# The Pliocene: an accessible example of a world in equilibrium with 400 ppmv $CO_2$?


Alan Haywood

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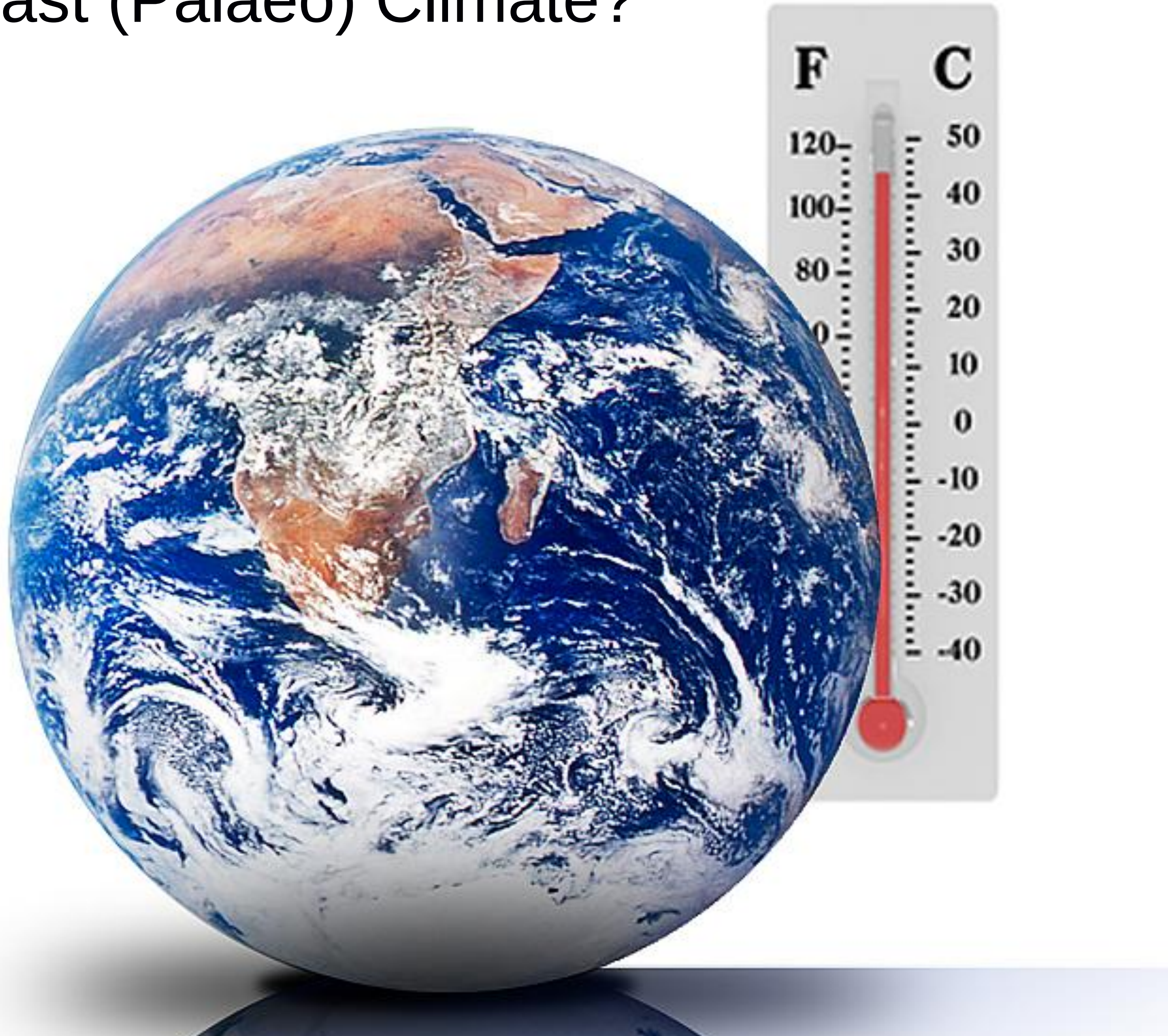
Royal Meteorological Society Meeting- April 2019

# Why Past (Palaeo) Climate?



# Model Predictions and Climate Sensitivity

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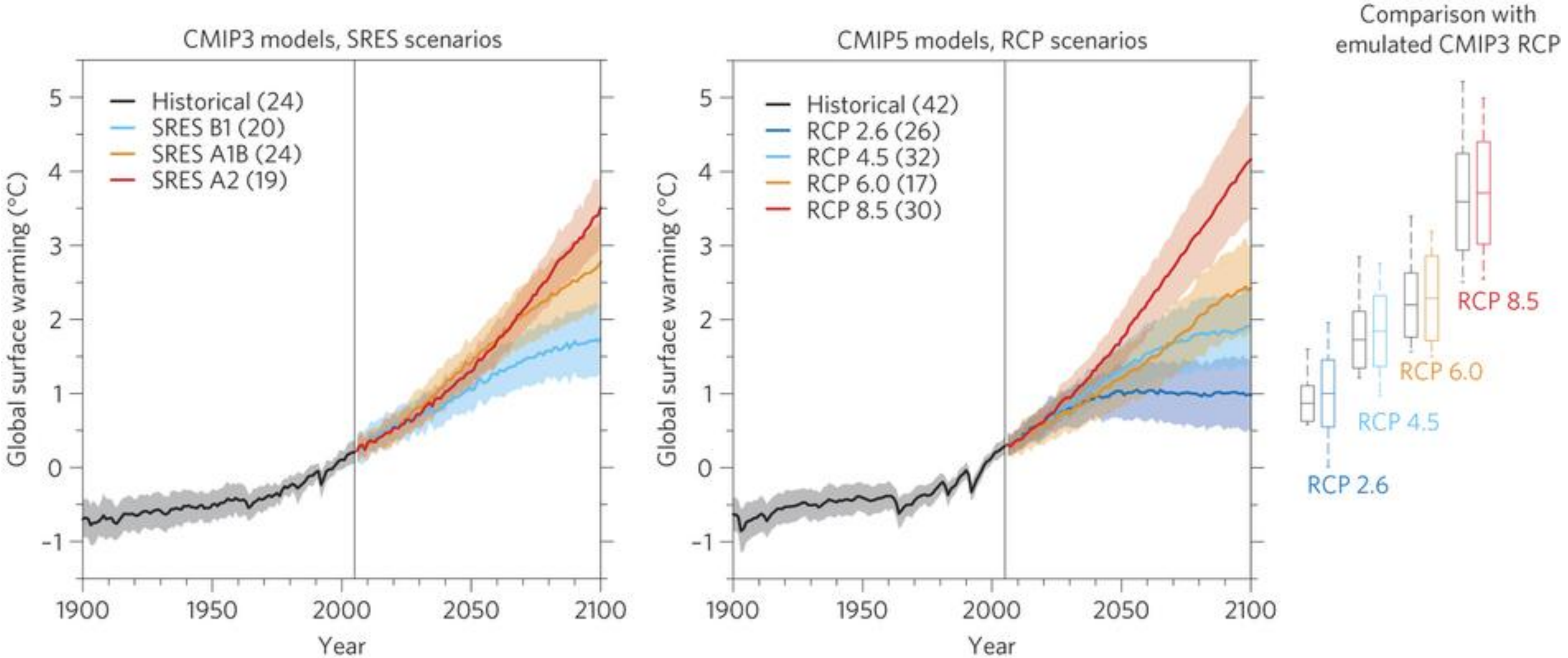
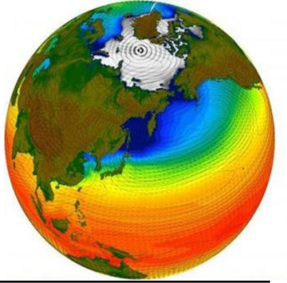
## <u>Prediction</u>, mitigation, adaptation

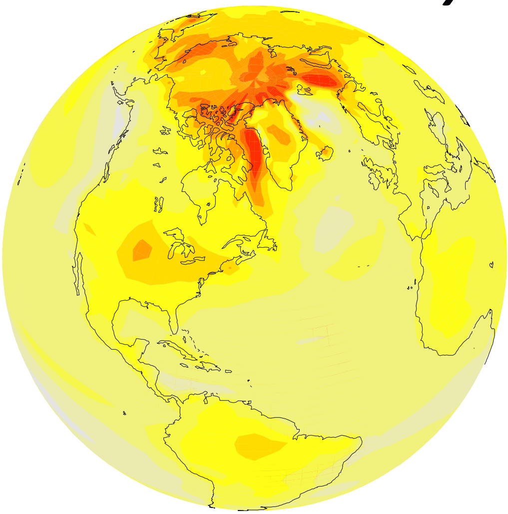



Knutti and Sedláček (2013)

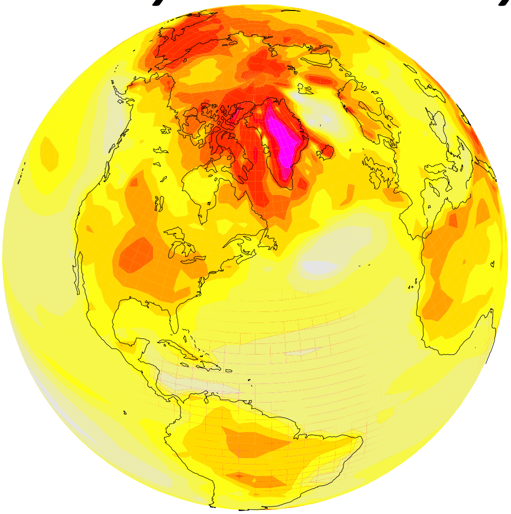
# Palaeo Constraints on Climate and Longer Term Sensitivity

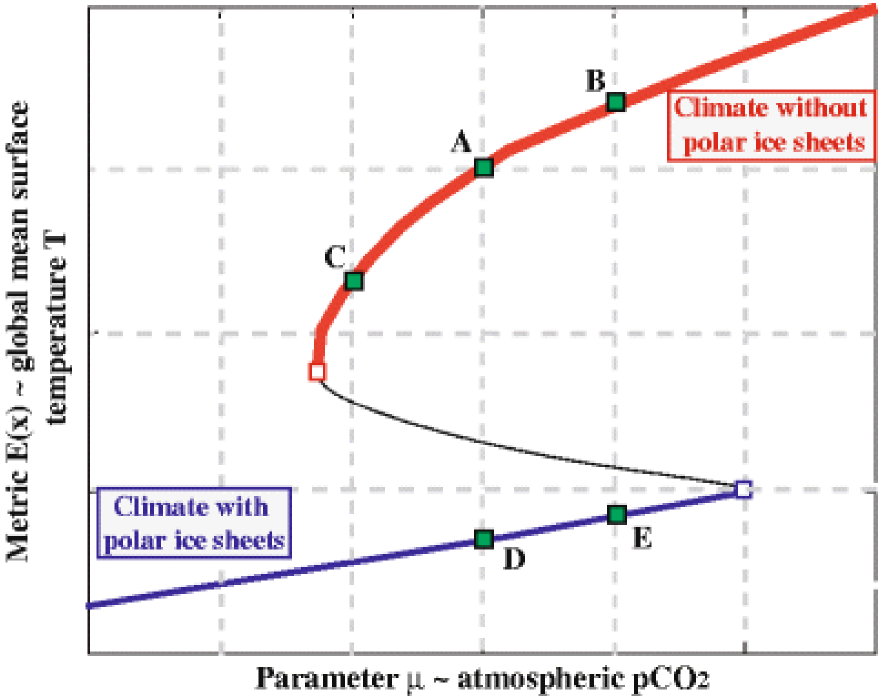


***Climate Sensitivity***



***Earth System Sensitivity***






# Global Temperatures & Impacts

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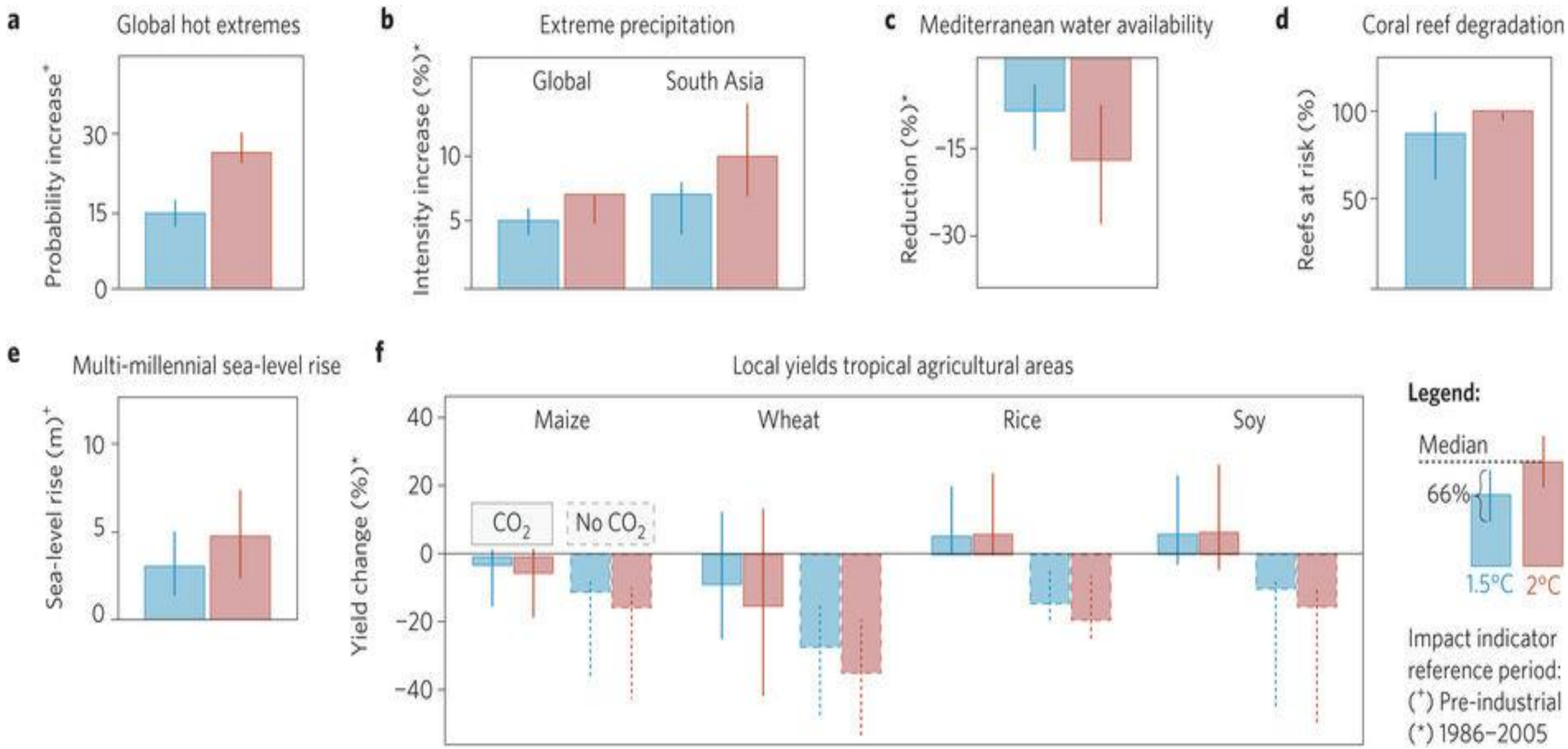


a, Increase in global occurrence probability of pre-industrial 1-in-a-1000 day extreme temperature events. b, Increase in extreme precipitation intensity for the global land area below 66° N/S and South Asia. c, Reduction in annual water availability in the Mediterranean. d, Share of global tropical coral reefs at risk of long-term degradation. e, Global sea-level rise commitment for persistent warming of 1.5 °C and 2°C over 2000 years. f, Changes in local crop yields for present-day tropical agricultural areas (below 30° N/S). Dashed boxes: no increase in CO2 fertilization (No CO2); from Schleussner et al. (2016).

