The Last Interglacial climate in the high latitudes

Part I : A spatio-temporal surface temperature data synthesis

Part II: Toward improved Model-Data comparisons

Émilie Capron & Emma J. Stone

A. Govin, D. J. Lunt, V. Masson-Delmotte, S. Mulitza, B. Otto-Bliesner, A. J. Payne, T. L. Rasmussen, L. C. Sime, J. Singarayer, P. J. Valdes, C. Waelbroeck, E. W. Wolff.

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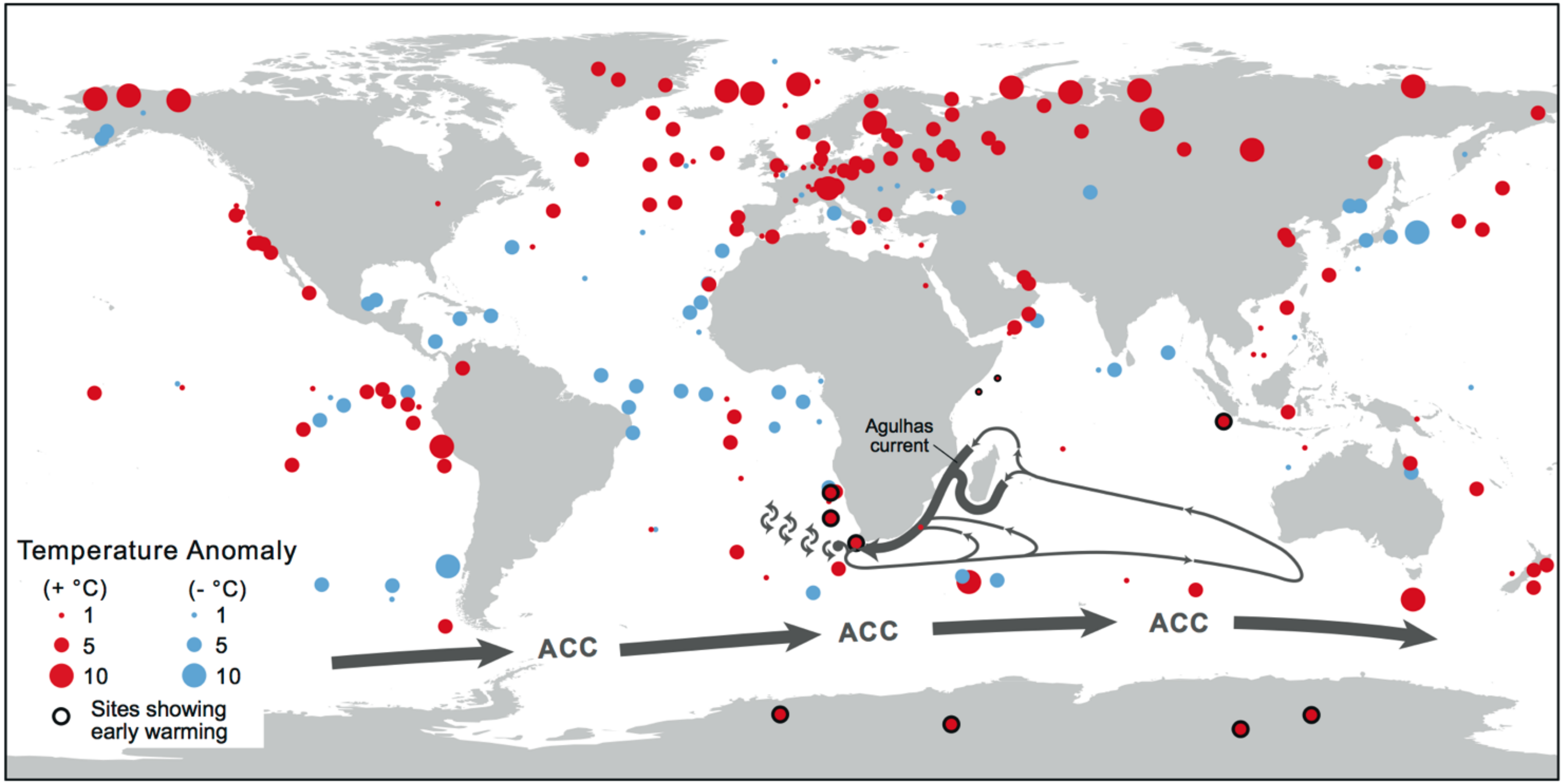
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
University of BRISTOL

The Last Interglacial (LIG, ~129-116 ka)

Last Interglacial Maximum Annual surface temperature (Turney & Jones, 2010)



Limitations of existing LIG data synthesis

→ Original chronologies are used

→Need for **HARMONIZED age scales** across the LIG
(Govin, Capron et al. QSR 2015)

Limitations of existing LIG data synthesis

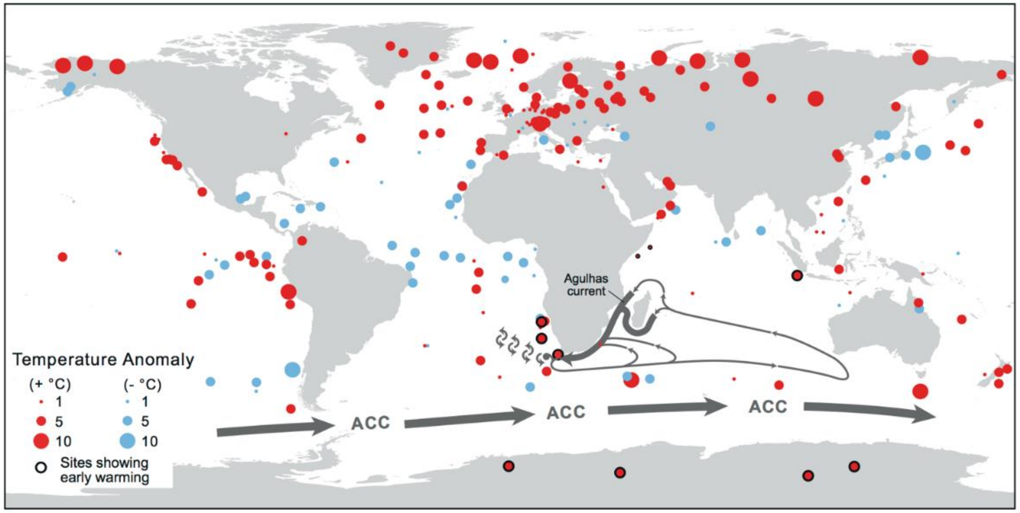
→ One UNIQUE time slice to represent the entire LIG

Underlying hypothesis:

Maximum LIG Warmth occurred synchronously across the world

WRONG

e.g. Bauch et al. 2011; Govin et al. 2012



What is the sequence of climatic events over the LIG ?

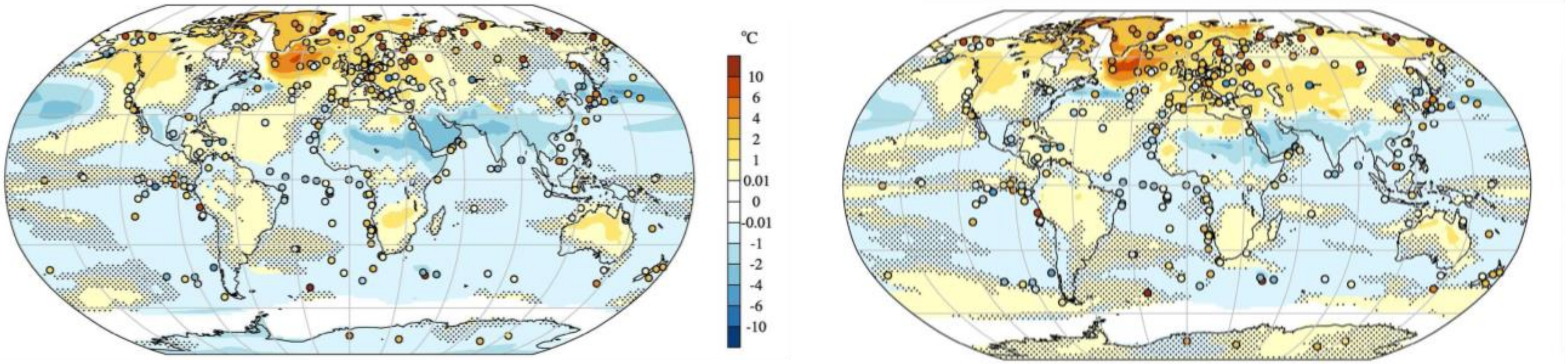
→ Need for a **<u>temporal</u>** in addition to a spatial climatic evolution over the LIG

LIG Model-Data Comparison

Surface temperature anomaly

125 ka - Pre Industrial

130 ka - Pre Industrial



CCSM3 model simulations from Otto-Bliesner et al. 2013

Simulations for different time intervals are tested against a *unique* LIG time slice:

→ Could partly explain model-data mismatches (*Bakker & Renssen 2014*)

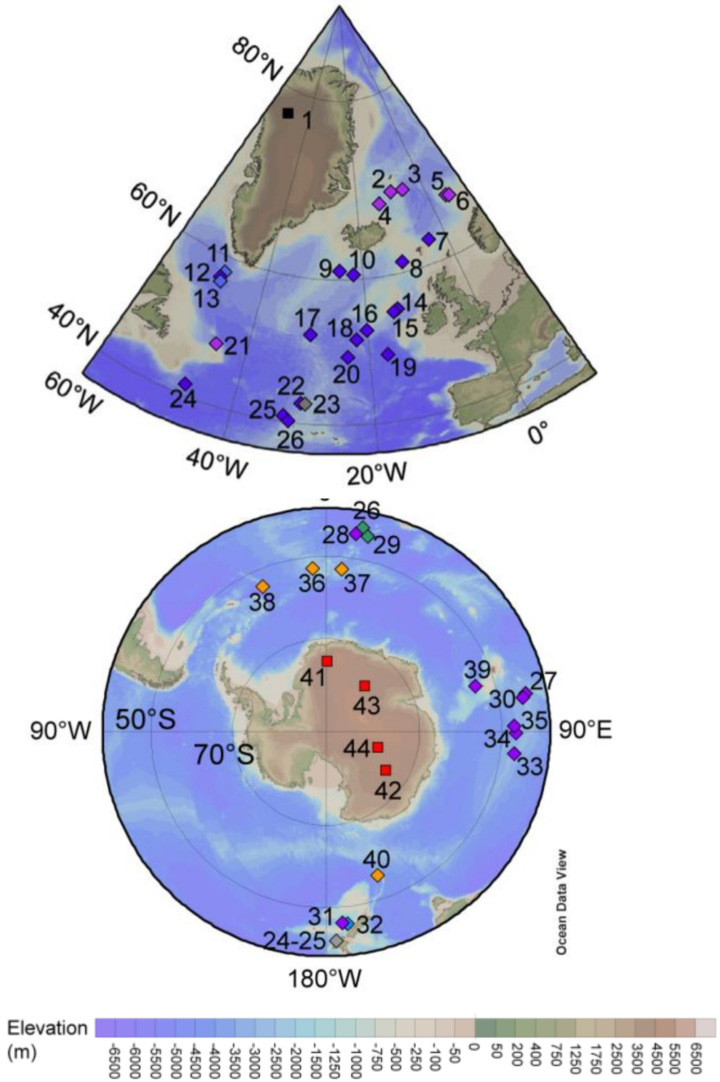
Need for **multiple time slices** for more robust Model-Data comparison

Objectives of the study

- New data synthesis: to document the magnitude and spatio-temporal evolution of temperature changes across the LIG
    - ✓ To define a *consistent time frame for multiple ice and marine records*
    - ✓ To define *4 time slices* of temperature anomalies
    - ✓ To estimate and propagate *temperature & age uncertainties*

- Model-data comparison: to illustrate the potential of the new LIG data synthesis as improved benchmark for climate models

LIG Data Selection



- 5 ice cores
- 39 marine sediment cores (42 SST records)
- High latitudes: **> 40° N** & **> 40° S**
- Surface air temperature & SST records
- Temporal resolution of at least 2000 years
- Annual or summer signals

