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WND-conferentie 16 december 2023

Paleoklimaat simulaties:

fascinerend, *uitdagend*, *relevant*

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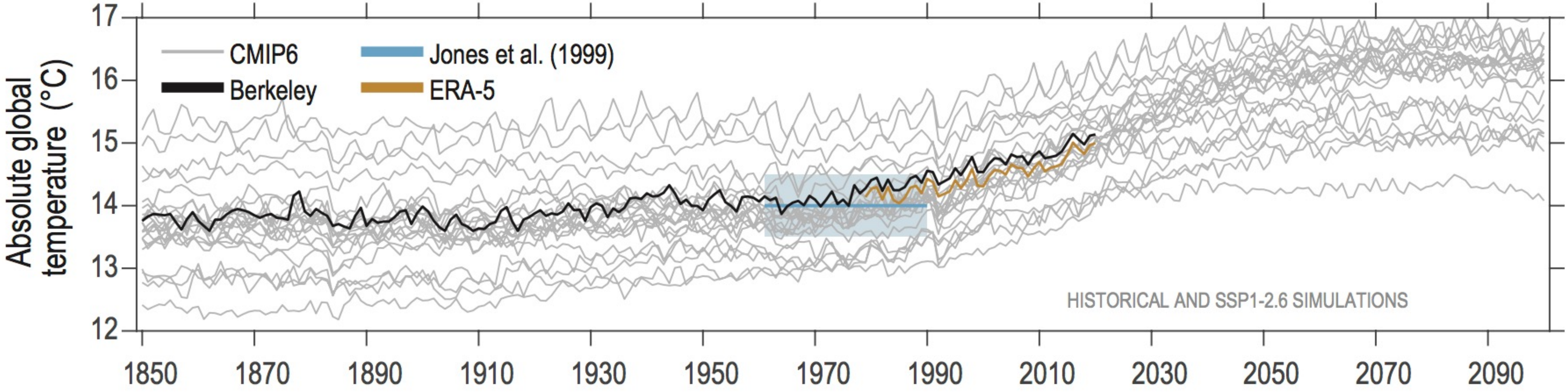
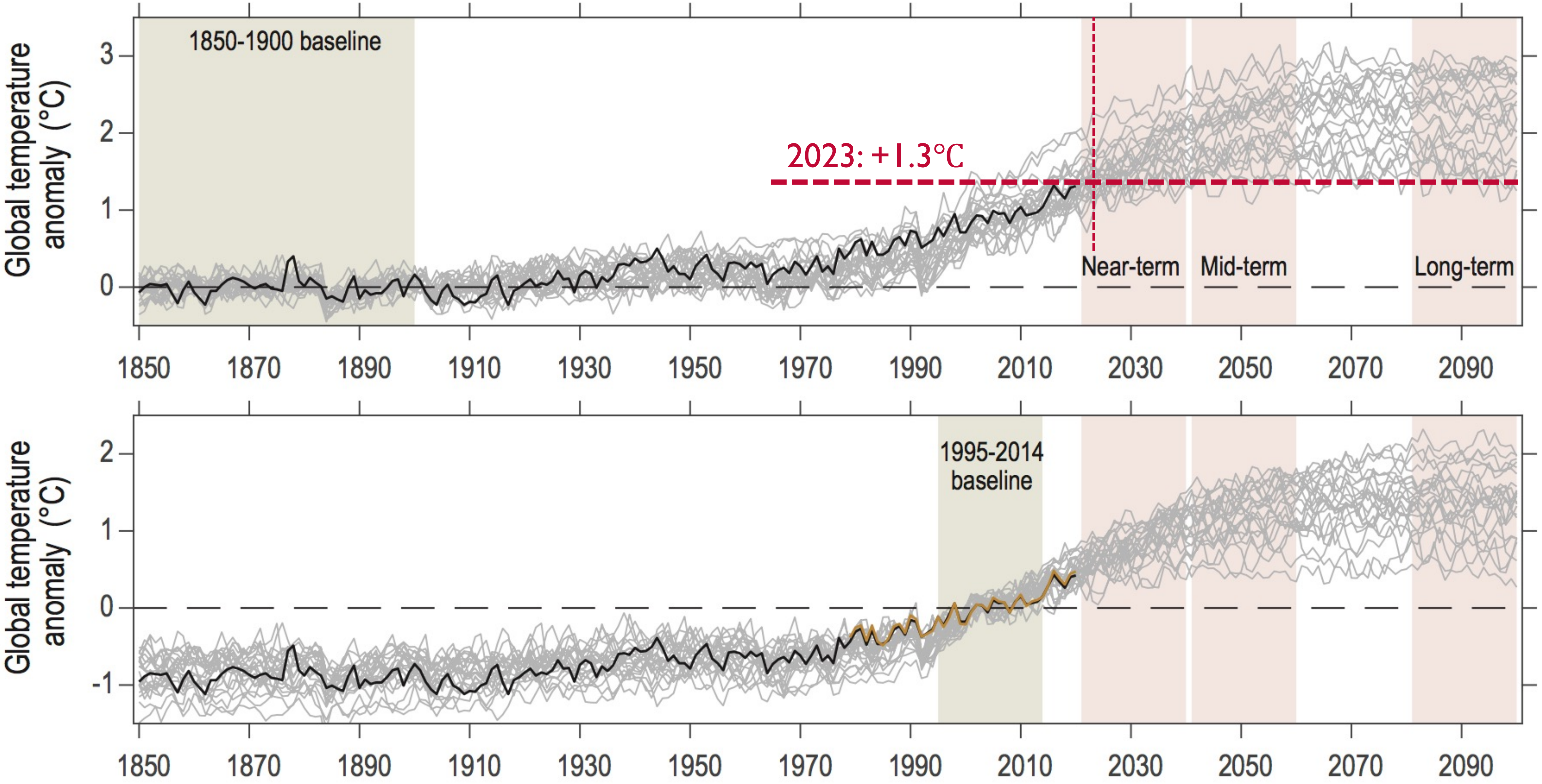
Model biases

Global <u>temperature</u> in *CMIP6* models:



- <u>Large biases</u> compared to historical record!
- These biases are <u>corrected</u> for in the analysis.

Model biases in CMIP6



Biases in climate models

'*All models are wrong*…

… **but some are useful**!' (*George Box, 1976*)

A climate model is an imperfect representation of climate;
→ biased in *mean*, but also *variability* and *correlations*.

- To check *biases*, we need observable quantities;
  → e.g. temperature, precipitation, clouds, radiation.
- Alternative to observations: model reanalysis.
- Models are tuned to minimise biases wherever possible.

Weather versus climate models

Many different (operational) weather models are used;

- *Global*: GFS (NCEP), IFS (ECMWF), UKMO, JMA, GEM, ICON, Arpège, …
  Resolution: 15-50km, simulation length: 5-15 days.

- *Regional*: WRF, RACMO, HiRLAM, ICON, …
  Resolution: 5-15km, simulation length: 2-5 days.

- *Local*: WRF, HARMONIE, AROME, COSMO/ICON-D2, …
  Resolution: 1-4km, simulation length: 1-3 days.

Only atmosphere, sometimes also land and/or sea surface.

For these models, initial and boundary conditions are very important!

Weather versus climate models

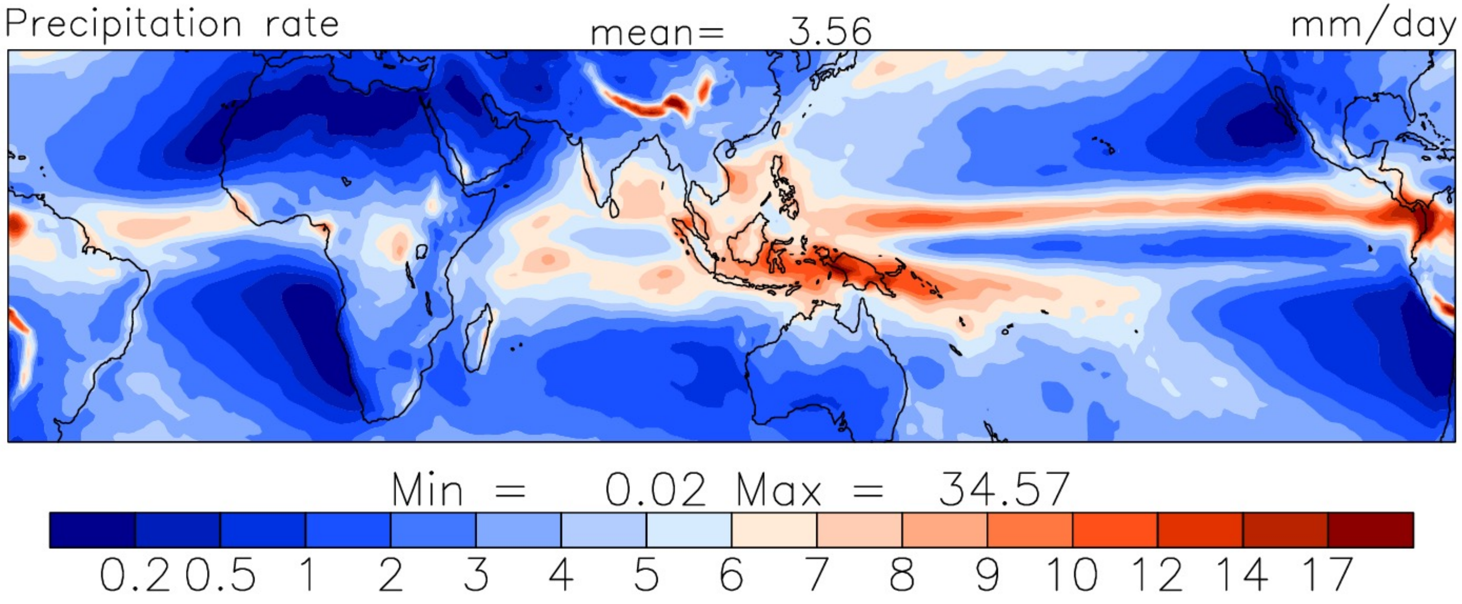
A *climate* model is <u>principally the same</u> as a *weather* model; but run <u>much longer</u>.
IFS → EC-Earth, GFS → CESM, UKMO → HadCM, GFDL, IPSL, …
Rather than days to weeks, we want to simulate decades or even centuries.

This has several <u>consequences</u>:

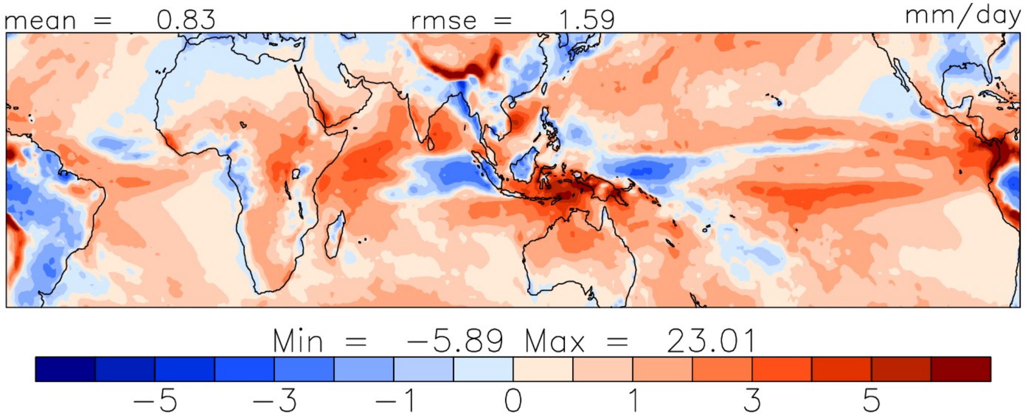
- The <u>conservation of energy/momentum</u> becomes very important;
- Climate models can (almost) only be <u>global</u>;
- Many more <u>active components</u> are needed compared to weather models: Atmosphere, Ocean, Land, Ice, Vegetation, Chemistry.
- Simulations need a <u>spin-up</u> or equilibration.
- Model complexity and simulation length limit the <u>resolution</u> (50-200km).
- We consider *climate*, rather than *weather*.

Model bias: CAM5 (CESM) tropical precipitation

Simulated:

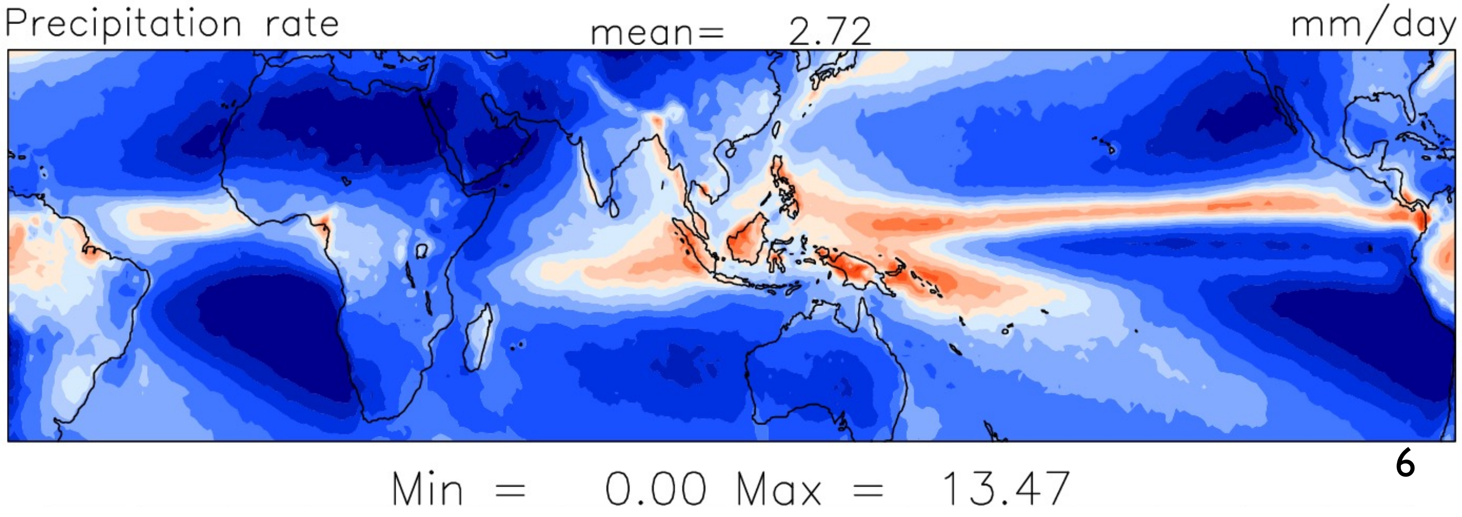


Difference:

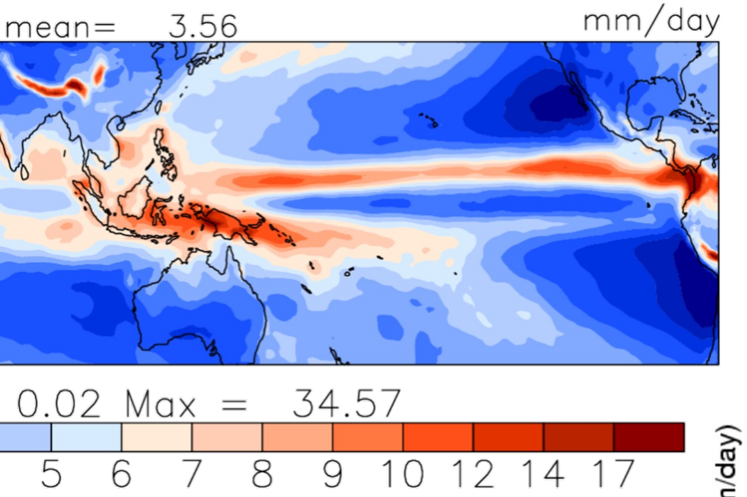


TRMM

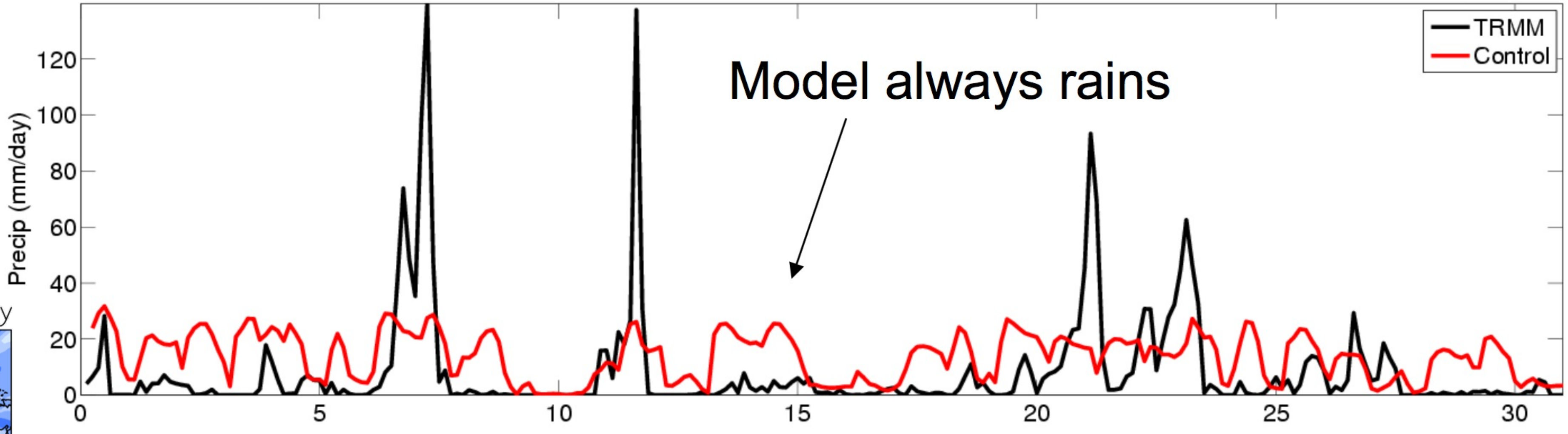
Observed:



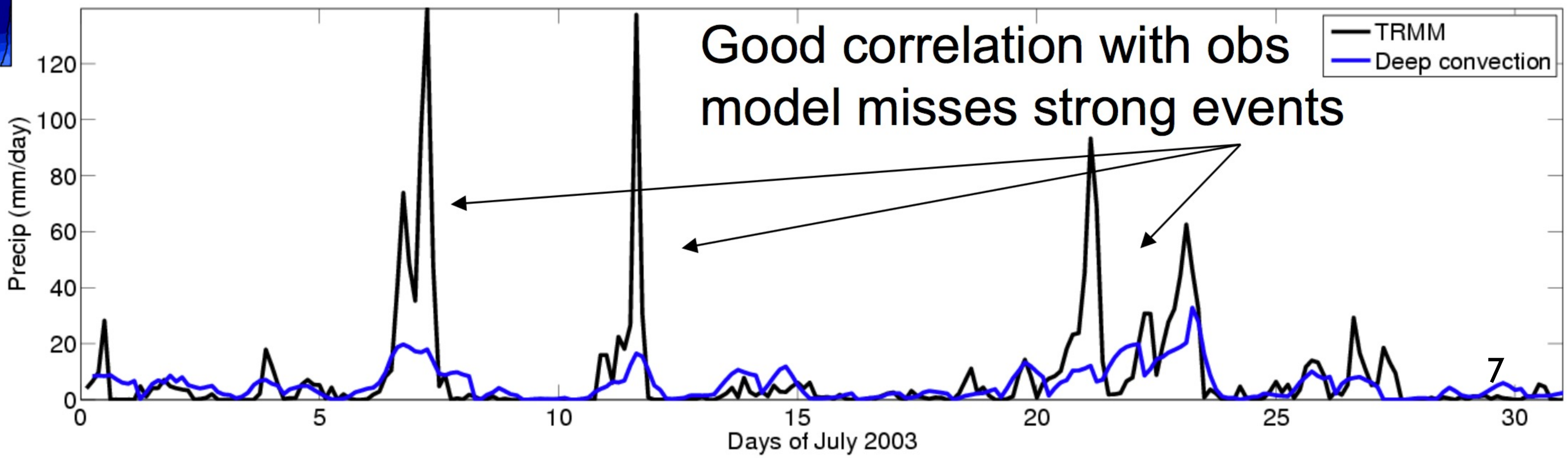
Example: hourly rainfall over tropical E Pacific



CAM3



CAM4



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Model 'tuning'

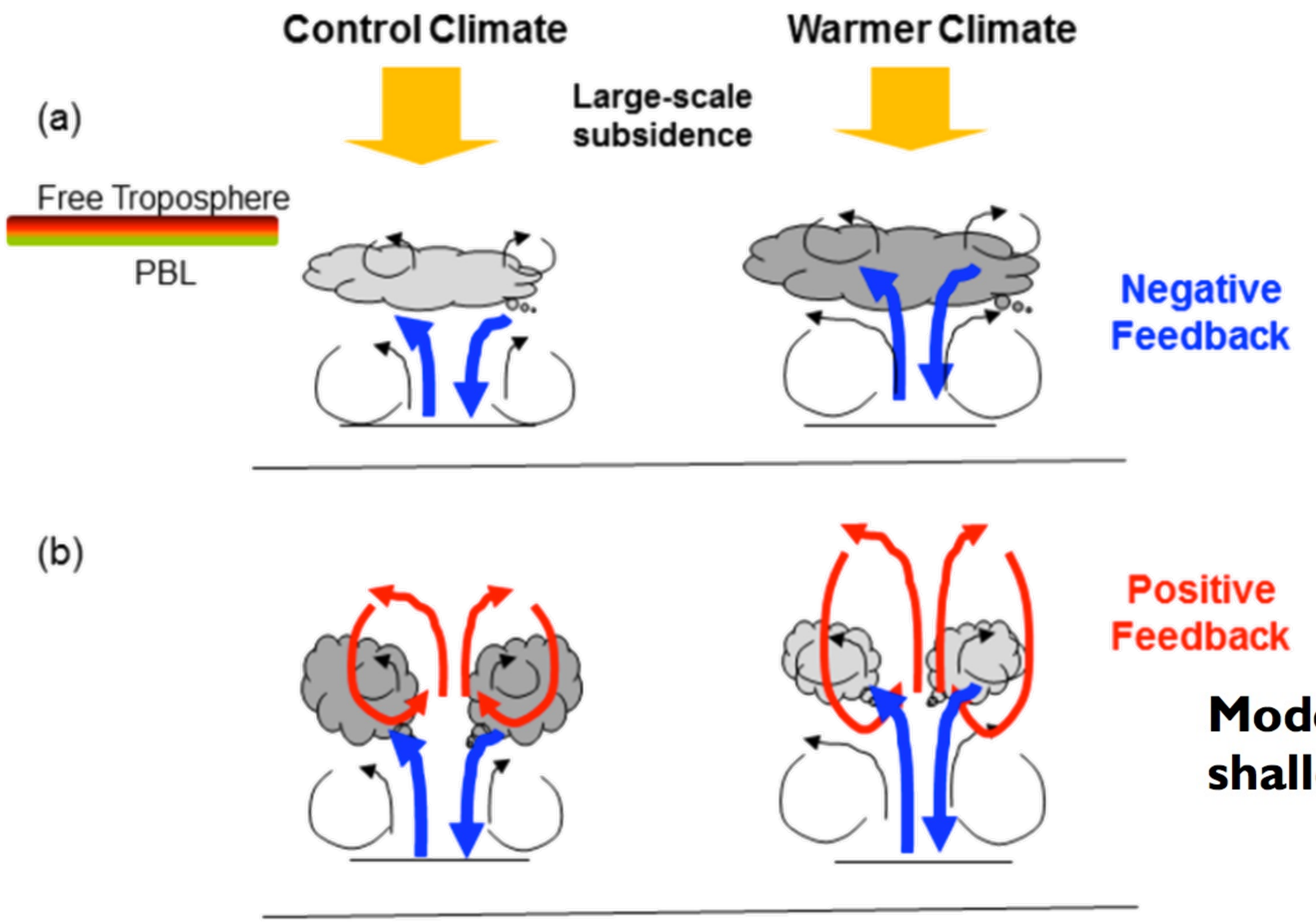
Tuning: *adjusting parameters to improve agreement with observations*

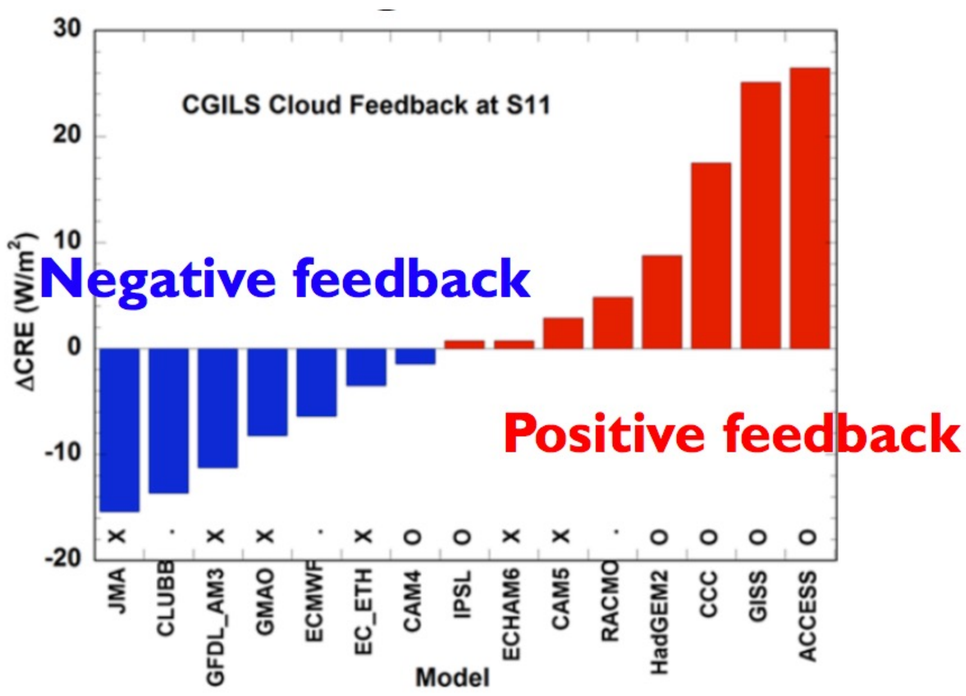
Which parameters are used for tuning?
Those *weakly constrained* by the observations.
(e.g. convection, clouds, aerosols, radiation, fluxes)

Examples:
(>20 in CAM5)

rhminl	relative humidity threshold for low clouds
a2l	Evaporative enhancement factor for stratocumulus-top entrainment rate
rpen	Penetrative entrainment efficiency at the top of shallow convective plume
co_lnd co_ocn	Auto-conversion efficiency of cumulus condensate into precipitation over land and ocean
Dcs	Critical diameter for ice to snow auto-conversion
dp1	parameter for deep convection cloud fraction.

Example: parameterisation of shallow convection





Models with no active shallow convection

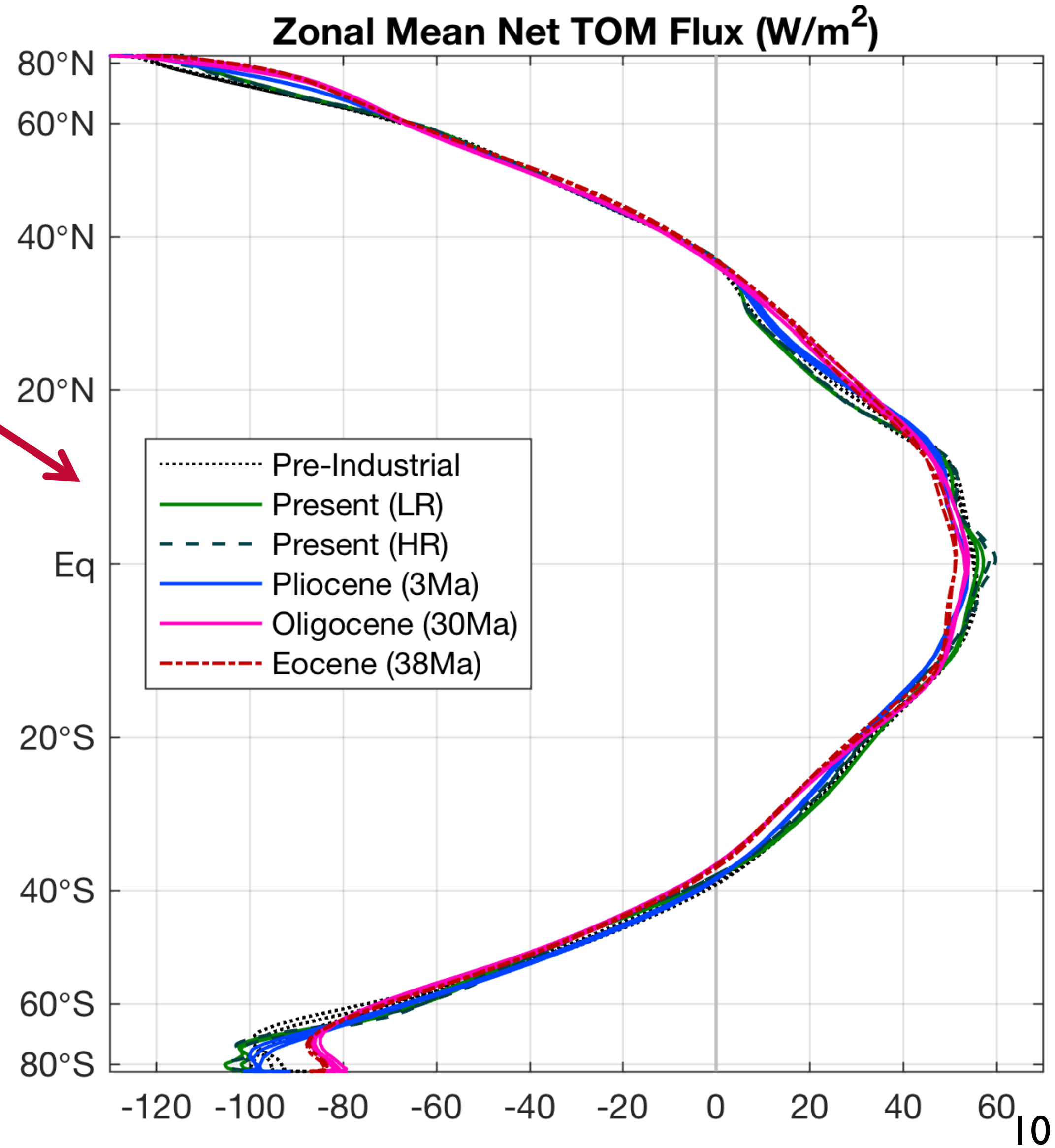
Models with active shallow convection

Model 'tuning'

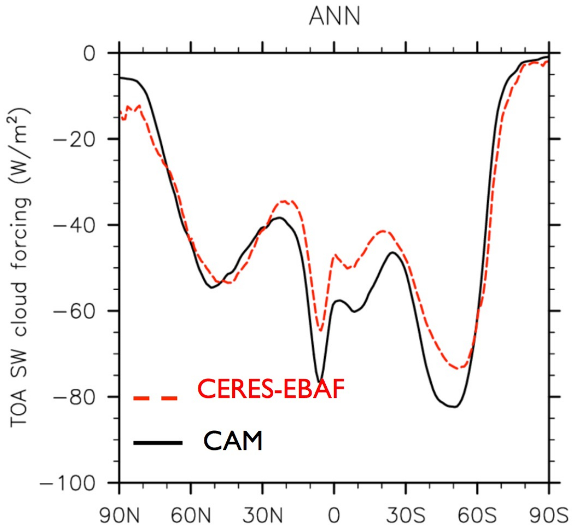
Most commonly used variables:

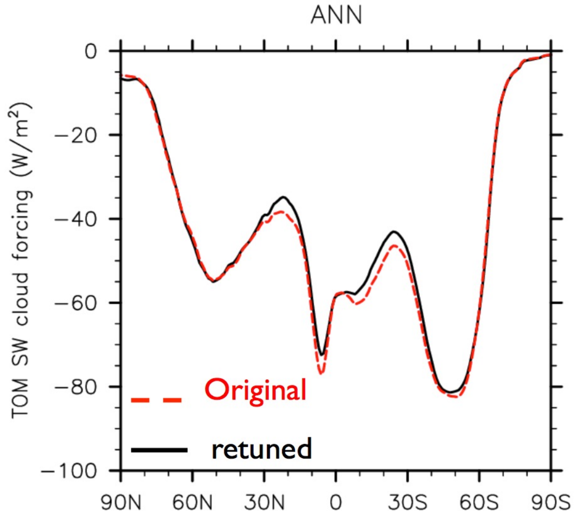
- Top of atmosphere ***radiative balance***;
- Shortwave/longwave cloud forcing;
- Total precipitable water;
- Precipitation.

These variables are compared against the available *observational* and *reanalysis* datasets, using *coupled/uncoupled* simulations.



Model tuning example: CAM6





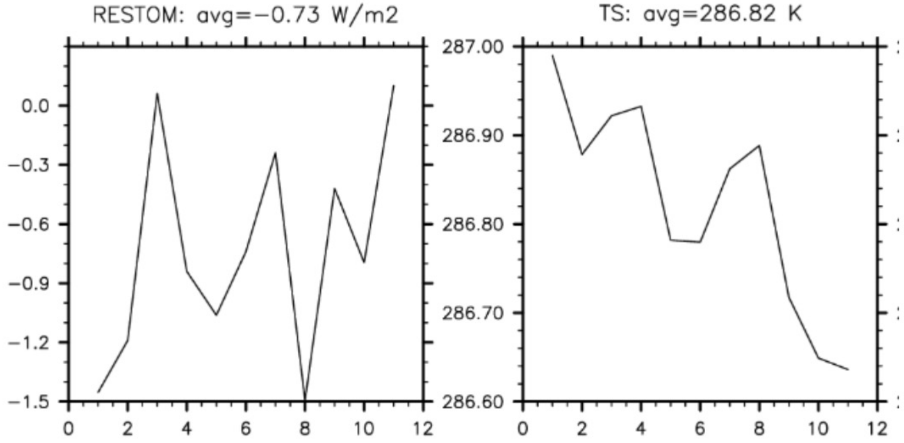
- <u>Cool model bias</u>, radiative imbalance.
- <u>SWCF too strong</u>, parameters adjusted to reduce low clouds.

- <u>Adjusted model</u> version has much better balance and temperatures.

- <u>TOA radiative balance</u> very important (drift).

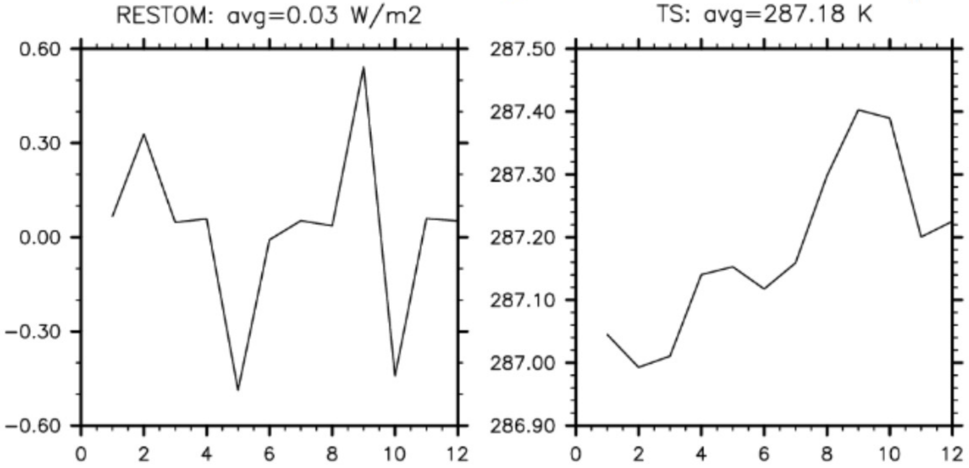
Original:

Imbalance of -0.73 W/m2; surface temperature cooling



Retuned:

Imbalance of 0.03 W/m2; better surface temperature



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Summary model bias and tuning

- **Models are never perfect!**
- **Model biases** detected with observations, also not perfect!

- **Tuning models**: adjust parameter settings;
  Consider variables poorly constrained by observations.
- **All models need tuning**, often delicate process.

Open questions:

- We tuned our climate model to our best capabilities;
  How will it perform under different conditions?
- The underlying physics are sound, but what about the parameterisations?