# The Last 5 Million Years

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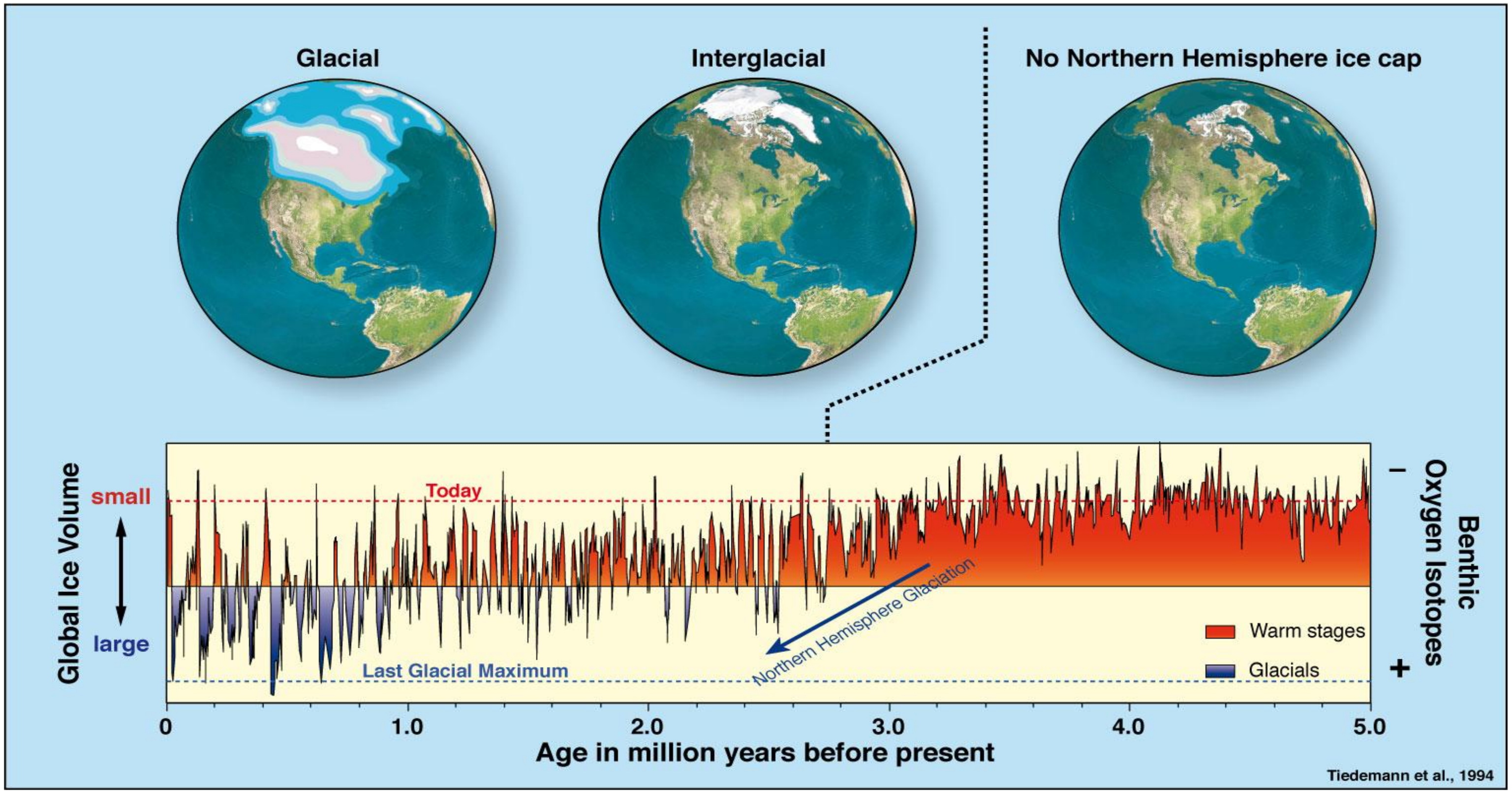


- We have abundant geological data for the Pliocene
- Pliocene $CO_2$ concentrations were almost the same as today
- Continents were in their modern positions
- Pliocene ecosystems were the same as modern

# $CO_2$ during the Pliocene

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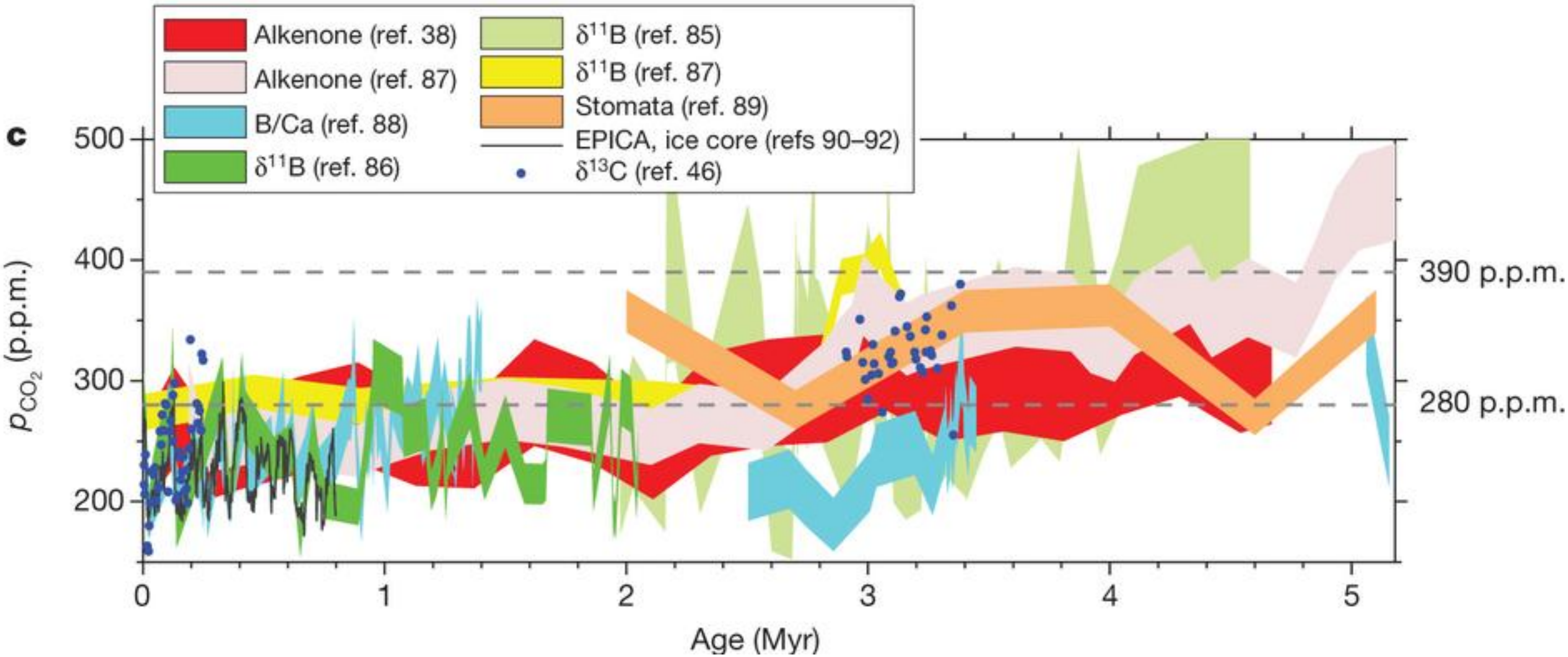
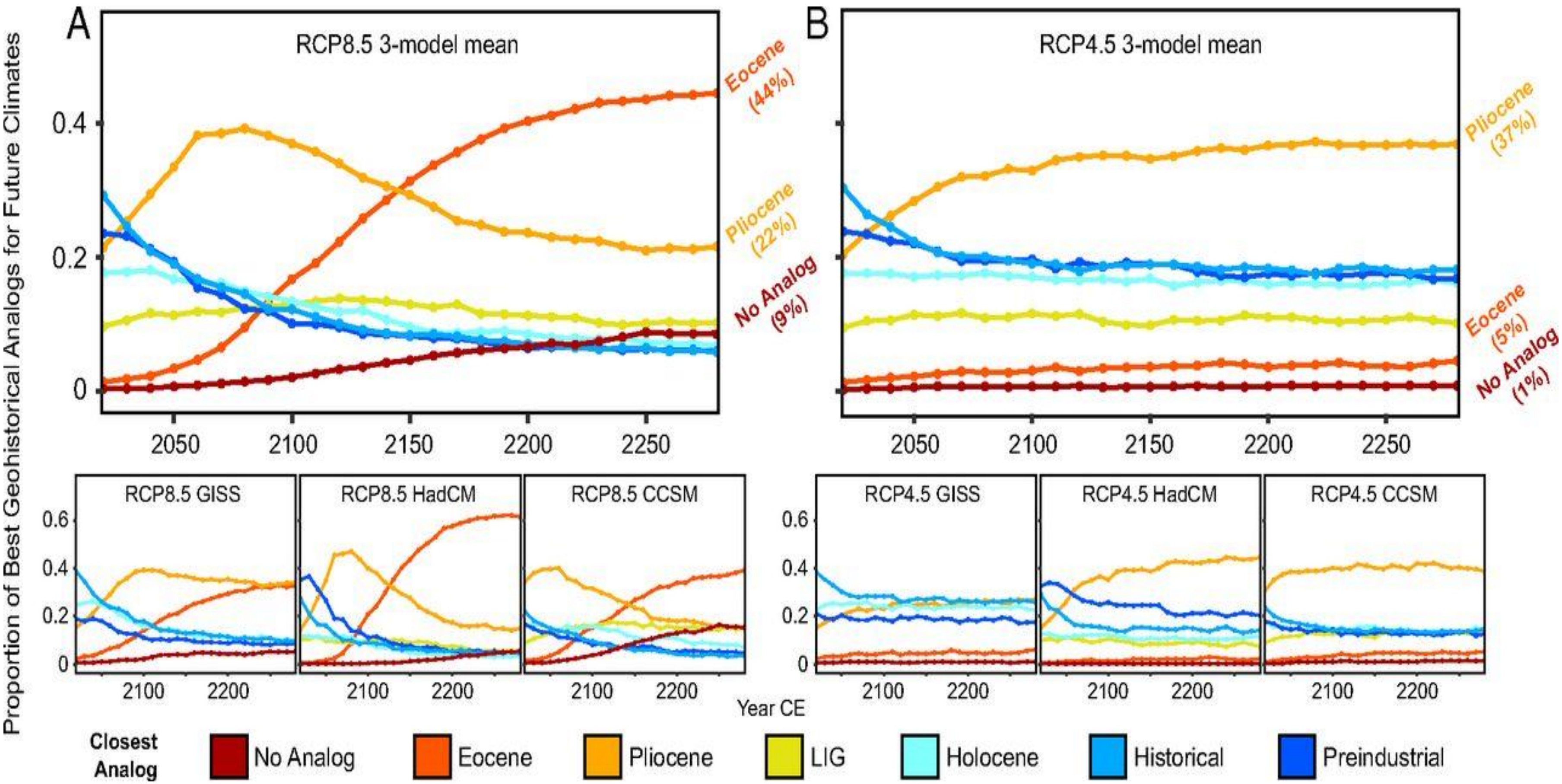



*(Federov et al, 2013: Nature)*

# Time-series of the Closest Geohistorical Climatic Analogues (2020–2280)




K. D. Burke et al. PNAS 2018;115:52:13288-13293.

# Geological Boundary Conditions

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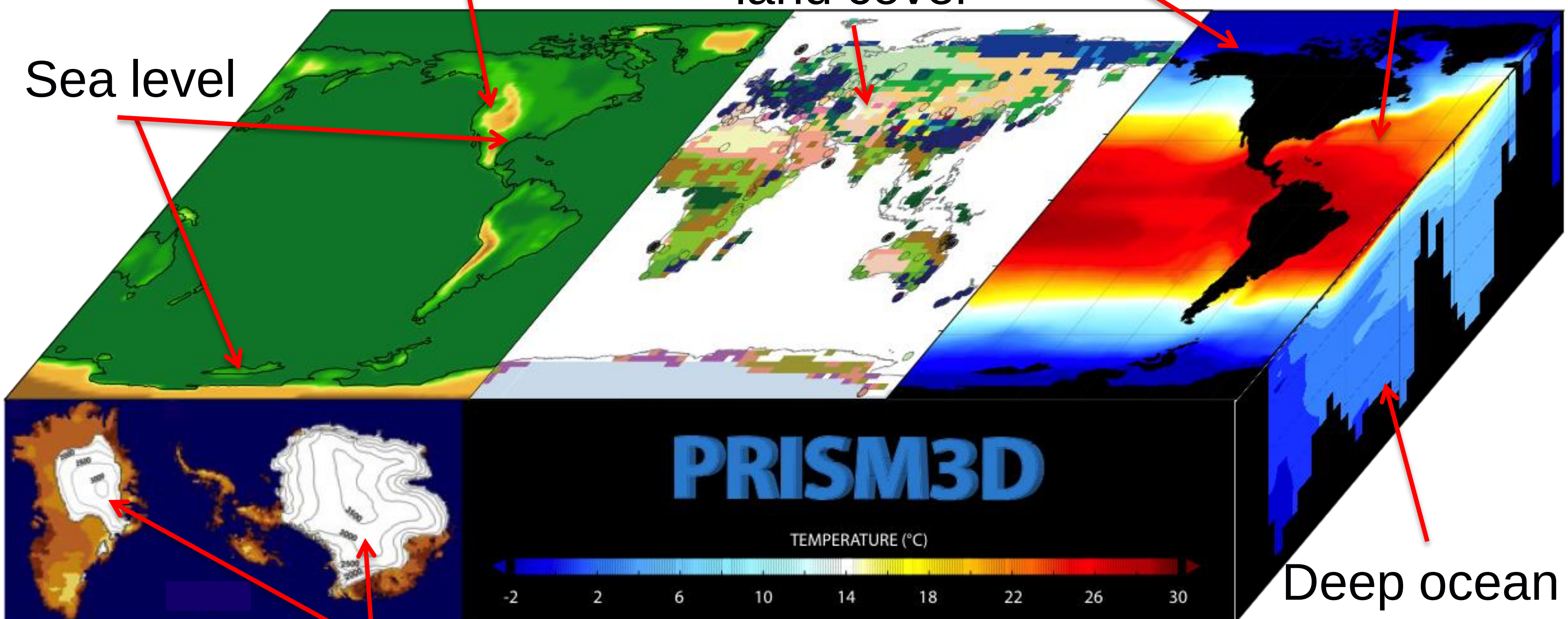
Topography

Vegetation, land cover

Sea surface temperature

Sea level




Deep ocean temperature, circulation

**Land ice**

$CO_2$ = ~400 ppmv

# Geological view of Pliocene environments – ice and ocean surface

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Less land ice = higher sea level

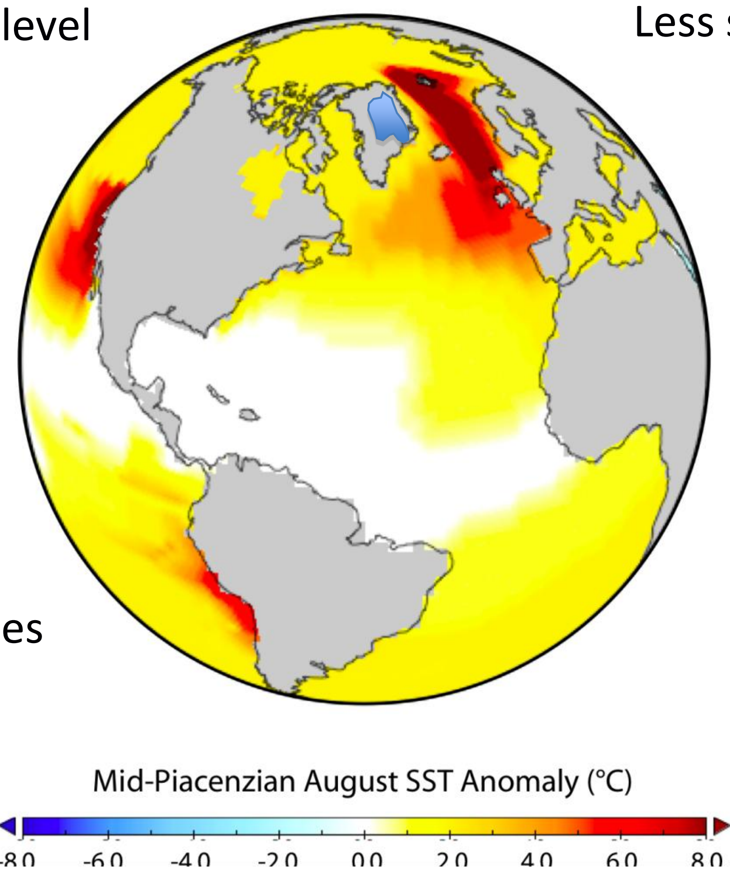
Less sea ice in the high latitudes

Reduced equator to pole surface temperature gradient

Altered ENSO variability?