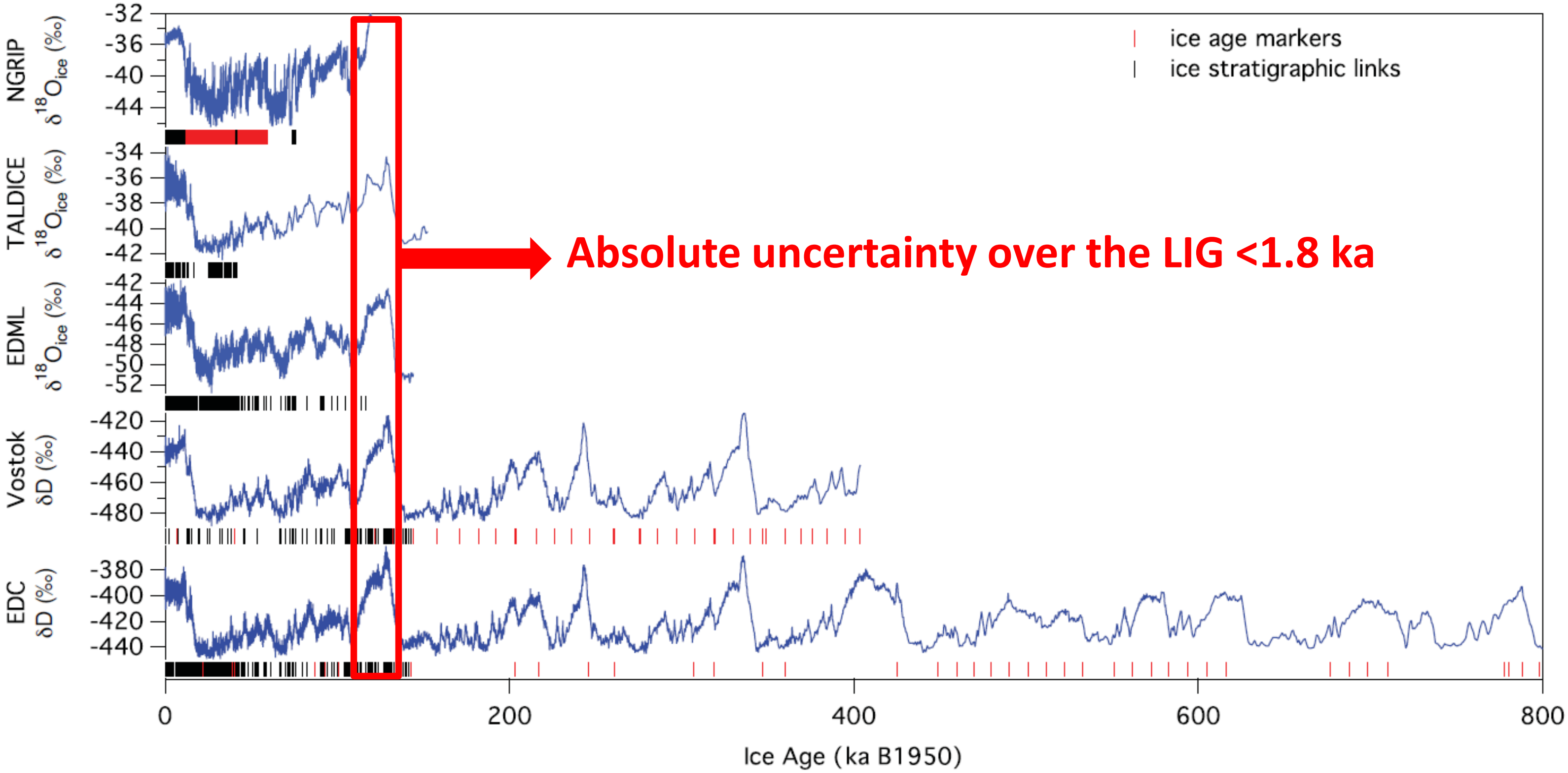
Air surface temperature (ice cores)

SST:
- MAT (forams)
- % NPS
- Mg/Ca
- alkenones
- radiolarians
- diatoms

Strategy for building a consistent time frame

AICC2012 as the reference time scale (Bazin et al. 2013, Veres et al. 2013)

- Common to 5 ice cores
- LIG absolute dating error < 1.8 ka (1σ)



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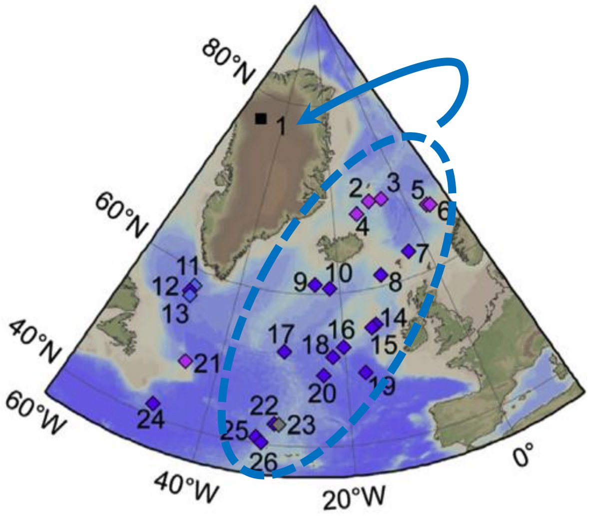
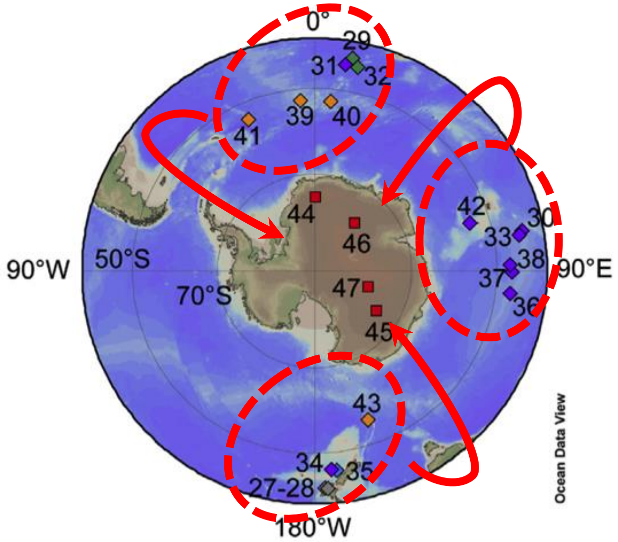
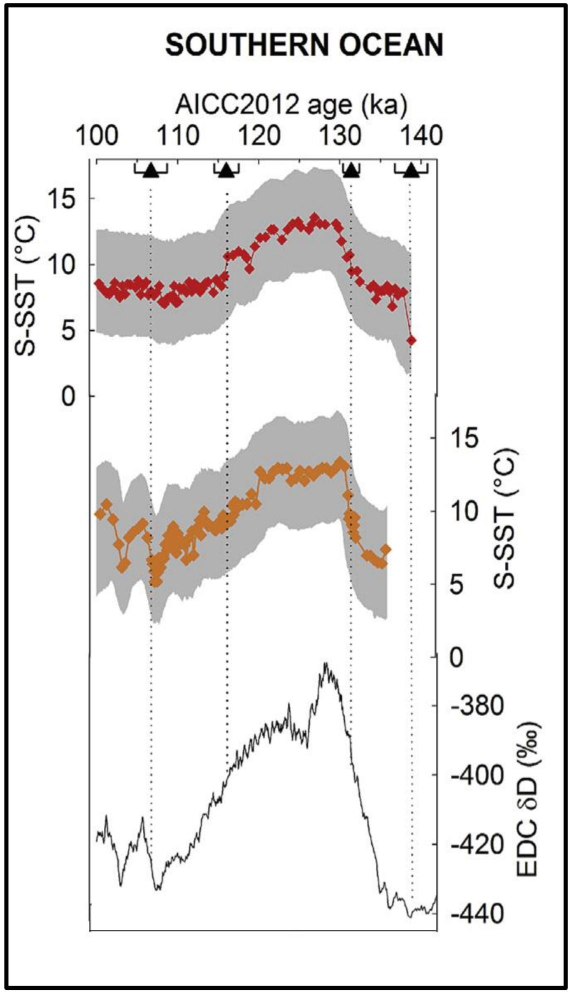




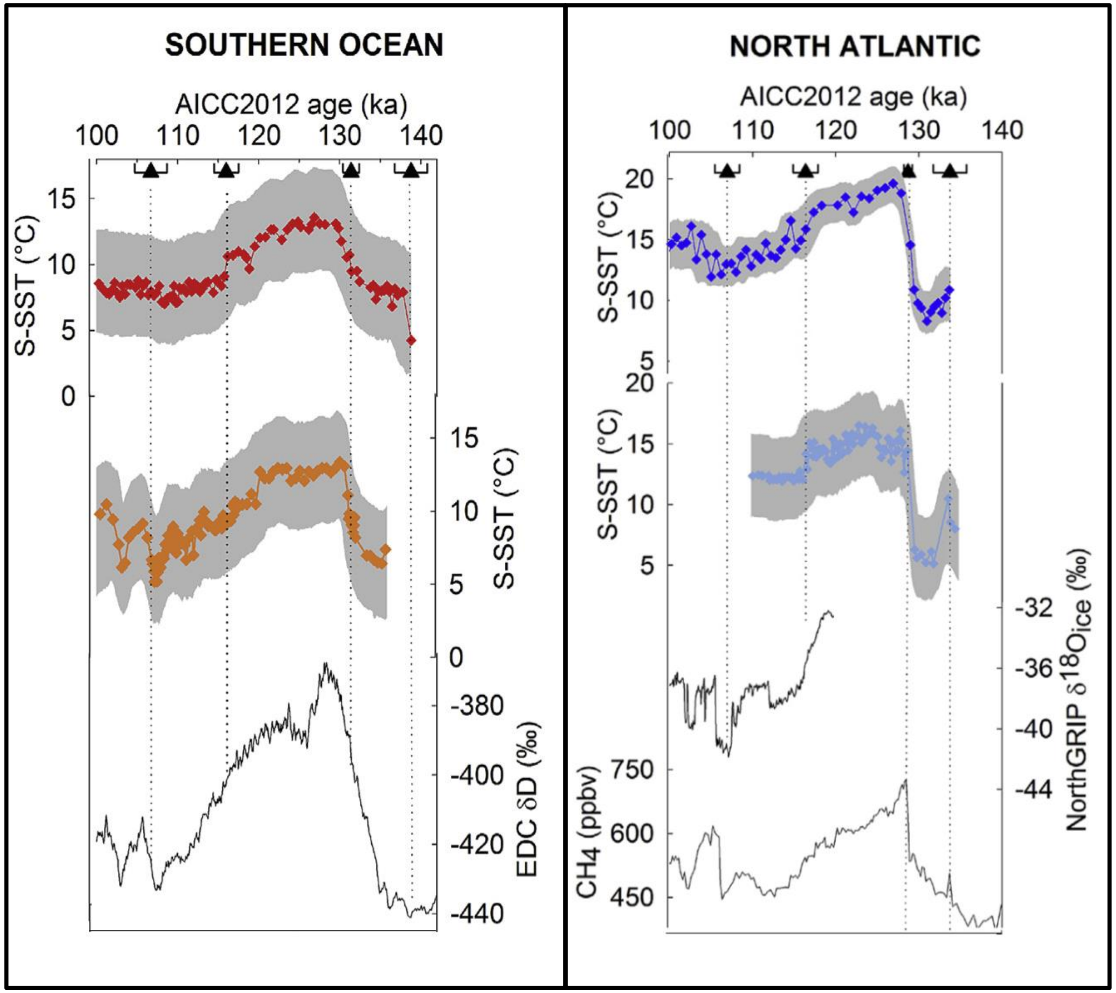
Hypothesis (Govin et al. 2012) : SST changes in the sub-antarctic zone of the Southern Ocean (resp. North Atlantic) occurred *simultaneously* with **air temperature** over Antarctica (resp. Greenland)

Strategy for building a consistent time frame



Southern Ocean **SST** tied to EPICA Dome C **δD** record

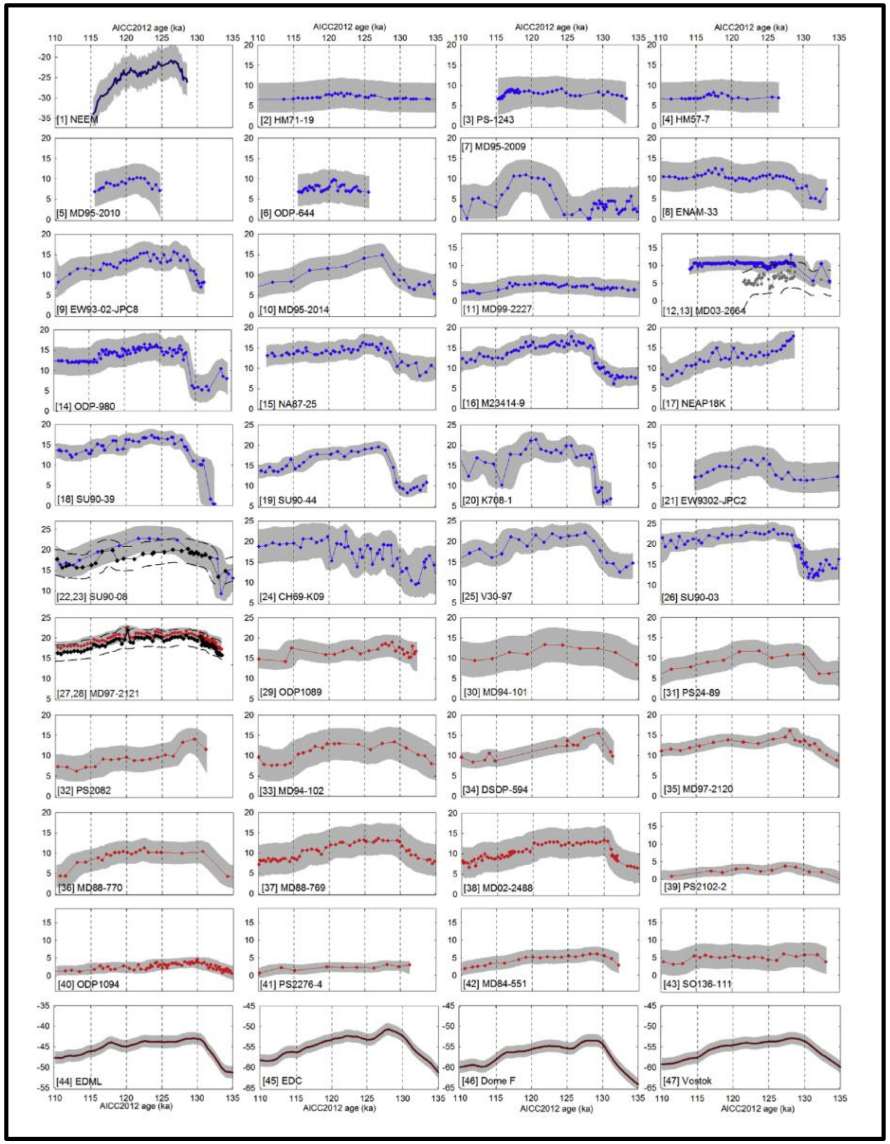
Strategy for building a consistent time frame