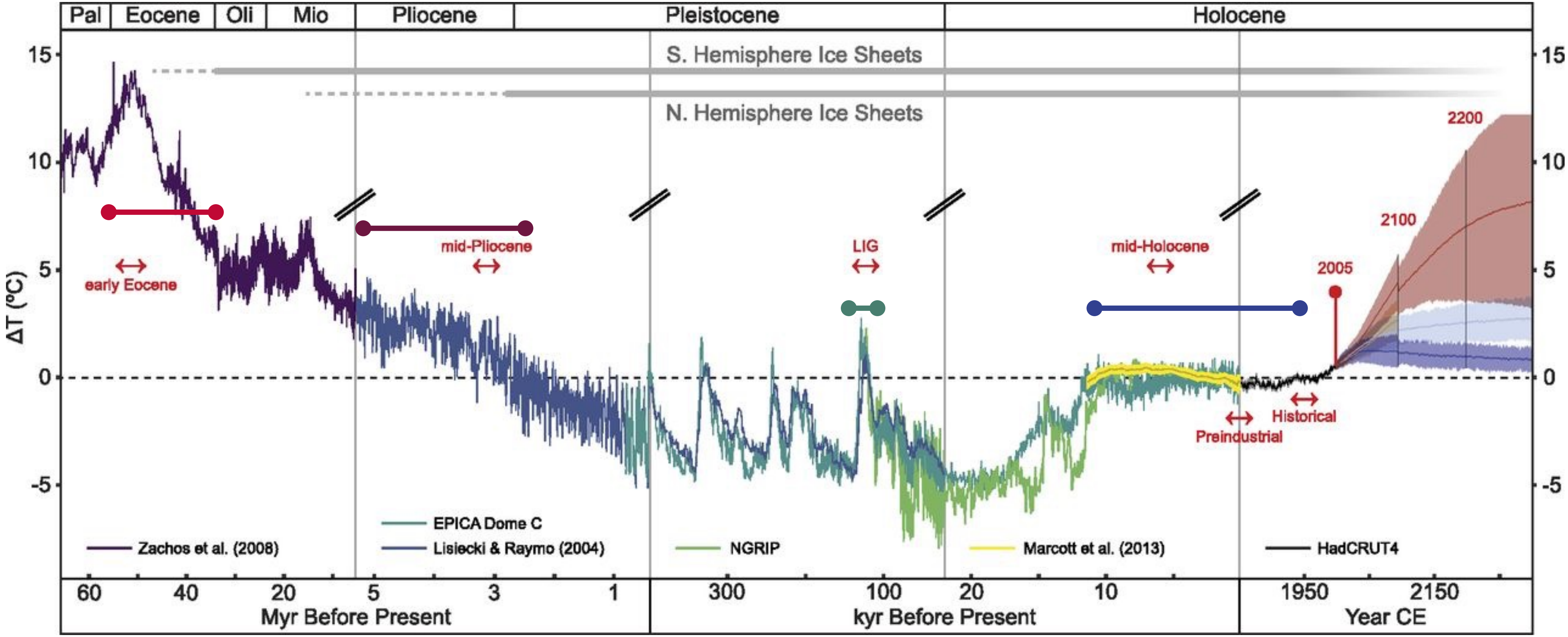
Paleoclimate modelling: learning from the (deep) past

Eocene: *'hothouse'*

Pliocene: *400ppm analogue*

Last Inter-Glacial: *present analogue*

Holocene: *'Stable' reference*

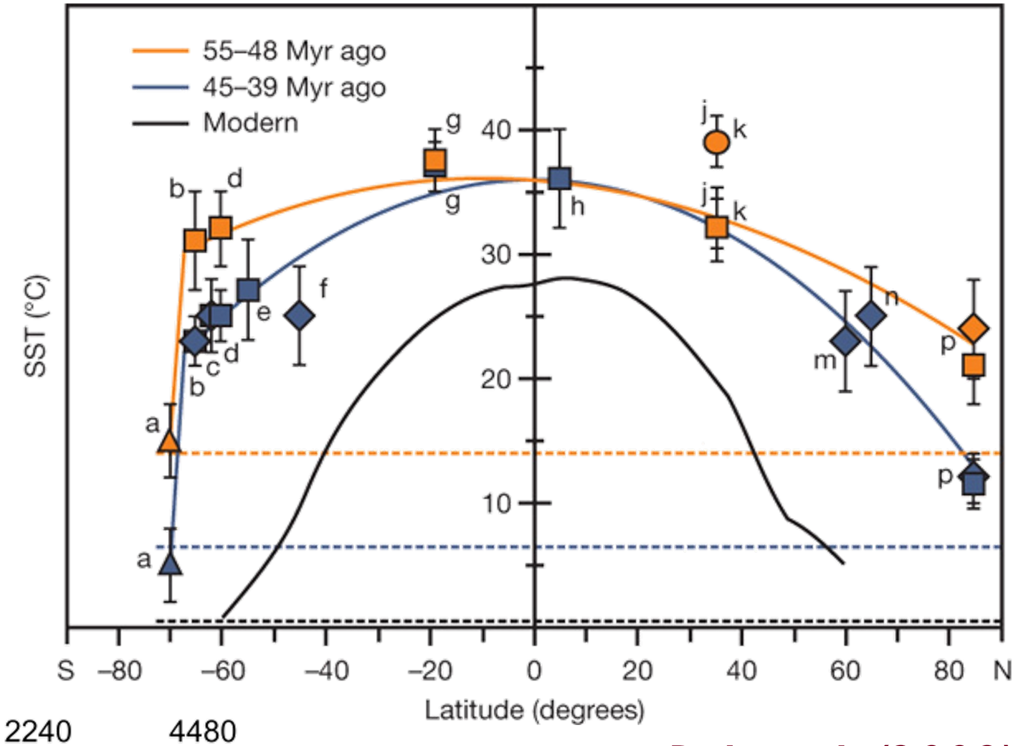


Burke et al. (2018)

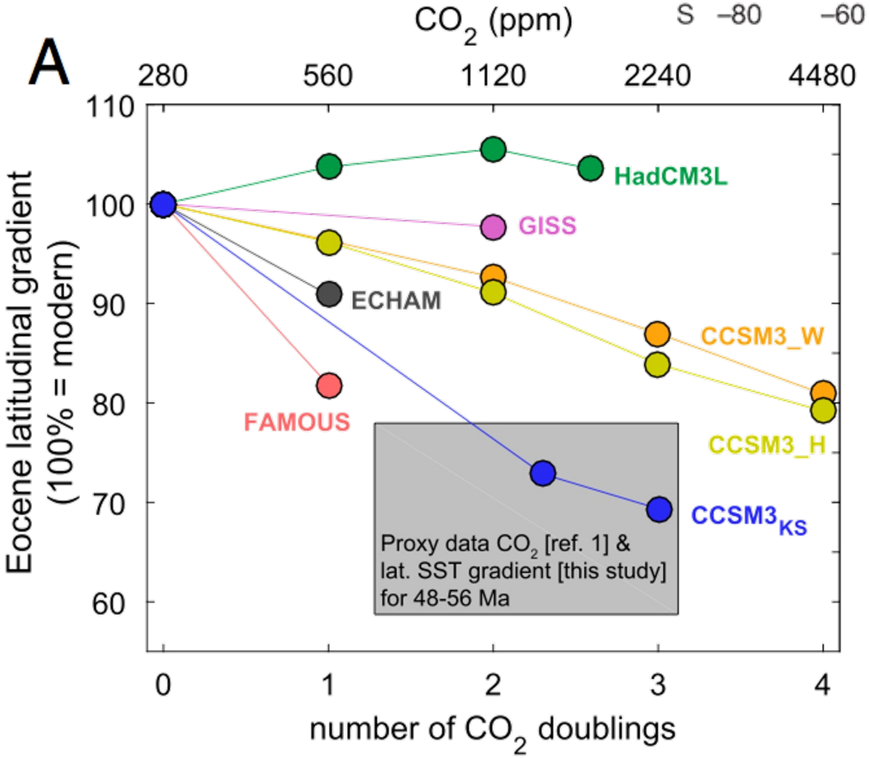
Why do we simulate paleoclimate?

- Understand palaeoclimate; very *limited* data.
- Find out fundamental properties of warm climates.

- Find and study analogues for *present/future* climate.
- Test climate models beyond their *comfort* zone.
- Challenge: '*Equable*' climates



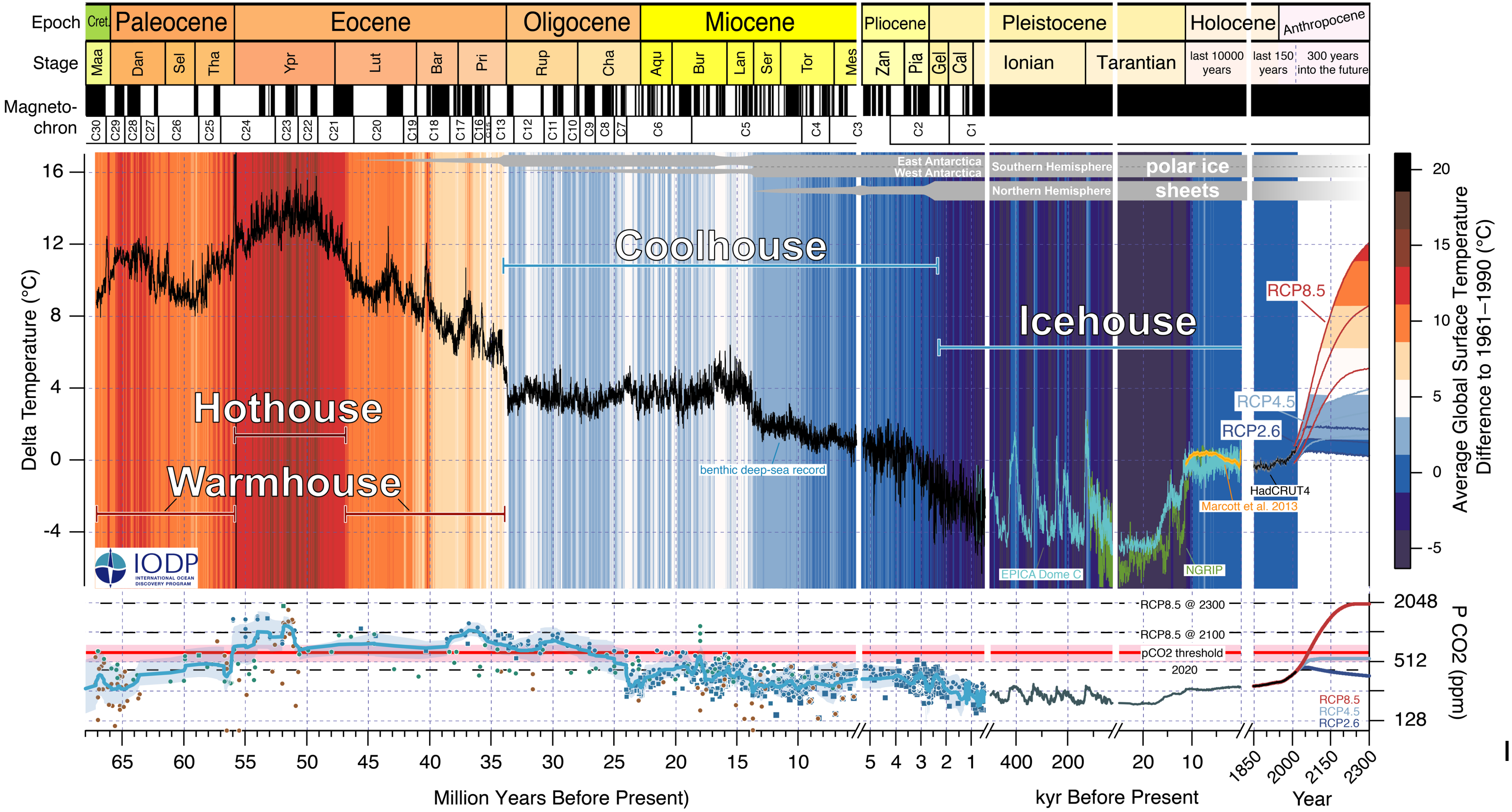
Bijl et al. (2009)



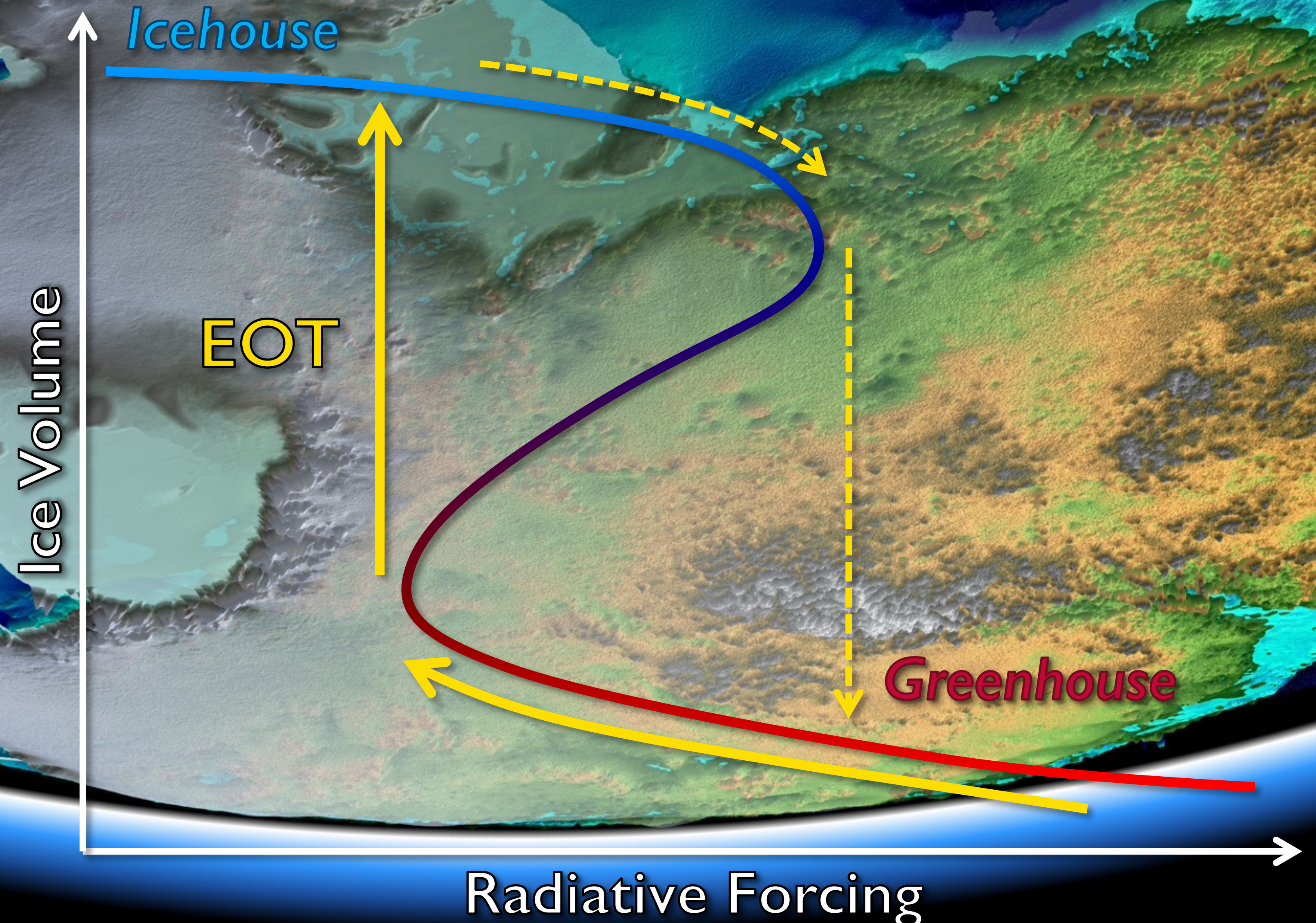
Evans et al. (2018)

Putting these time scales into perspective

Westerhold et al. (2020)



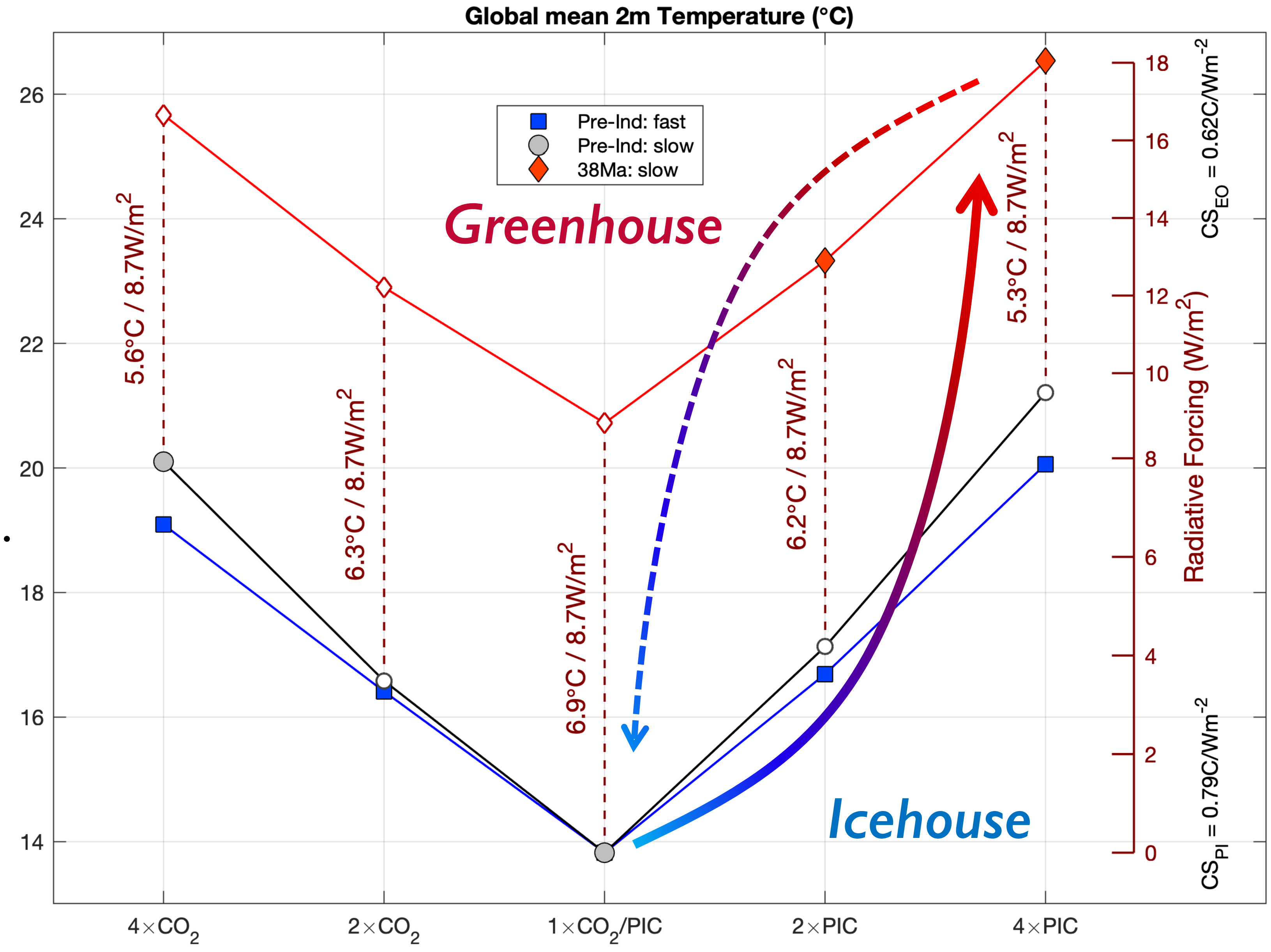
The EOT: a prime example of a climate tipping point?