Enhanced poleward ocean heat transport/$CO_2$ increase

Warmer upwelling zones



# Geological view of Pliocene environments - vegetation

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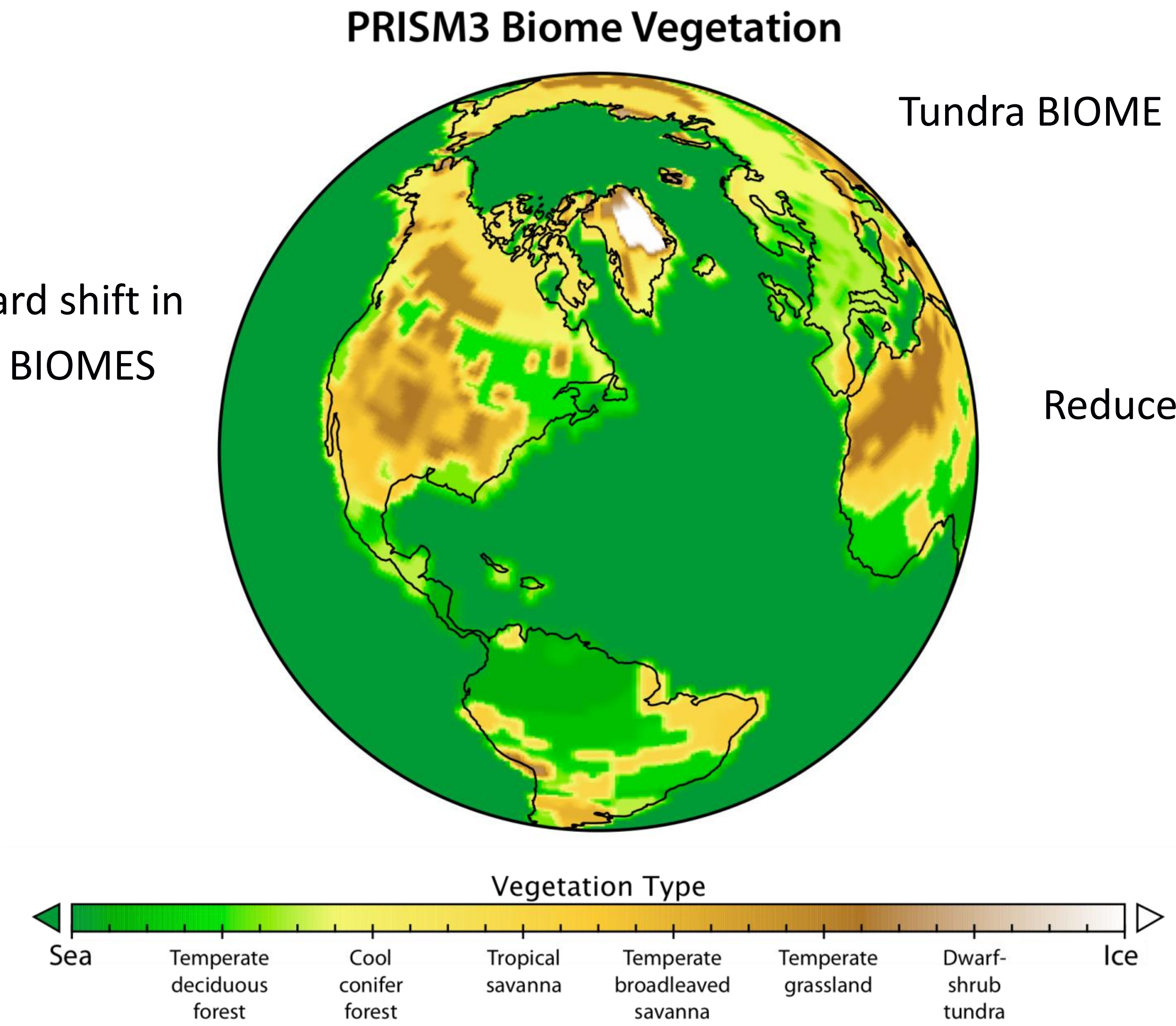


Tundra BIOME nearly absent

Poleward shift in most BIOMES

Reduced deserts

# Geological view of Pliocene environments – ocean circulation

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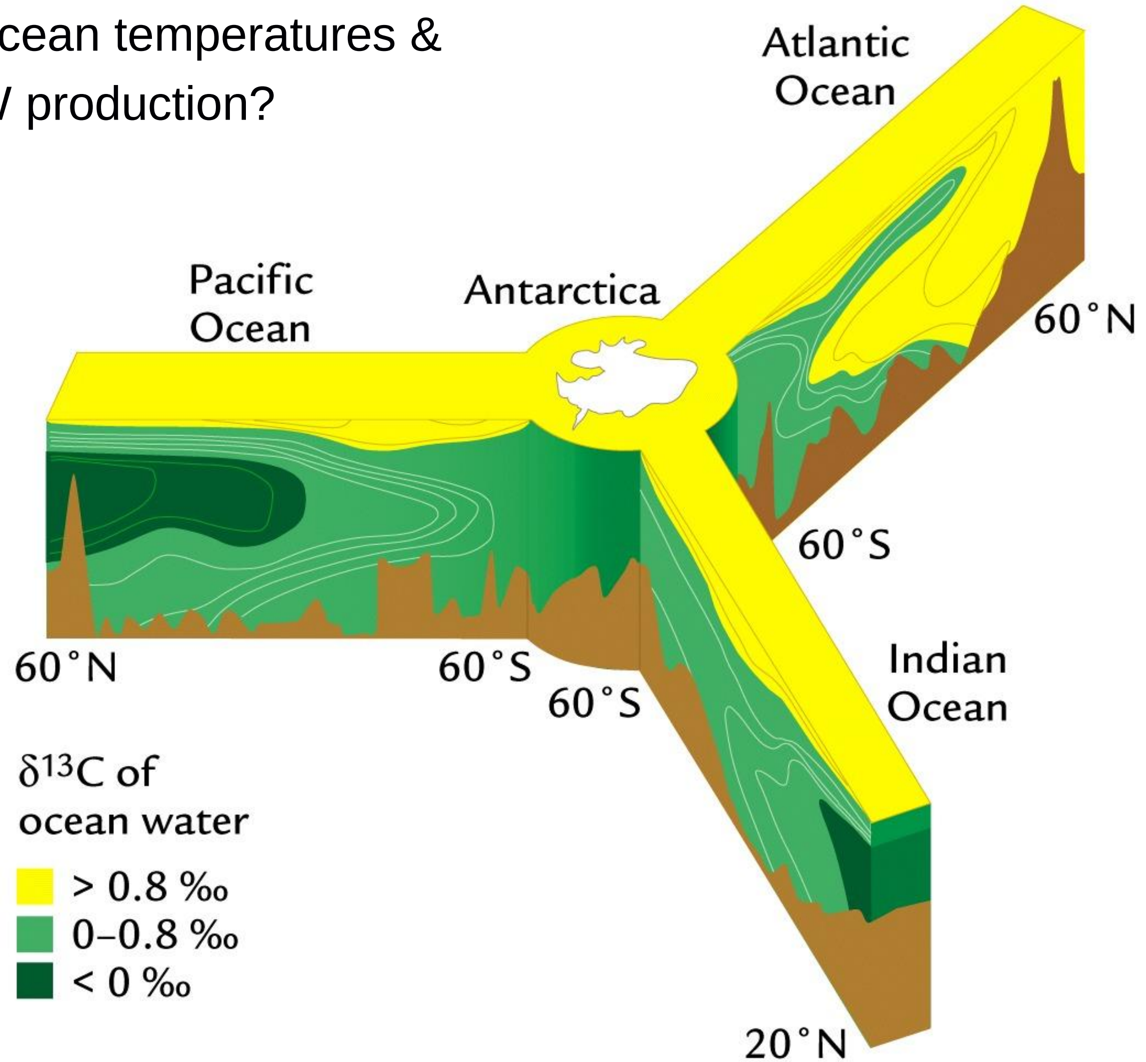
Warmer deep ocean temperatures &
Enhanced NCW production?



# Pliocene Model Intercomparison Project (PlioMIP)

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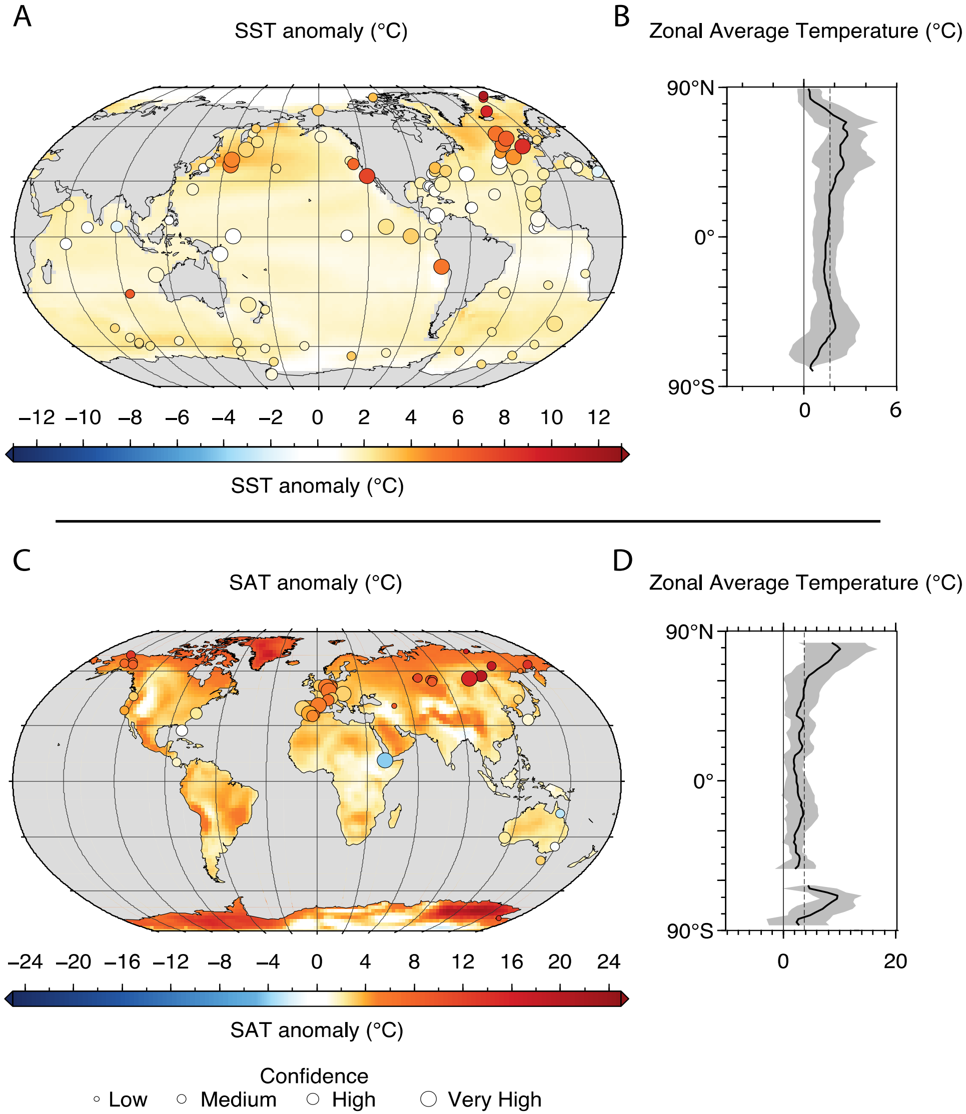


PlioMIP1 – 8 modelling groups

- > 65 published papers
- Monsoons, AMOC, energy balance, ENSO, DMC (marine/terrestrial)

Key findings of PlioMIP Phase 1 leading to the development of PlioMIP Phase 2.