North Atlantic SST tied to:

- NGRIP ice $\delta^{18}O$ (100-120 ka)
- EDC CH_4 (128-140 ka)

LIG high latitude climate temporal reconstructions



Need for uncertainty estimates on the surface temperature records

LIG high latitude climate temporal reconstructions

- Monte Carlo Analysis with 1000 age model simulations taking into account :

(1) Errors on SST reconstruction method : from 0.6 to 2.1° C (average of 1.4° C)

(2) Age Uncertainties on tie point definition : from 0.5 to 4 ka

± 2.6° C (2σ) in average

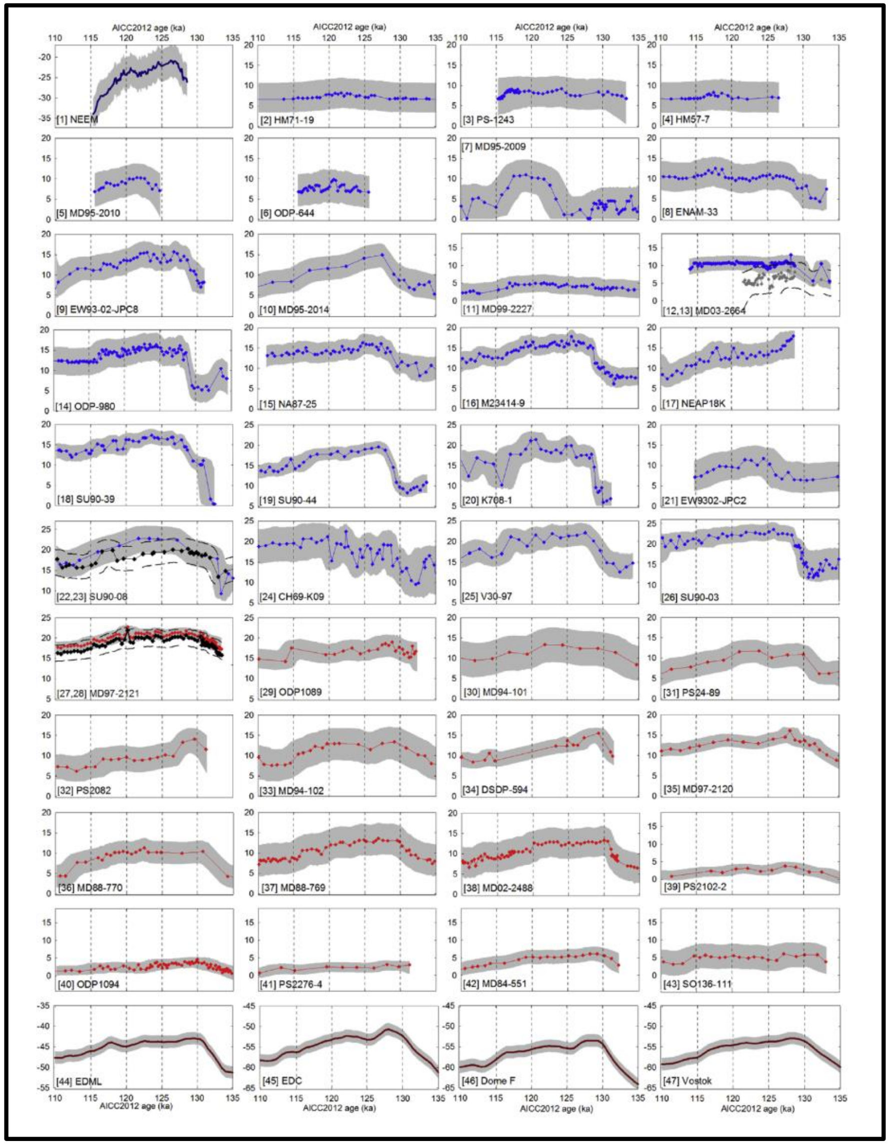
MD02-2488 (Southern Ocean)

Depth_cm	Age_ka	Error_ka
2250.9	102.6	**0.7**
2279.4	103.8	**0.7**
2330.2	106.7	**0.7**
2424.5	110.3	**1**
2503.0	117.4	**1.5**
2552.6	131.0	**0.7**
2658.5	135.9	**2**

ODP 980 (North Atlantic)

Depth_cm	Age_ka	Error_ka
1389.9	105.6	**1**
1411.0	107.5	**1**
1436.6	112.0	**1**
1498.7	116.2	**1.5**
1738.5	128.7	**0.5**
1869.4	146.4	**3**

LIG high latitude climate temporal reconstructions



Useful benchmarks for transient climate simulations

e.g. Loutre et al. 2013; Pfeiffer et al. in revision

4 time slices of temperature anomalies & errors

115 ka (114-116 ka)

120 ka (119-121 ka)

125 ka (124-126 ka)

130 ka (129-131 ka)

4 time slices of temperature anomalies & errors

115 ka (114-116 ka)	**120 ka** (119-121 ka)	**125 ka** (124-126 ka)	**130 ka** (129-131 ka)

→ Temperature anomalies relative to present day

- **Ice cores:** instrumental mean annual surface air temperature
- **Marine cores:** World Ocean Atlas (WOA) 1998 SST (10-m deep) *(Kucera et al. 2005)*

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→ Temperature anomalies relative to present day

- **Ice cores:** instrumental mean annual surface air temperature
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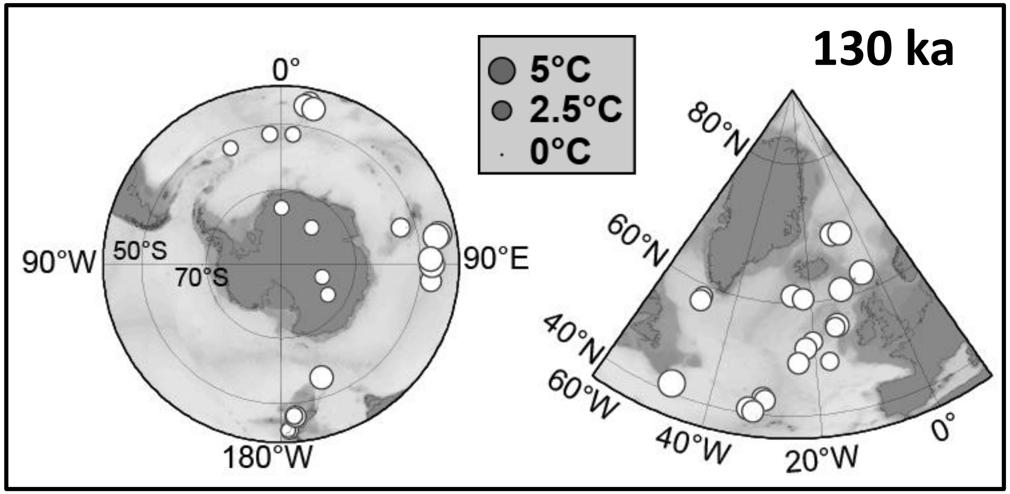
→ Estimation of **temperature errors**



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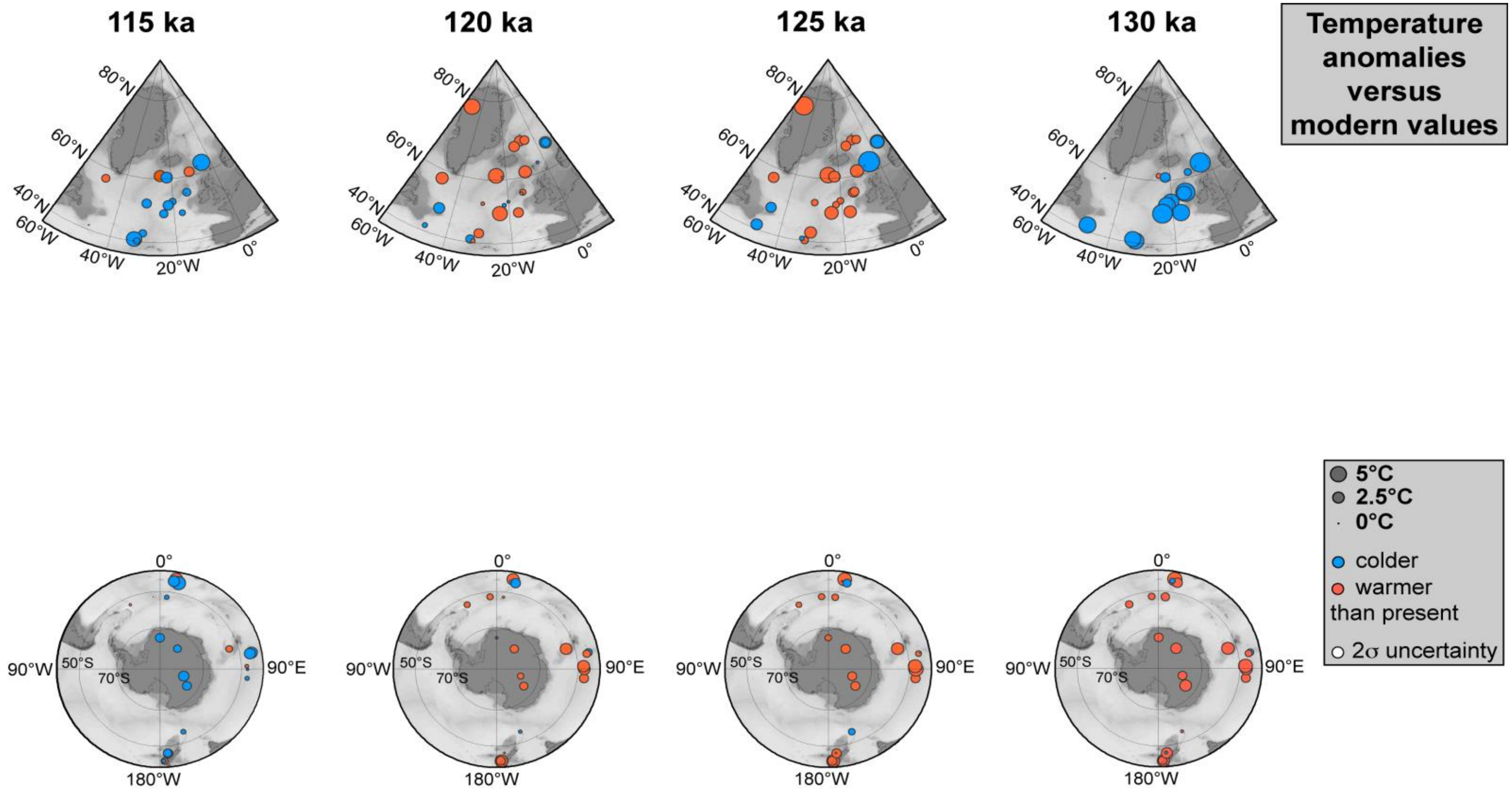
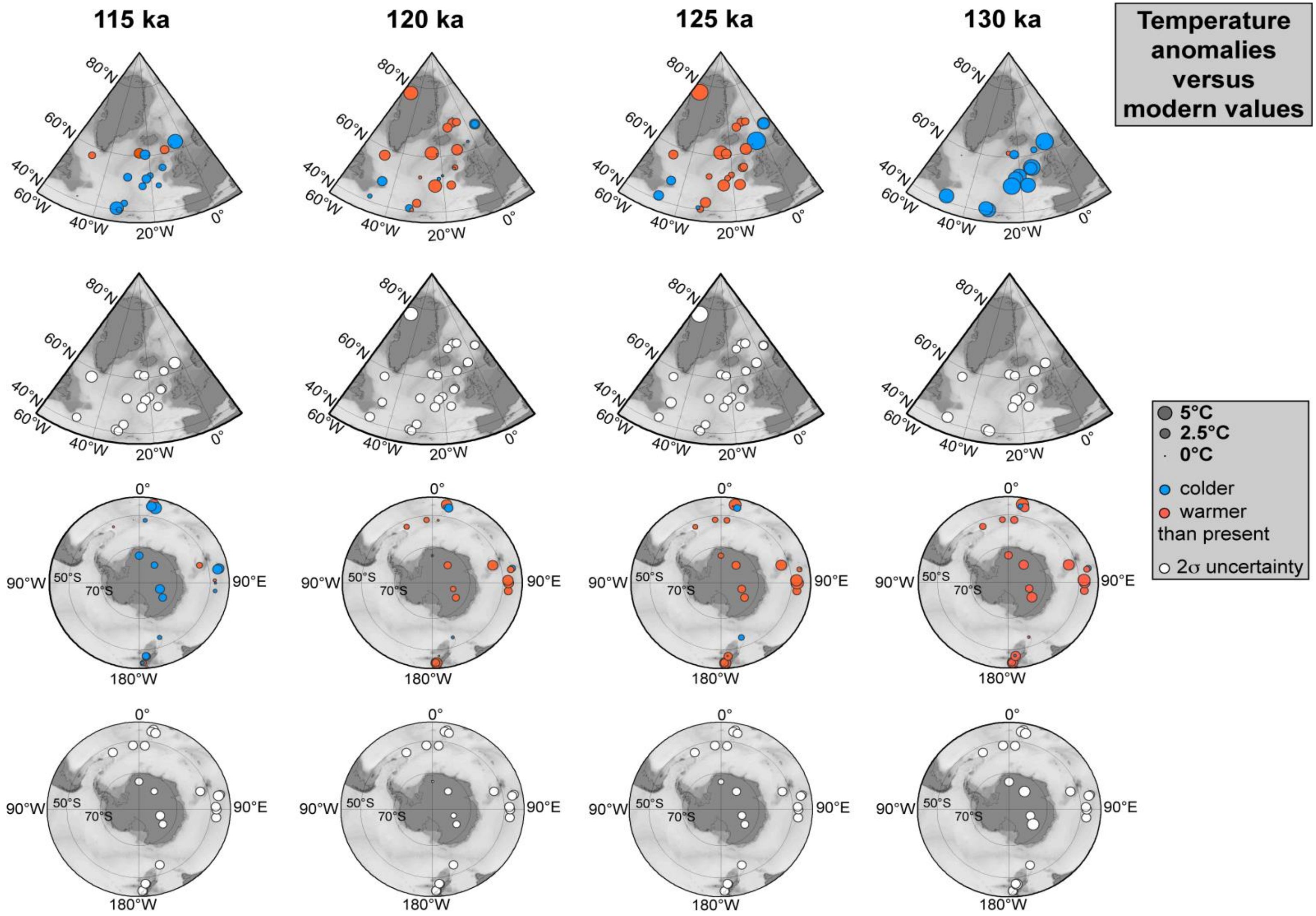