Climate state hysteresis: greenhouse vs icehouse

- Boundary conditions in the model are *fixed;*
- *Eocene* climate is much warmer than *today.*

- *Different* states; ice, vegetation, clouds, …
- *Equilibrium* state versus current rapid change;
- Possible *analogue* for a distant future?



At IMAU: CESM 1.0.5 for paleoclimate

The CESM:

- Global, fully-coupled *climate* model;
  Atmosphere – Ocean – Ice – Land – Vegetation.
- 2010 state-of-the-art (IPCC AR5); *limited* complexity.

Deep-time model set-up:

- Horizontal resolution: ~2° (*atmosphere*) / ~1° (*ocean*).
- Altered boundary conditions:
  - *Atmospheric* composition (aerosols, greenhouse gases);
  - *Geography*, *ice* and *vegetation* cover (some are long-term *feedbacks*);
  - *Astronomical* configuration (orbital parameters).
- Idealised initialisation, *long* spin-up (1000s years)

Paleoclimate simulations at IMAU:

Pre-industrial/present:

- Pre-industrial *reference*: 3000+3000 years;
- CO_2 doubling / quadrupling: 1000+1500 / 2000 years.

Pliocene:

- 400ppm CO_2 '*reference*': 2000 years;
- 280 / 560ppm CO_2 '*sensitivity*': 1000 years each;

Miocene: simulations are underway.

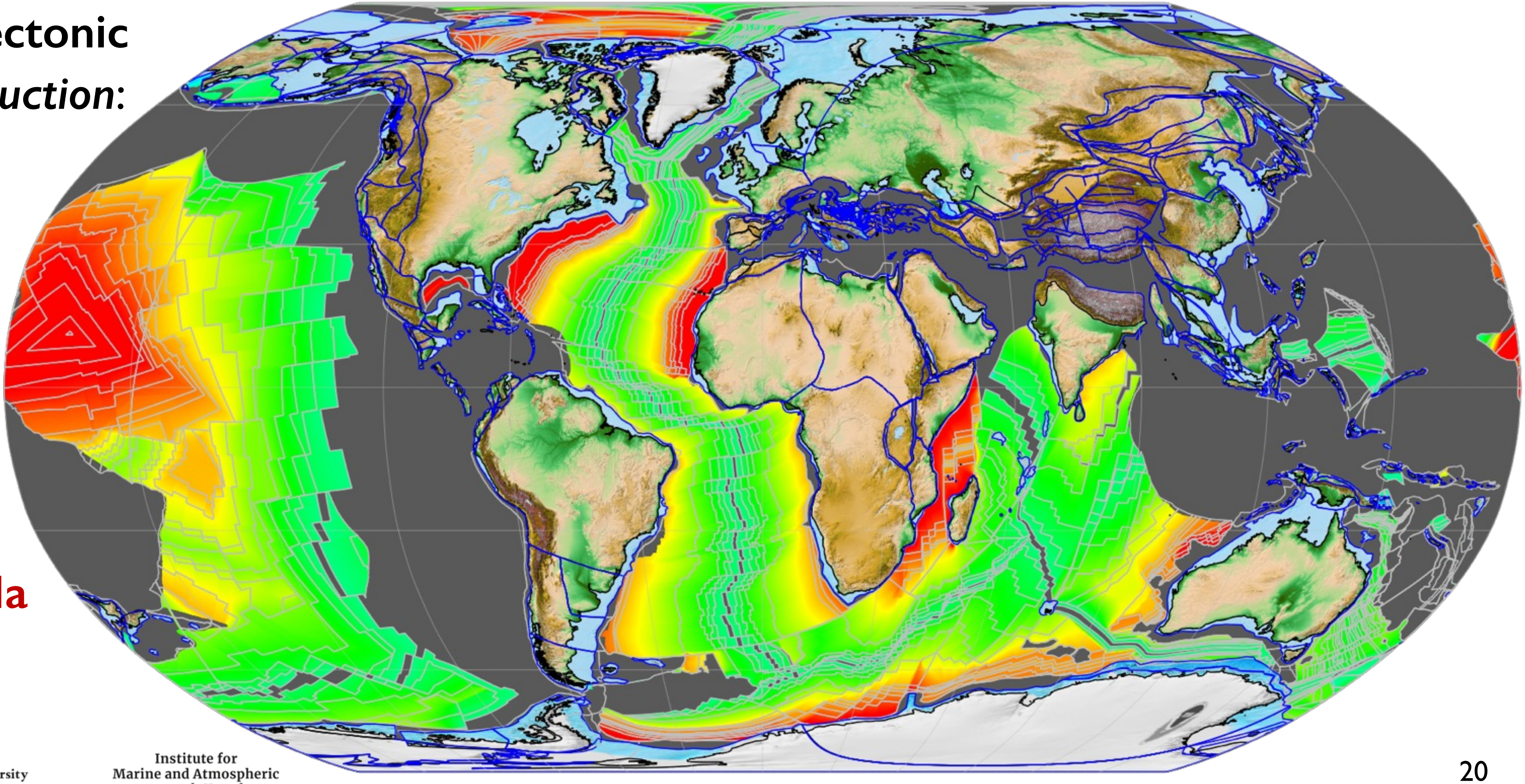
Eocene:

- 30Ma 1× / 2× PIC: 3500 years each + 1200 years (*FW*);
- 38Ma 2× / 4× PIC: 3600 / 4600 years;
- 38Ma low insolation orbit: 4 times 500 years.

Over 30.000 *model years*

Paleoclimate modelling: geography reconstruction

Plate-tectonic
***reconstruction*:**



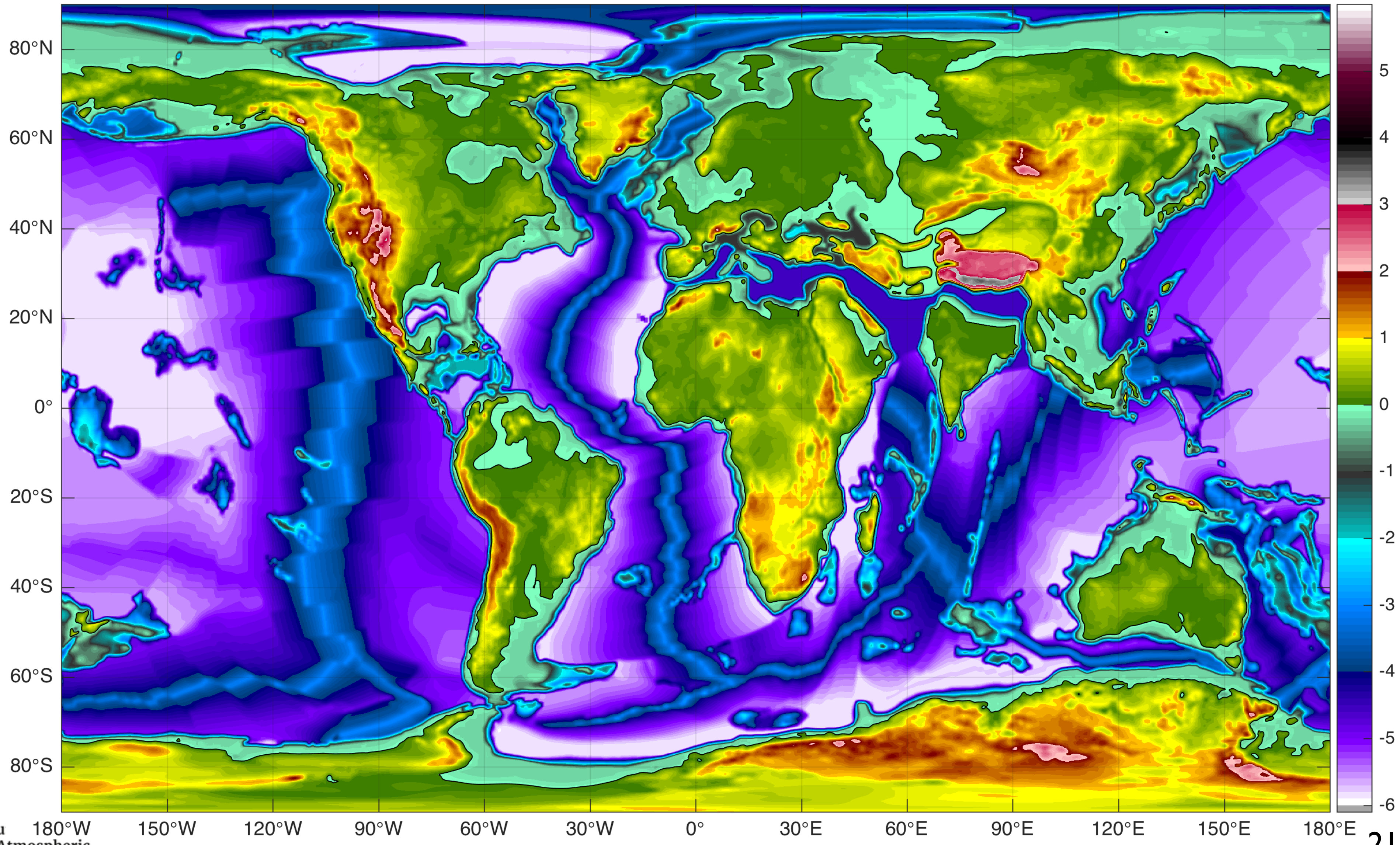
e.g. **38Ma**

Paleoclimate modelling: geography reconstruction

Final *gridded* <u>paleogeography</u> reconstruction for 38Ma:

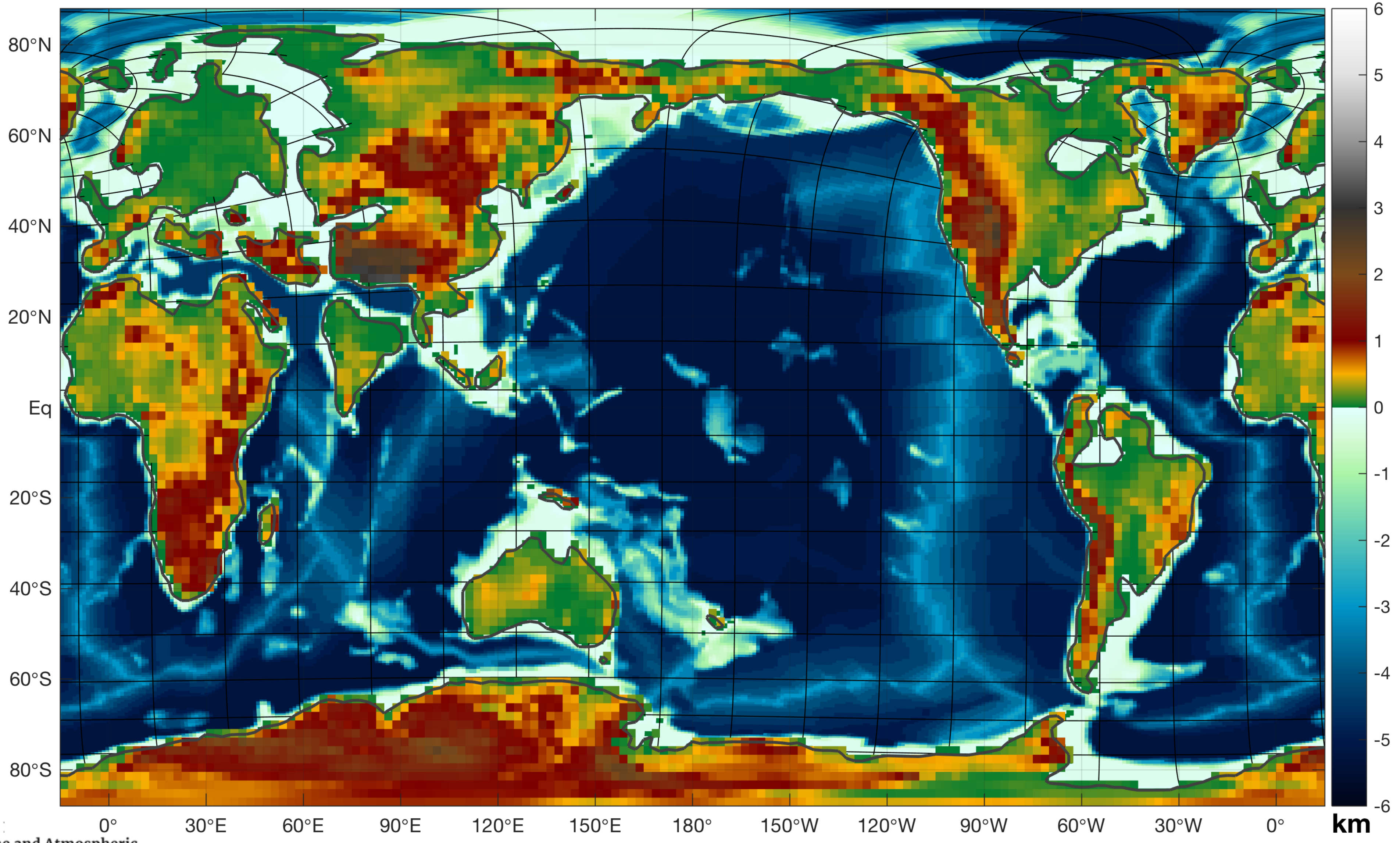
Areas of interest:

- *Eurasia*
- *India*
- *Antarctica*
- *Neotethys*
- *Arctic*
- *Gateways*



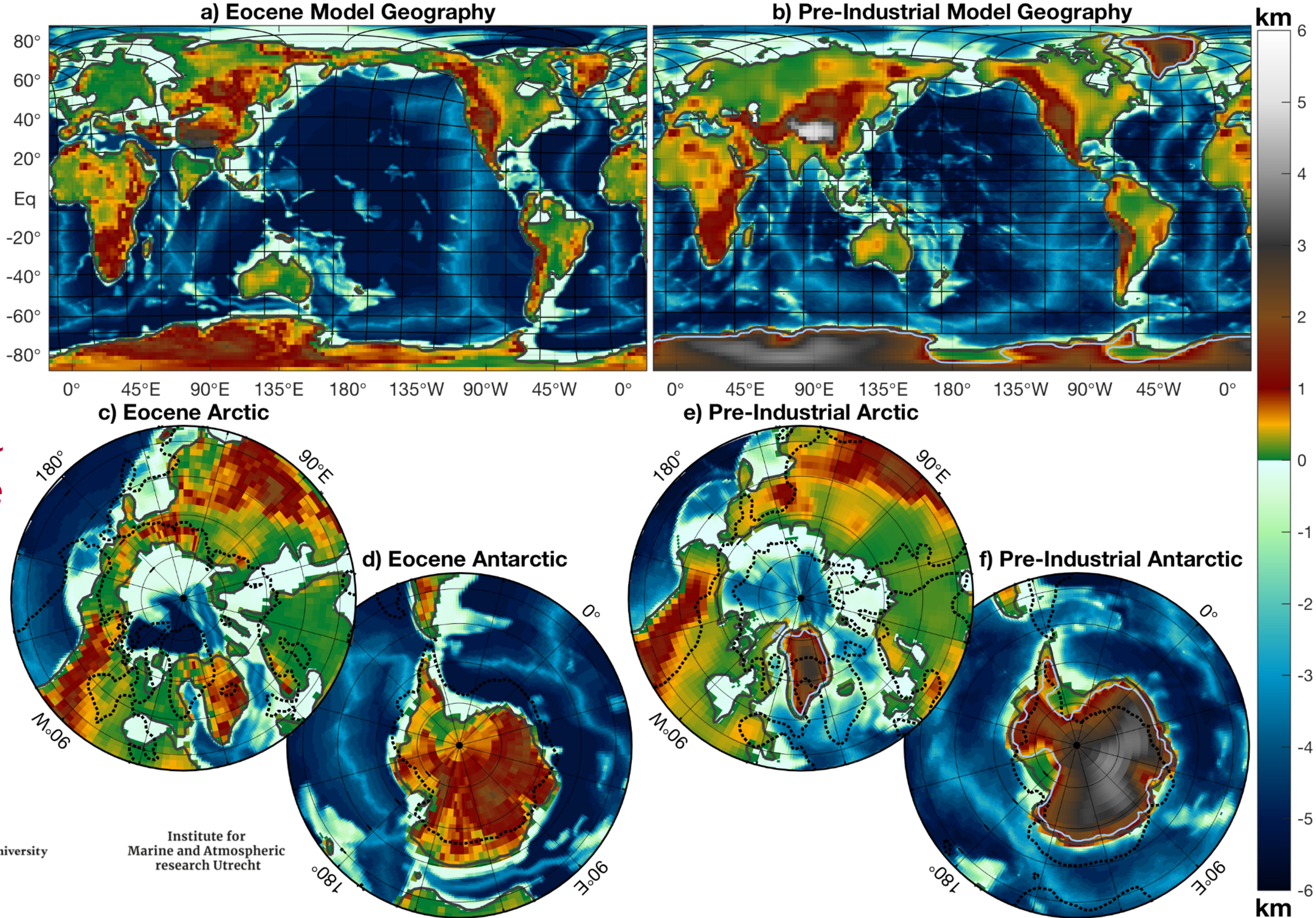
Paleoclimate modelling: geography reconstruction

<u>Model version</u>
of *gridded* **38Ma**
paleogeography:



38Ma

Eocene



Present

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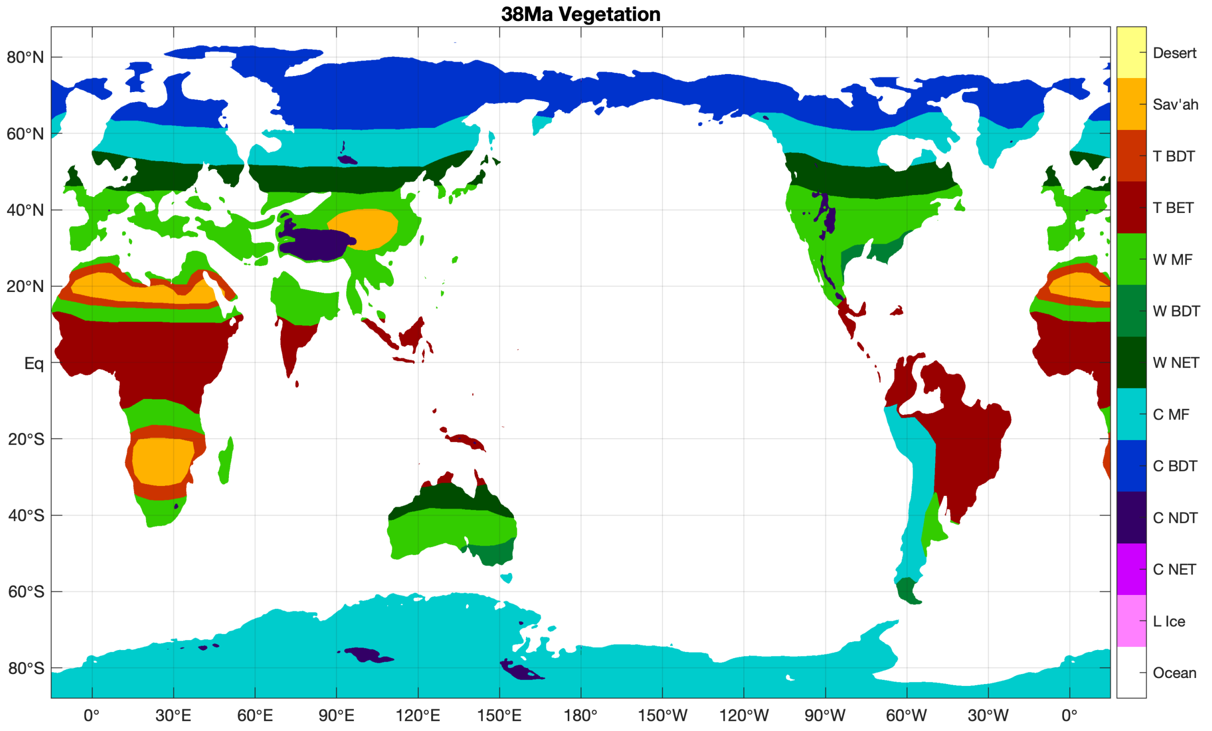
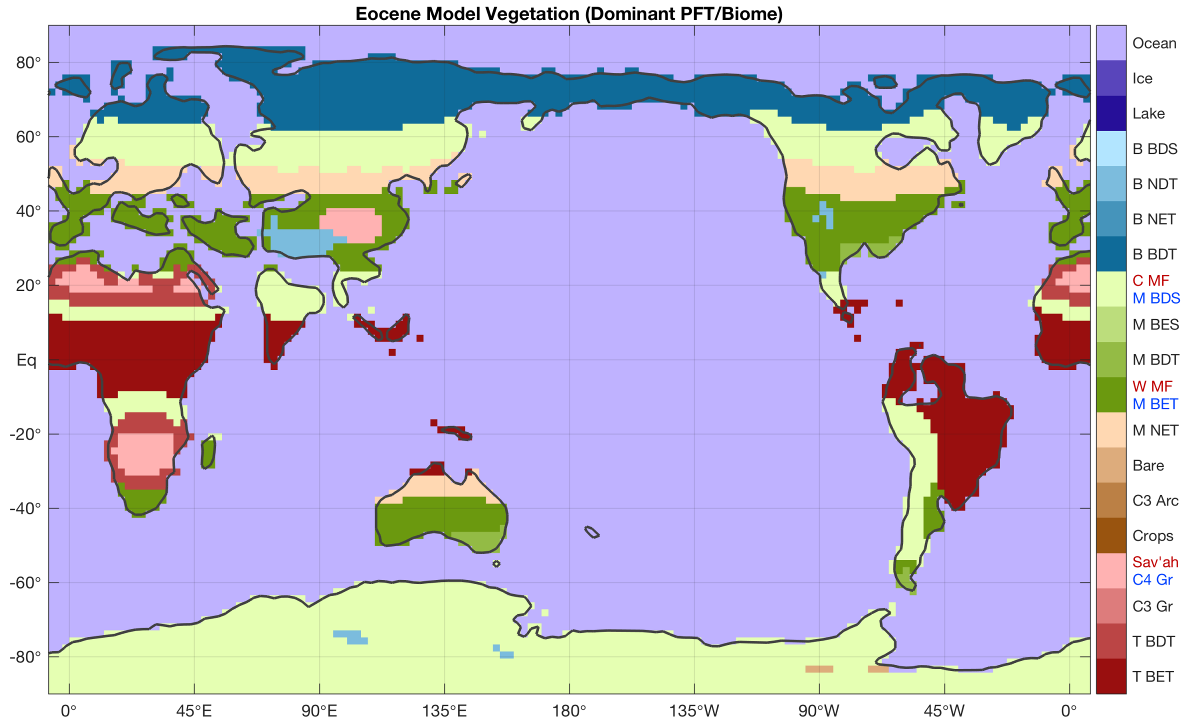
Vegetation: can’t see the forest for the trees



In the model: ‘*Plant Functional Type*’ (PFT)

→ Reconstructed <u>biomes</u> translated into distribution of these PFTs.

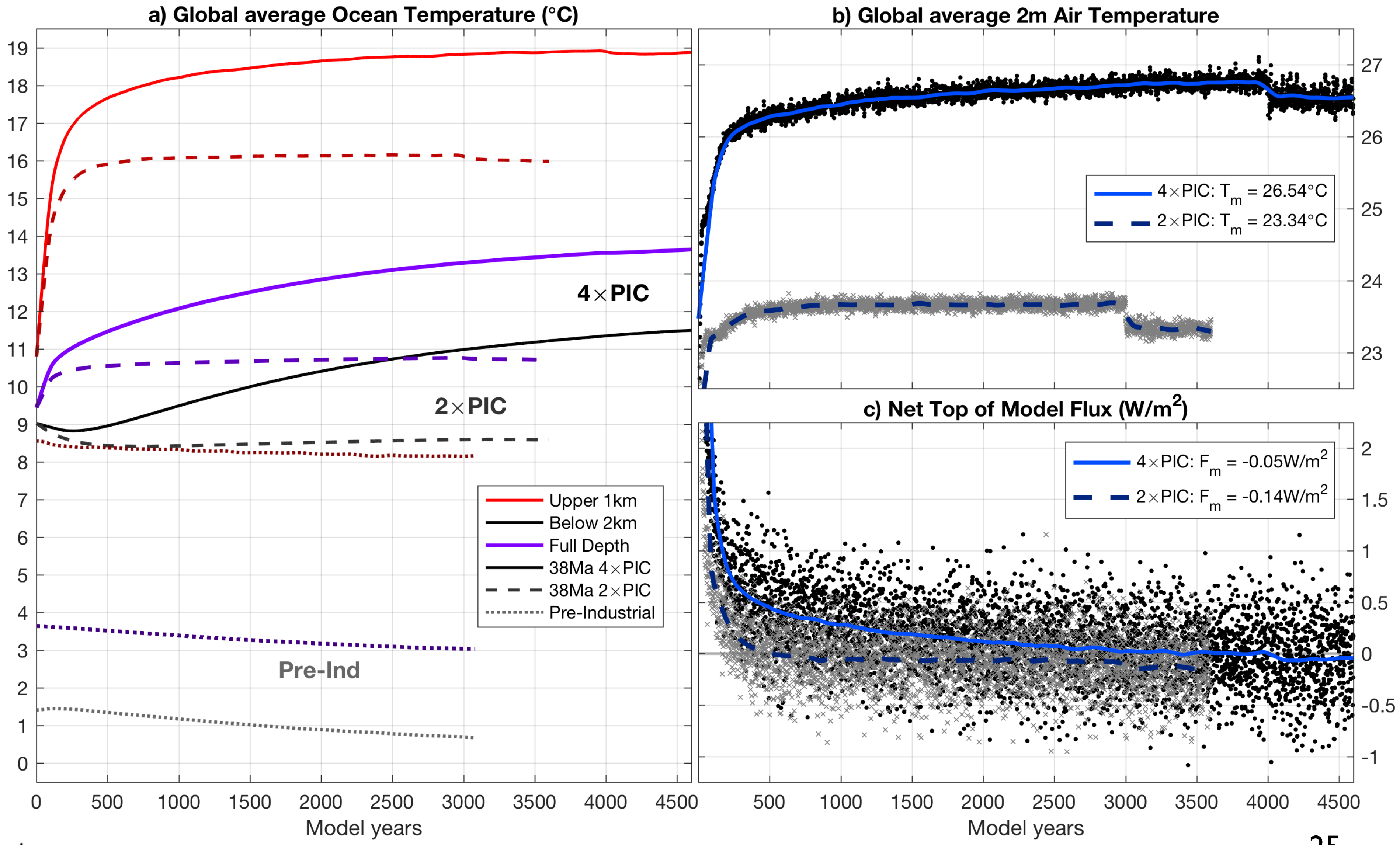


This did not always go according to plan…

Model initialisation and spin-up: example

<u>Highly idealised</u> initial *temperature* and *salt* distributions are used.

A very <u>long spin-up</u> is needed to *equilibrate* the simulated climate!



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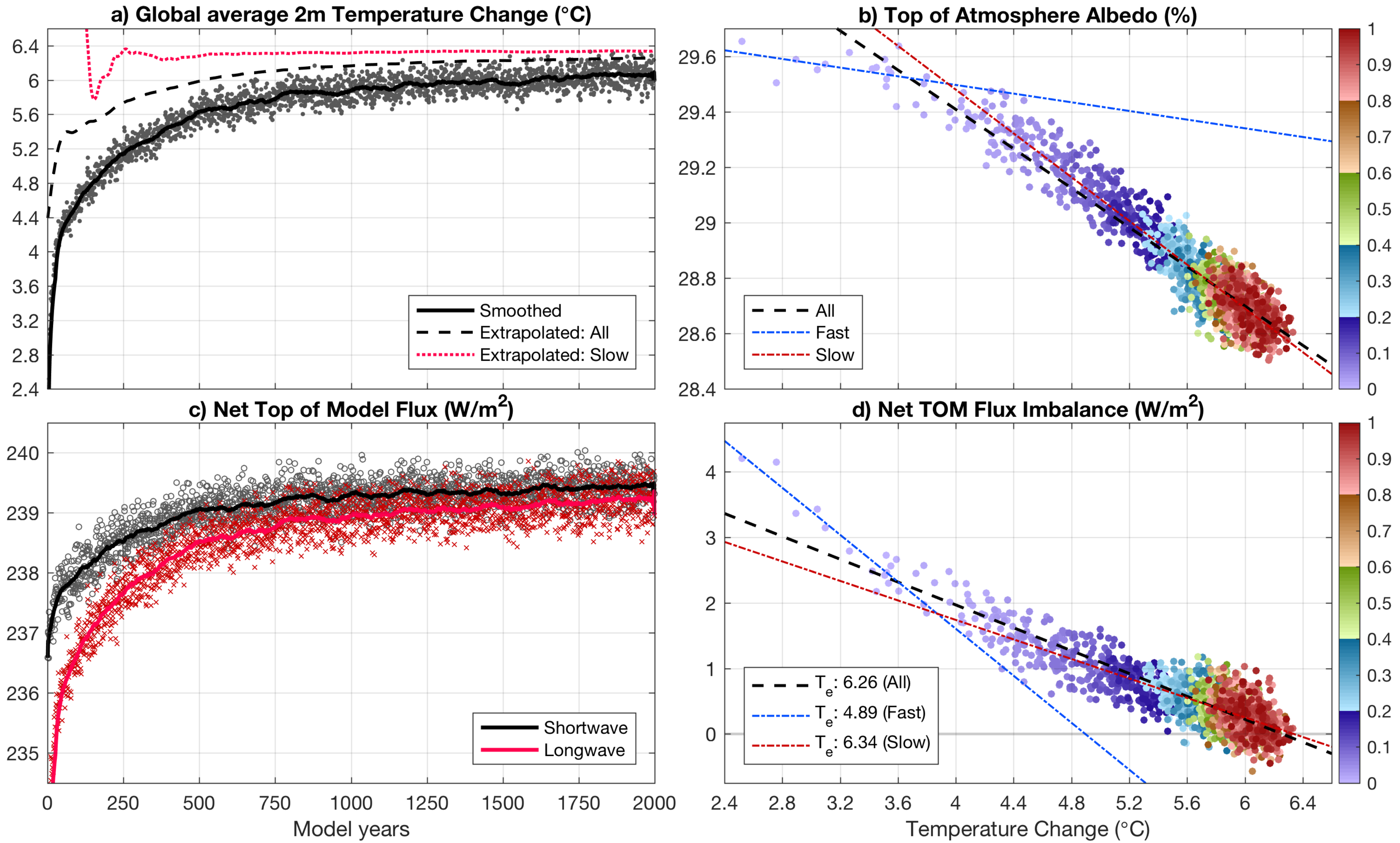
Climate sensitivity: CO_2 doubling/quadrupling



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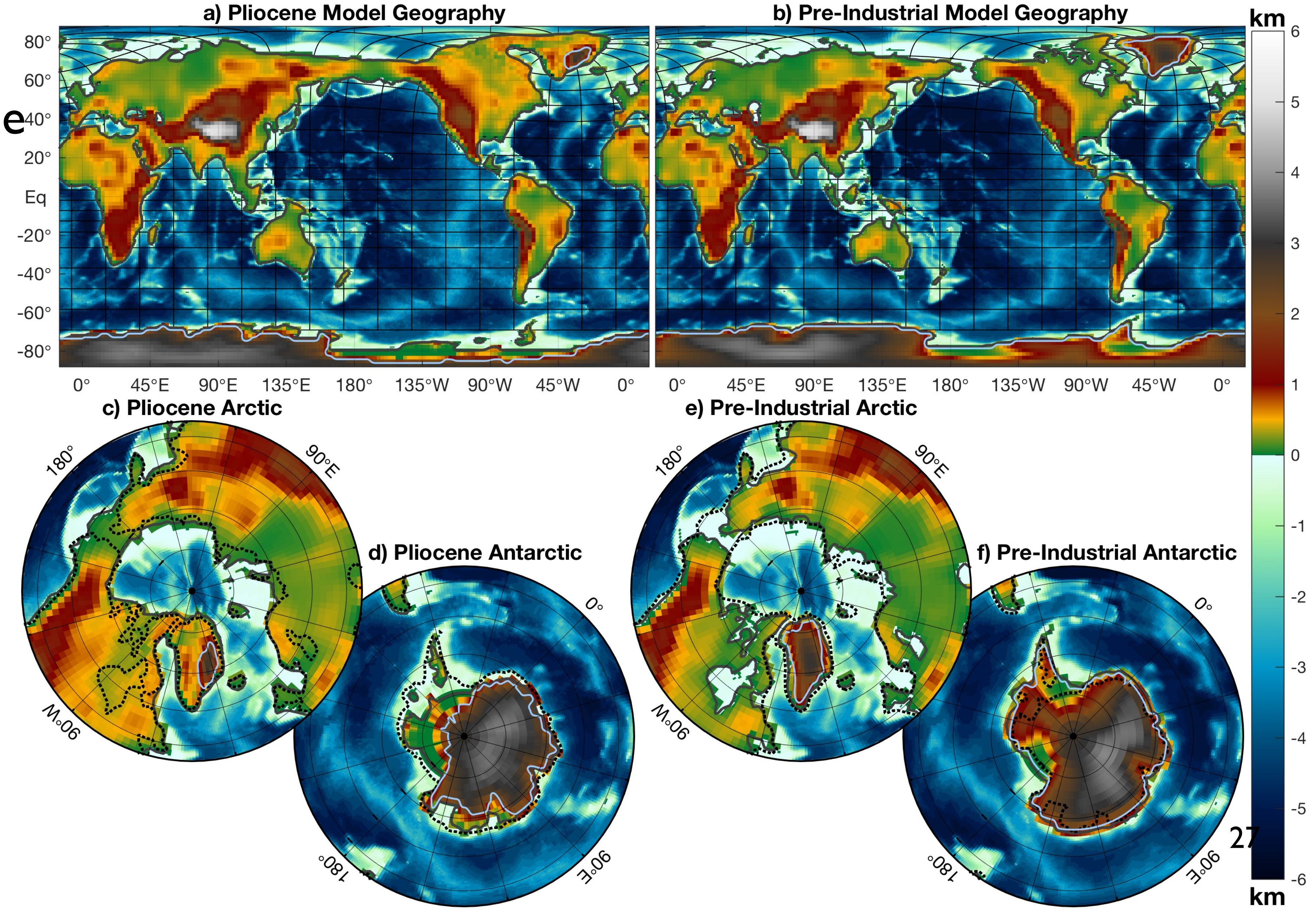
The Pliocene: a 400ppm (~2015) world

Often considered as the *best* candidate for a '*future analogue*'

Higher CO_2, but also <u>other adjustments</u>;