*(IPCC, 2013)*

# Consistent Model Results?

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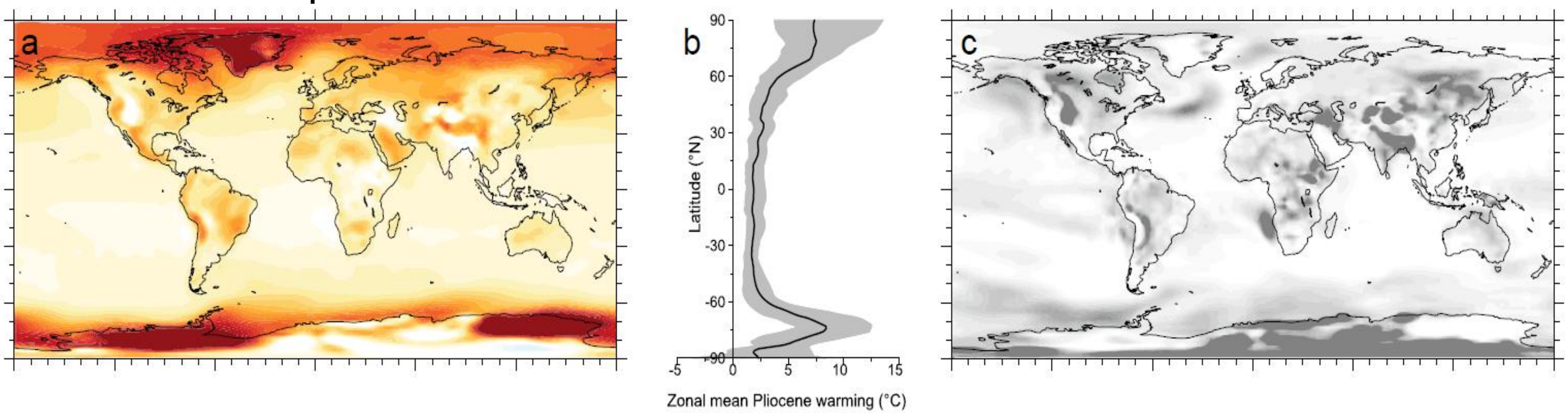
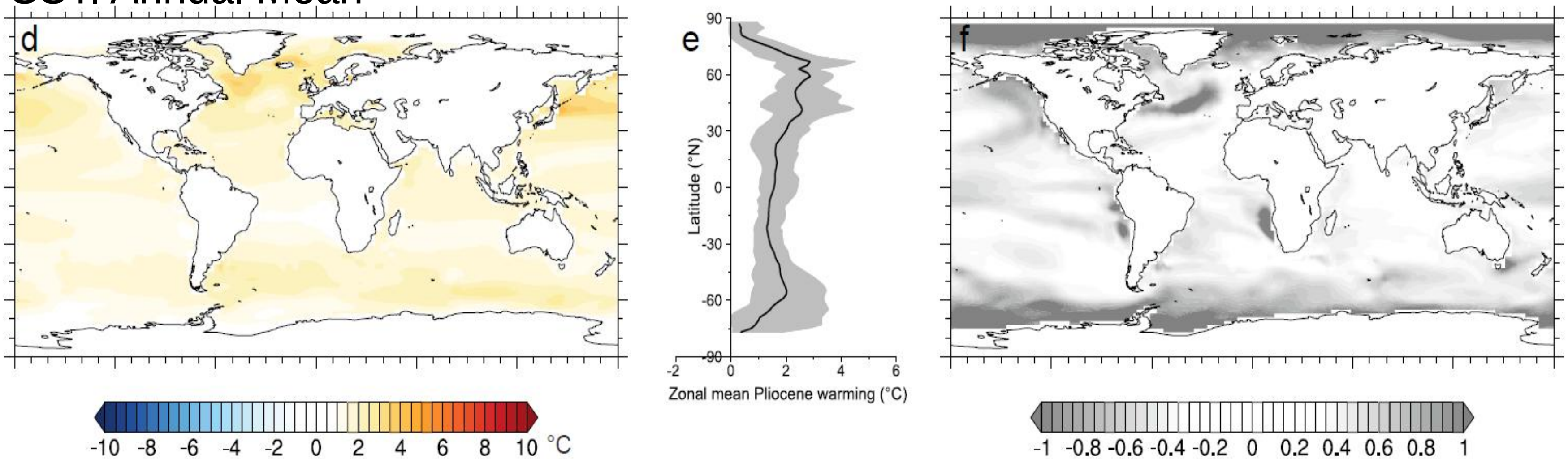
Surface Air temp. Annual Mean




SST. Annual Mean




**Haywood et al. (2013). Hill et al. (2014), both in CP**

# Energy Balance Analysis

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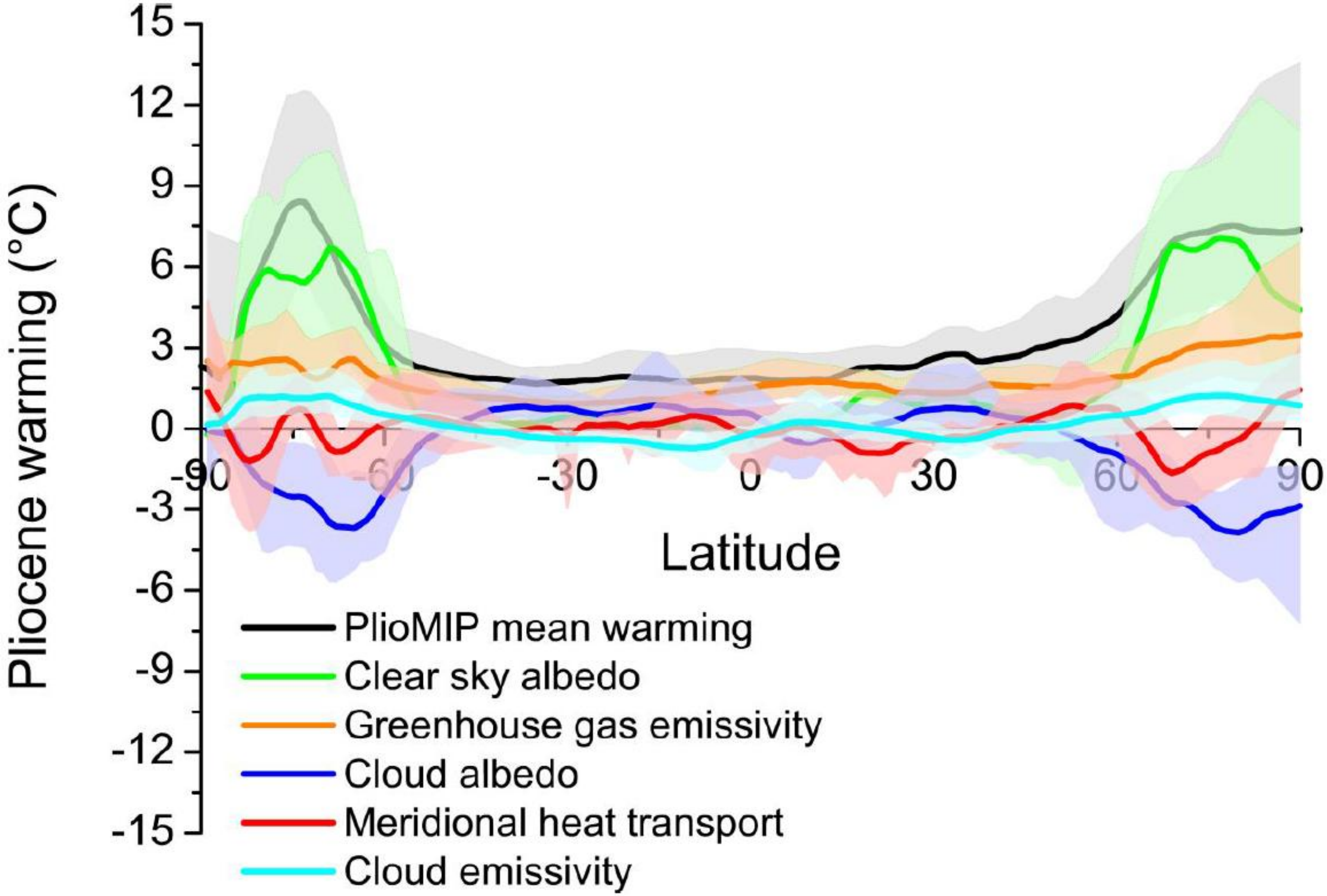


**Hill et al. (2014). CP**

# Tropical Atmospheric Circulation

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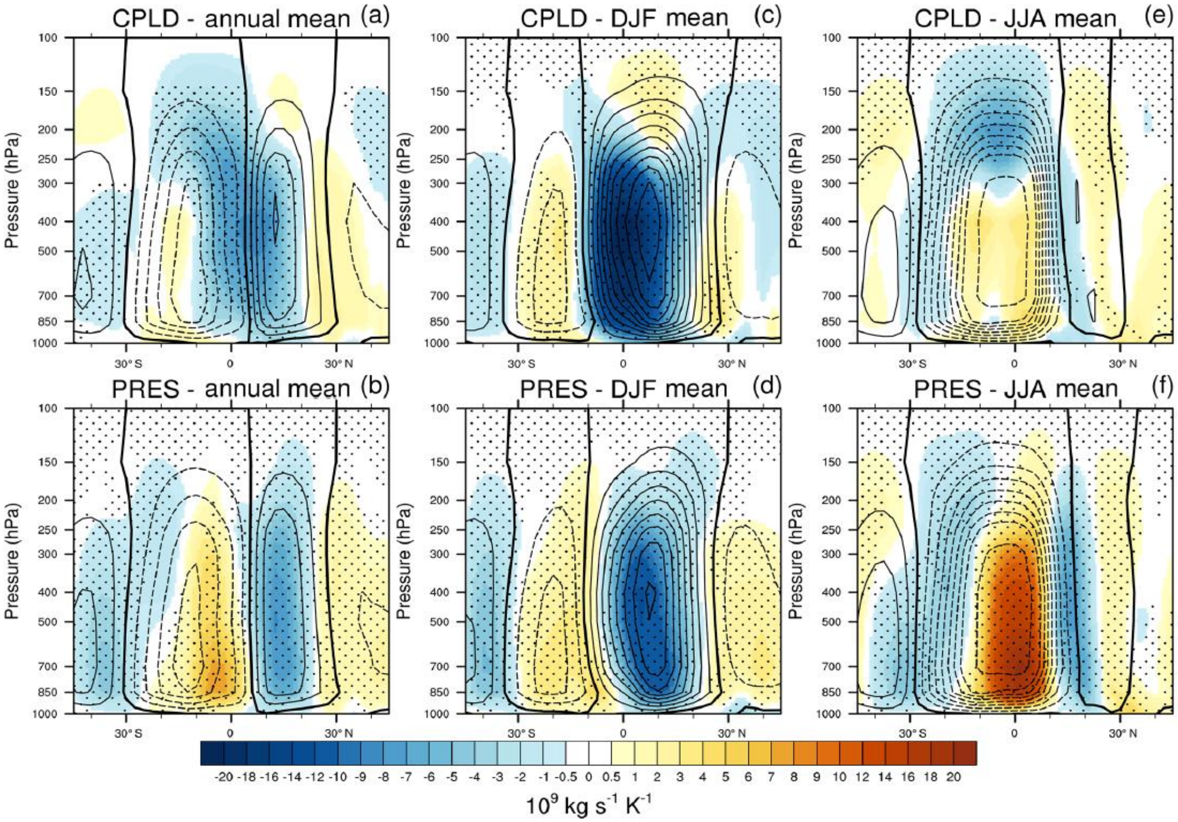


Meridional mass stream function response (shading) and pre-industrial control climatology (contours, interval $2 \times 10^{10}$ kg $s^{-1}$, with dashed lines as negative and the zero line thickened): (a, b) annual mean, (c, d) DJF mean, (e, f) JJA mean.

- Tropical circulations weaker in the Pliocene than the pre-industrial, like simulations of future climate change.
- Weakening HC consistent with future climate projection
- Weakening of WC is less robust in PlioMIP than in future projections

Corvec and Fletcher (2017) - CP

# Pliocene Versus Pre-Industrial Tropical Cyclones

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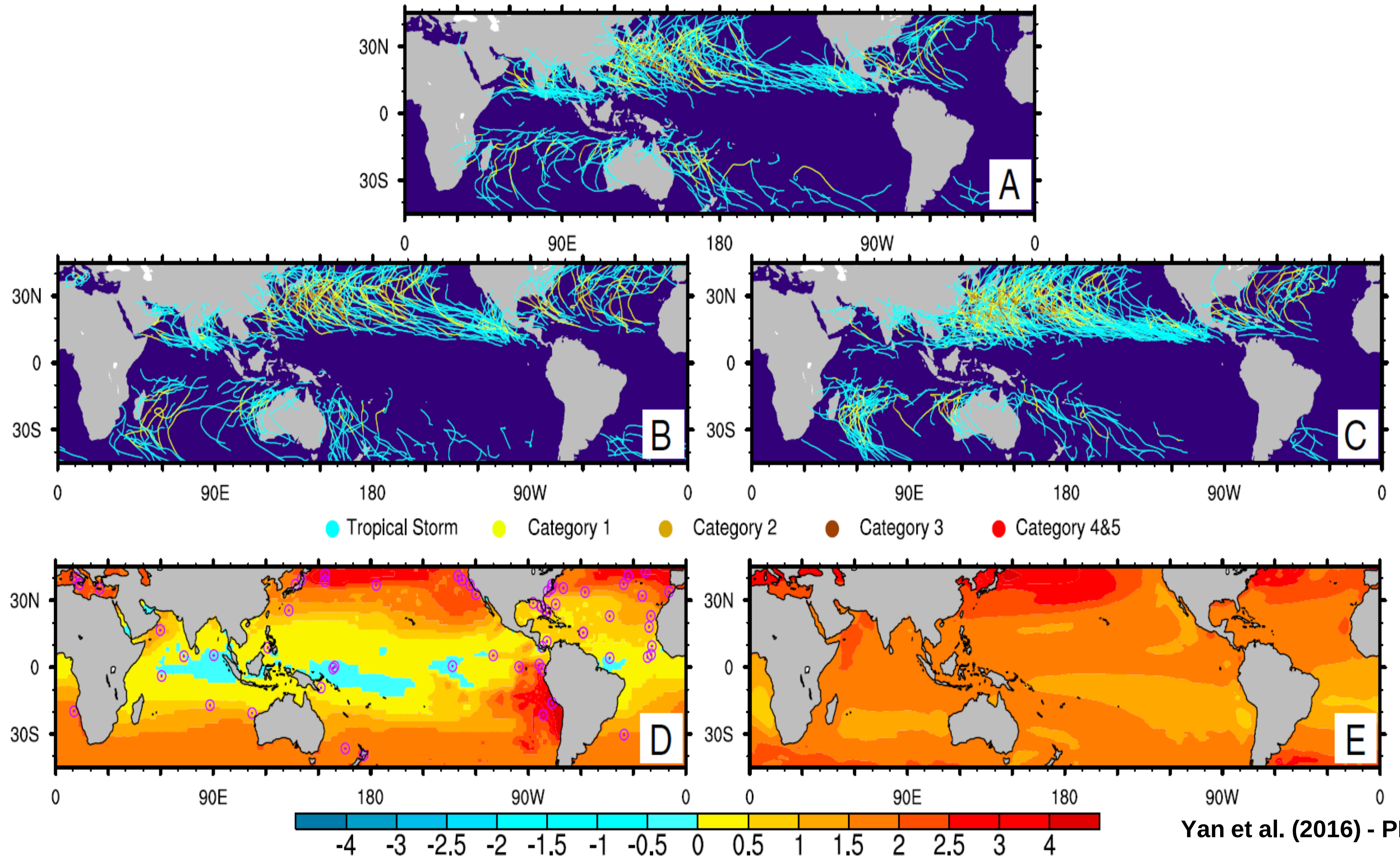


