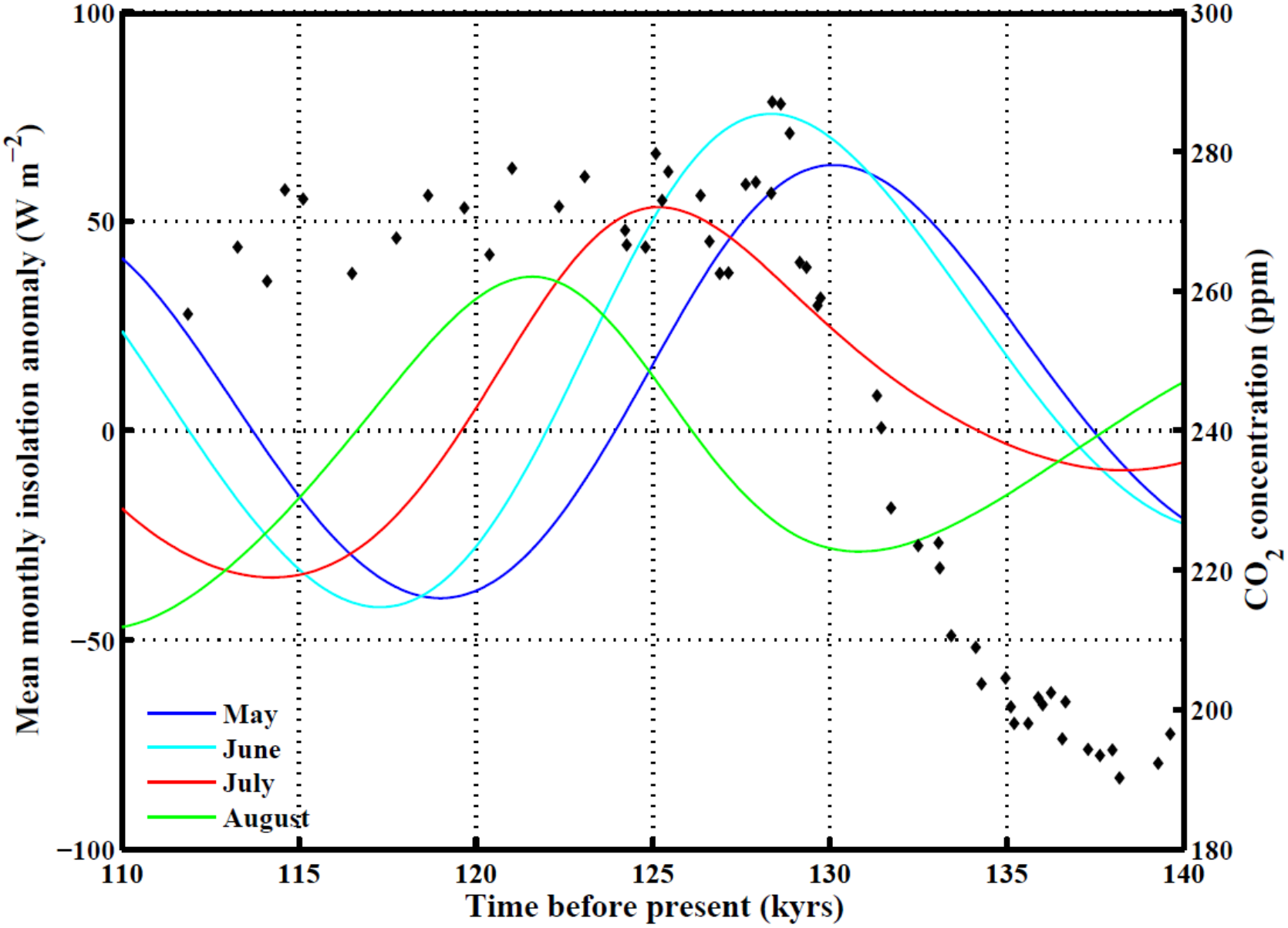
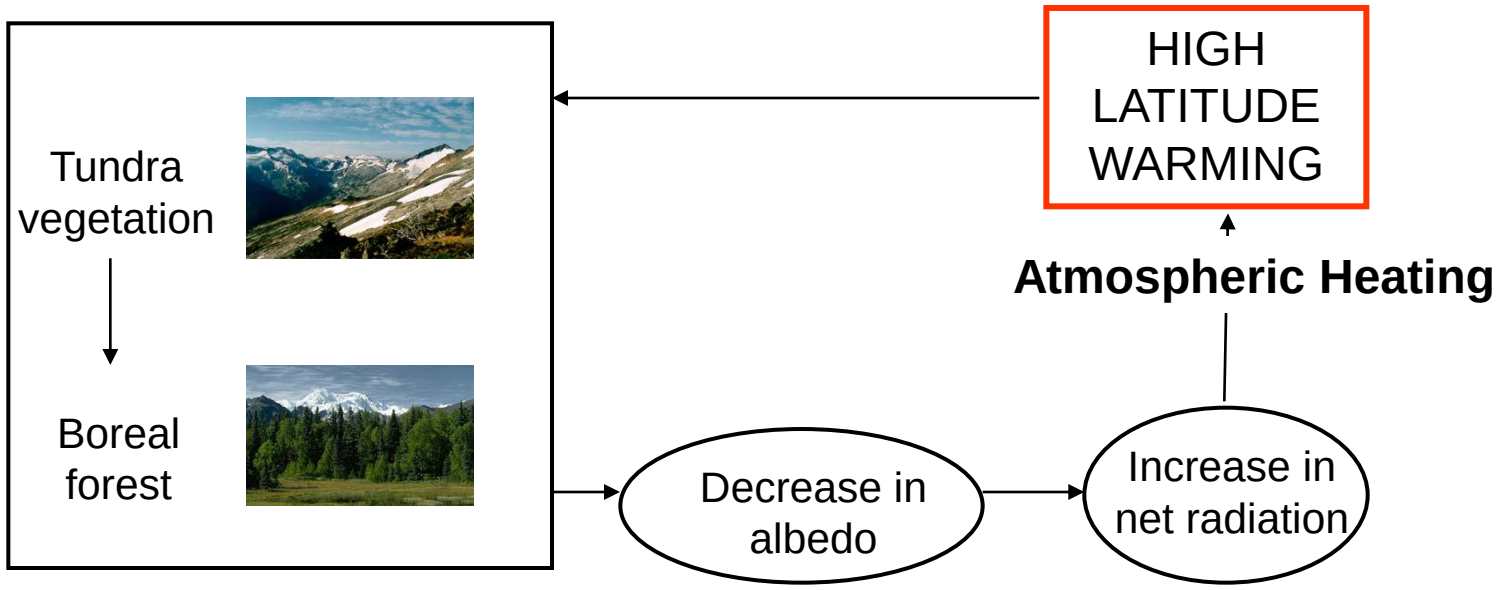


Feedback processes: amplification for LIG warming

- Ice-albedo feedback
- Ice-elevation feedback
- Vegetation-snow-climate feedback



Previous studies on GrIS contribution to sea level

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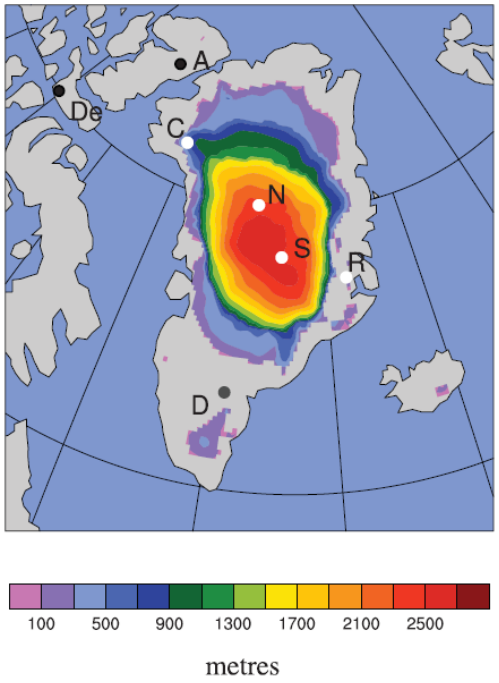
Study	Method	Sea level (m)
Letreguilly *et al.* (1991)	Palaeothermometry & ice sheet model	~1.5
Cuffey & Marshall (2000)	Palaeothermometry & ice sheet model	4 - 5.5
Tarasov & Peltier (2003)	Palaeothermometry & ice sheet model	2 - 5.2
Lhomme *et al.* (2005)	Palaeothermometry & ice sheet model	3.5 - 4.5
Otto-Bliesner *et al.* (2006)	AOGCM output and ice sheet model	1.9 - 3.0