- *Geography*
- *Ice sheets*
- *Vegetation*
- *Aerosols*



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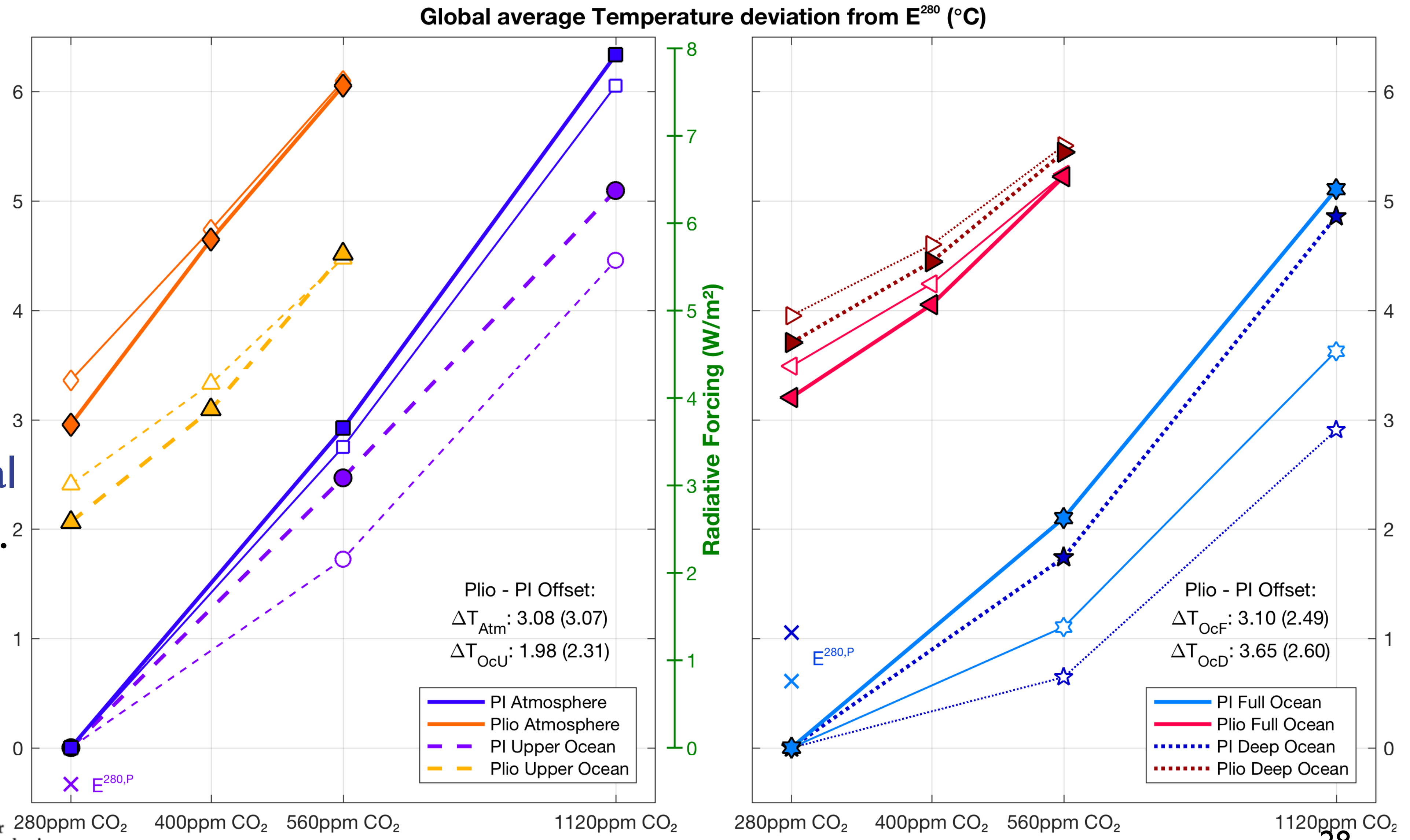
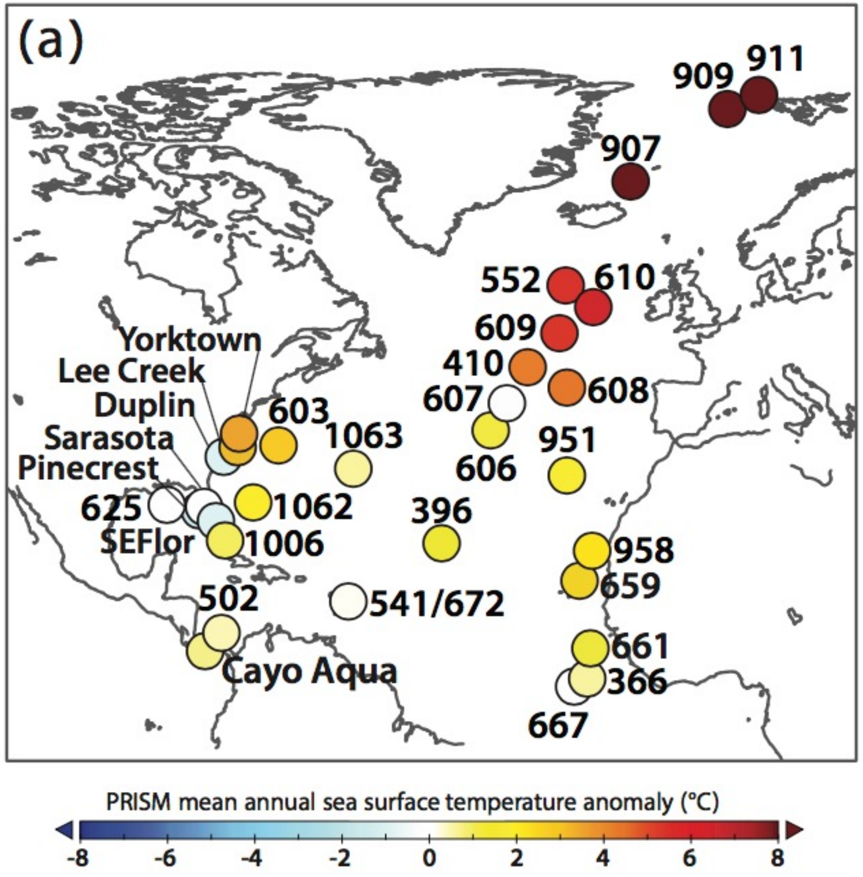
The Pliocene: not just greenhouse gases

Boundary conditions have a *large* effect.

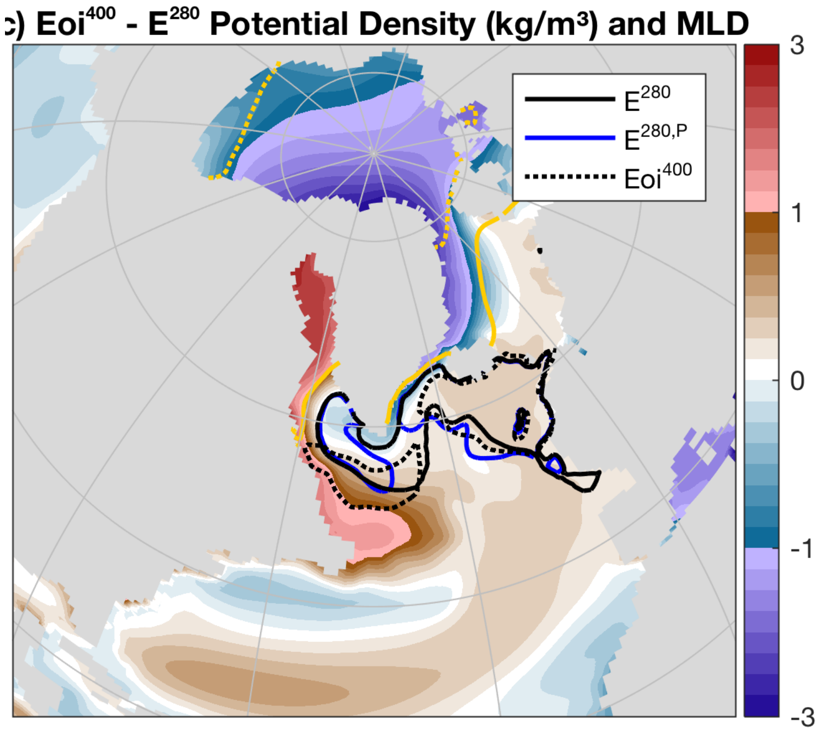
Pliocene – pre-industrial *similar* to CO_2 doubling.

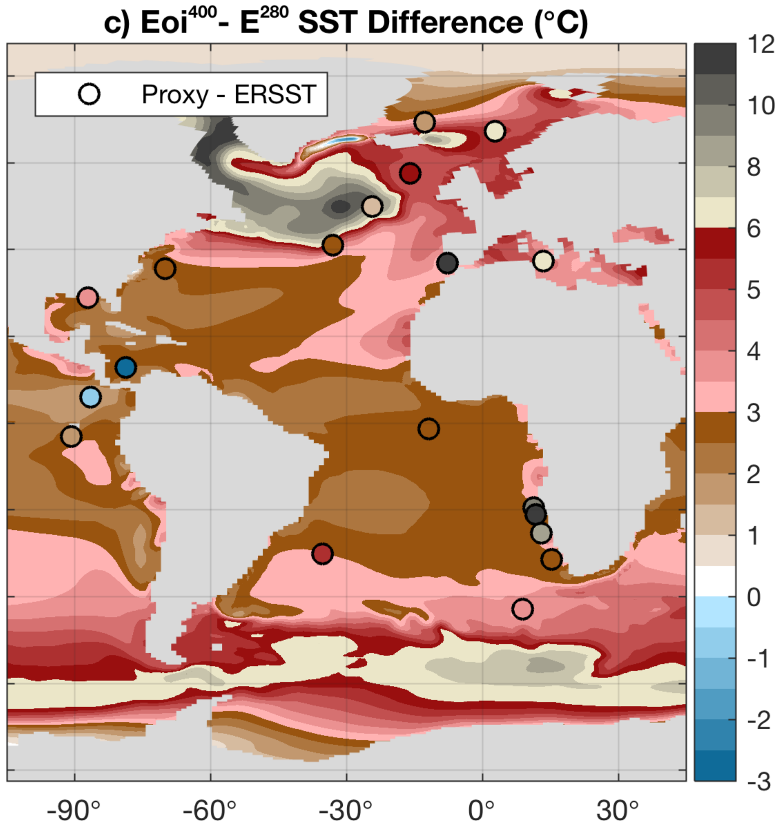


Pliocene: North Atlantic warmth



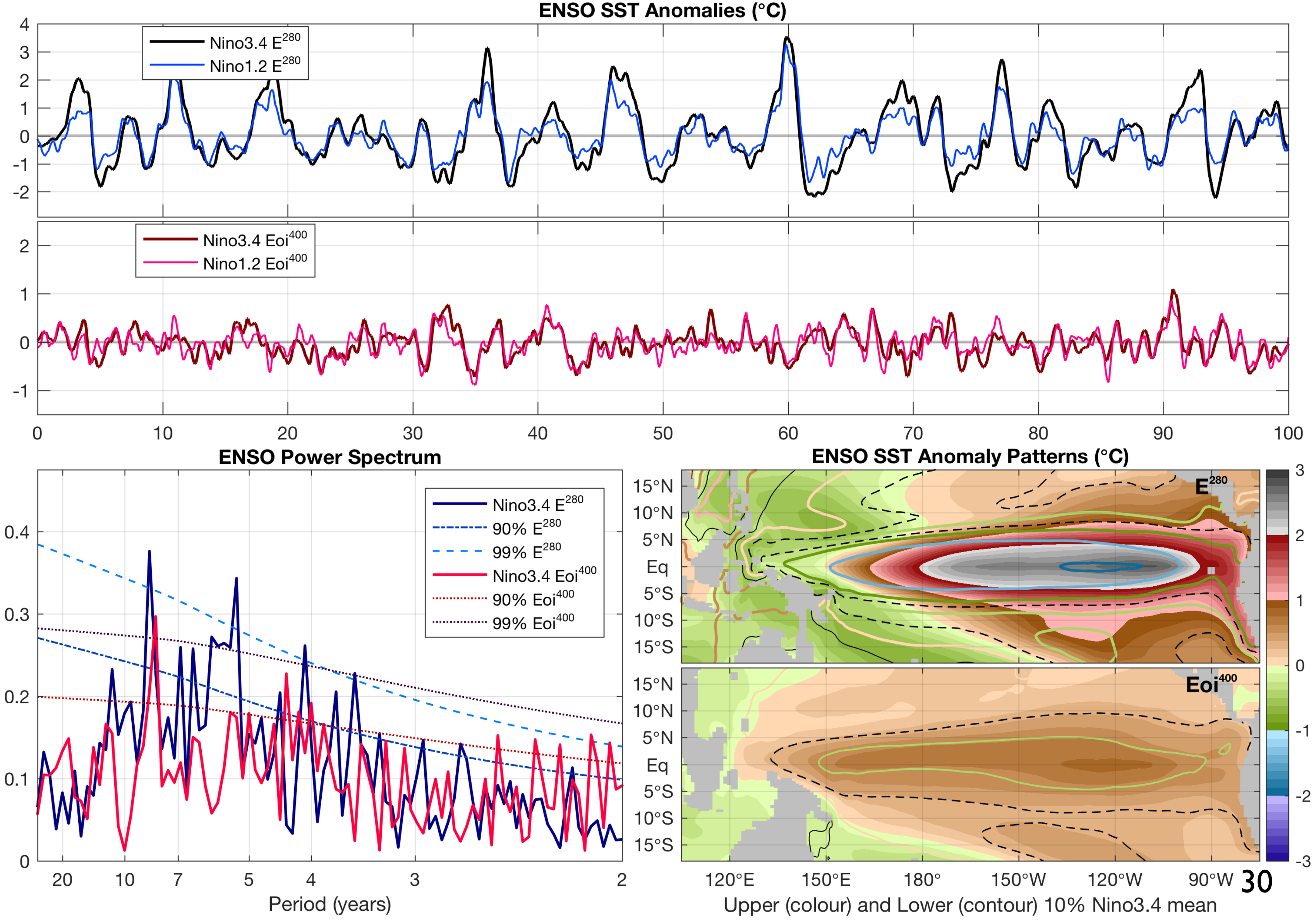
Strength of the <u>Atlantic Meridional Ovcerturning Cicrulation</u> (*AMOC*) is *highly* sensitive in the models to a *closure* of <u>Arctic gateways</u>;





Pliocene: permanent El Niño?

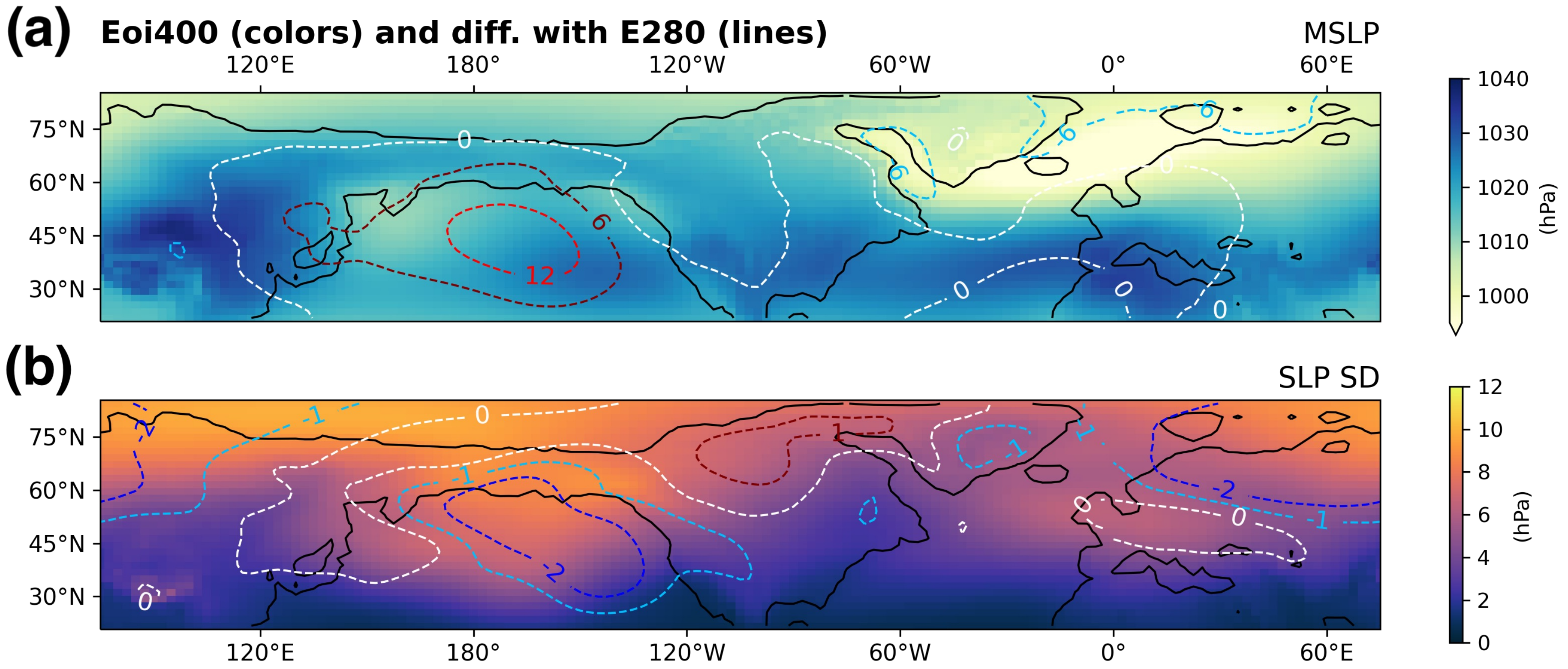
- ENSO <u>variability</u> is much *weaker* in Pliocene simulations.
- Often suggested that there was a so-called *permanent El Niño*.
- <u>Not supported</u> by models; mostly weaker, but *no* specific state.



Pliocene as future analogue: what about variability?

- Pliocene temperatures *comparable* to ~2100.
- Patterns of sea level pressure *change*.
- Variability patterns change even *more*.

The *Weather* conditions may be very different!