Yan et al. (2016) - PNAS

# Pliocene Versus Pre-Industrial ENSO

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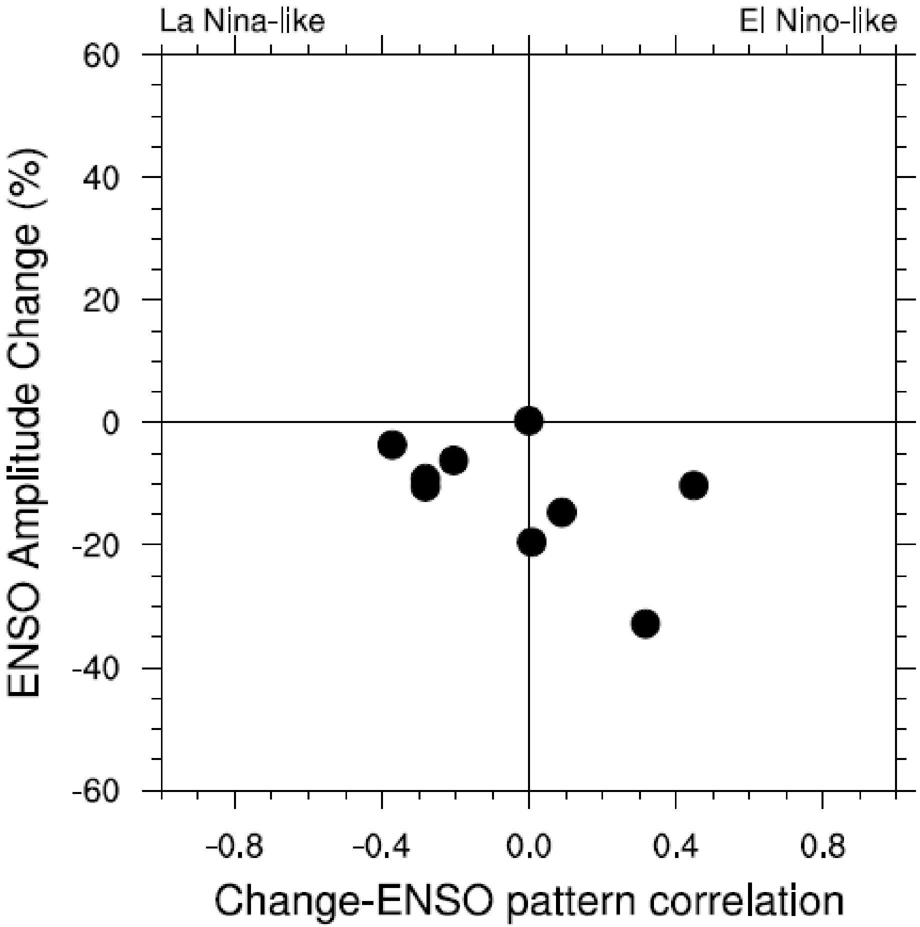
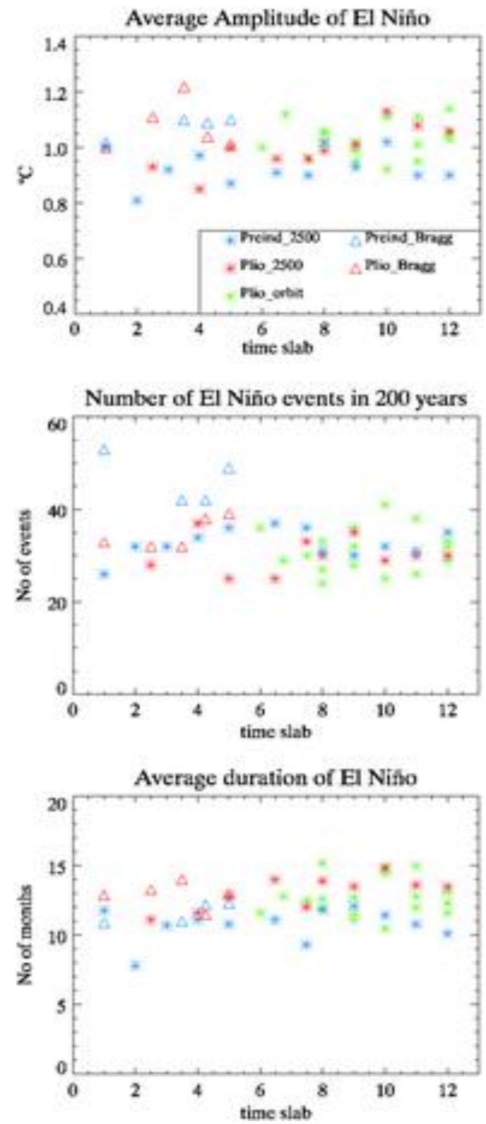



Brierley (2015) - CP




Tindall et al. (2016) – Paleoceanography & Paleoclimatology

# Pre-Industrial and Pliocene Sea-Ice Results – Annual Cycle

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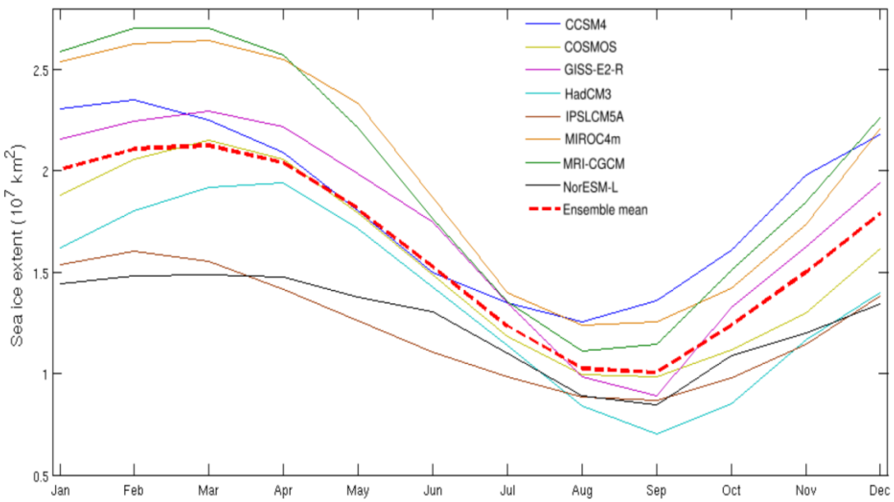


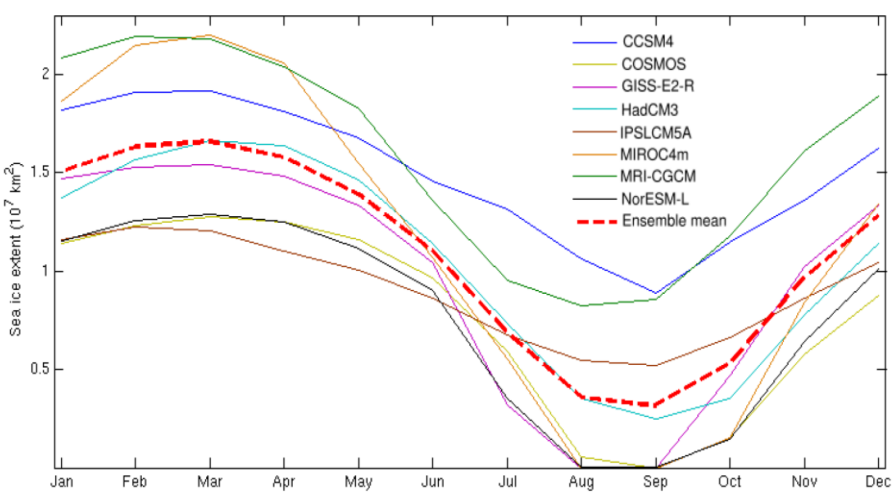


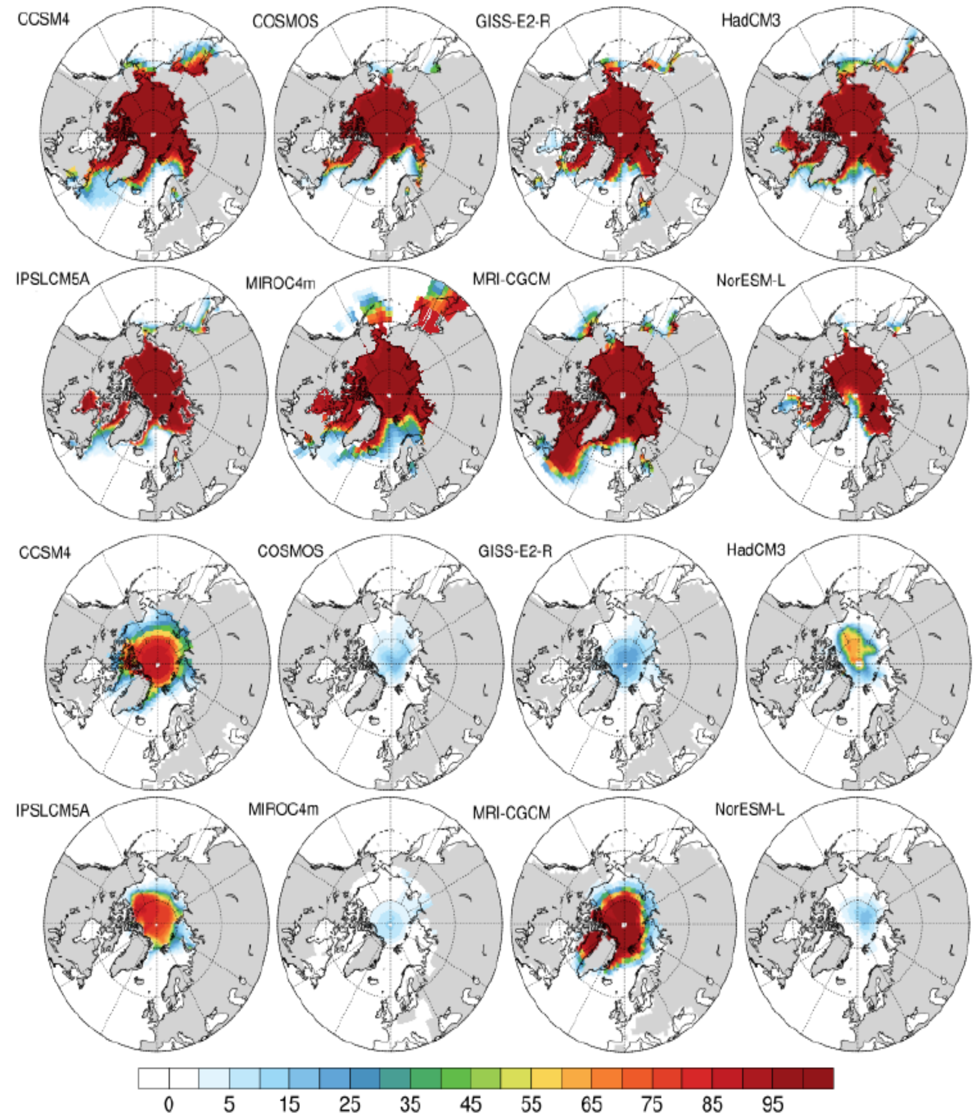

# Pre-Industrial and Pliocene Sea-Ice Relationships

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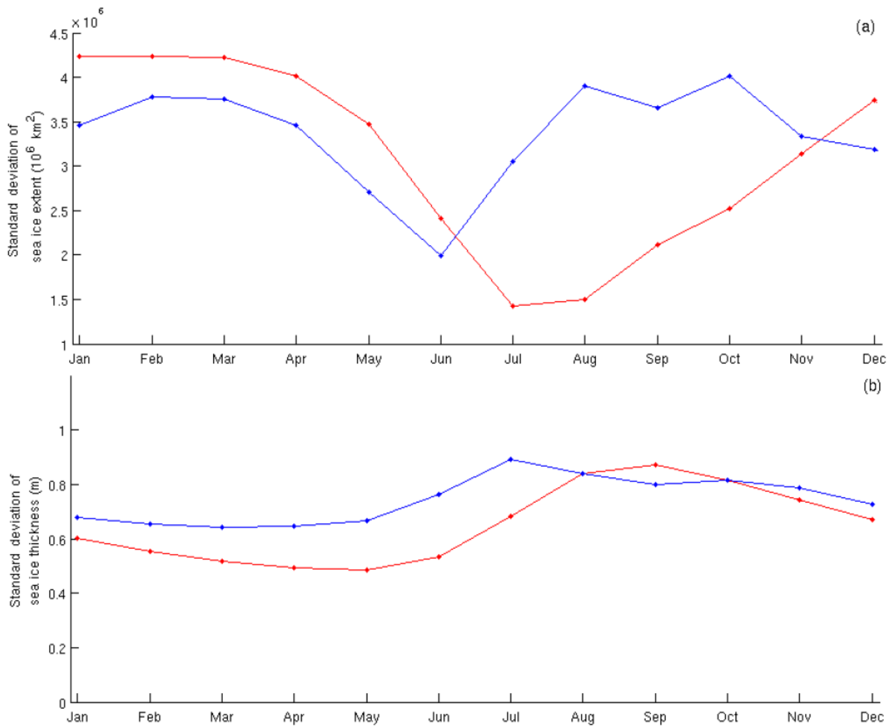


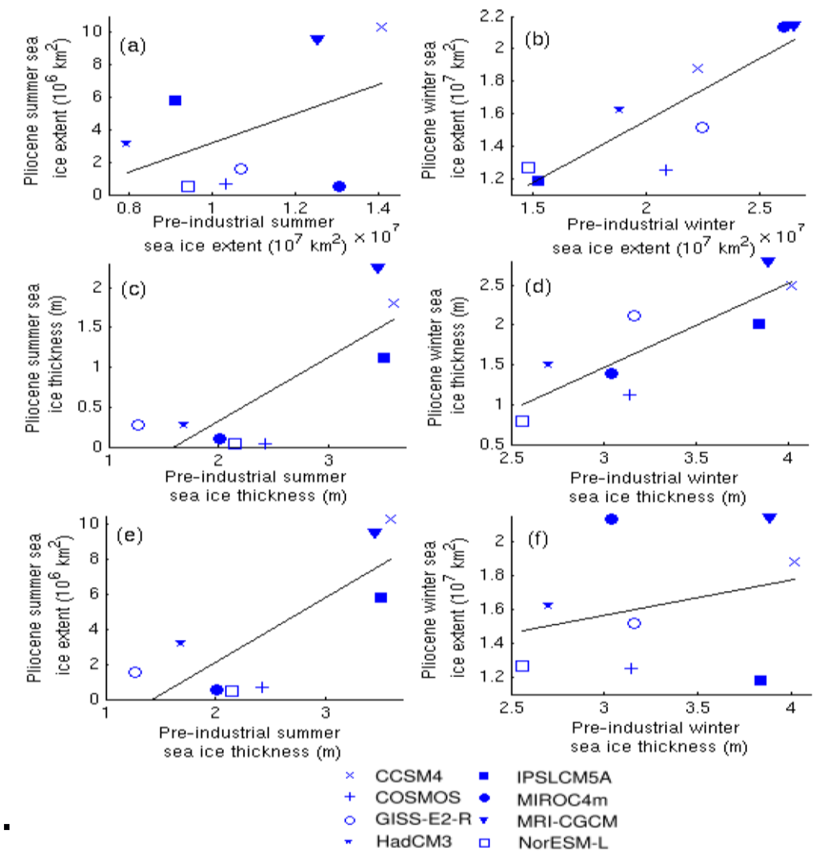


- Reduced sea-ice in the warm Pliocene.
- Spread in model predicted sea ice extent twice as great for the Pliocene.
- Correlation between predicted temperature and Pliocene Arctic sea ice twice as strong.