Minimum extent of GrIS (IPCC, 2007)

A new approach

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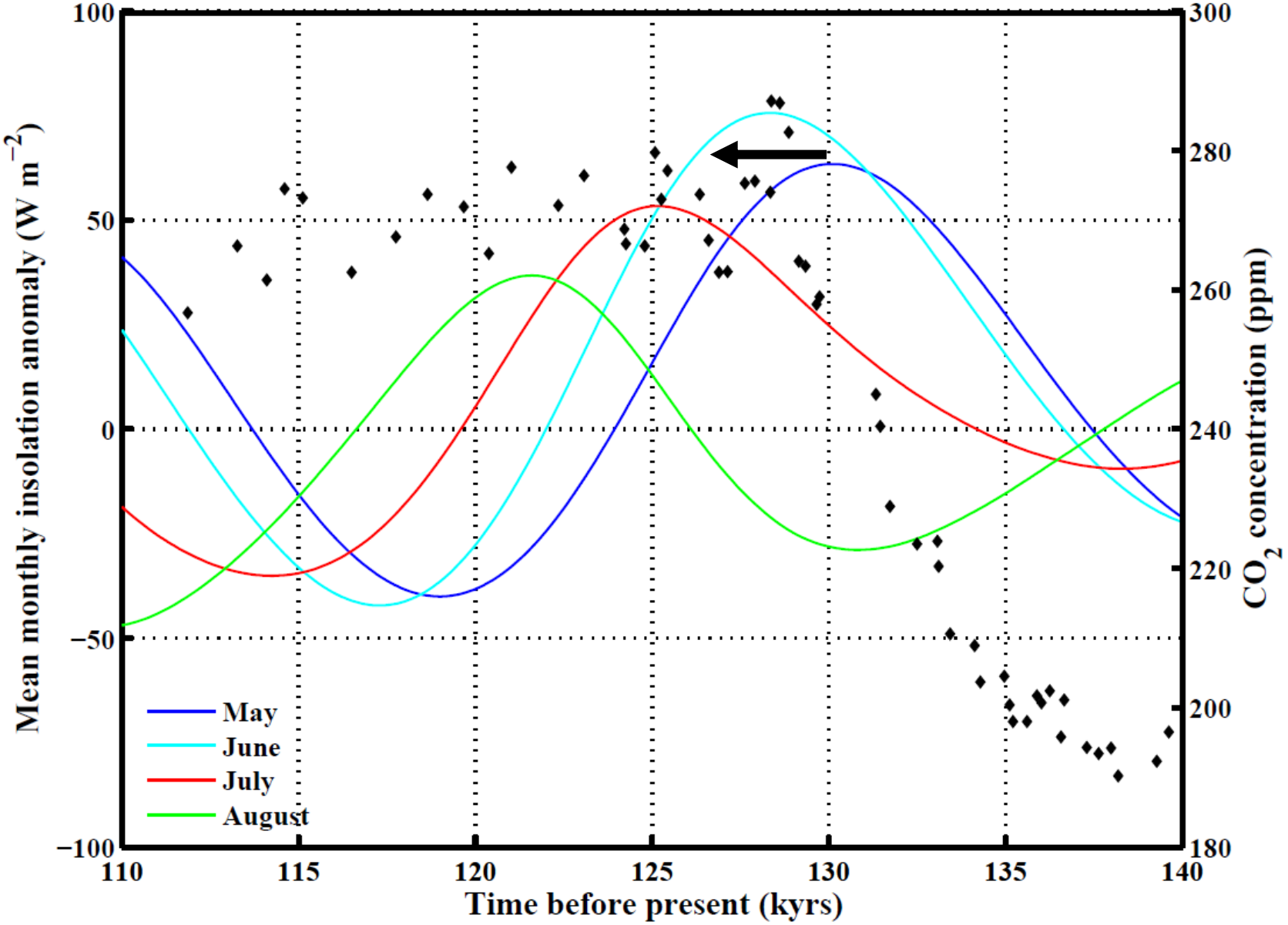

A new approach

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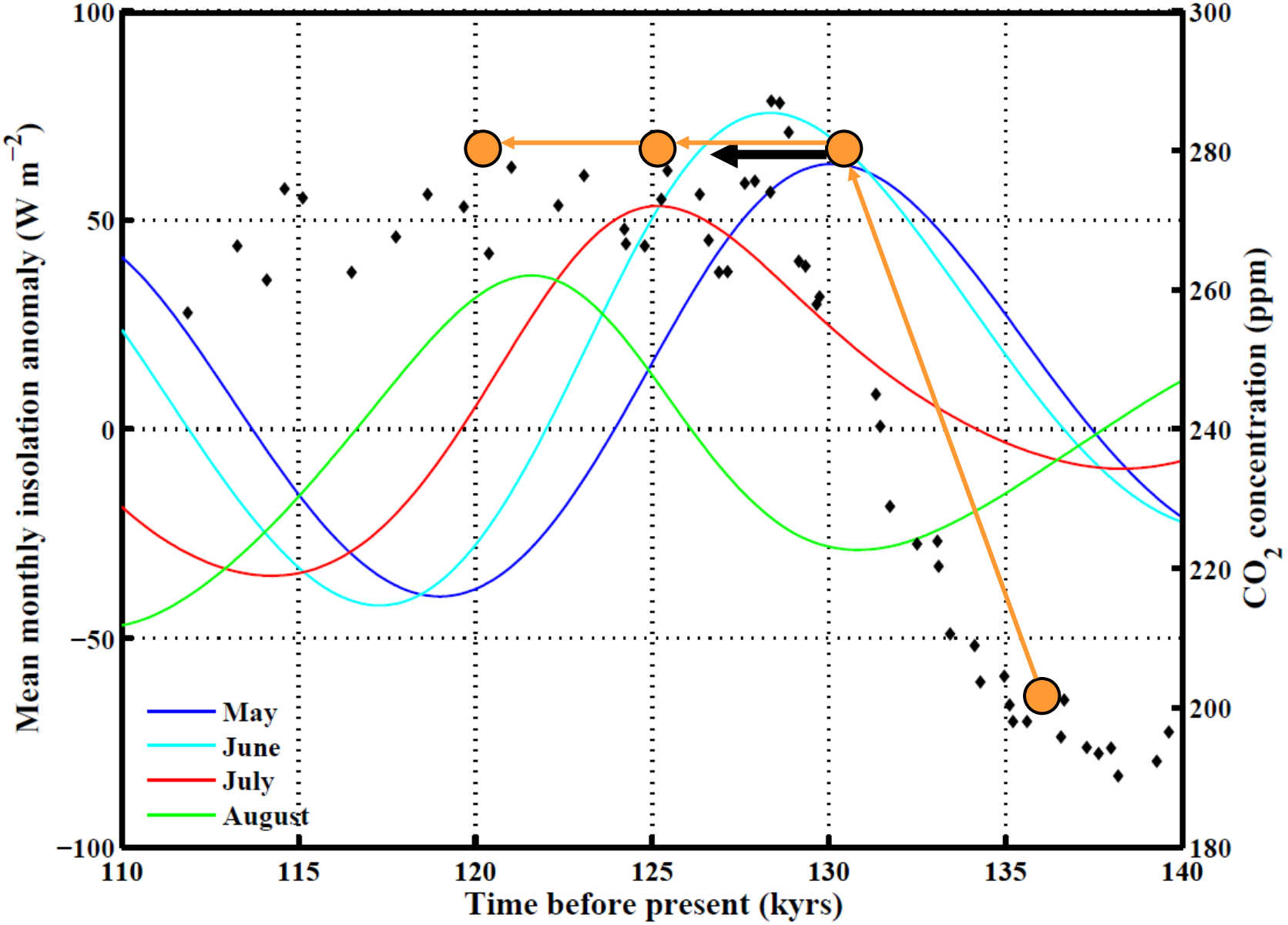