4 time slices of temperature anomalies & errors

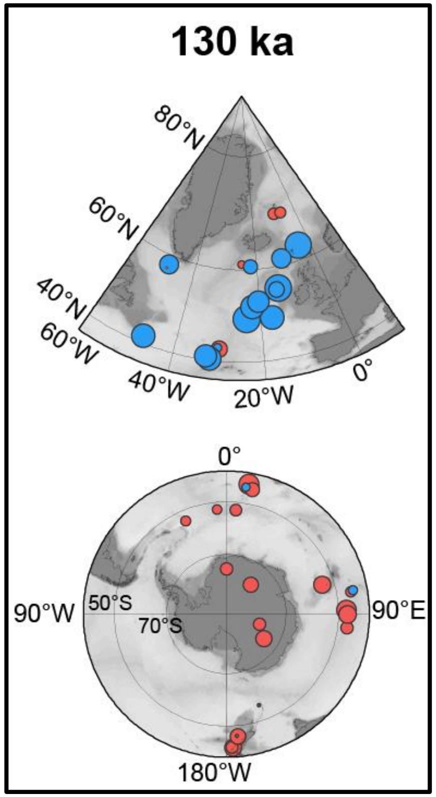


LIG spatio-temporal evolution of temperatures

- **Early Southern Hemisphere warming** (130 ka) compared to the North Atlantic region

Temperature anomalies

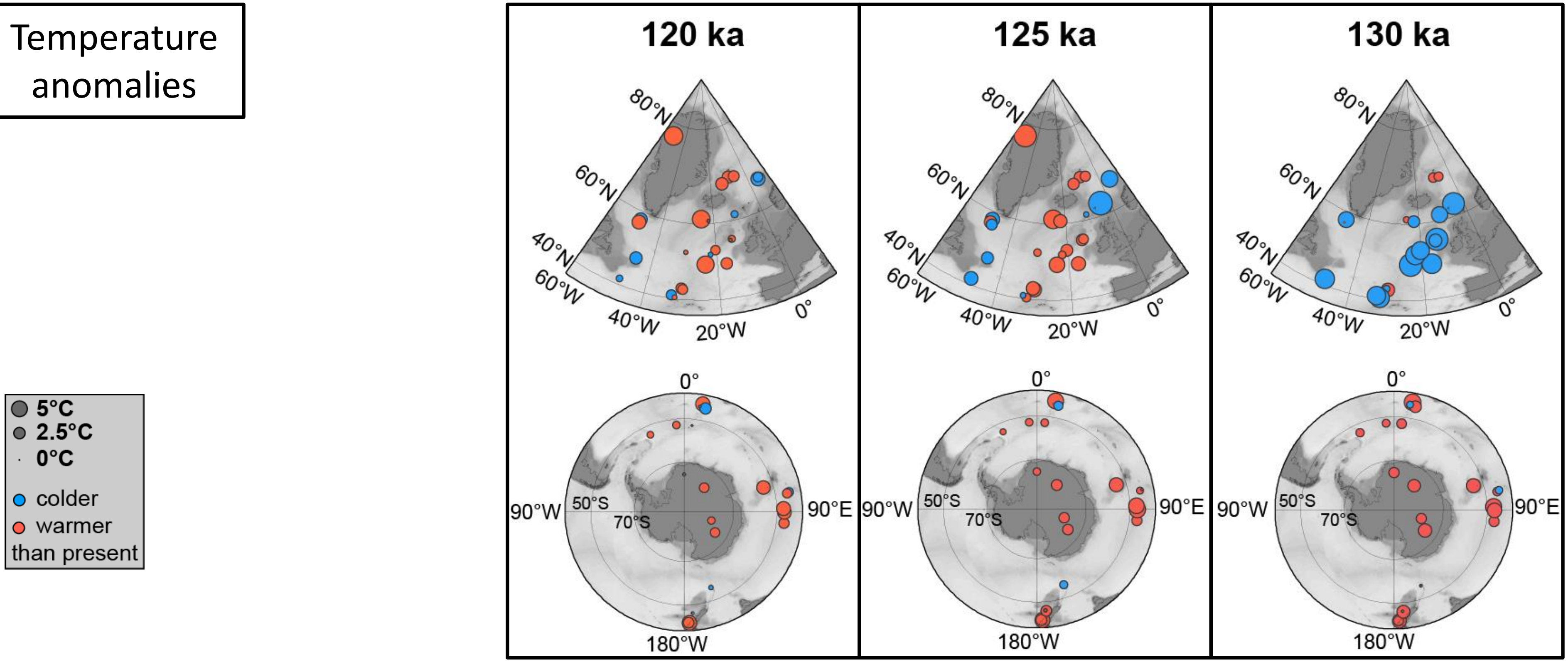
5°C
2.5°C
0°C
colder
warmer
than present



LIG spatio-temporal evolution of temperatures

- **Early Southern Hemisphere warming** (130 ka) compared to the North Atlantic region
- **Warmer-than-present conditions** in both hemispheres (125 ka, 120 ka)

Temperature anomalies



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- **Early Southern Hemisphere warming** (130 ka) compared to the North Atlantic region
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- **Longer period** of warmer-than-present conditions in the **SH** (vs. the North Atlantic)

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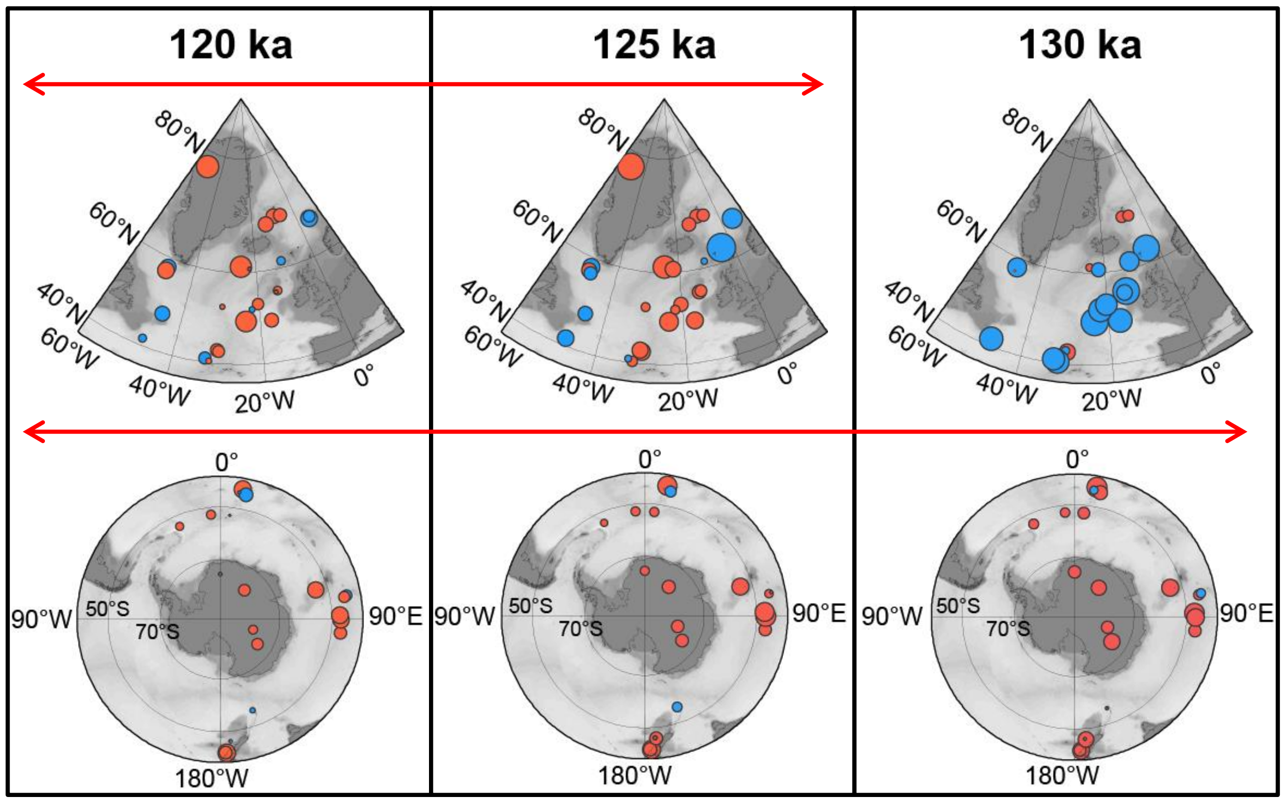

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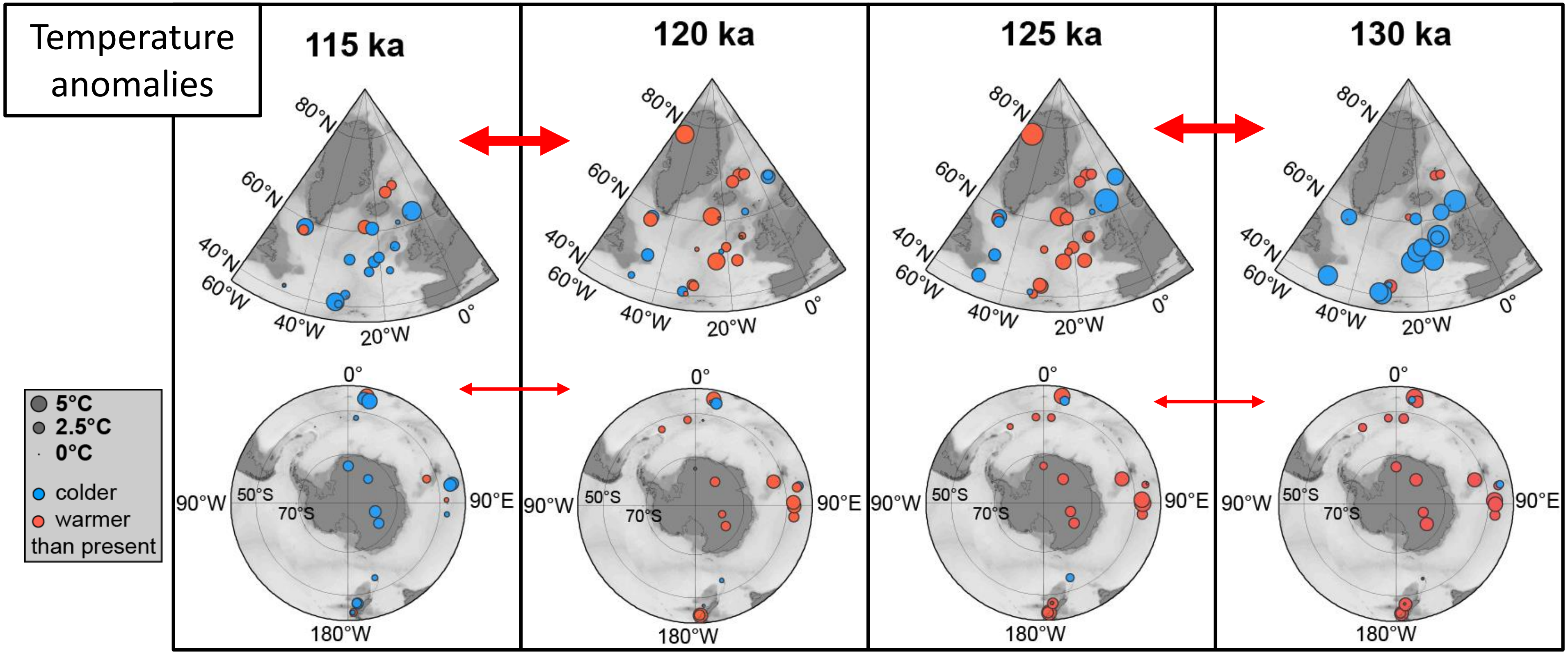
- **Warmer-than-present conditions** in both hemispheres (125 ka, 120 ka)
- **Longer period** of warmer-than-present conditions in the **SH** (vs. the North Atlantic)
- **Larger amplitude** of **North Atlantic** temperature changes into and out of the LIG



Summary

New LIG data synthesis of high-latitude surface temperatures
(Capron et al. QSR 2014)

- ✓ Consistent time frame for marine and ice core records;
- ✓ Spatio-temporal evolution of LIG surface temperatures;
- ✓ 115, 120, 125 & 130 ka time slices of surface temperature anomalies with 2σ errors (including temperature & age uncertainties).

Inputs for ice sheet models to investigate the contribution of Greenland and Antarctic to sea level changes during the LIG.