Howell et al. (2016) - CP

# Pliocene Versus Pre-Industrial Ocean Circulation

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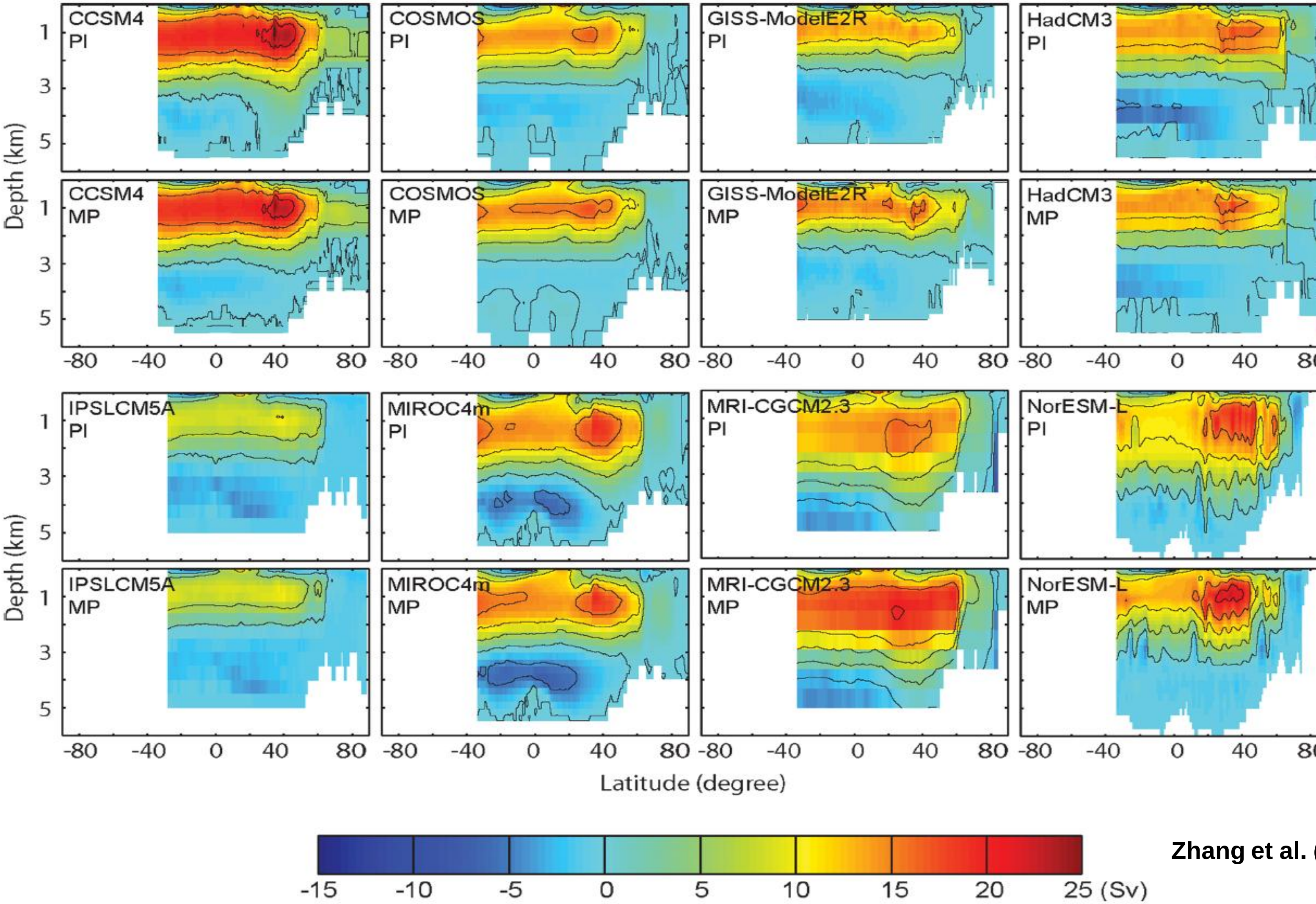


Zhang et al. (2016) - CP

# Data/model comparison - SSTs

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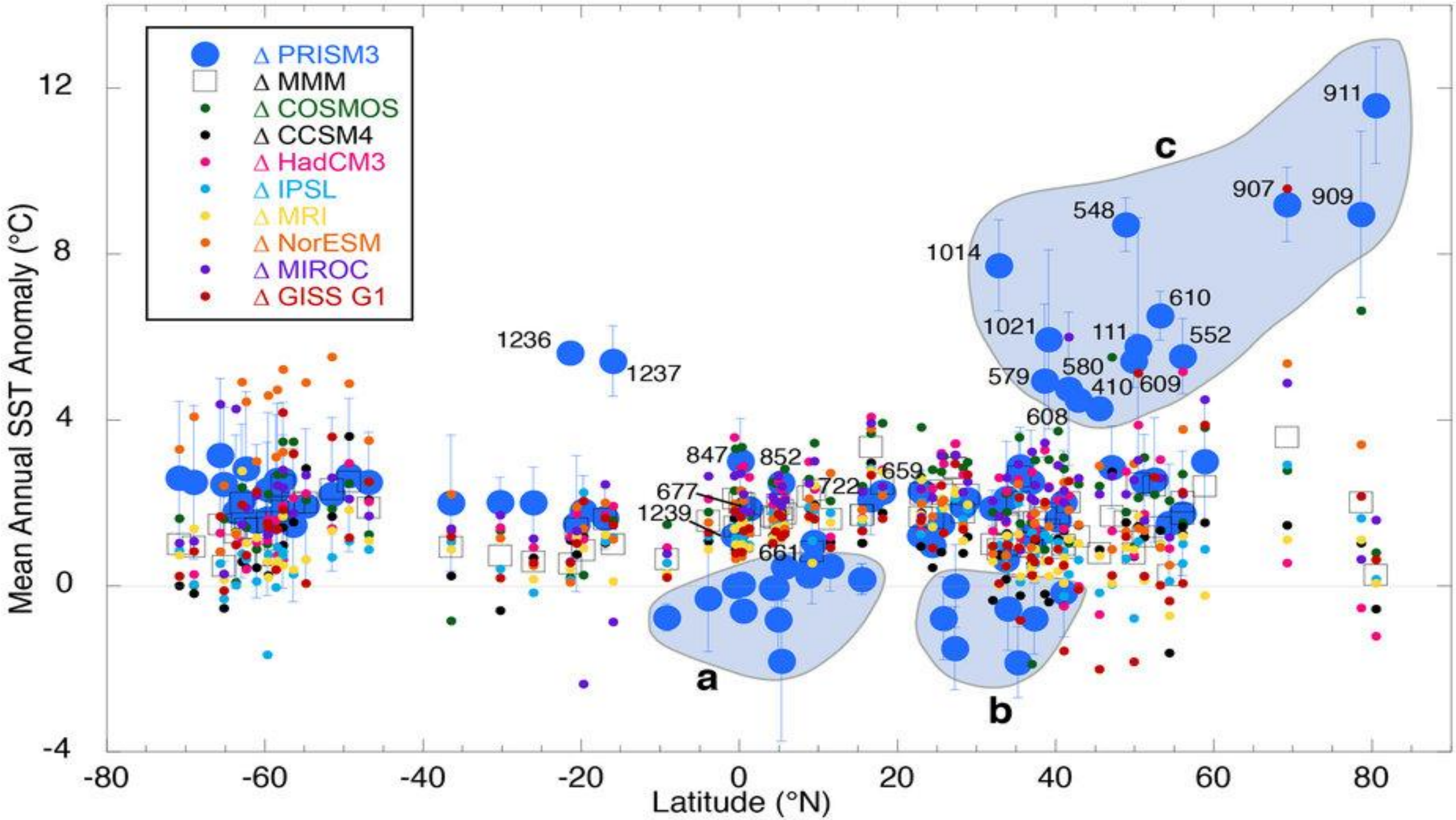


Dowsett et al. (2013). Scientific Reports.

# Data/model comparison – SATs

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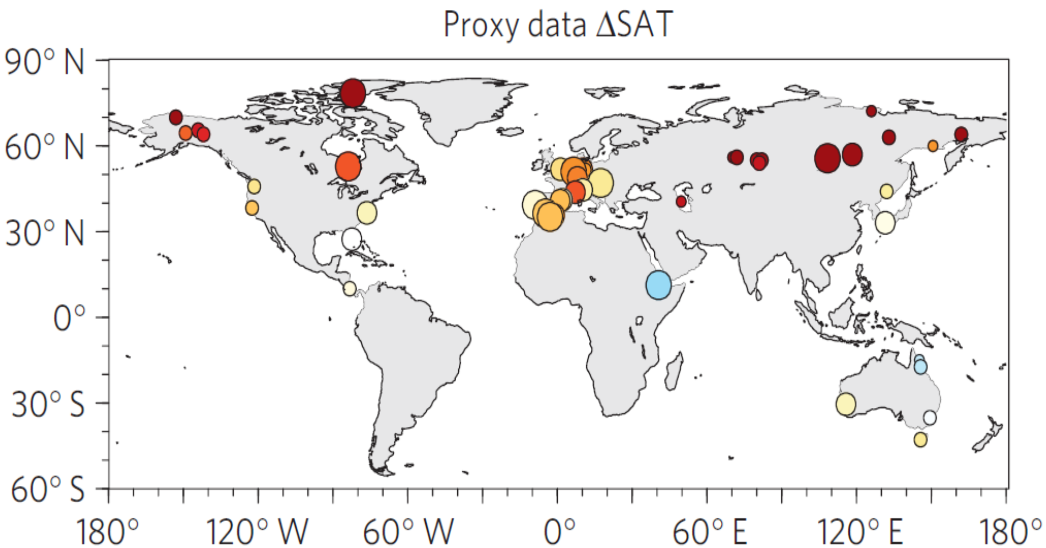
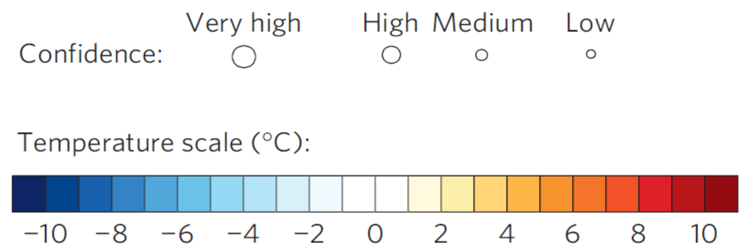
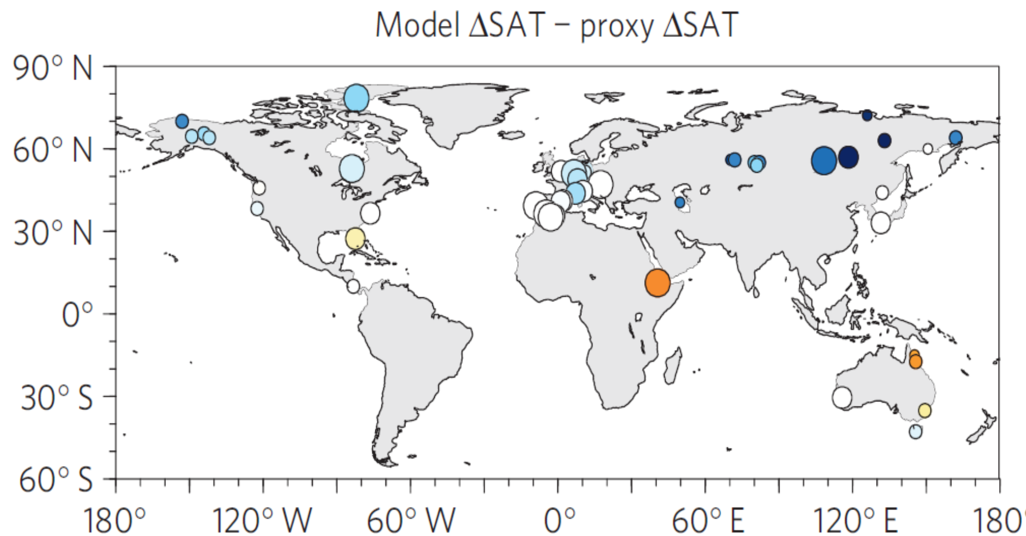



Proxy-based temperature anomaly




Degree of data-model discordance (anomaly versus anomaly)




(Nature Climate Change– Salzmann et al. 2013)

# Orbital Variability and Pliocene Climate

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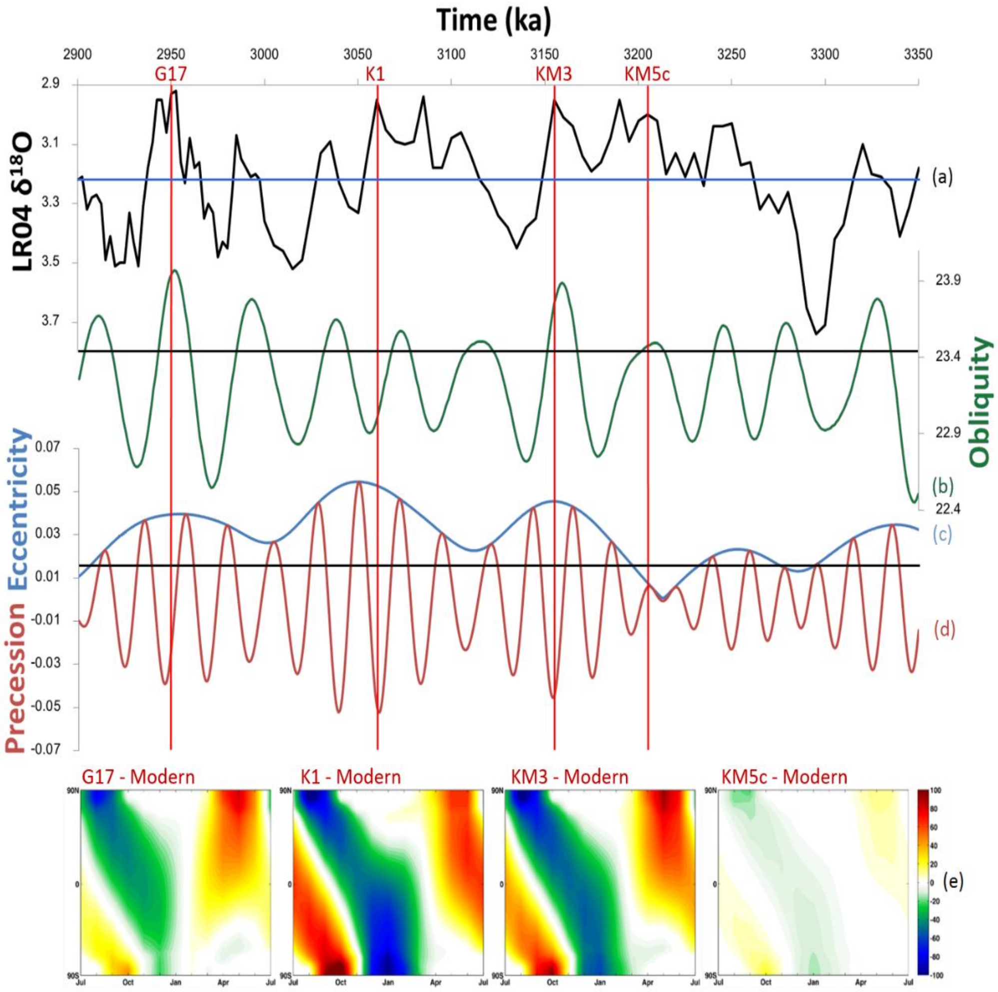


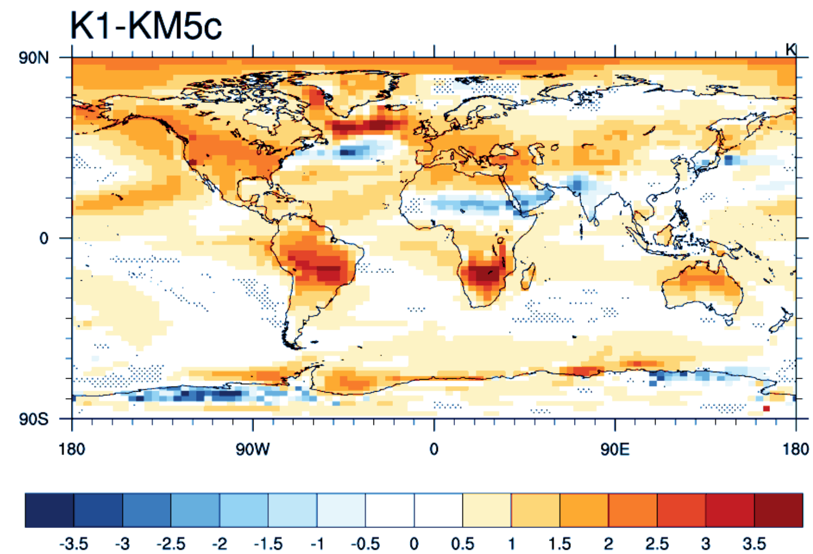


- Model results showing the differences in annual mean SAT between two interglacial events during the Pliocene (Prescott et al. 2014).