A new approach

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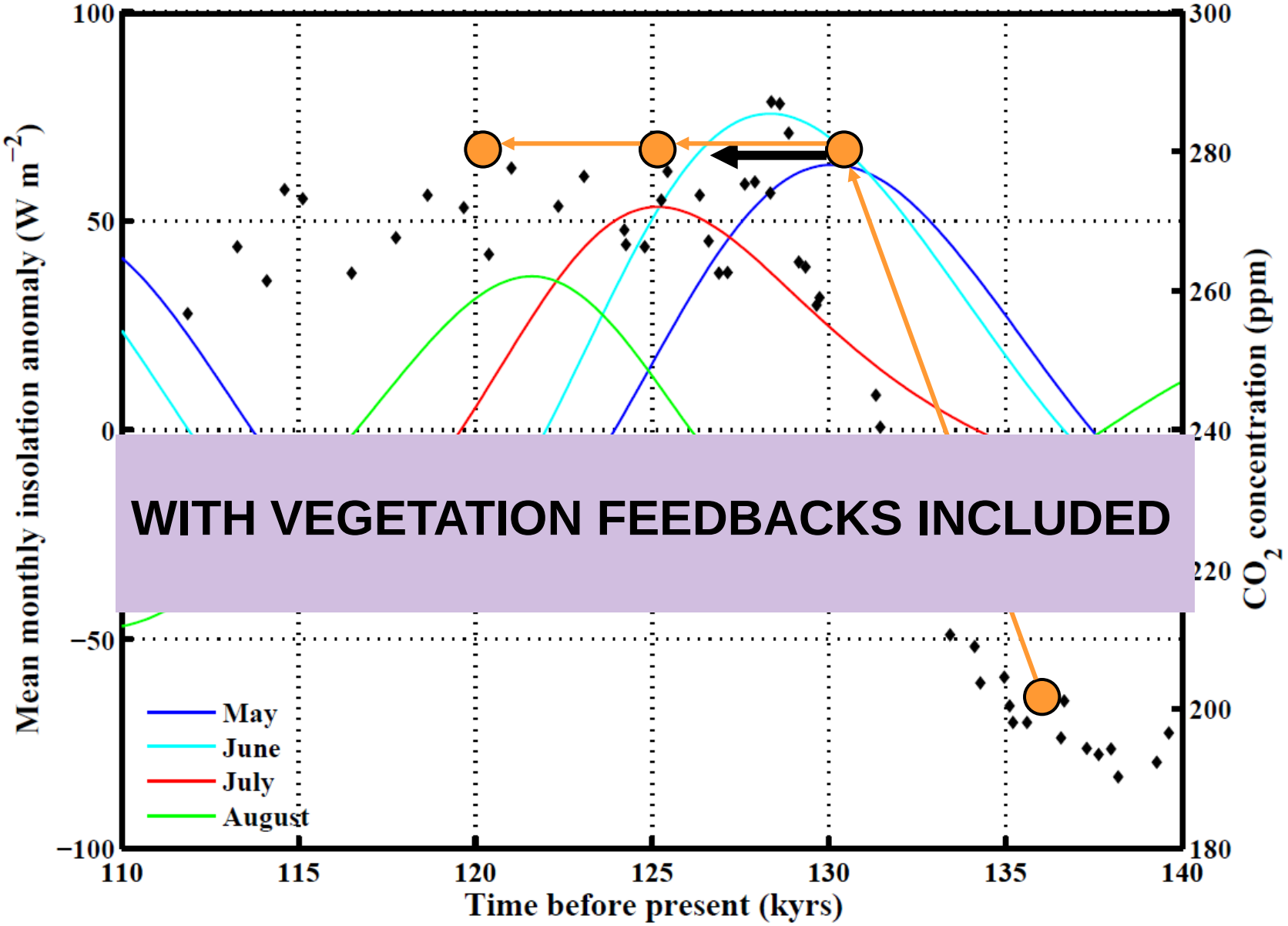
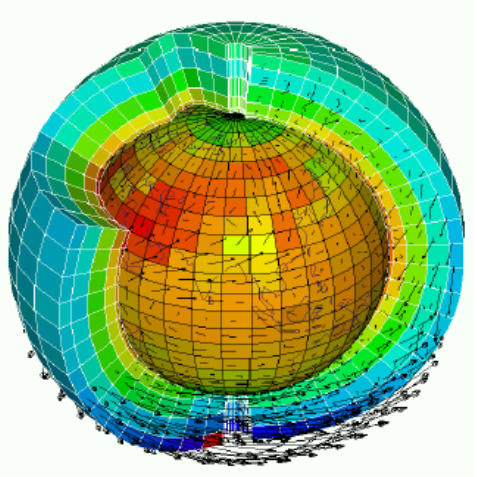


WITH VEGETATION FEEDBACKS INCLUDED

Experimental design: the models

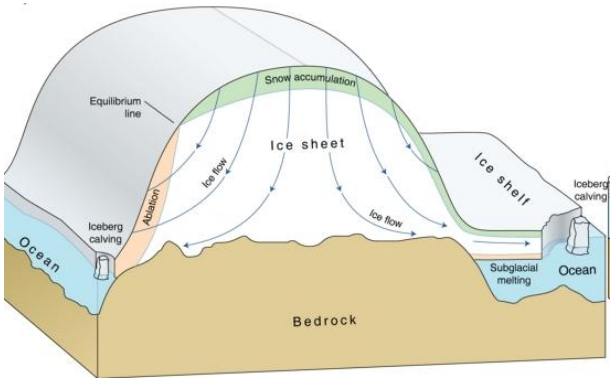
- **HadCM3 (UK Met Office Model)**

  - Coupled atmosphere-ocean sea-ice models
  - Ocean has a resolution of 1.25° x 1.25°
  - Horizontal resolution 2.5° x 3.75°
  - 19 levels in the vertical

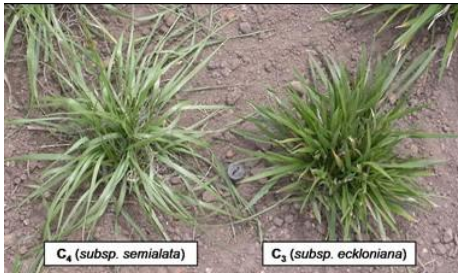


- **Glimmer (Payne, 1999; Rutt *et al*., 2009)**

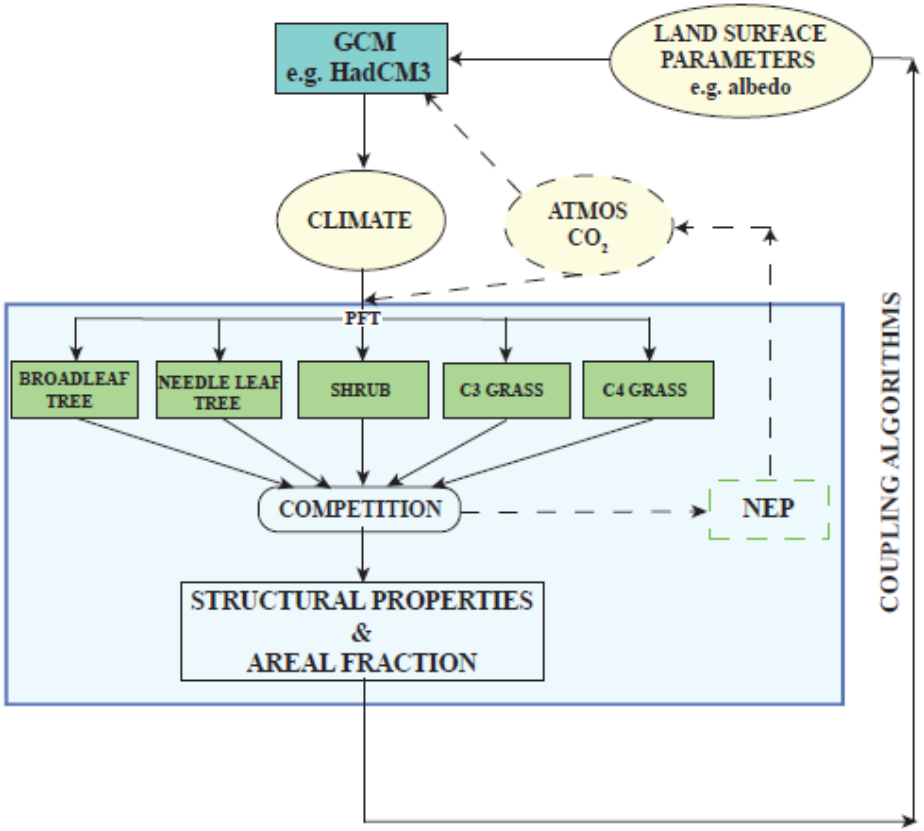
  - PDD Surface mass balance model
  - Coupled ice flow
  - Thermodynamics & ice-thickness evolution
  - Isostatic readjustment