→ **Toward improved LIG climate model-data comparisons *(Capron et al. QSR 2014; Stone et al. in revision)***

The Last Interglacial climate in the high latitudes

Part I : A spatio-temporal surface temperature data synthesis

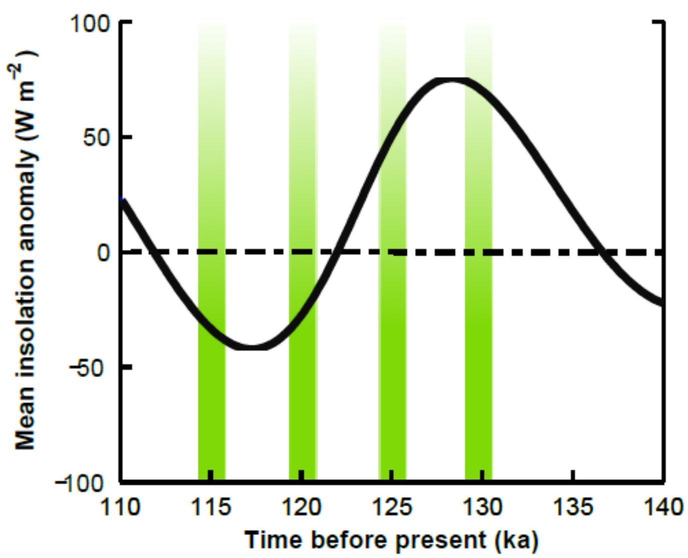
***Part II:* Toward improved Model-Data comparisons**

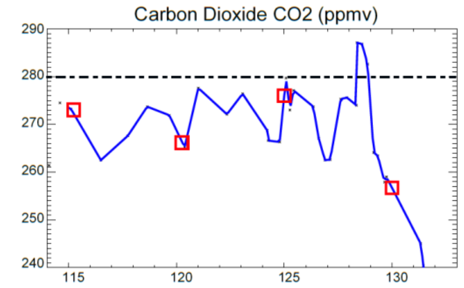
Modelling the LIG climate

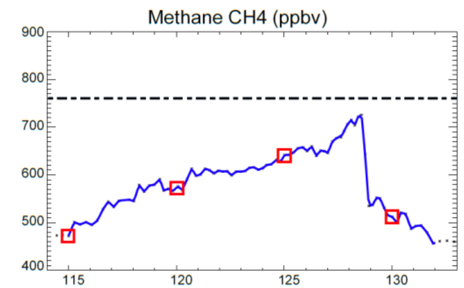
- Changed orbital parameters (insolation) ✓
- Changed GHGs ✓
- Changed ice sheet ✗
- Vegetation feedbacks ✗
- Freshwater forcing ✗

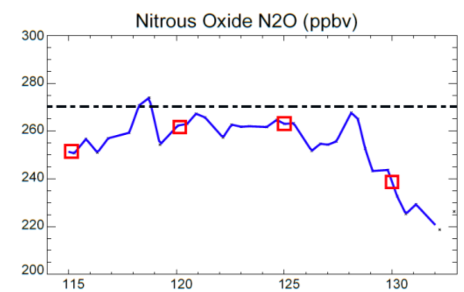
HadCM3 = SNAPSHOTS

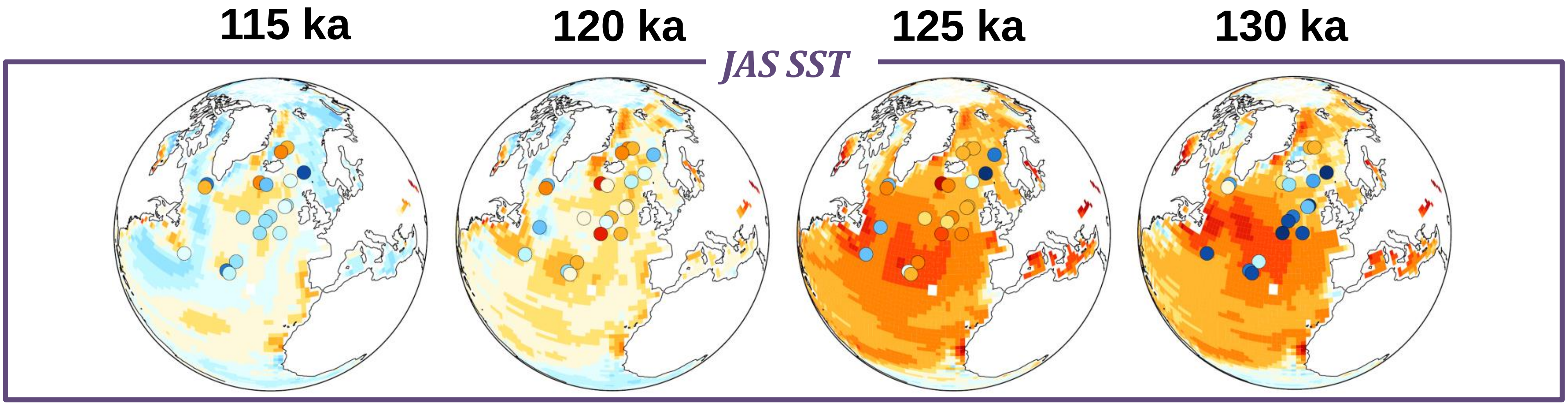
➢ 4 simulations of 550 model years: 130, 125, 120 and 115 ka (BP)

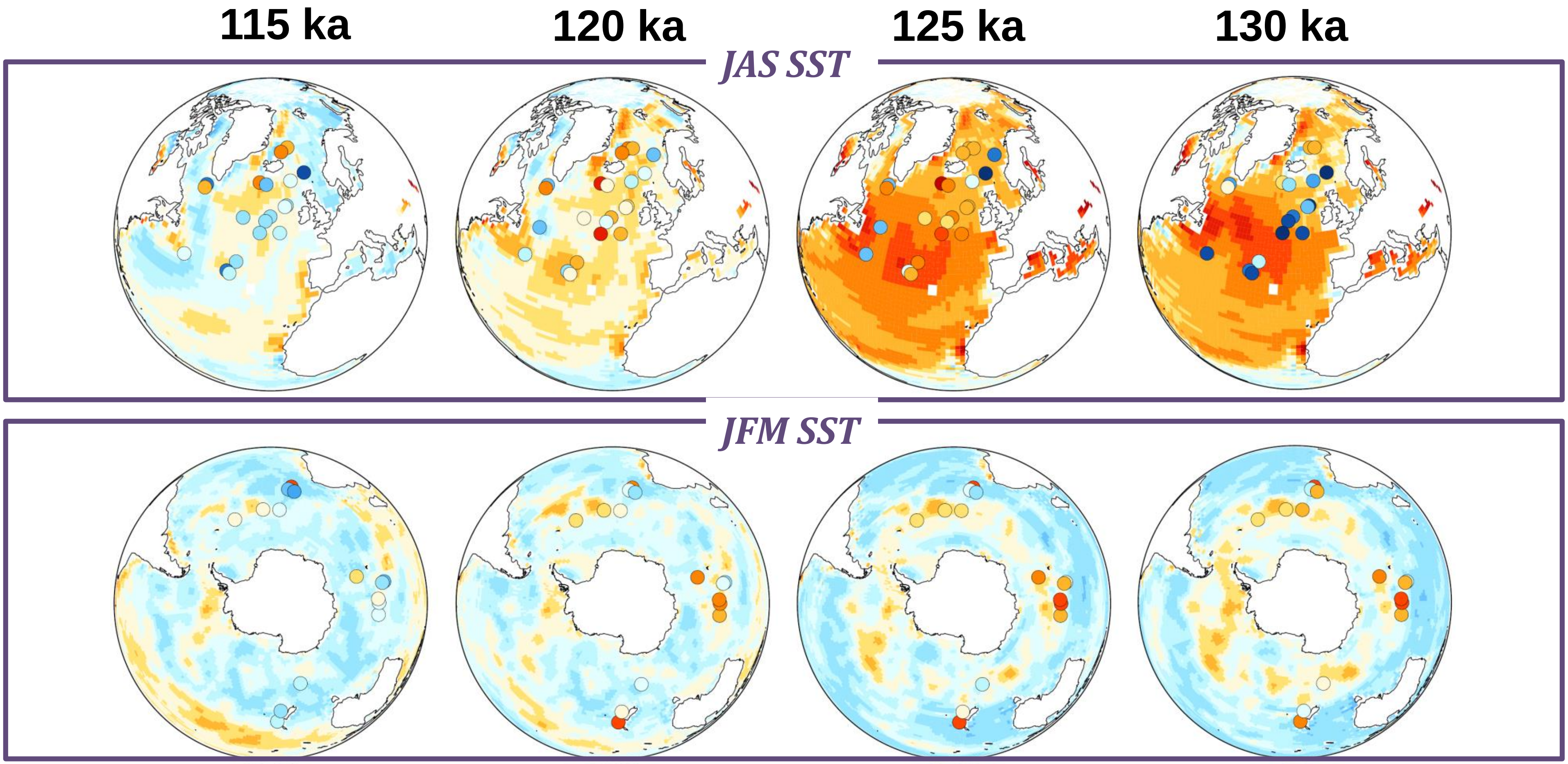




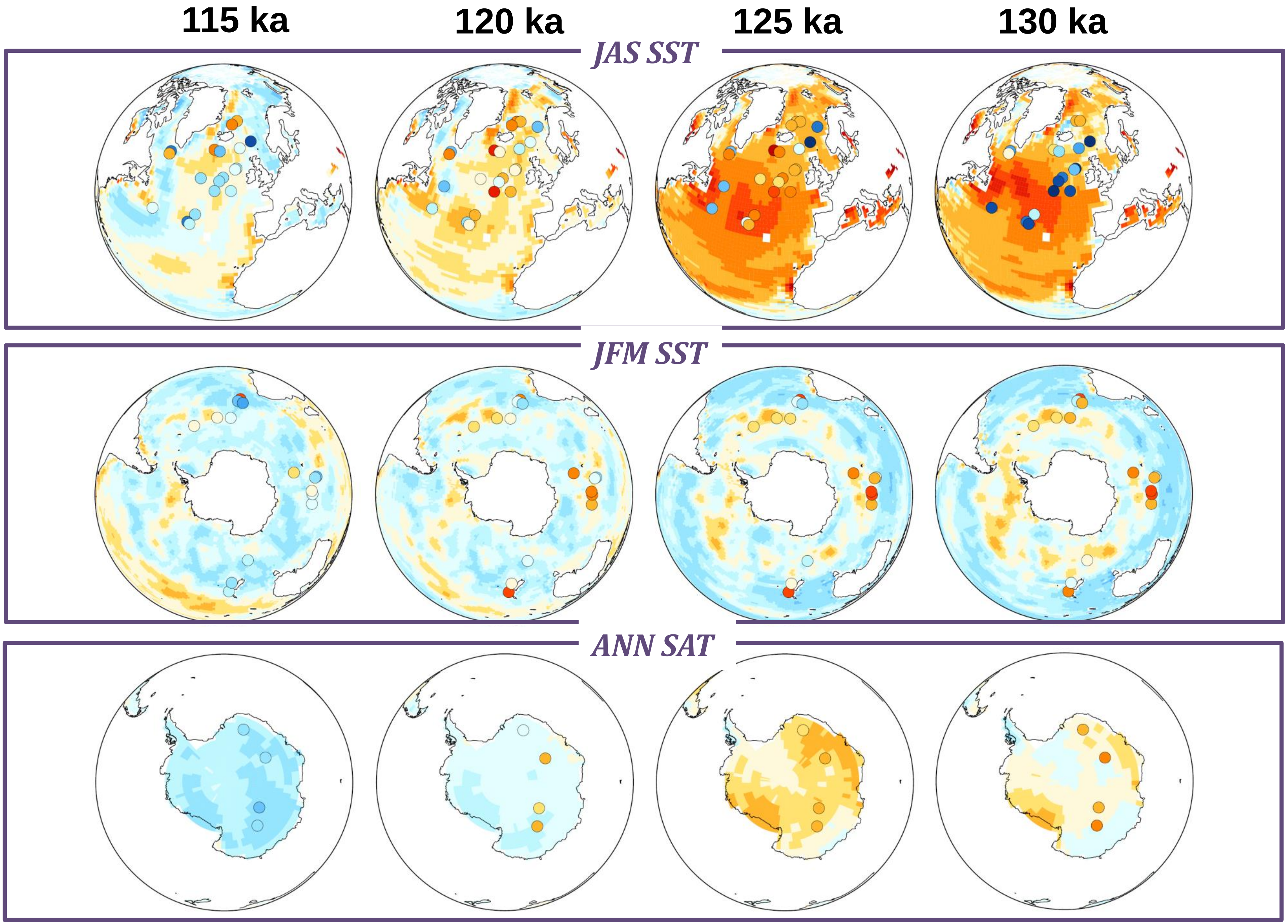





115 ka
120 ka
125 ka
130 ka
JAS SST



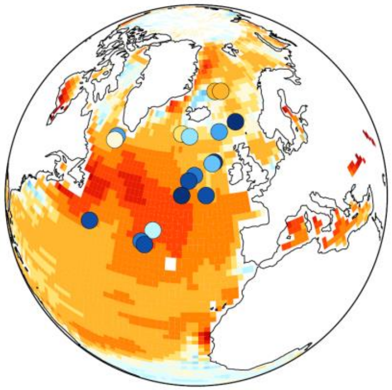
115 ka
120 ka
125 ka
130 ka
JAS SST
JFM SST



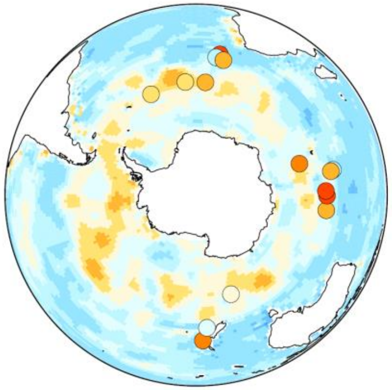
115 ka
120 ka
125 ka
130 ka
JAS SST
JFM SST
ANN SAT