# Indian Summer Monsoon Indices

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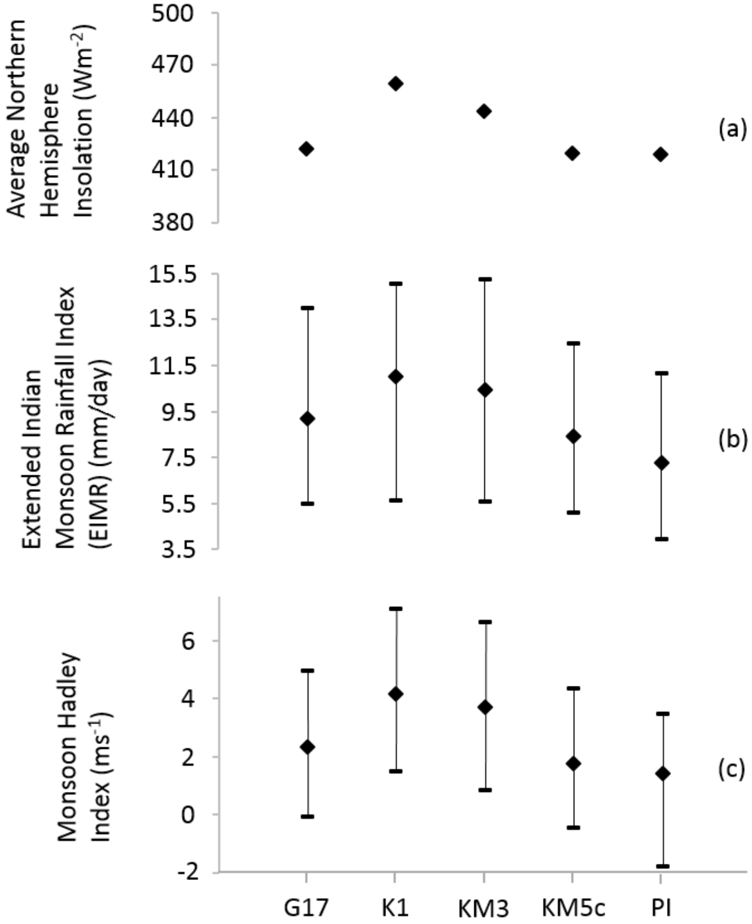



Indian Summer Monsoon Indices: (a) average northern hemisphere insolation ($Wm^{-2}$) for JJAS, (b) the Extended Indian Monsoon Rainfall (EIMR) Index (mm/day) and (c) The Monsoon Hadley Index (MHI) ($ms^{-1}$).

In (b) and (c) diamonds indicate the average monsoon index for the last 100 simulated summers. Bars show the minimum and maximum index within the last 100 simulated summers.

# A New SST Data Compilation

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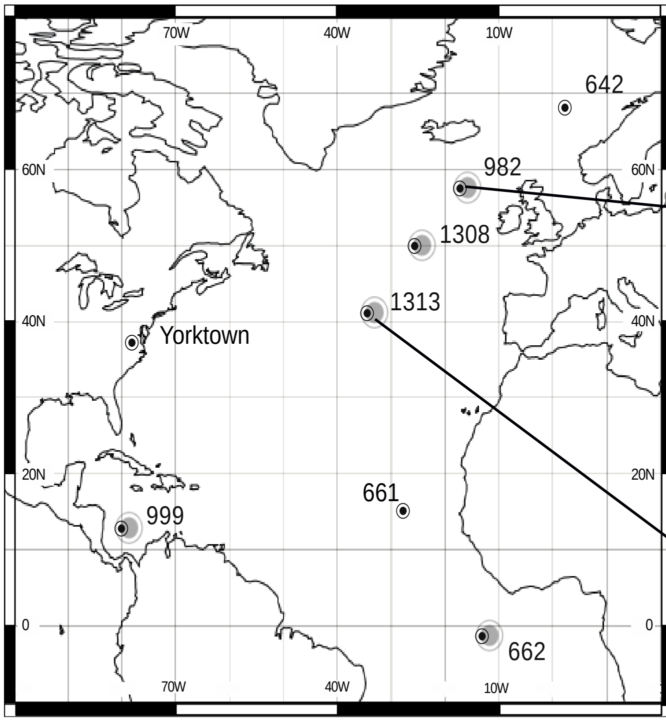
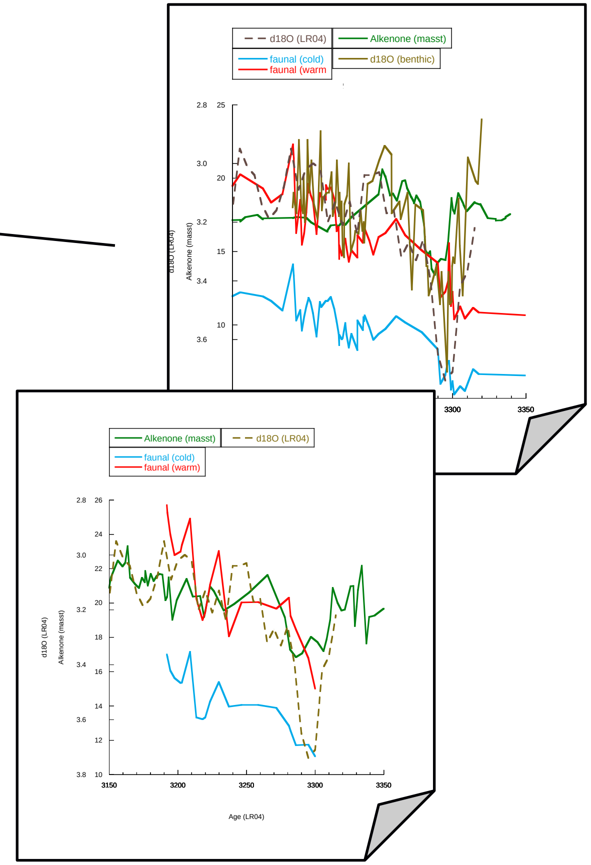



North Atlantic Time Series




Generating high-resolution time series to reconstruct palaeoenvironment at selected sites for data-model comparison.

# High resolution terrestrial records

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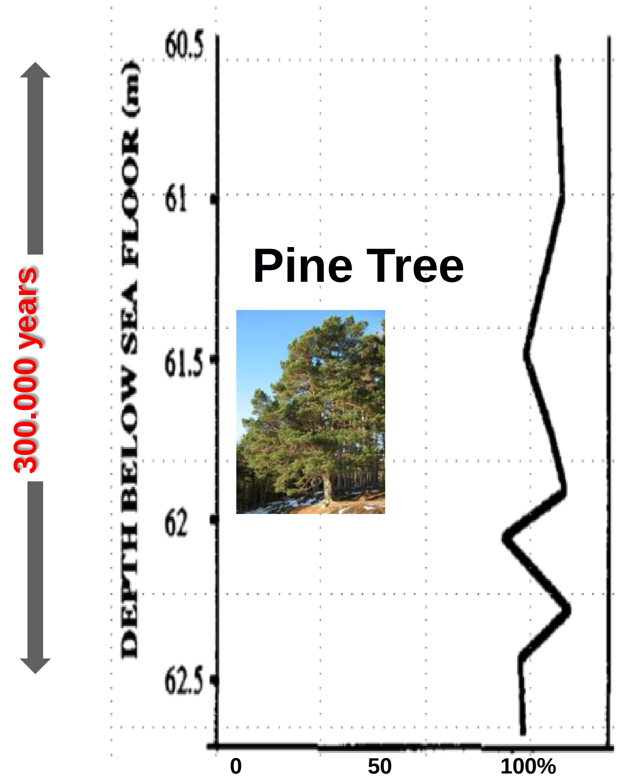
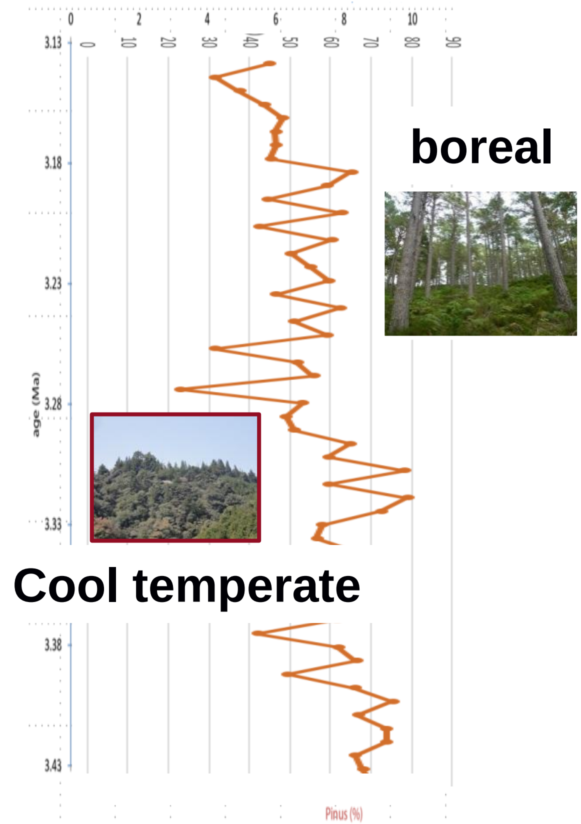
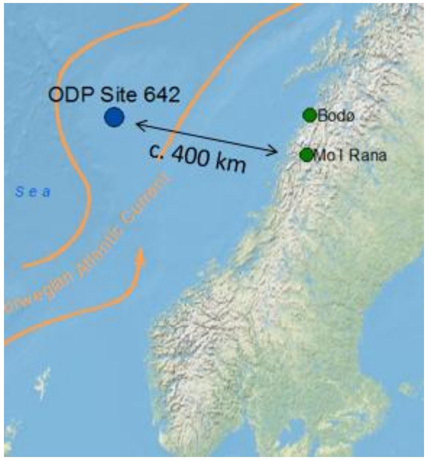



**Willard (1994)**

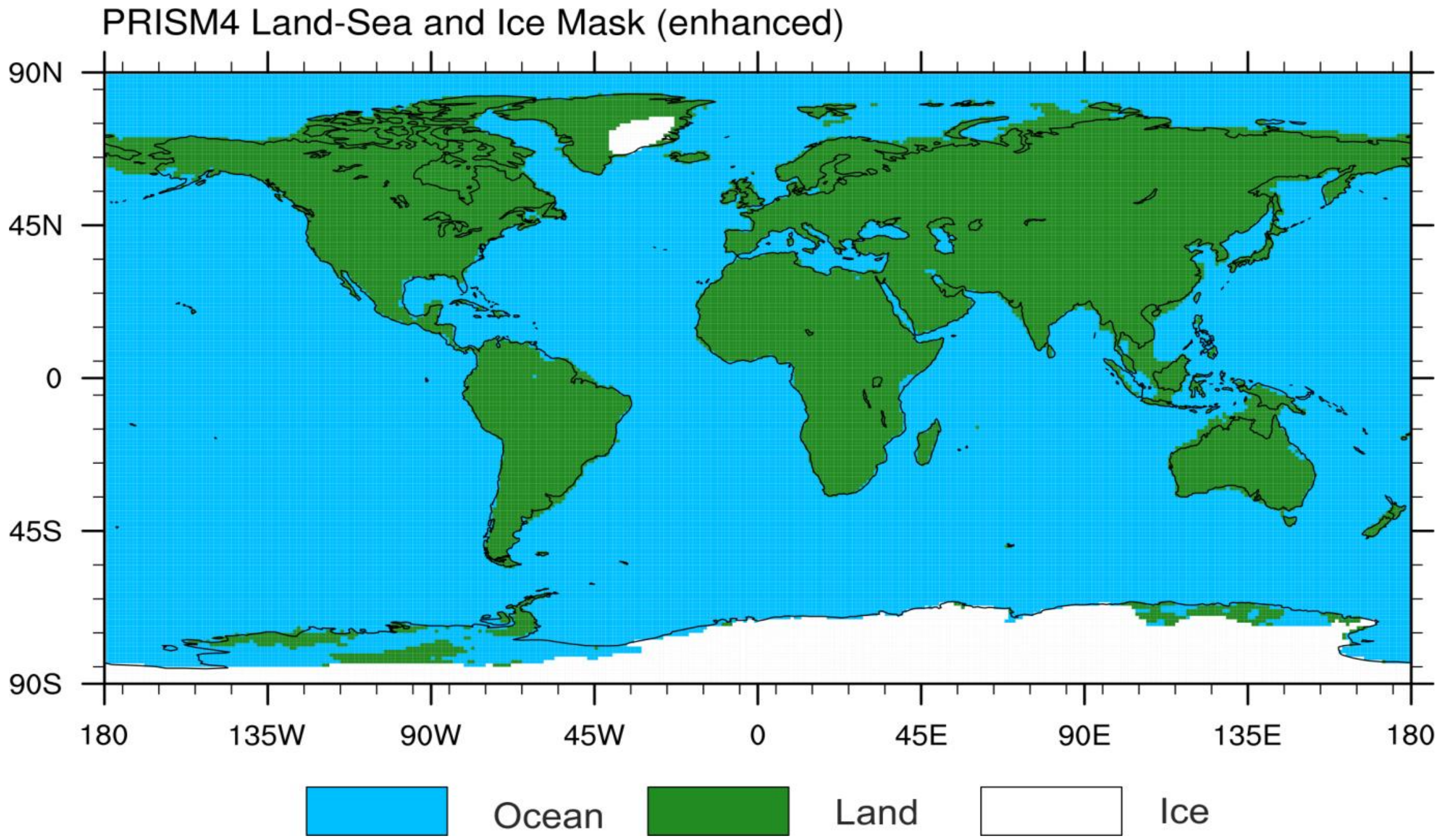



**IODP Site 642**
**Norwegian**
**Sea**

**(Panitz et al., 2016 Clim. Past)**

# PRISM4 Land Sea/Ice Mask




- Futher developments – soils and lakes (Pound et al. 2014).

