The Pliocene: an accessible example of a world in equilibrium with 400 ppmv CO$_2$?

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Why Past (Palaeo) Climate?
Model Predictions and Climate Sensitivity

Prediction, mitigation, adaptation

Knutti and Sedláček (2013)
Palaeo Constraints on Climate and Longer Term Sensitivity

**Climate Sensitivity**

**Earth System Sensitivity**
Global Temperatures & Impacts

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

- We have abundant geological data for the Pliocene
- Pliocene CO₂ 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

(Federov et al, 2013: Nature)
Time-series of the Closest Geohistorical Climatic Analogues (2020–2280)


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Geological Boundary Conditions

- Topography
- Vegetation, land cover
- Sea surface temperature
- Land ice
- Deep ocean temperature, circulation

CO$_2$ = ~400 ppmv
Reduced equator to pole surface temperature gradient

Enhanced poleward ocean heat transport/CO₂ increase

Less land ice = higher sea level

Less sea ice in the high latitudes

Altered ENSO variability?

Warmer upwelling zones

Geological view of Pliocene environments – ice and ocean surface
Geological view of Pliocene environments - vegetation

PRISM3 Biome Vegetation

- Tundra BIOME nearly absent
- Poleward shift in most BIOMES
- Reduced deserts
Geological view of Pliocene environments – ocean circulation

Warmer deep ocean temperatures & Enhanced NCW production?
Key findings of PlioMIP Phase 1 leading to the development of PlioMIP Phase 2.

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

(IPCC, 2013)
Consistent Model Results?

Haywood et al. (2013). Hill et al. (2014), both in CP.
Energy Balance Analysis

Hill et al. (2014). CP
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

Meridional mass stream function response (shading) and pre-industrial control climatology (contours, interval 2x10^{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.
Pliocene Versus Pre-Industrial Tropical Cyclones

Yan et al. (2016) - PNAS
Pliocene Versus Pre-Industrial ENSO

Brierley (2015) - CP

Tindall et al. (2016) – Paleoceanography & Paleoclimatology
Pre-Industrial and Pliocene Sea-Ice Results – Annual Cycle
- 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.
Pliocene Versus Pre-Industrial Ocean Circulation

Zhang et al. (2016) - CP
Data/model comparison - SSTs

Dowsett et al. (2013). Scientific Reports.
Data/model comparison – SATs

Proxy-based temperature anomaly

Degree of data-model discordance (anomaly versus anomaly)

(Nature Climate Change – Salzmann et al. 2013)
• Model results showing the differences in annual mean SAT between two interglacial events during the Pliocene (Prescott et al. 2014).
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

IODP Site 642
Norwegian Sea

Pine Tree

Cool temperate

boreal

Willard (1994)

(Panitz et al., 2016 Clim. Past)
• Further developments – soils and lakes (Pound et al. 2014).
Ice Sheets - Greenland

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

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

- Closed Canadian Archipelago, Bering Straight, Central American Seaway

*(Dowsett et al. 2016)*
Effect of boundary condition change

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

• 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.”