130 ka

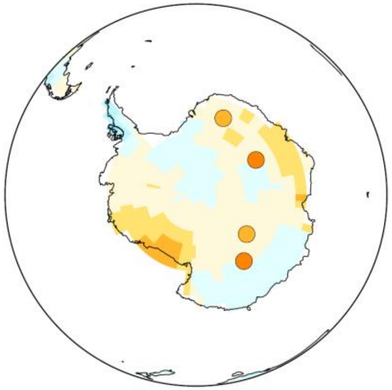
Model fails to reproduce **colder-than-present** North Atlantic Conditions



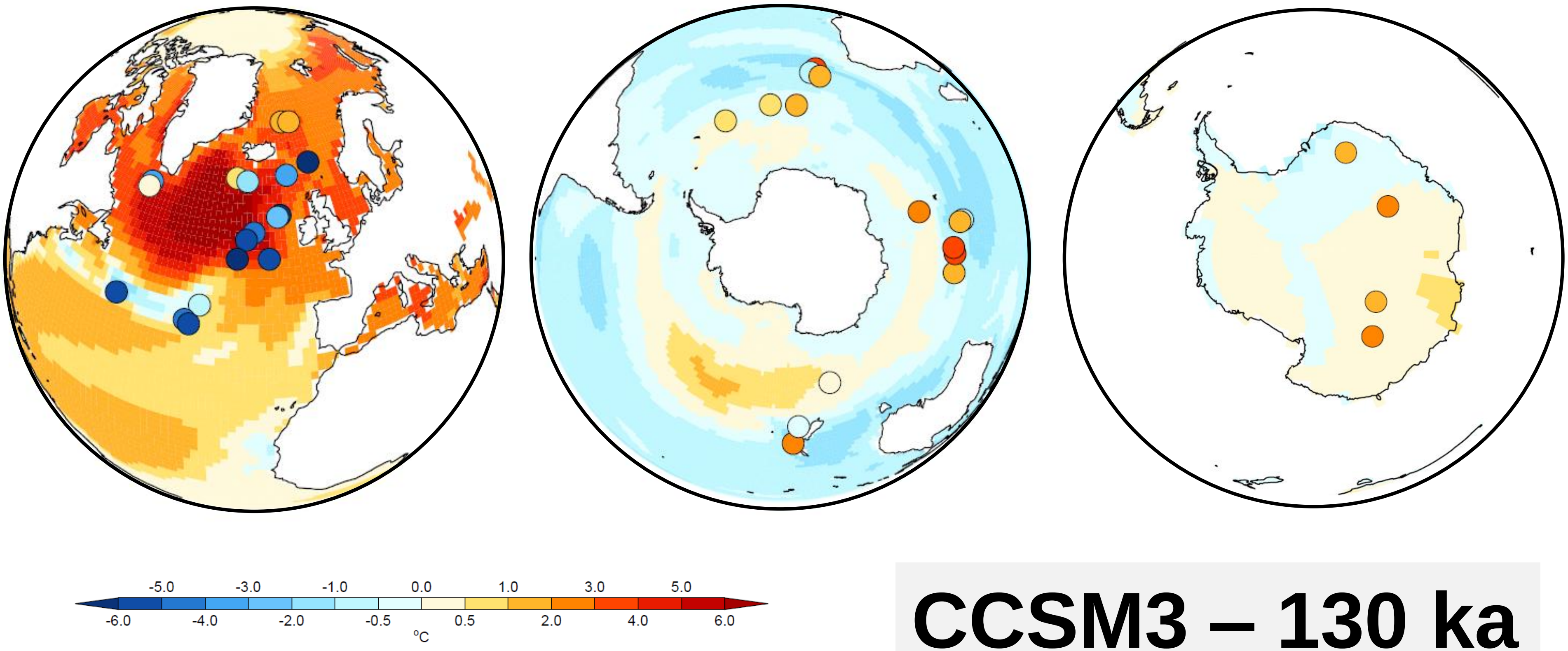
Model fails to reproduce **warmer-than-present** Southern Ocean Conditions



Model fails to reproduce **warmer-than-present** East Antarctic Conditions



What about other models?

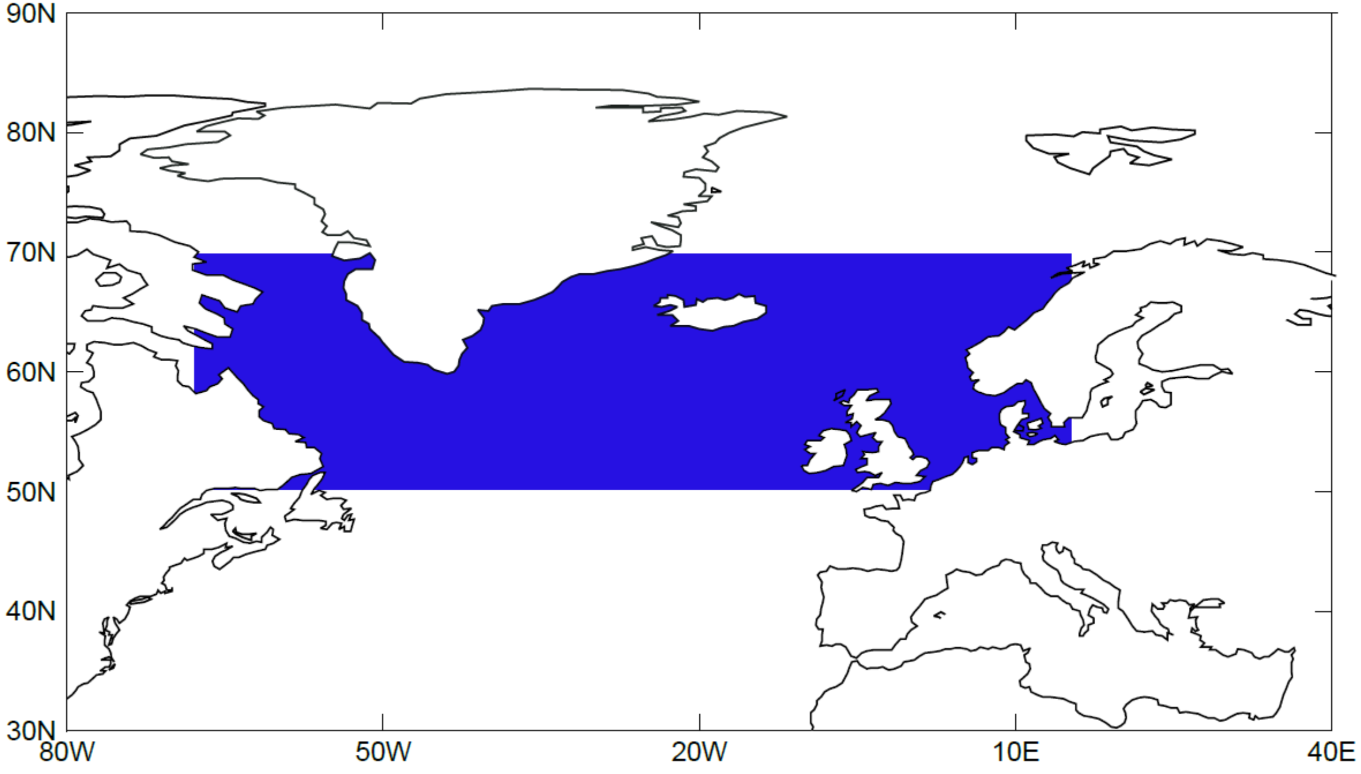


CCSM3 – 130 ka

Reconciling the mismatch between data and model

Models **NOT** run with full 130 ka climate conditions:

- Interactive ice sheets
- Interactive vegetation
- Freshwater fluxes

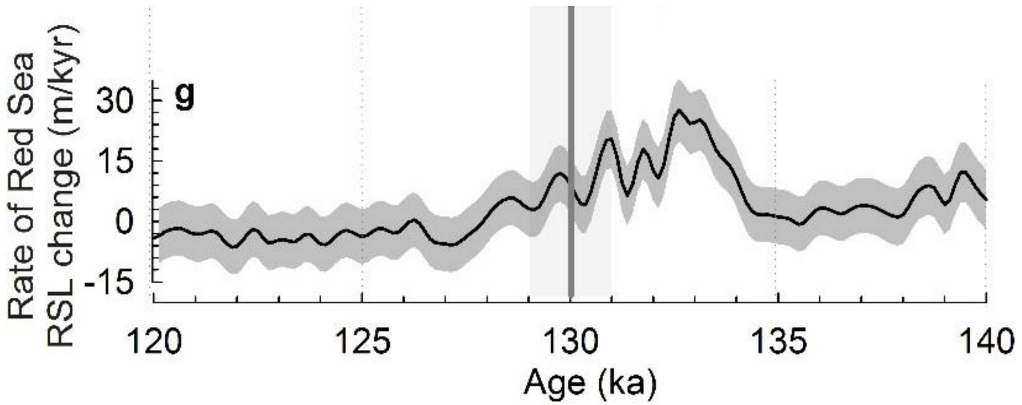


What about the melting of the NH ice sheets from the previous glaciation?

How much freshwater?

Sea level rate was ~22 m/kyr at 130 ka during the glacial-interglacial transition (Grant et al. 2012)

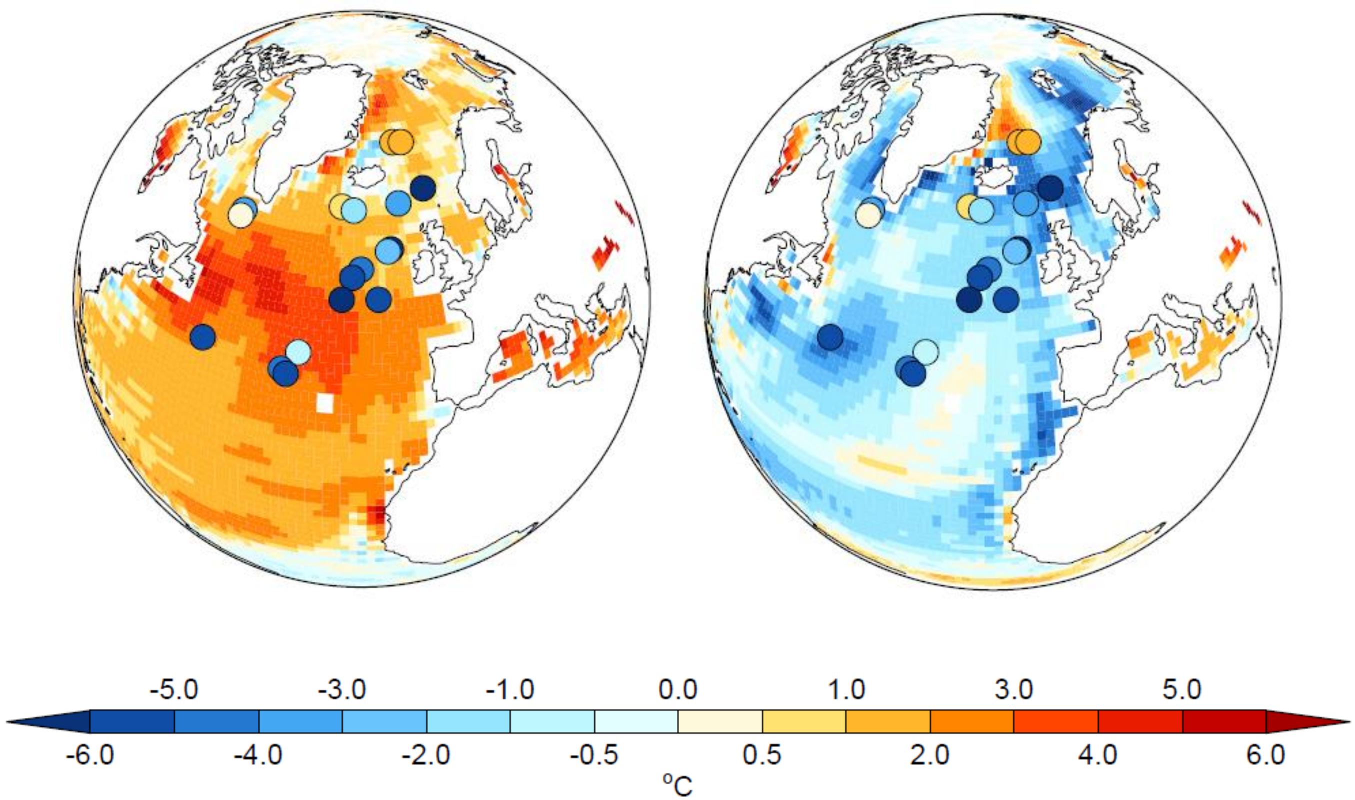
Changed orbital parameters (insolation)	✓
Changed GHGs	✓
Changed ice sheet	✗
Vegetation feedbacks	✗
Freshwater forcing	✓



Stone et al. (in revision)