# Ice Sheets - Greenland

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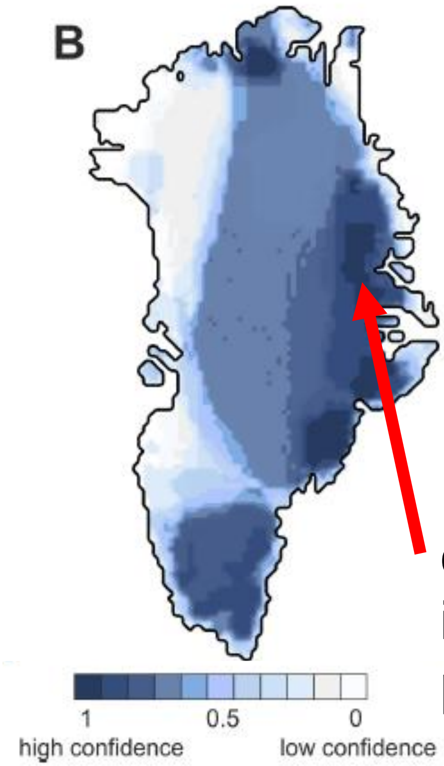
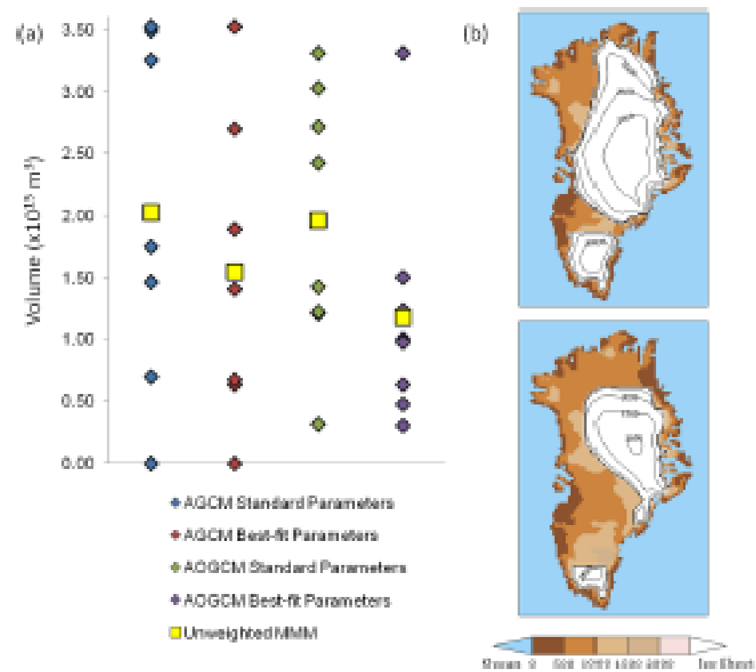



**Pliocene Ice Sheet Modelling Intercomparison Project**

(PLISMIP; Dolan et al., 2012)

High confidence in ice sheet presence




Tested climate and ice sheet model dependency of simulations of the Greenland and Antarctic Ice Sheets

*(Koenig et al., 2015; Dolan et al., 2015)*

# Climate Forcing Uncertainty - Antarctica

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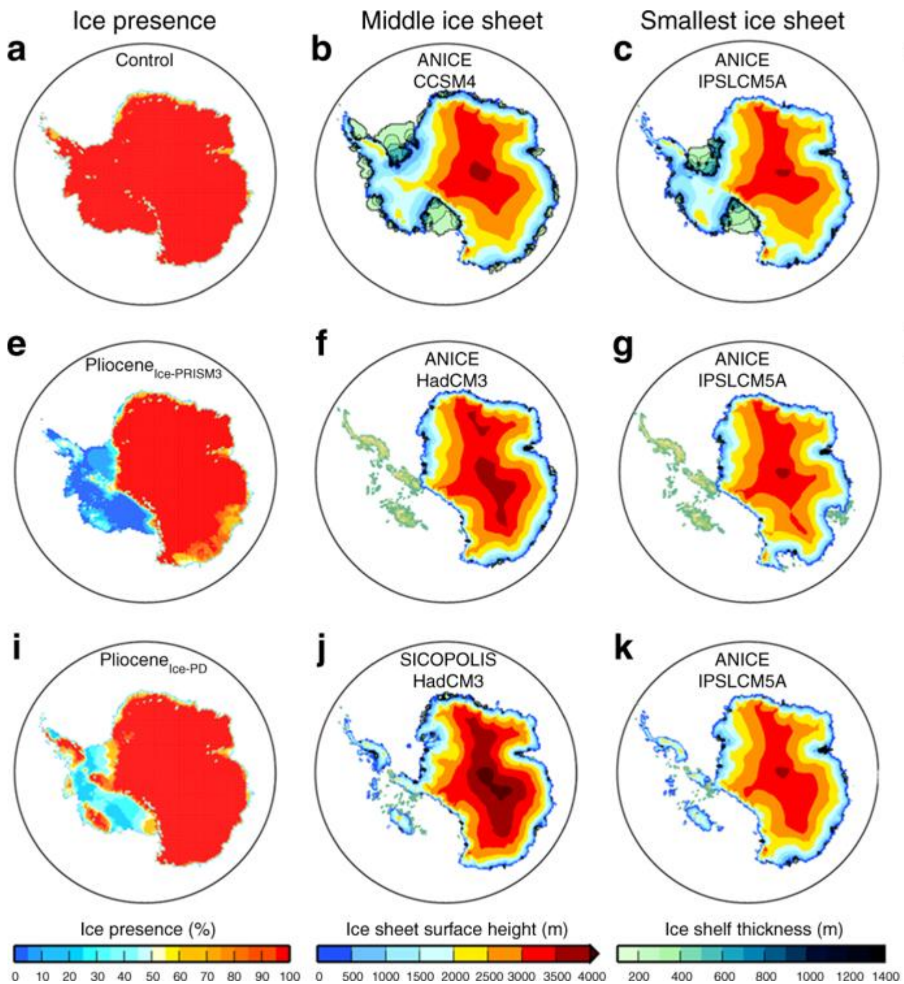


Summary of ice-sheet predictions. a, e, i Ice-sheet presence prediction for each of the climate scenarios (as a percentage of the total ensemble members). Also shown is the middle (b, f, j), smallest (c, g, k) and largest (d, h, l) ice-sheet configuration (surface height (m) and ice-shelf thickness (m)). Middle is the 5th ranking ice volume from the list of 10 SIA-SSA model results.

*(Dolan et al., 2018)*

# The Importance of Palaeogeography

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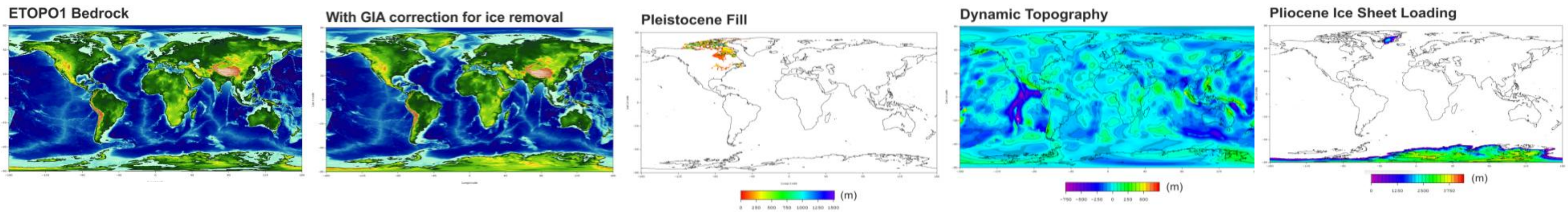
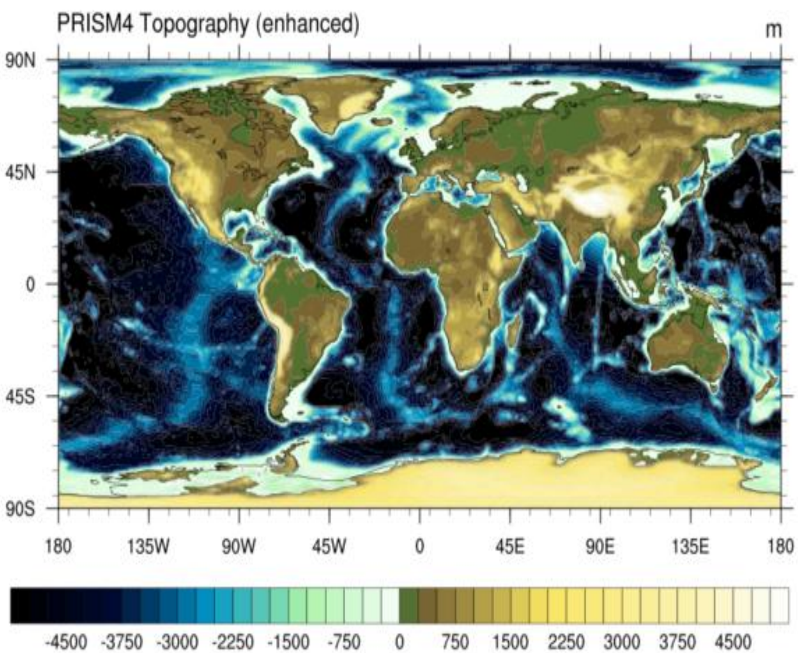
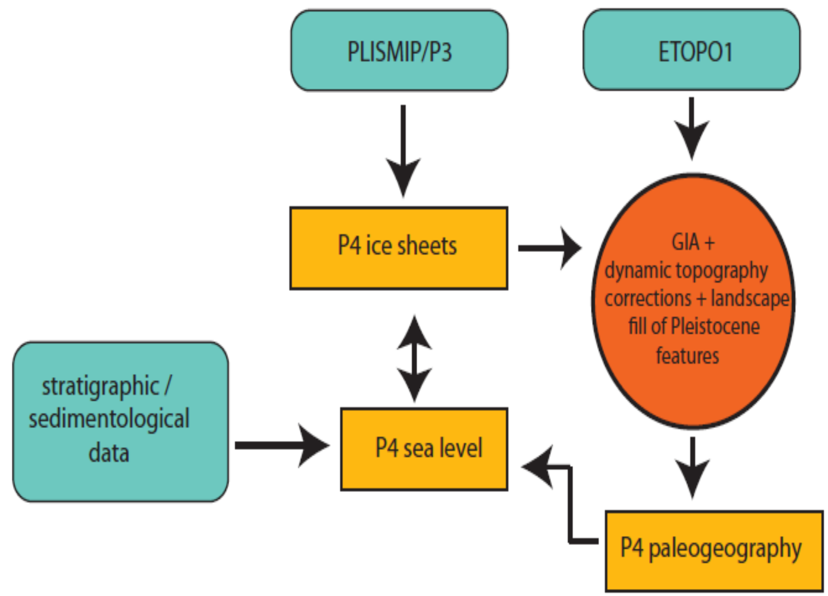


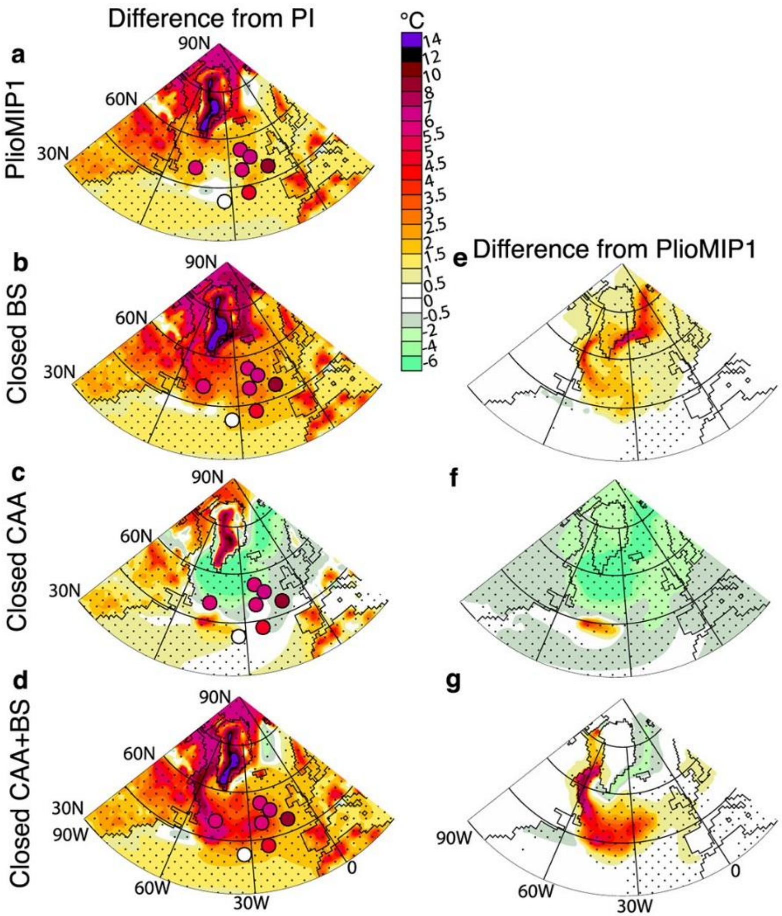



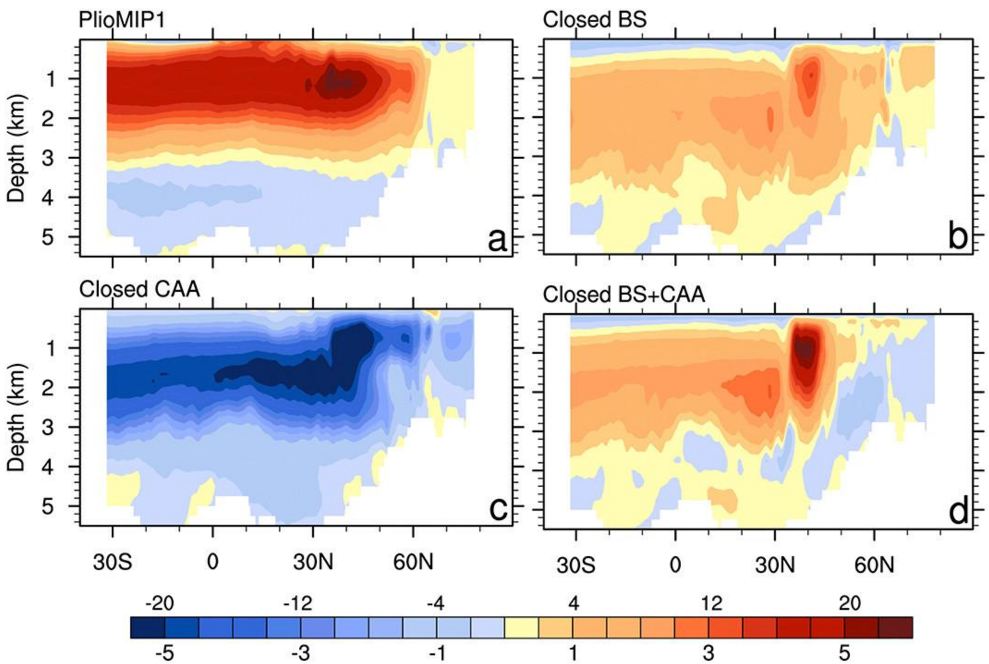




- Closed Canadian Archipelago, Bering Straight, Central American Seaway

*(Dowsett et al. 2016)*

# Effect of boundary condition change




*(Bette Otto-Bliesner et al., 2017)*

# Summary

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- Intervals within the Pliocene epoch were warmer and wetter than the pre-industrial era, although the character of climate change was time specific and related to the pacemaker of orbital forcing.
- Global annual mean temperature was ~1.8 to 3.6°C warmer, and global annual mean precipitation rates enhanced by up to 6%.
- A clear pattern of polar amplification is reconstructed as well as simulated.
- The Arctic Ocean may have been ice free in the summer, and forests reached the Arctic coastline.
- The Greenland and Antarctic Ice Sheets lost mass, and therefore sea-level increased, but the exact nature of ice sheet and sea-level change is very challenging to reconstruct as well as simulate.
- Statistical studies confirm the utility of the Pliocene as a geo-historical analogue for the near future.

*“After studying the Pliocene for 21 years, and all things being equal in the decades ahead, I will experience first hand a climate state that has not existed for more than 3 million years.”.*