Experimental design: vegetation



C3 & C4 grass



Shrub

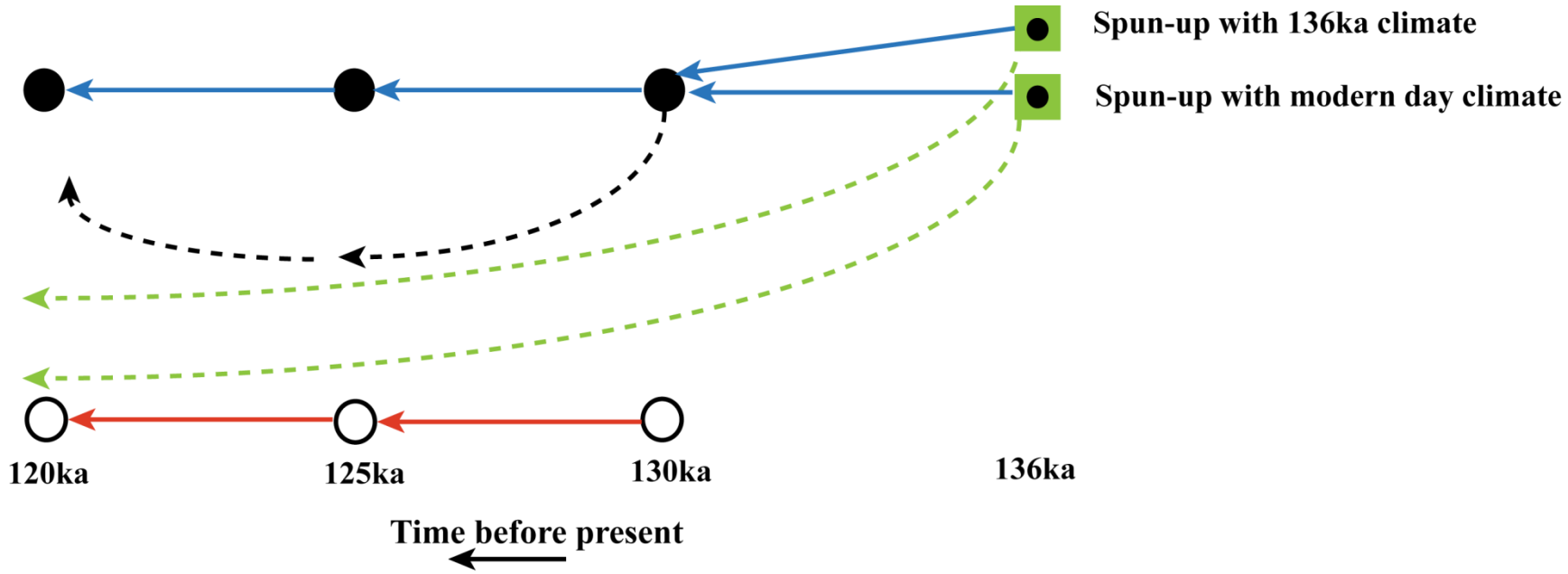
Needle Leaf tree

Broadleaf tree

Experimental design

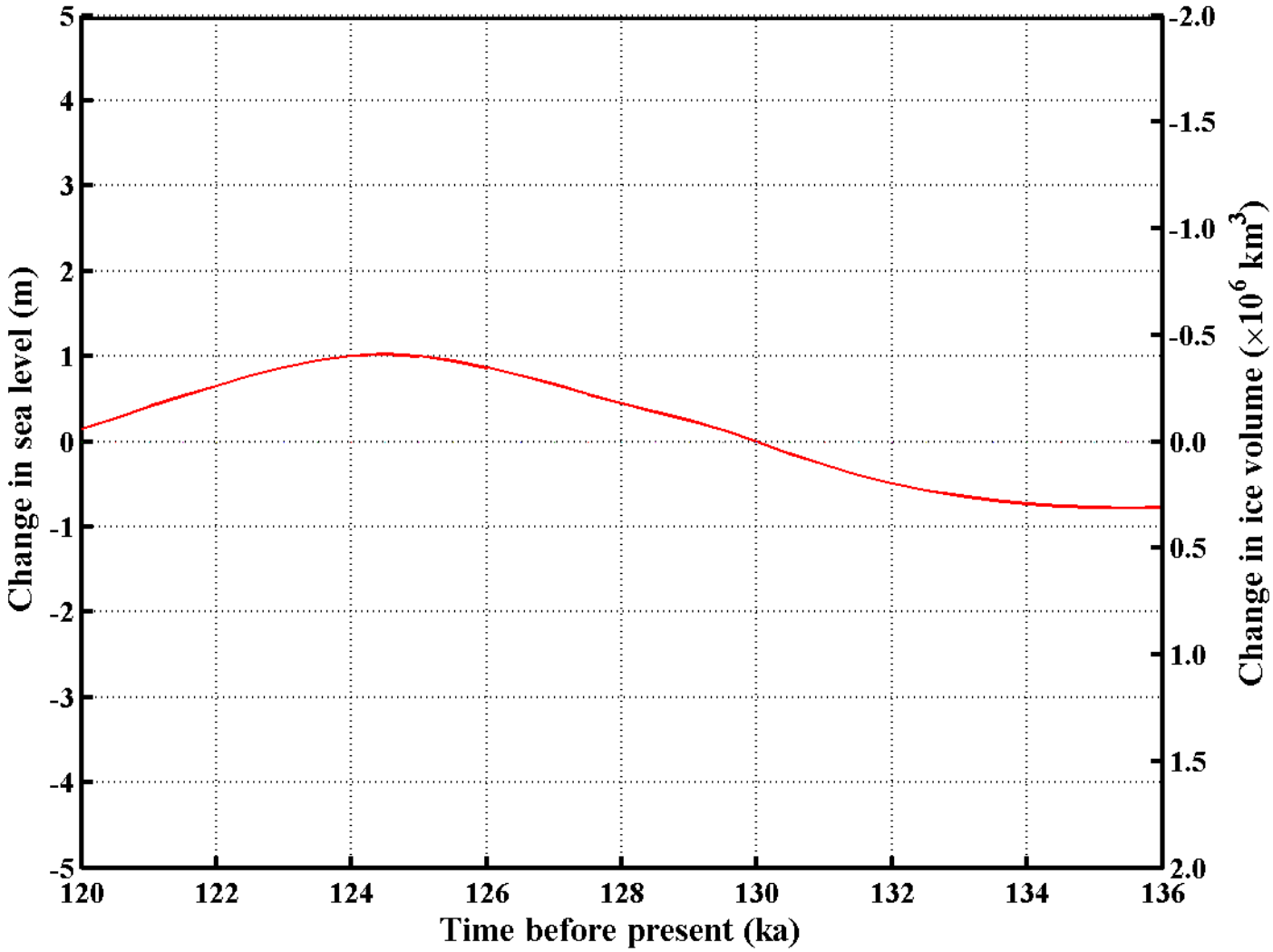
- Coupling HadCM3 to Glimmer computationally expensive