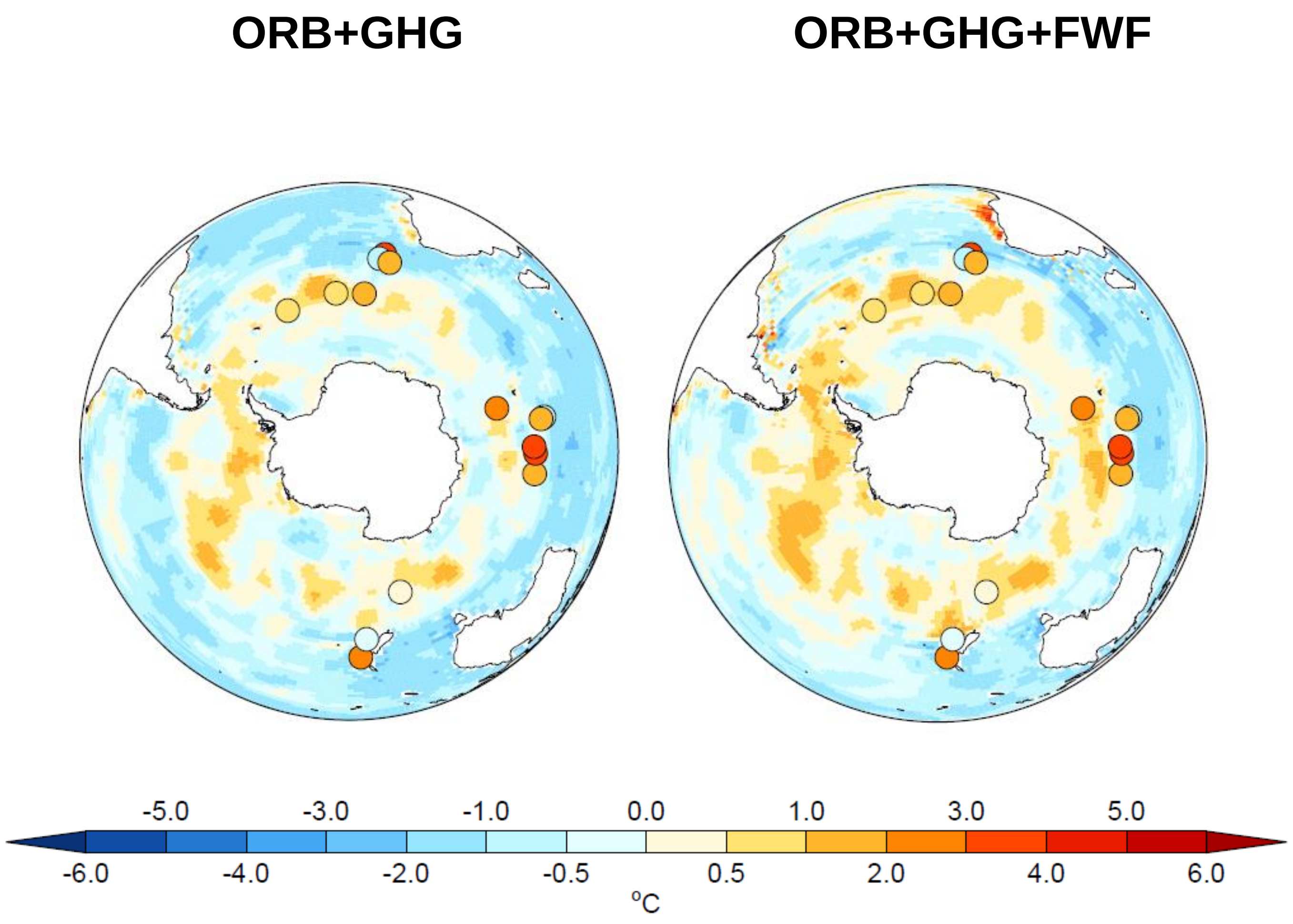
130 ka

ORB+GHG **ORB+GHG+FWF**



Stone et al. (in revision)

130 ka



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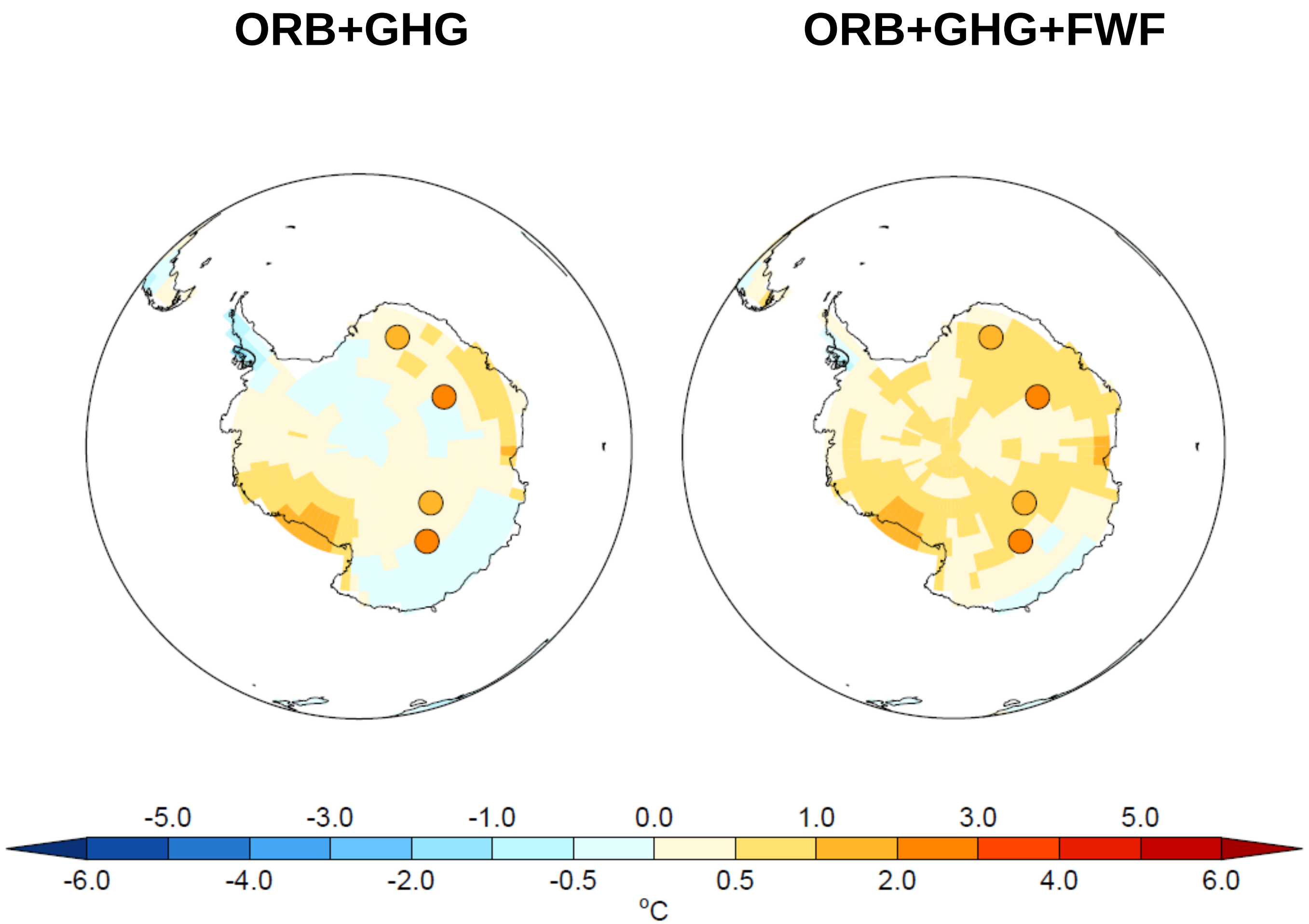
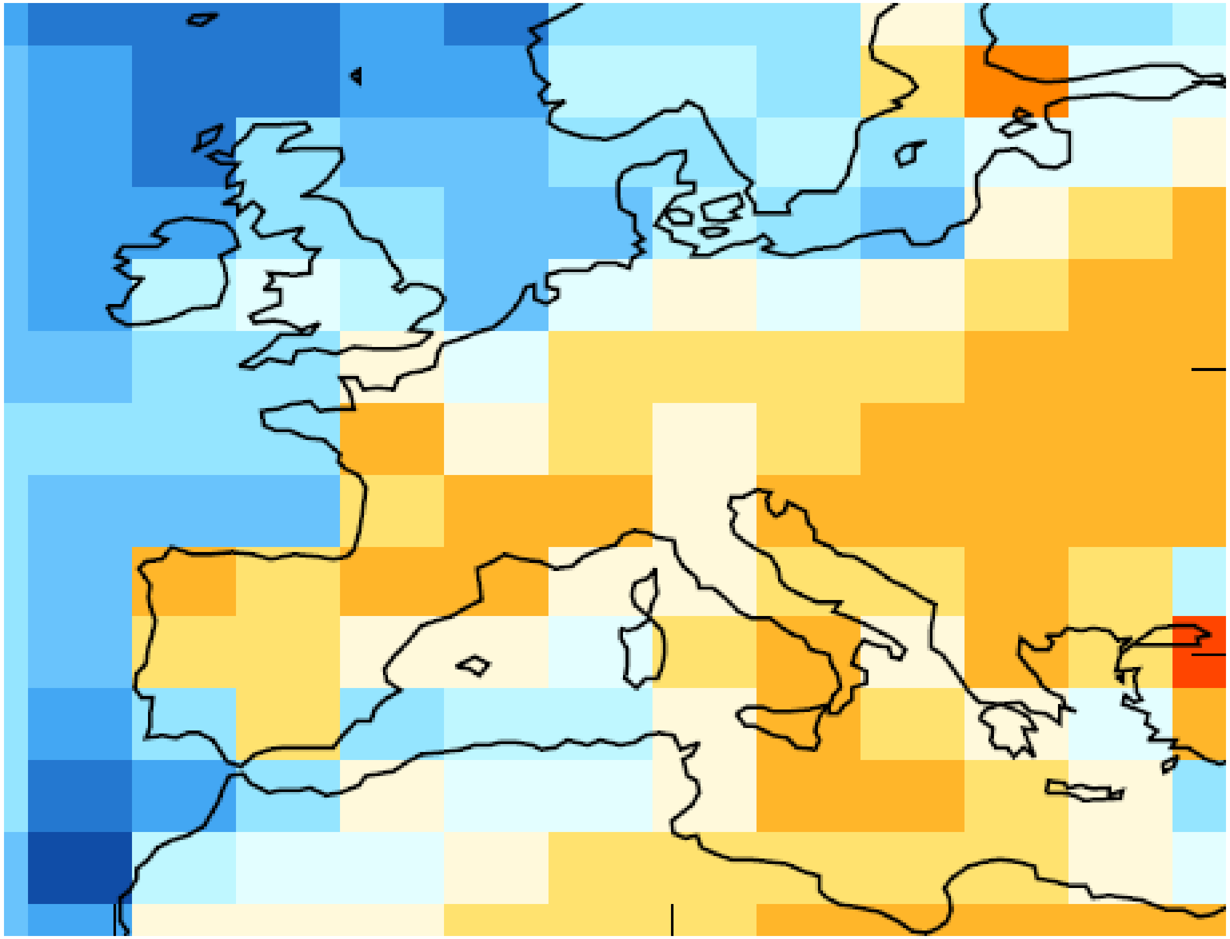
130 ka

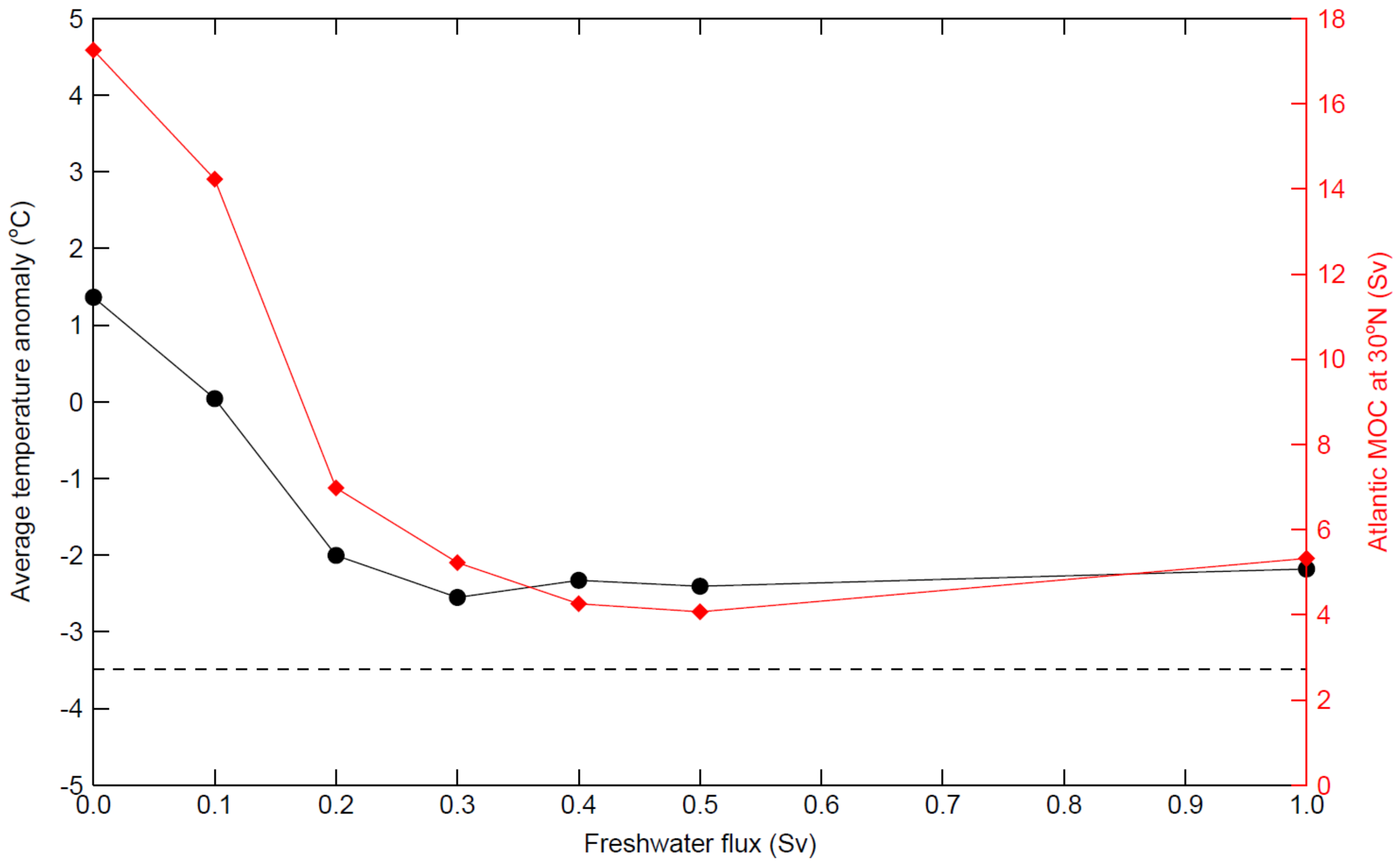


Stone et al. (in revision)