Oldeman et al. (in review)

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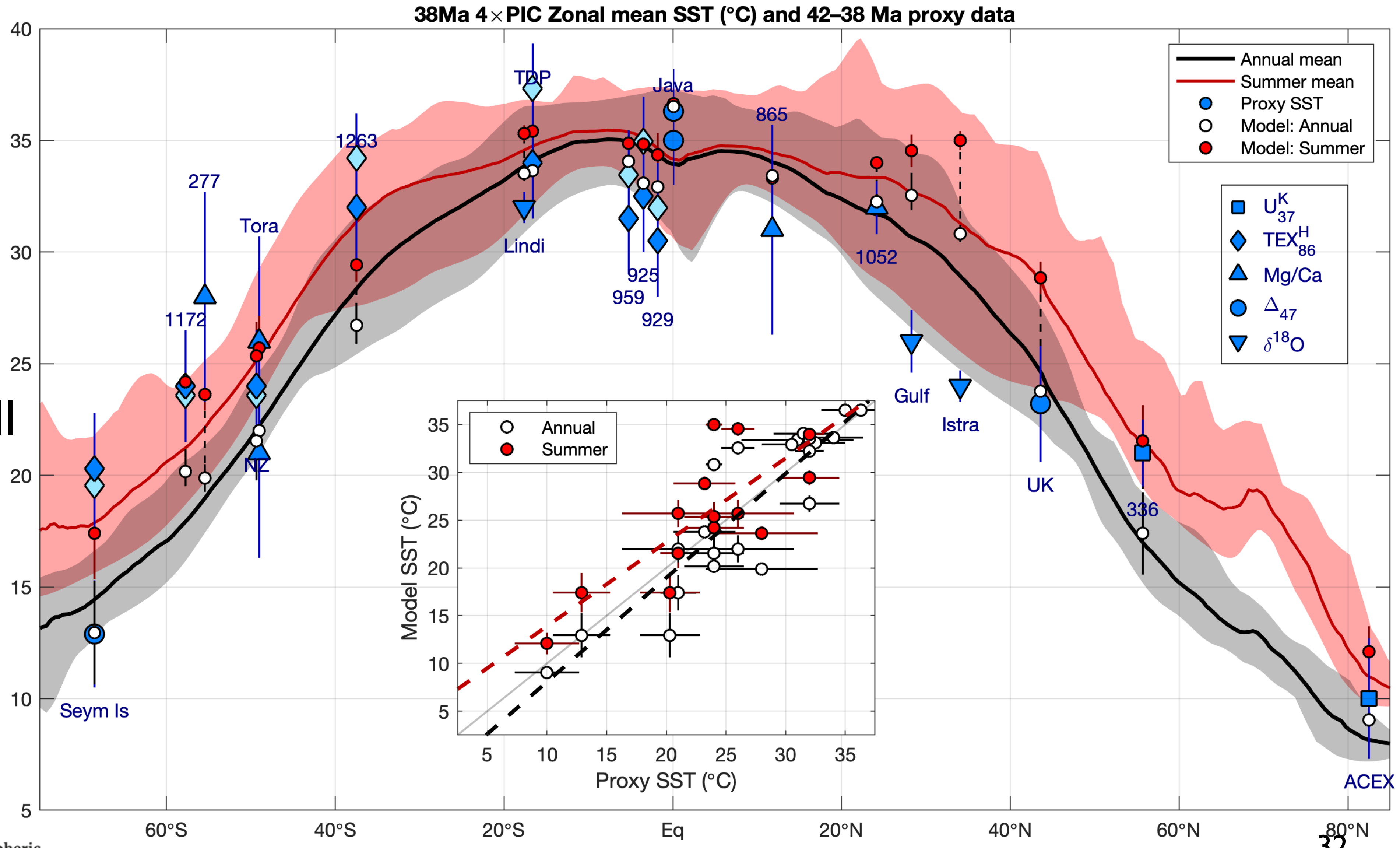
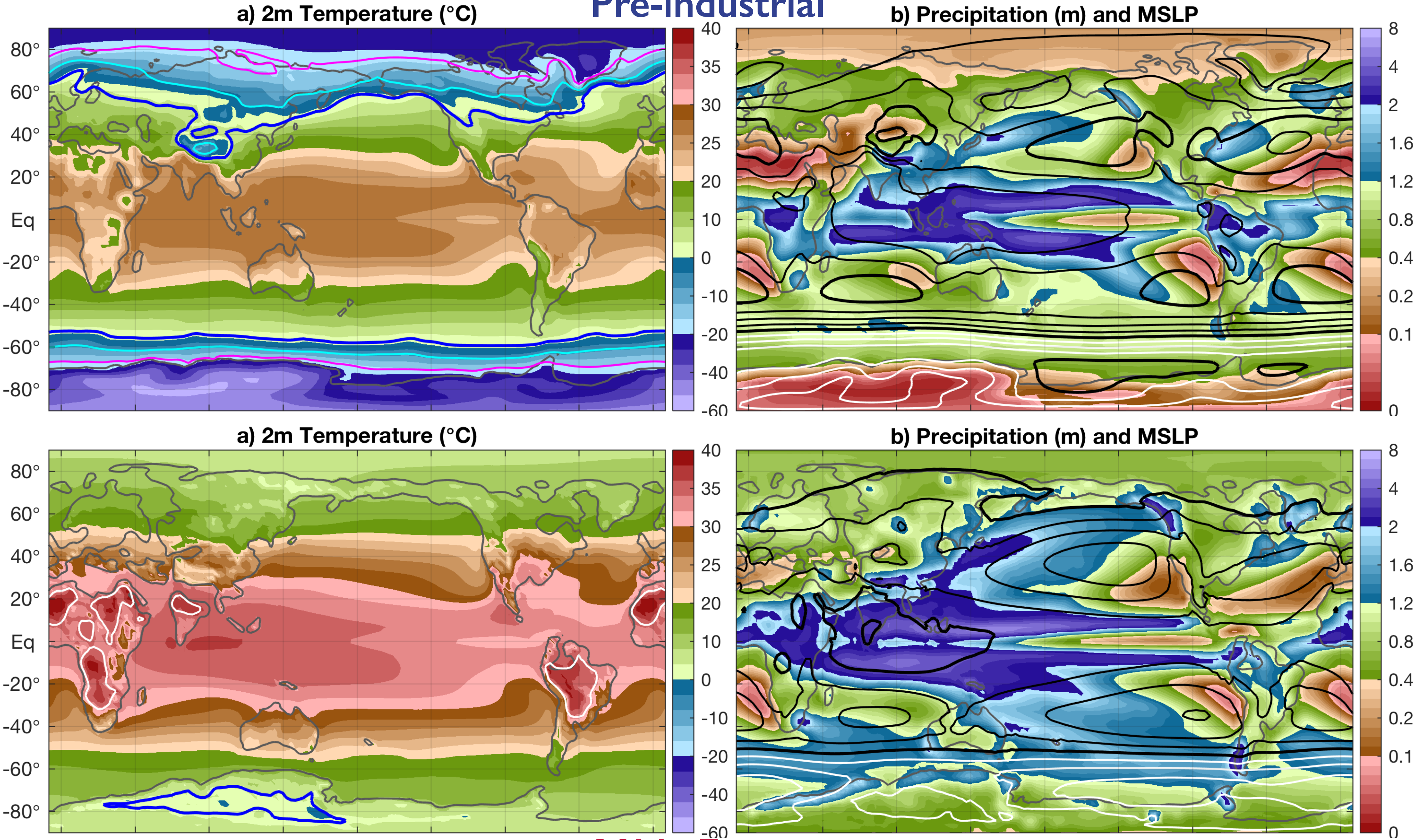
The Eocene hothouse: ocean temperature

- Comparison to SST '*proxies*'.
- Gradient captured well in simulation.

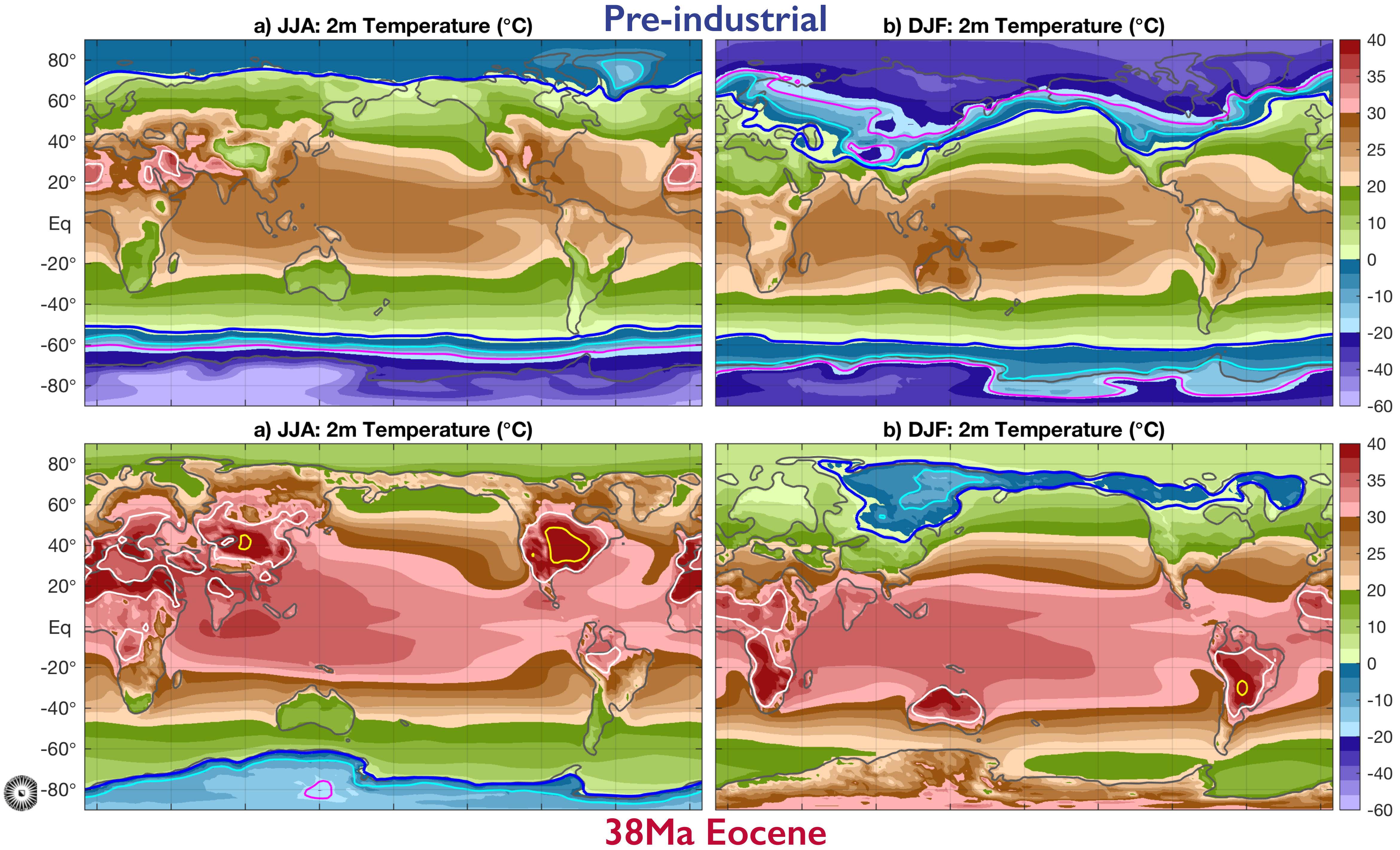
If the model does well *here*, can we trust it for other studies?



Pre-industrial



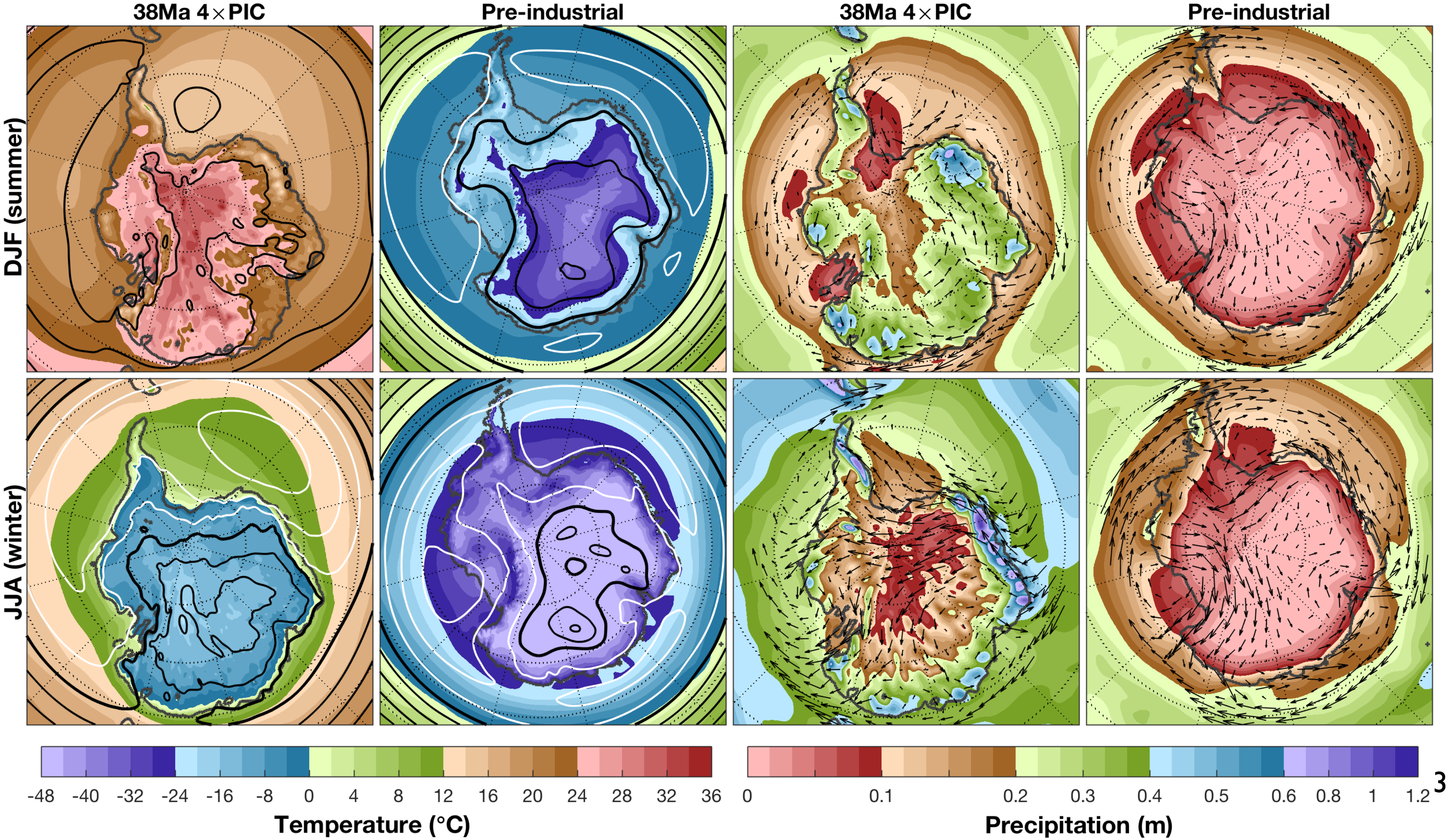
38Ma Eocene



Pre-industrial
a) JJA: 2m Temperature (°C)
b) DJF: 2m Temperature (°C)
a) JJA: 2m Temperature (°C)
b) DJF: 2m Temperature (°C)
80°
60°
40°
20°
Eq
-20°
-40°
-60°
-80°
40
35
30
25
20
10
0
-10
-20
-40
-60
38Ma Eocene

Eocene climate: what happens on Antarctica?

Very warm
in <u>summer</u>,
also *highest*
temperatures
near the <u>pole</u>.