- Perform 12 100 year equilibrium HadCM3 simulations
  - 6 FIXED vegetation
  - 6 DYNAMIC vegetation



Based on the method used by Pollard & DeConto (2009)

Results: ice volume & sea level



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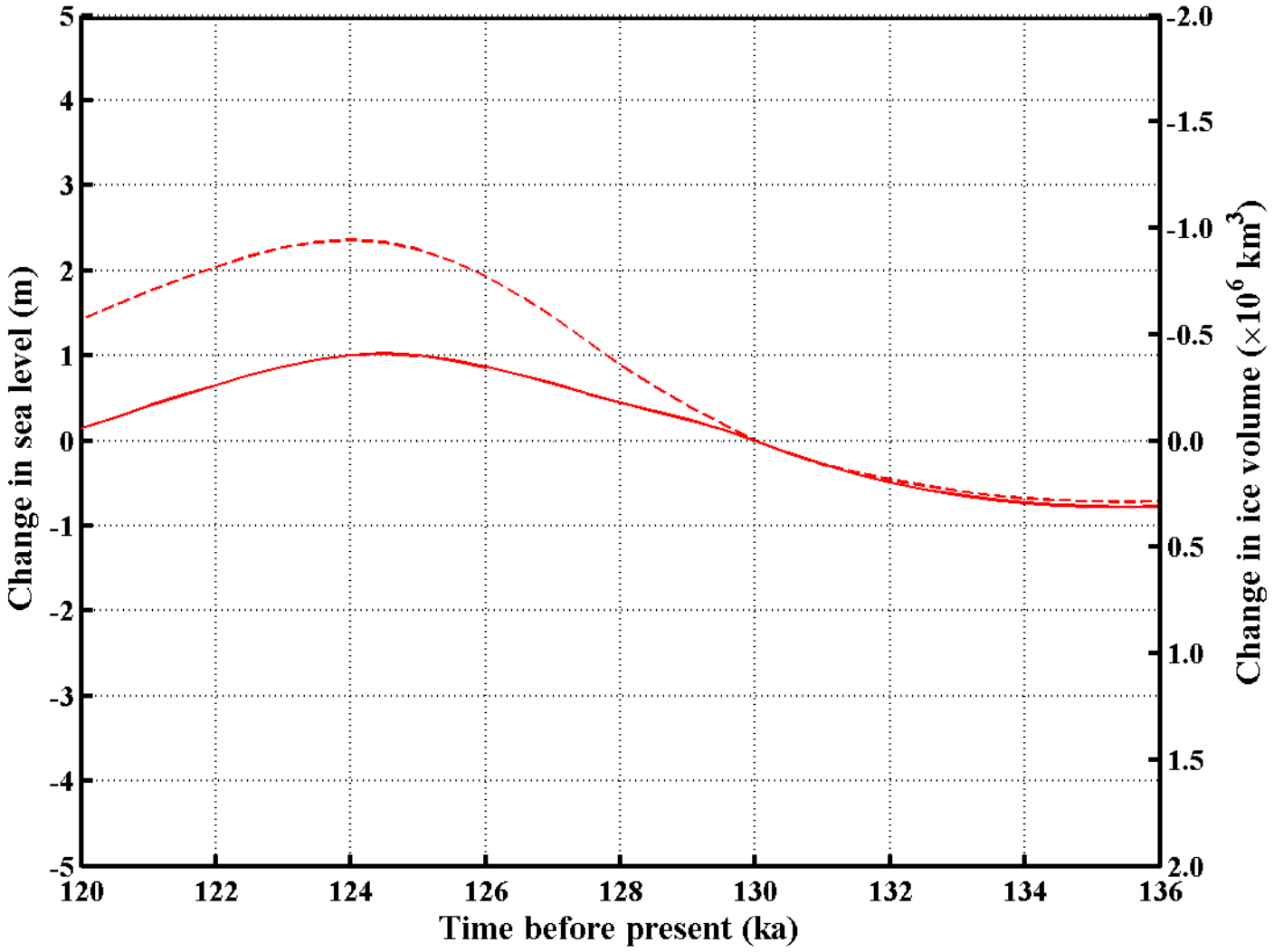