The effect of freshwater flux on Southern Europe climate at 130 ka



Model sensitivity to different amounts of freshwater



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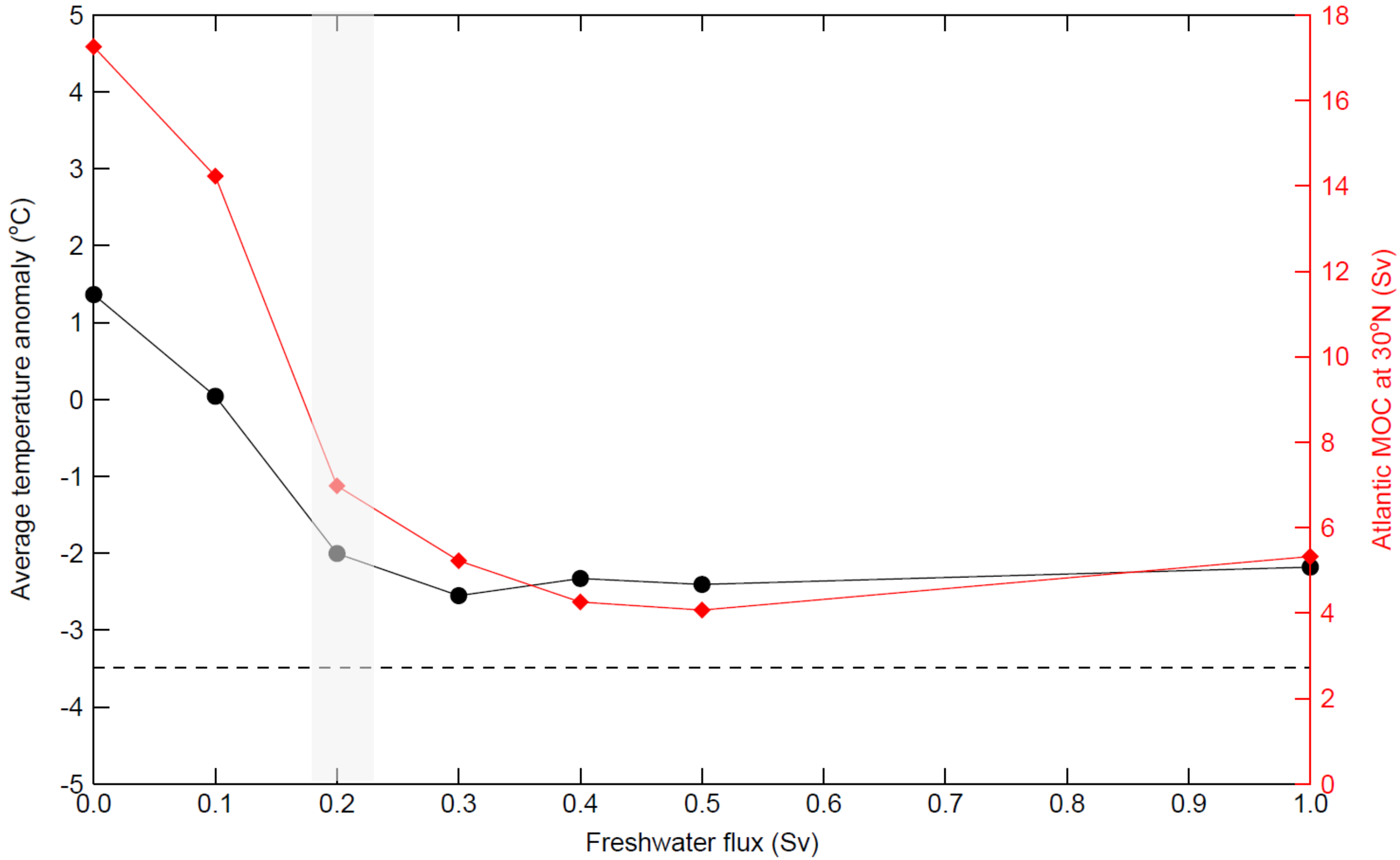
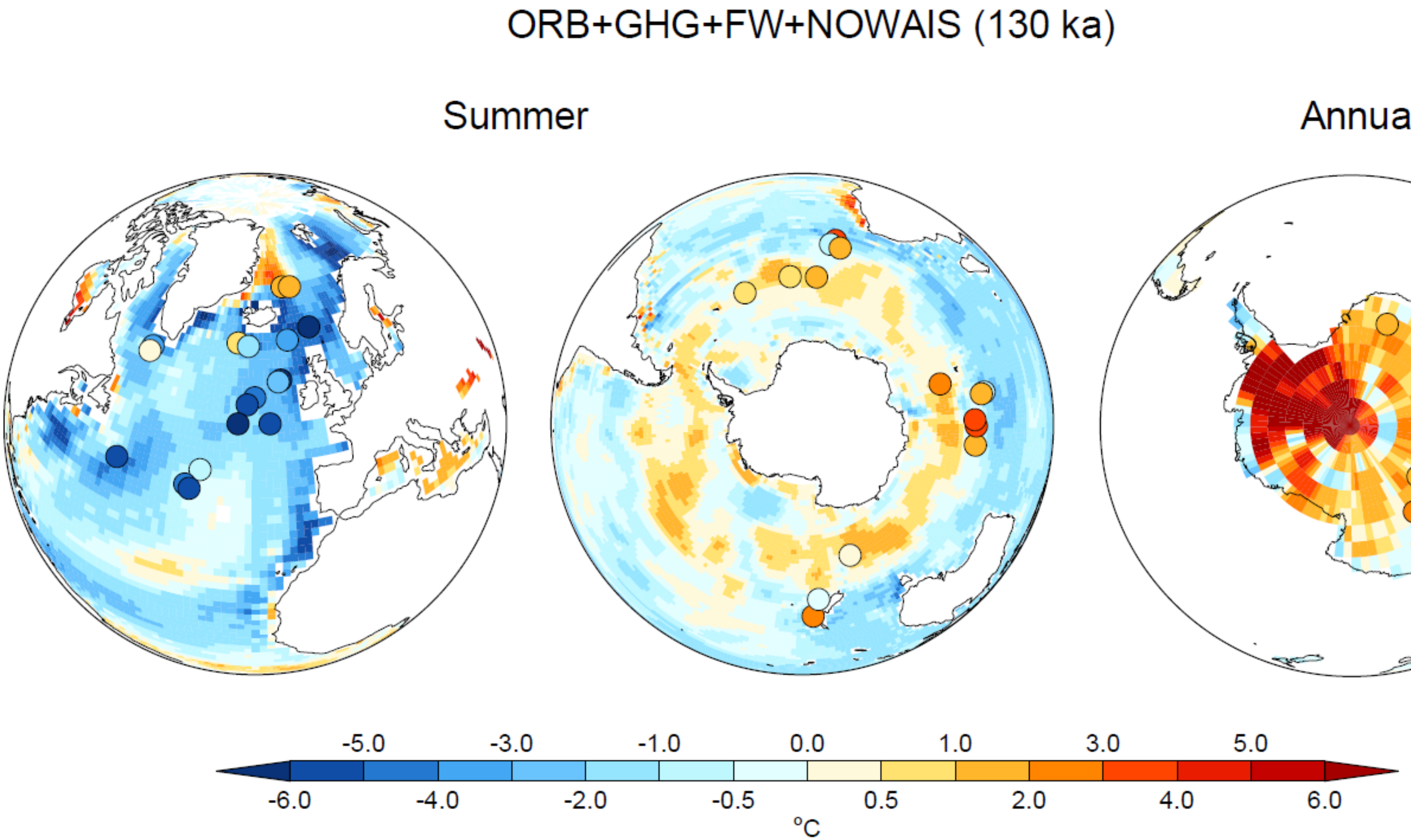


Stone et al. (in revision)

The effect of removing WAIS



Stone et al. (in revision)

Summary

Comparison with model simulations (ORB+GHG only) shows that:

- The models **cannot** predict the warmer-than-present-day conditions shown in North Atlantic records
- The reconstructed early Southern Ocean and Antarctic warming is not captured

University of BRISTOL

Summary

Comparison with model simulations (ORB+GHG only) shows that:

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MISSING processes/feedbacks in the models – **freshwater forcing from the penultimate glaciation?**

•The bipolar seesaw mechanism between the hemispheres at 130 ka can partially explain the asynchrony in hemisphere temperature response with a freshwater hosing of 0.2 Sv or more

•Lowering the WAIS with freshwater forcing only produces a **small improvement in model-data comparison** over Antarctica

Summary

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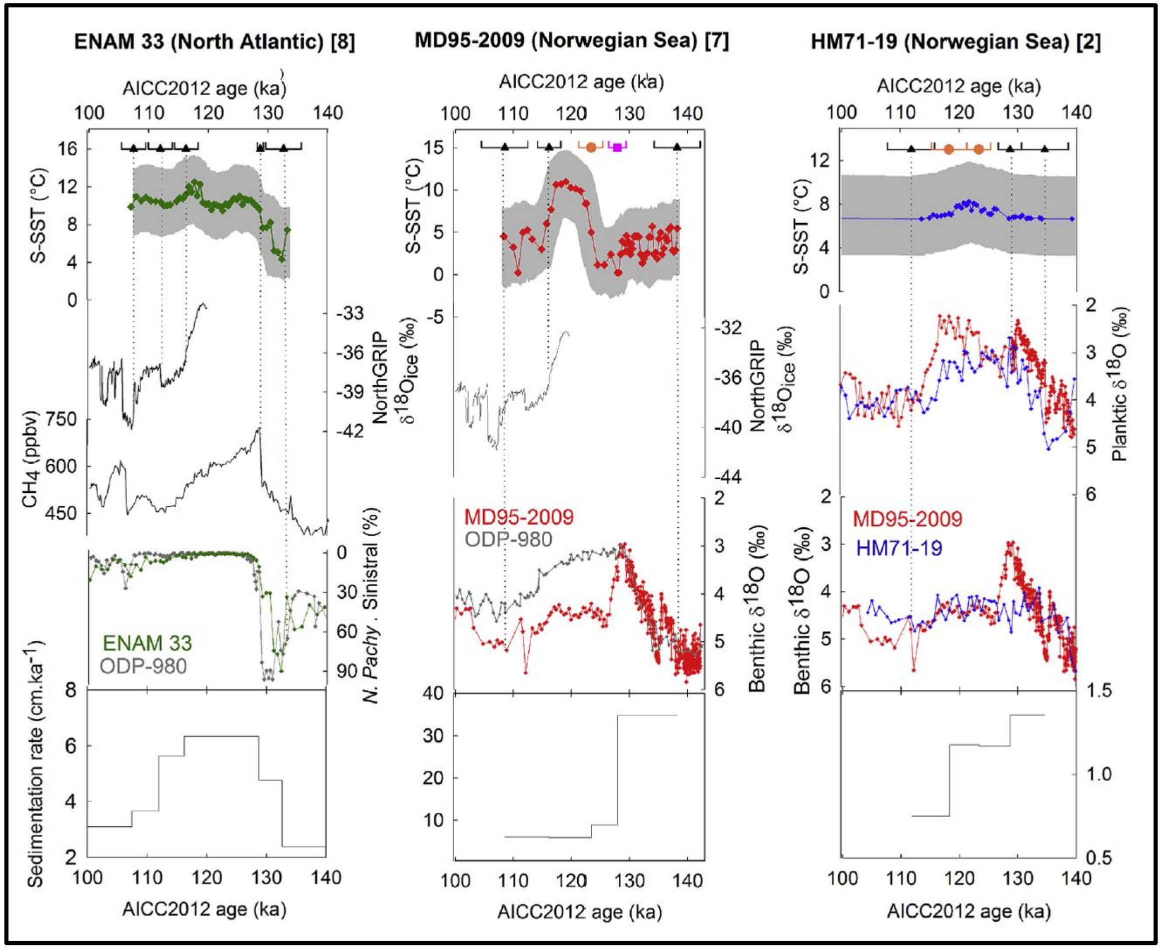
Some further points to consider:

- **Not transient** simulations
- Data needed in the vicinity of the WAIS
- What other feedback processes could fully reconcile the mismatch?
- Contributions of freshwater from the different ice sheets at the onset of the LIG

Strategy for building a consistent time frame



Difficulties to define robust age model in the Norwegian Sea !

Core MD95-2009 linked to core ENAM33 thanks to ash layer 5e-Low/bas-IV (orange dot) & climatic alignment.

Core HM71-19 aligned onto core MD95-2009 based on ash layers 5e-Midt/RHY & 5e-Low/bas-IV (orange dots) & climatic alignment.

4 time slices of temperature anomalies & errors

→ **Choice of the "Modern Reference" for marine records ?**

SST measurements from WOA 1998 (10m-deep) **vs** Sediment core Top SST values