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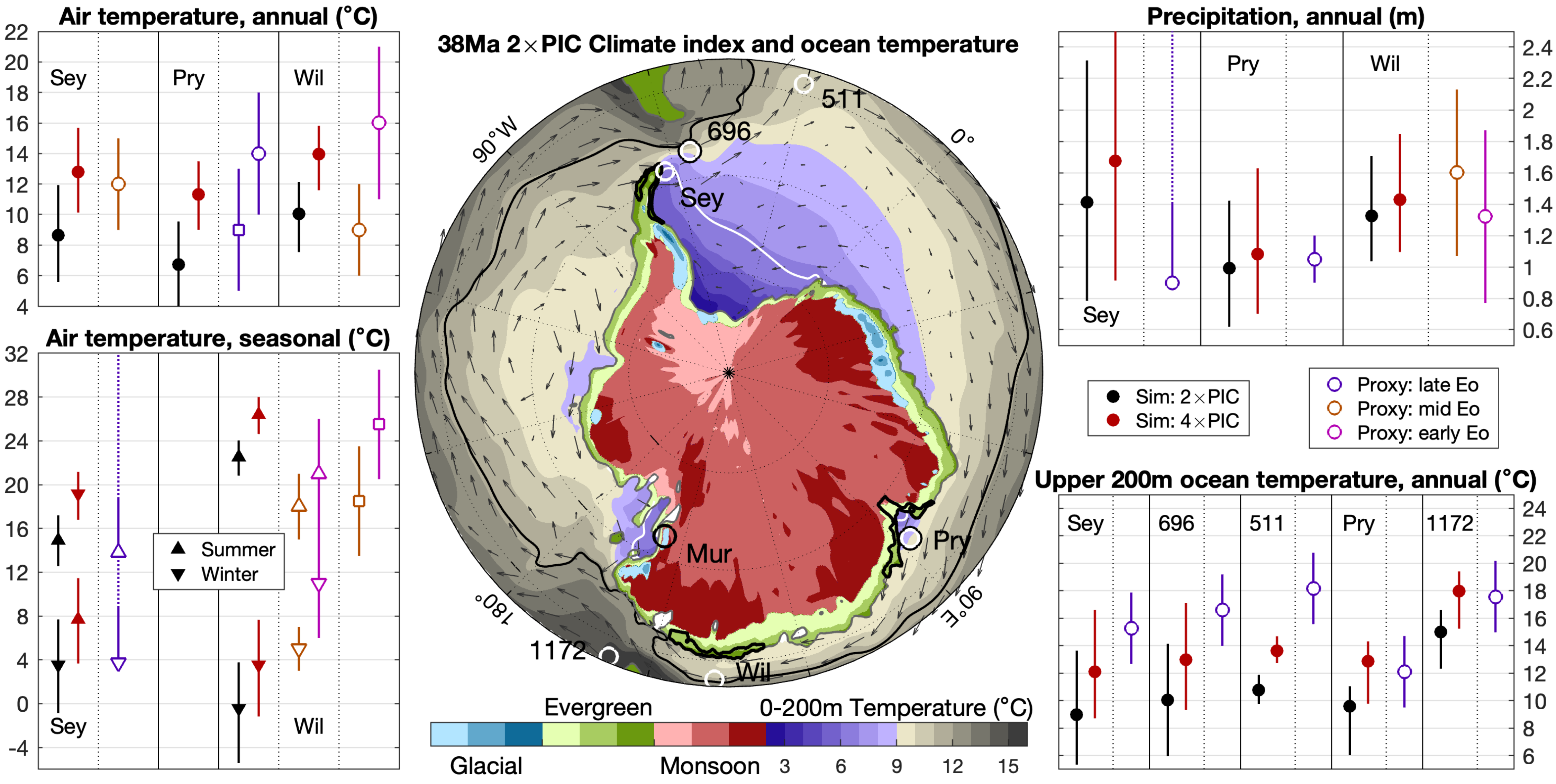
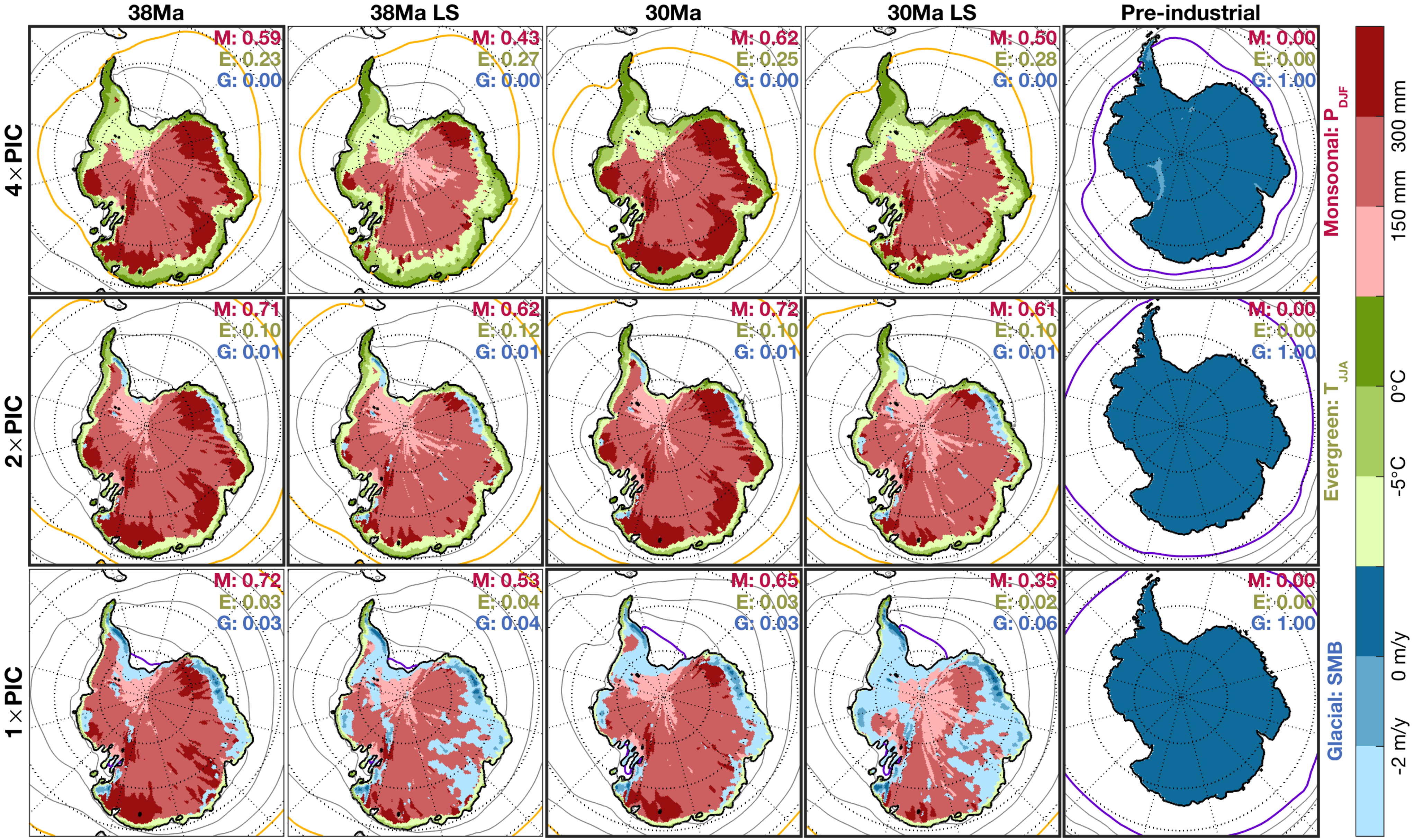
Antarctic monsoons: vegetation and ice?



Antarctic monsoonal climate is very resilient



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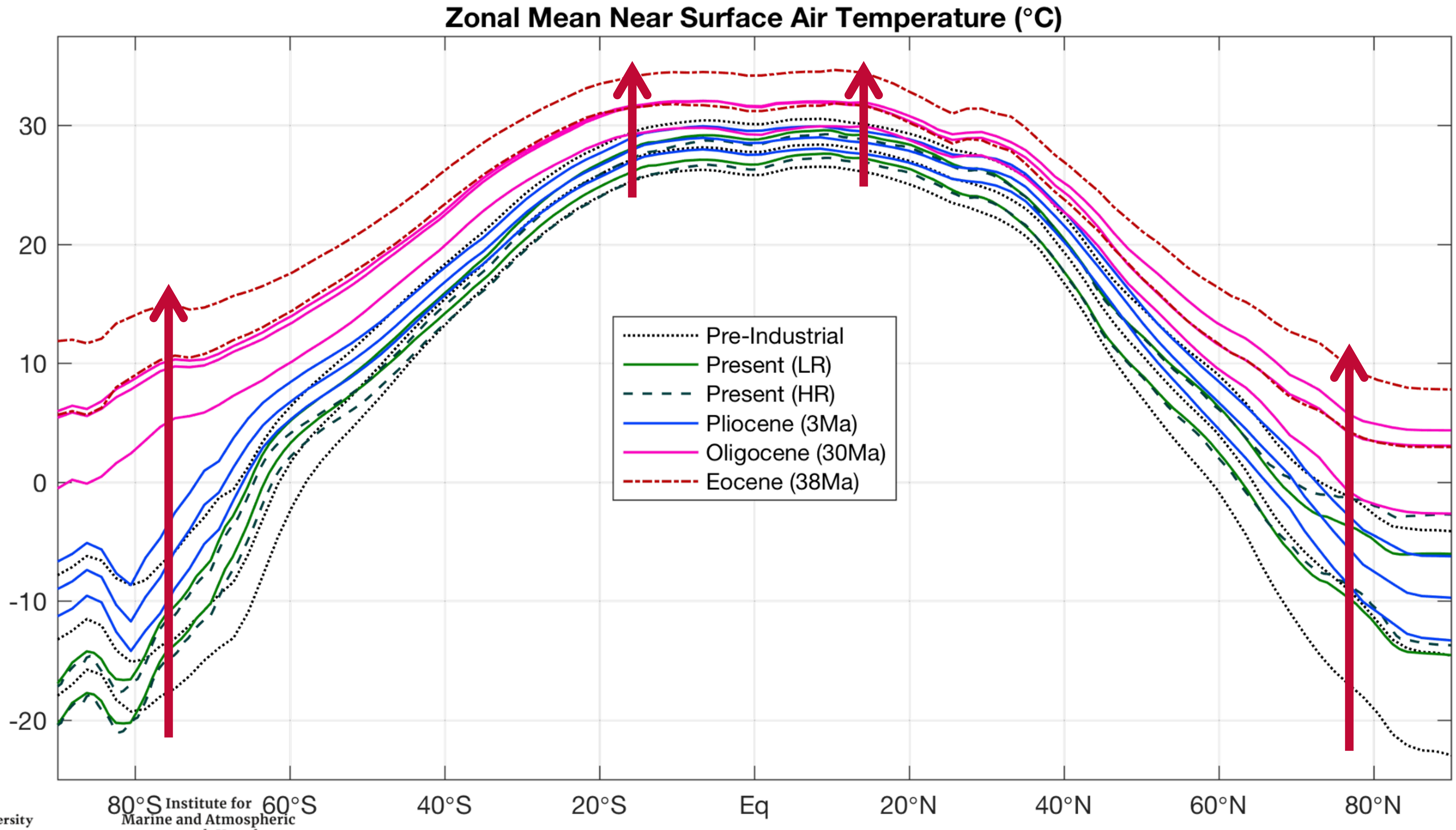
General lessons from past warm climates



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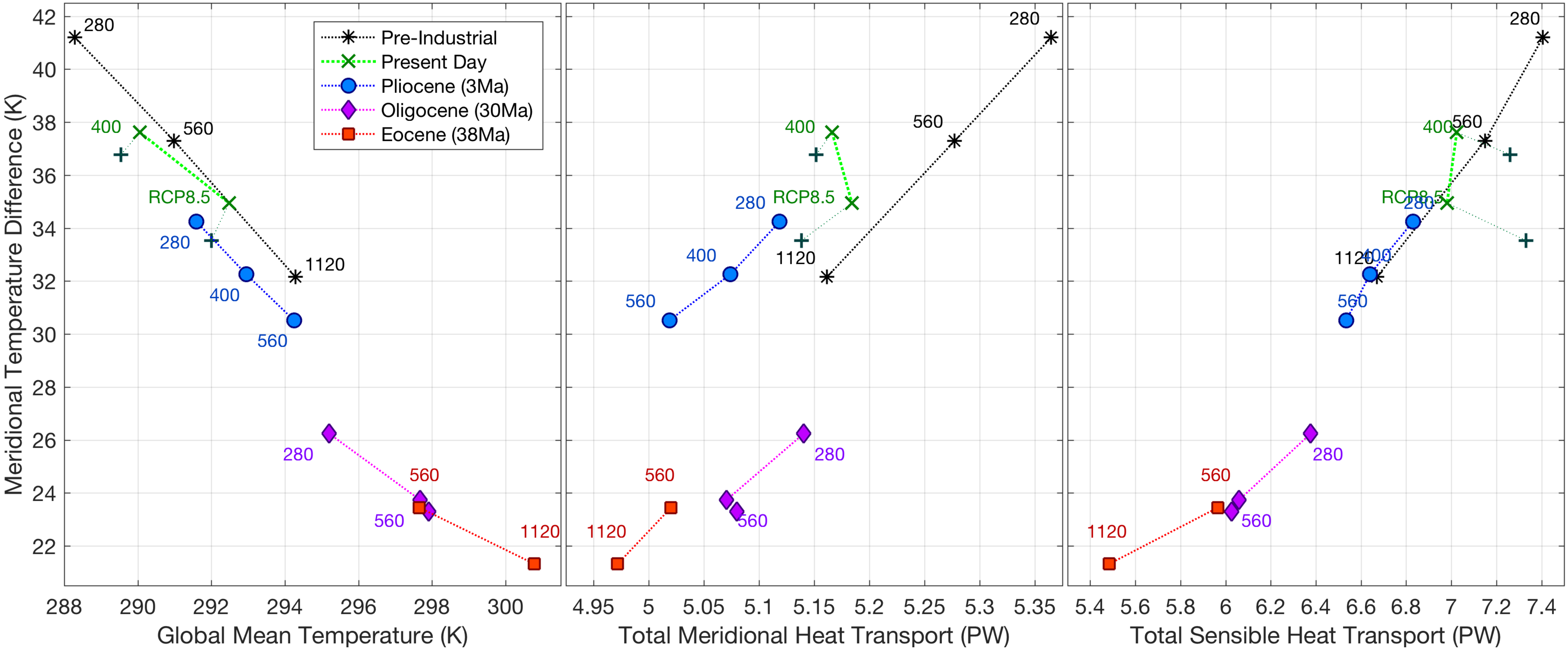
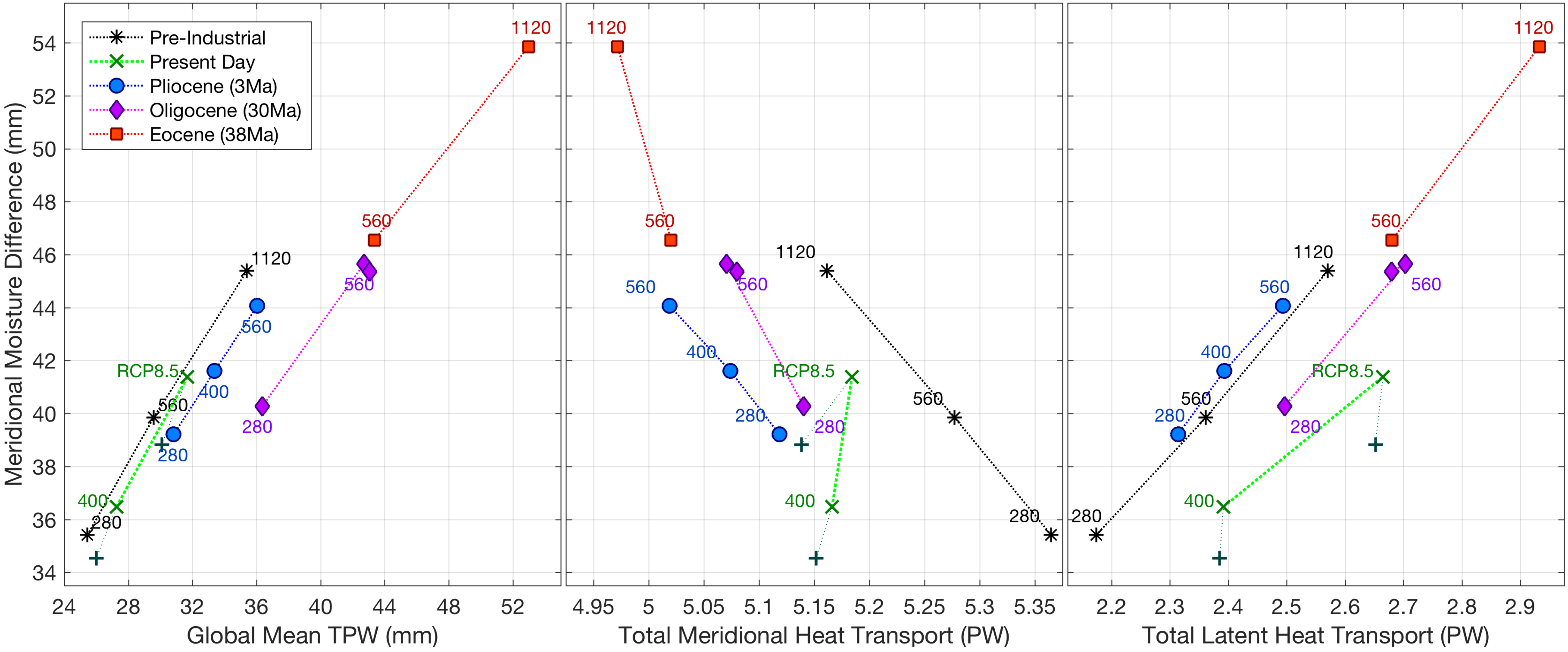
Equable climates: a heat flux paradox?

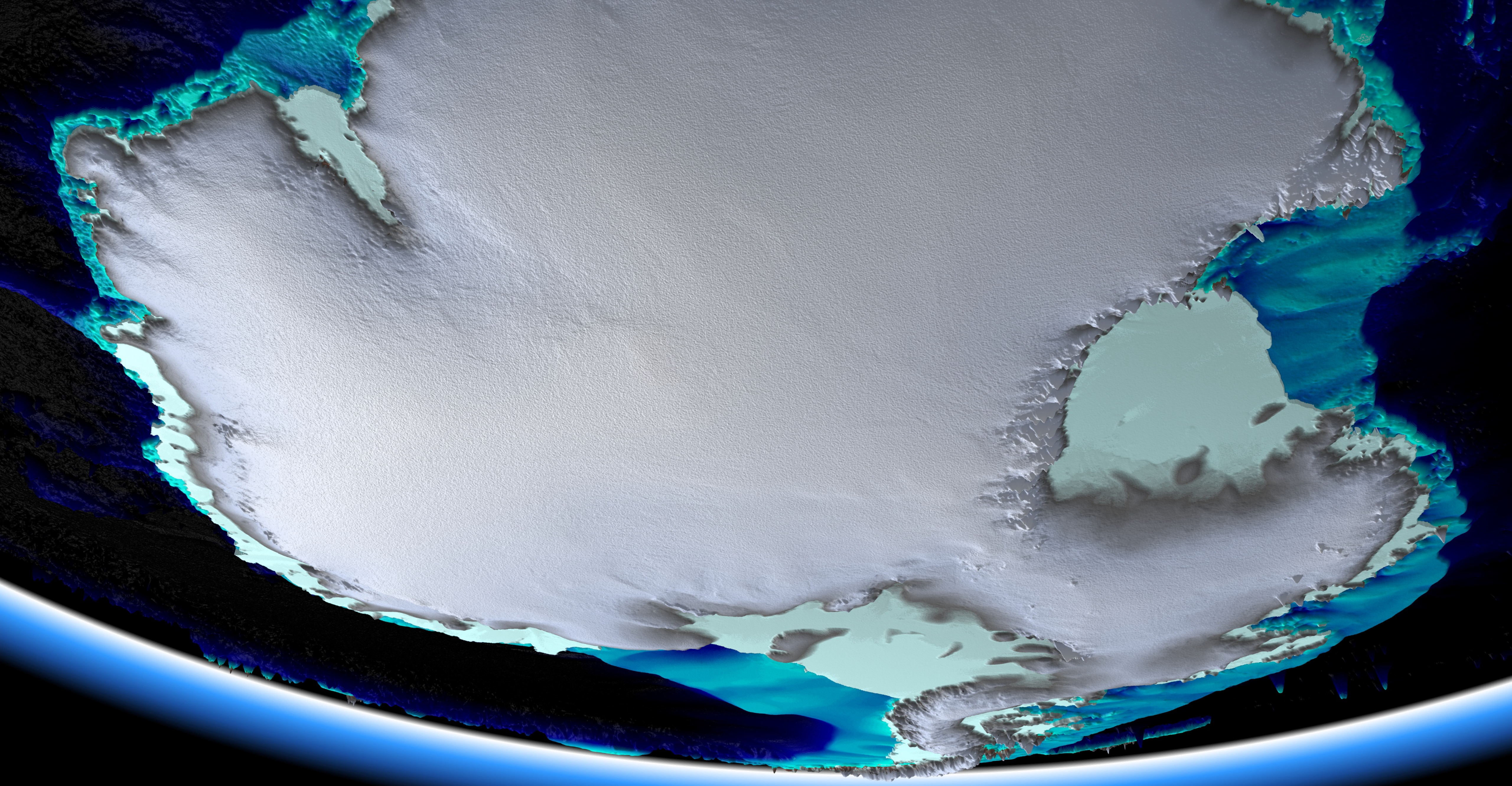


Warmer → *reduced* gradient → *weaker* transport

Equable climates: not in terms of moisture!



Warmer → *enhanced* gradient → *stronger* transport



Thank you for listening!

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