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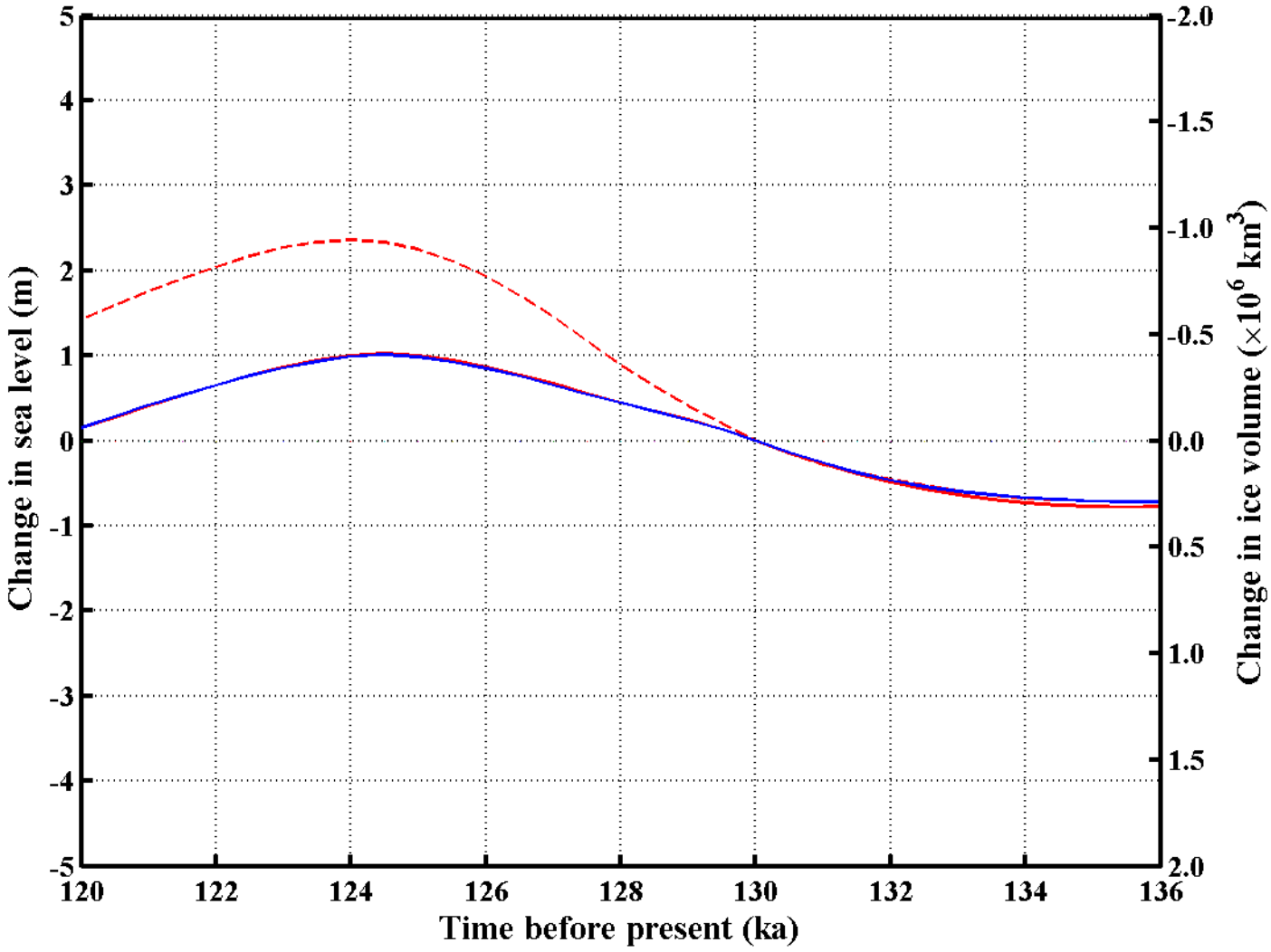
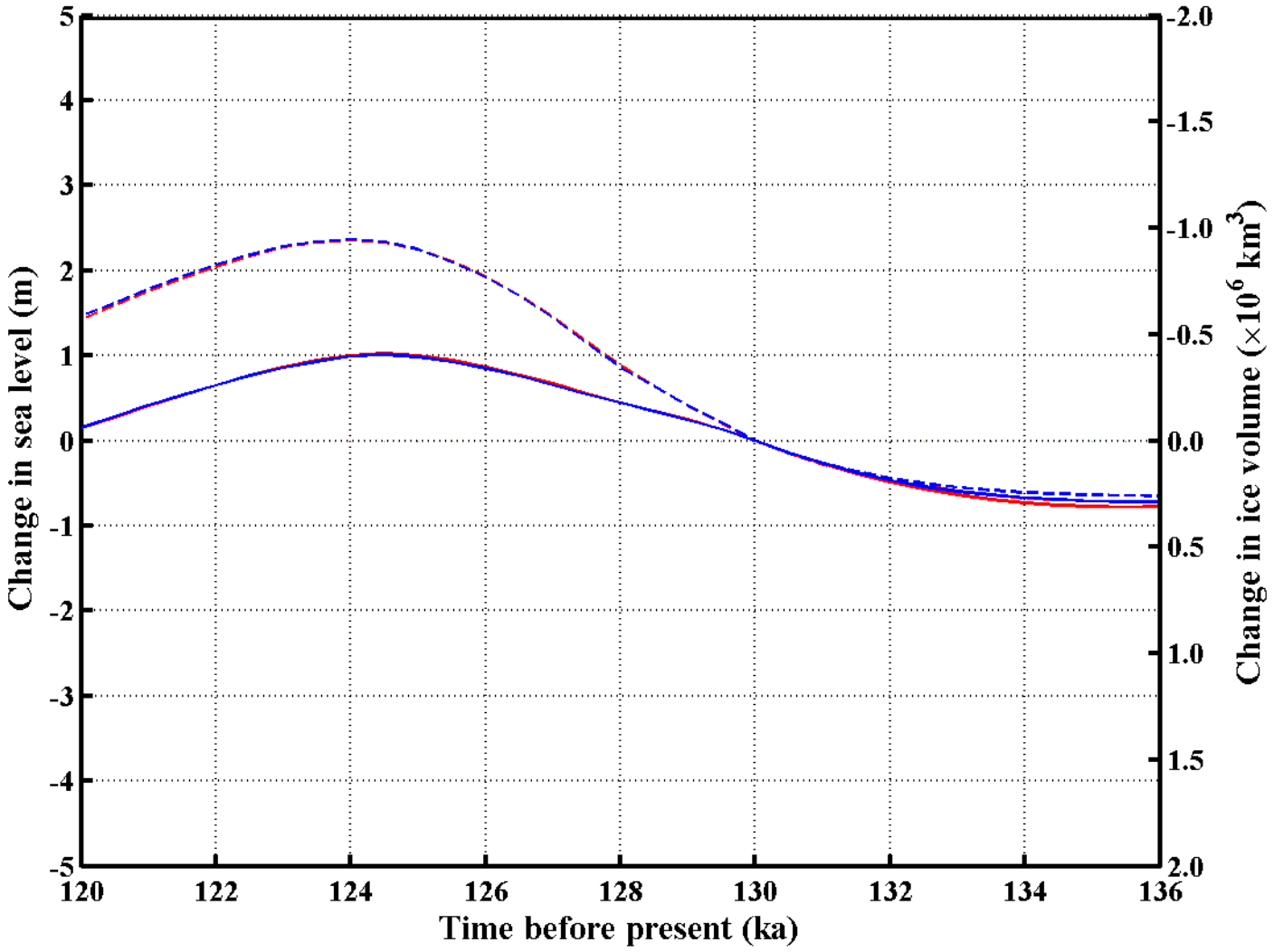
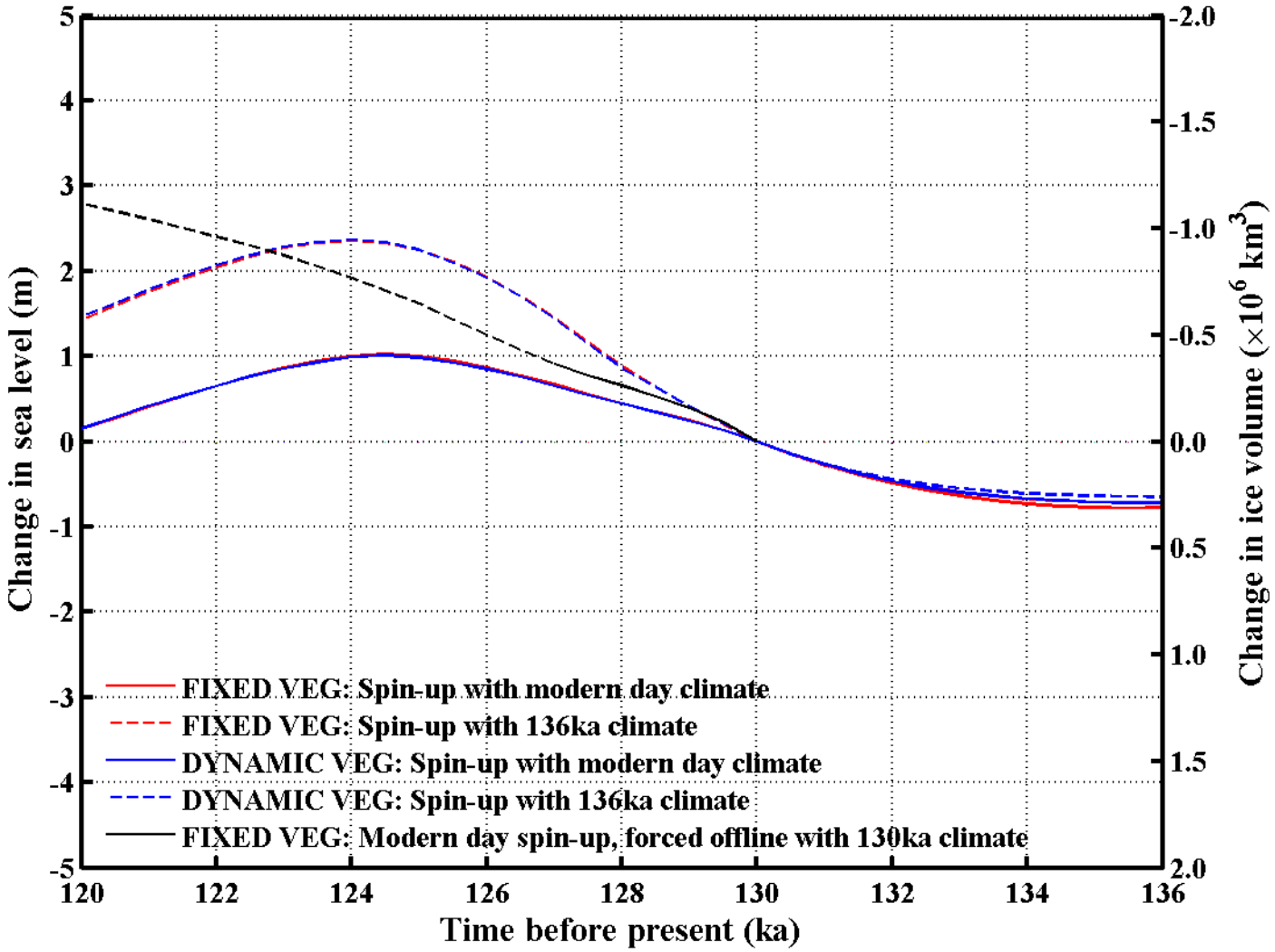


Results: ice volume & sea level



Results: ice volume & sea level



Results: GrIS minimum extent

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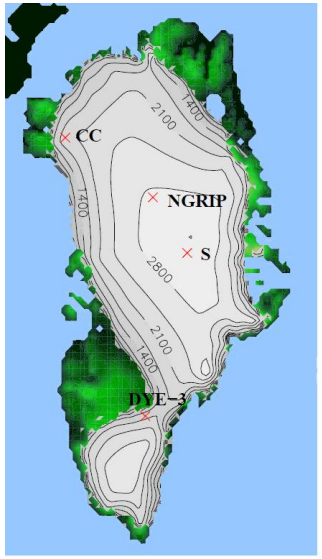
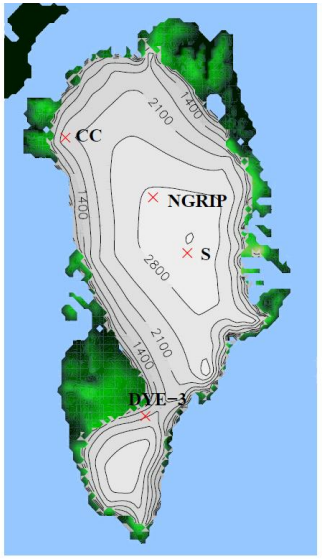
FIXED VEGETATION

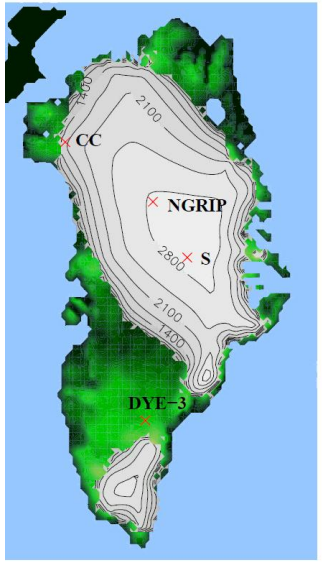


124.5ka

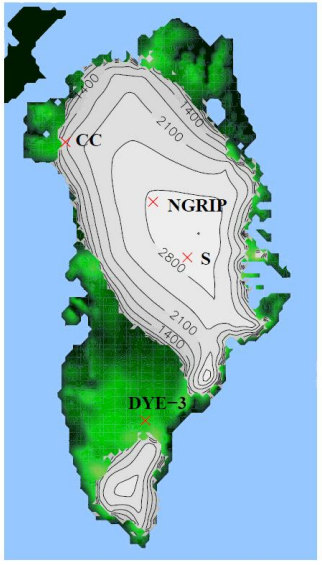


124.5ka

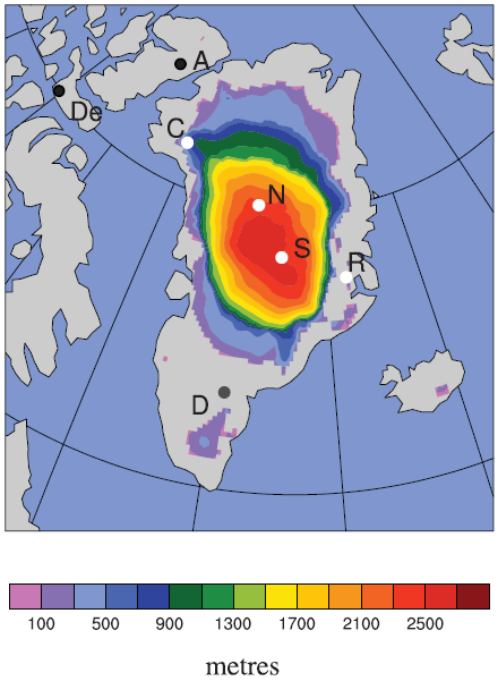
DYNAMIC VEGETATION



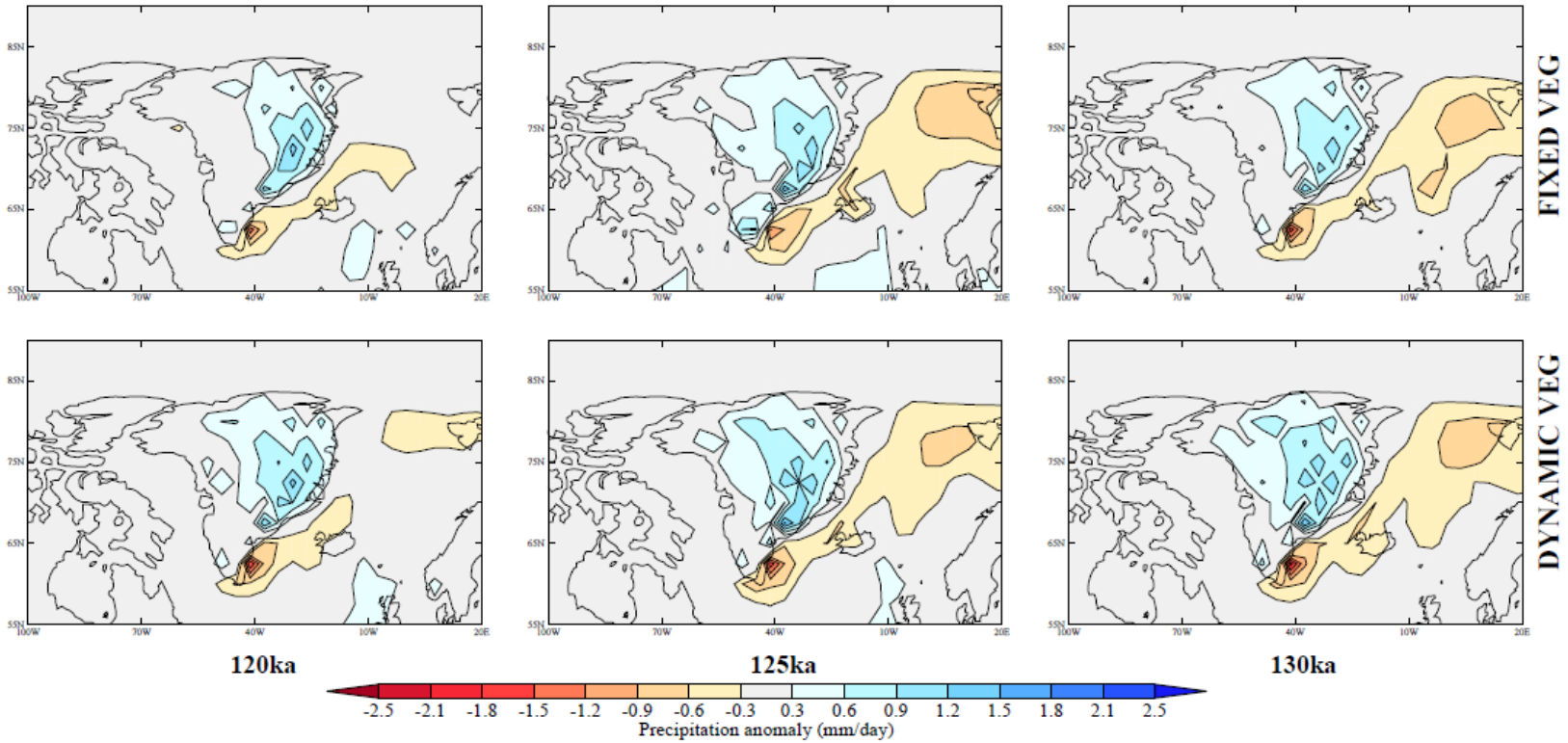
124.0ka



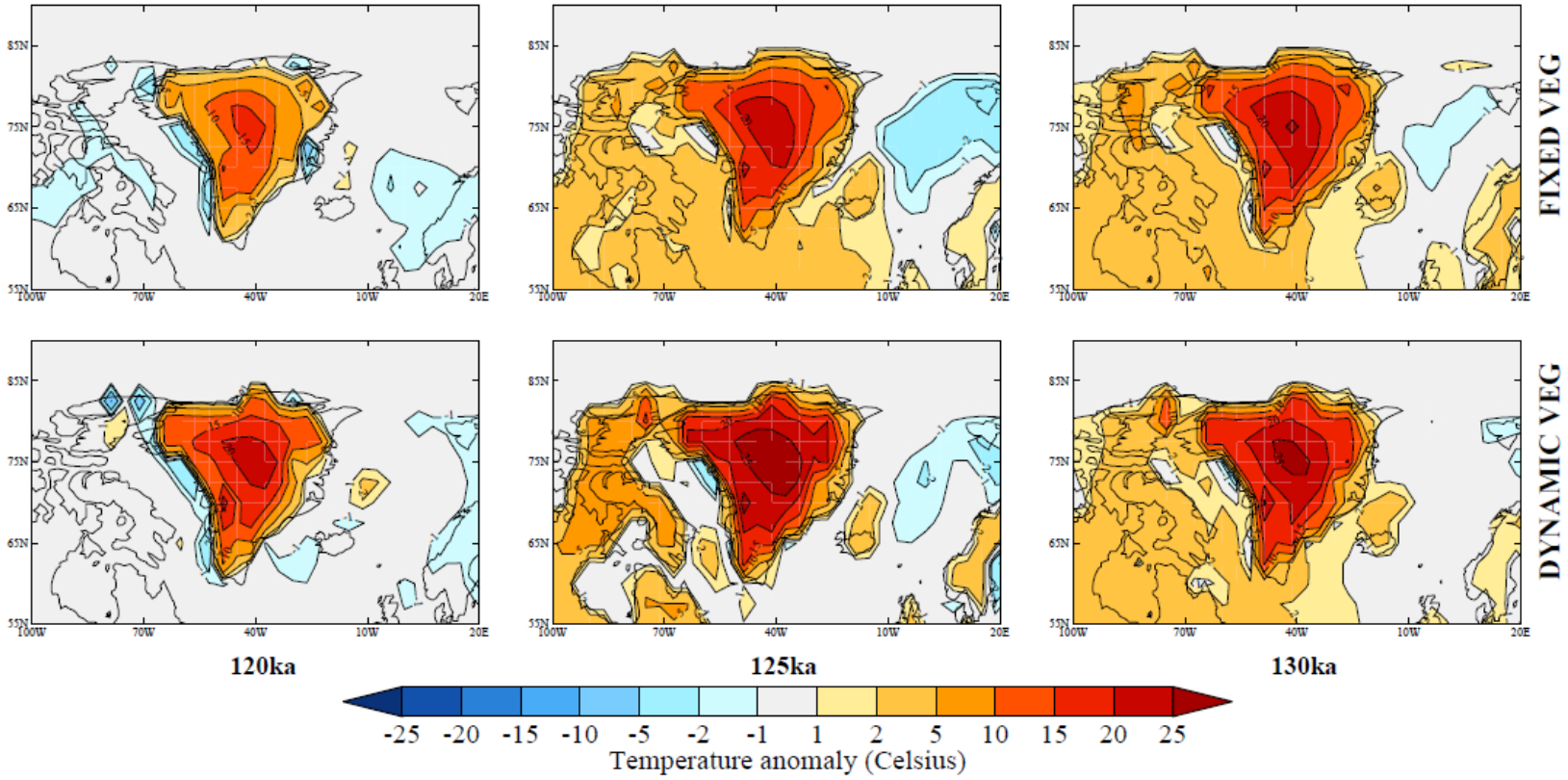
124.0ka



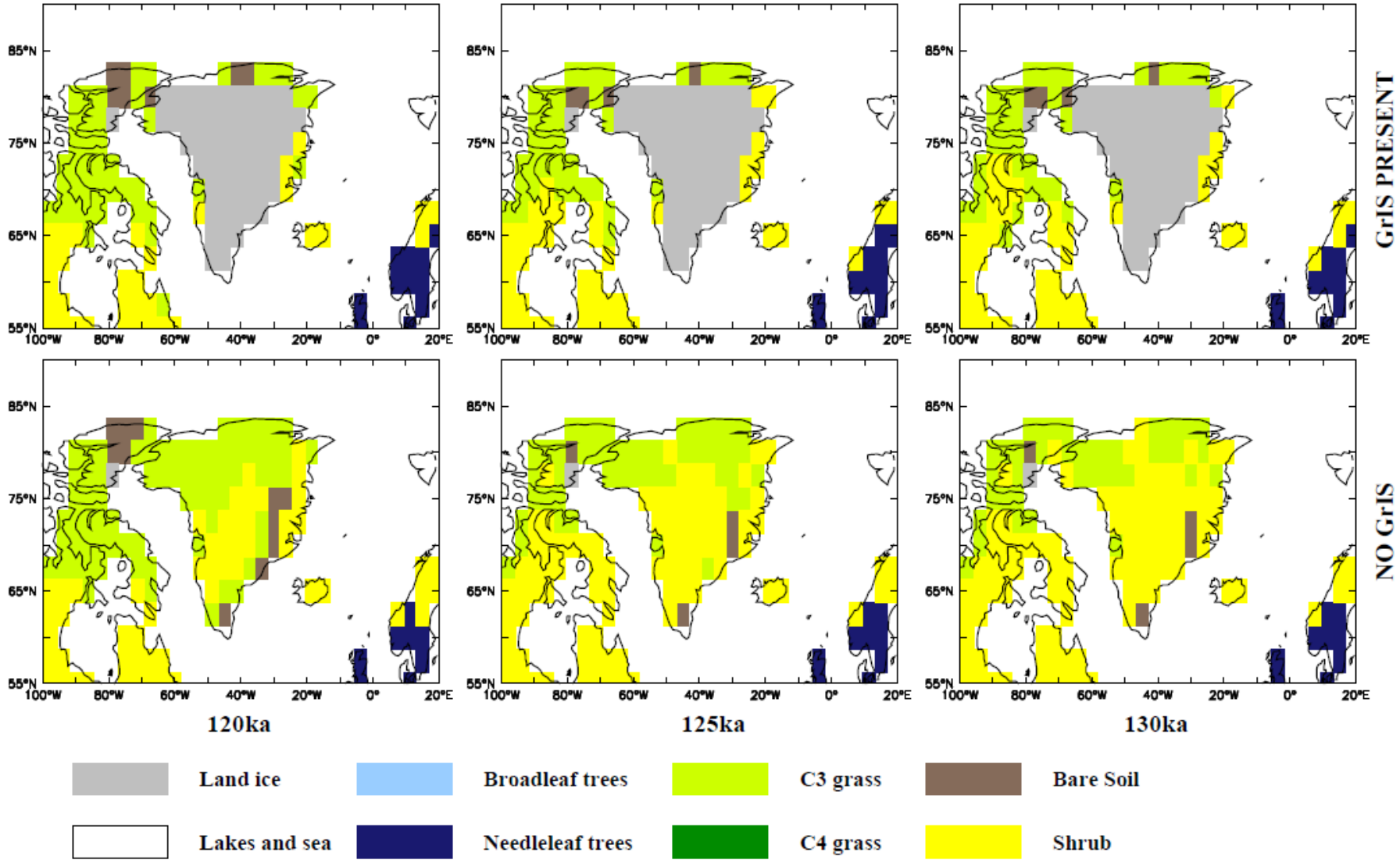
Results: annual precipitation



Results: summer temperature



Results: vegetation cover



Conclusions

- A summer warming of ~5 C is observed at 130ka consistent with previous studies
- A similar experiment to the GCM study by Otto-Bliesner *et al.* (2006) results in a more conservative estimate of ~1.0 m sea level rise
- Sea-level change evolves through time with a maximum at ~124 to125ka and a decrease thereafter broadly consistent with palaeo sea-level data
- Evolution of ice volume and extent of the GrIS is ***insensitive*** to the initial conditions chosen in this set of experiments
- ***Without*** vegetation feedbacks the maximum contribution to sea-level relative to 130ka is 1m compared with 2.4m when interactive vegetation ***is*** included
- In accordance with palaeo-data for the minimum extent of the GrIS, the Dye-3 core only becomes ice-free when vegetation feedbacks are included
- Only the simulations with interactive vegetation fall within the broad GrIS sea-level contribution from recent studies (1.9 to 5.5m)
- Less than half of the sea-level highstand (~4-6m) observed during the LIG comes from the GrIS indicating another source e.g. West Antarctic ice sheet
- Provides a potentially important analogue for future sensitivity of the GrIS to a warming climate

Future work

- Repeat experiments for ‘tuned’ set-ups of the ice sheet model

- Further investigation using different initial conditions

Thank you

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Results: how much difference did the methodology make?

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SPIN-UP WITH 136ka CLIMATE

SPIN-UP WITH MODERN CLIMATE

FIXED VEG

DYNAMIC VEG