The Influence of Orbital Forcing on Past Climate Change

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Introduction

Changes in **eccentricity**, **obliquity**, and **longitude of the perihelion** (Fig. 1) alter the seasonal and latitudinal distribution of Earth's incoming solar radiation. Amplified by internal climate feedbacks, these cycles have resulted in large variations in past climate, but many specifics of these interactions are still not fully understood.

We use the GFDL CM2.1, a fully-coupled Atmosphere Ocean GCM, to conduct idealized simulations where orbital forcing is altered while all non-orbital forcings are held at preindustrial levels. This allows us to isolate the climate responses to obliquity and precession without the competing effects from changes in greenhouse gases and ice sheet extent.

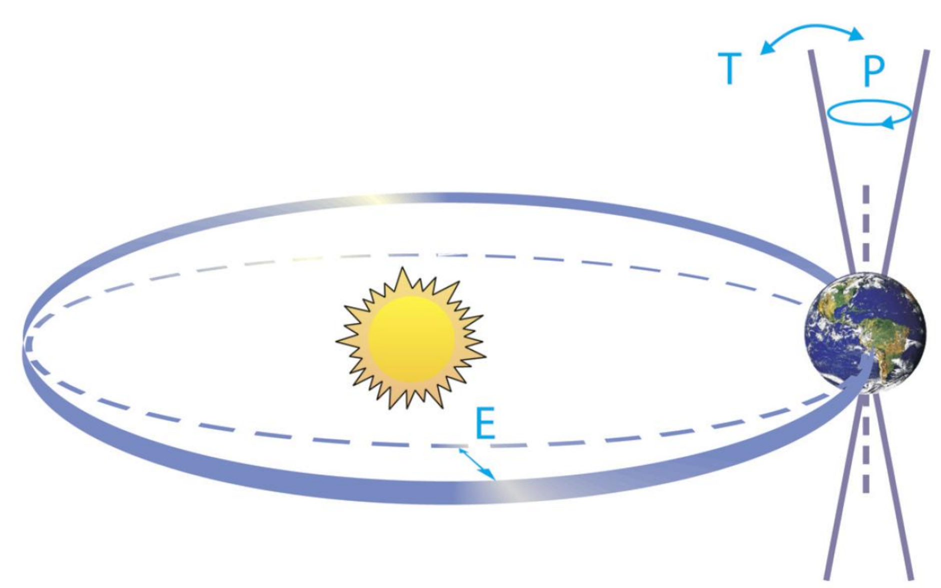

Fig. 1. Schematic of orbital cycles. From IPCC AR4.

Simulations:

Lo and **Hi**: Obliquity is set to its low (~22.1°) and high (~24.5°) extremes of the last 600kyr.

AE, **WS**, **VE**, and **SS**: Perihelion is set to the NH autumnal equinox, winter solstice, vernal equinox, and summer solstice. Eccentricity is raised to ~0.05 to amplify the signal.

We analyze the climate response and role of feedbacks under orbital forcing. What do we learn?

1. Global-mean climate change can result from a simple redistribution of insolation.

- Global-mean insolation change is zero in obliquity and precession experiments, but results in non-zero global-mean ΔT (Fig. 2).
- Radiative forcing is very small:
  - 0.10 Wm^{-2} for Lo-Hi.
  - -0.11 Wm^{-2} for WS-SS.
- Feedbacks must play a role.

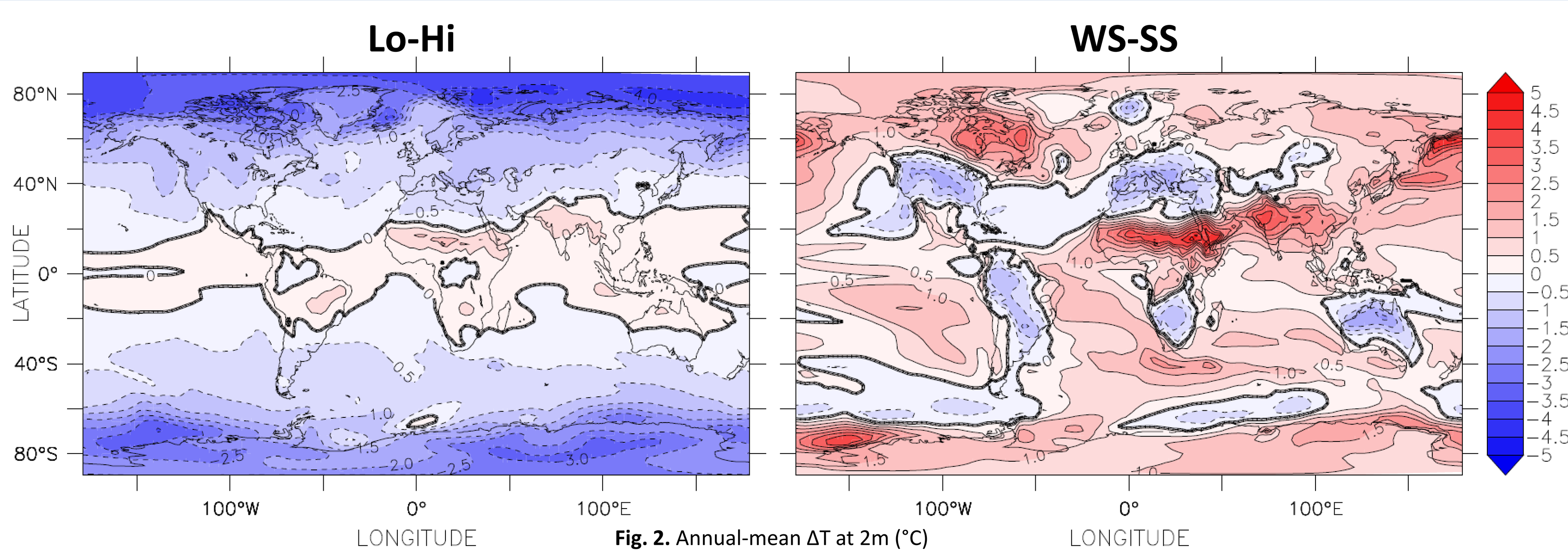

Fig. 2. Annual-mean ΔT at 2m (°C)

Mean ΔT: **-0.5°C**

Mean ΔT: **+0.6°C**

2. Feedbacks are important to the climate response, but the relative importance of each feedback depends on the temporal and spatial distribution of the forcing.

	Lo-Hi	*WS-SS*	*Doubled CO_2*
Surface Albedo	-0.27	0.31	0.61
Water Vapor	-0.20	0.19	4.02
Lapse Rate	-0.90	0.47	-0.70
Cloud	-0.67	0.74	1.06
Total	**-2.03**	**1.72**	**4.99**

Table 1. Global-mean effect of each feedback on net downward TOA radiation, ΔR_{net} (Wm^{-2}). Doubled CO_2 experiment shown for comparison. Values calculated using the kernel method of Soden et al. (2008).

- The relative importance of each feedback depends on the forcing (Table 1). Additionally, ΔT does not have to be the same sign as the radiative forcing, either locally or globally, if the effects of feedbacks are sufficient to overwhelm the direct radiative forcing.

3. Many aspects of feedbacks are a simple response to local ΔT, but some are not.

- Circulation changes: Lo-Hi has strengthened Hadley Circulation due to enhanced equator-to-pole temperature gradient. This affects water vapor, lapse rate, and cloud feedbacks.
- Monsoons: WS-SS has weakened NH monsoons and strengthened SH monsoons, related to changes in seasonality.

4. Cloud feedbacks may make glacial inception more difficult by damping NH high-latitude summer cooling.

- Orbital theory: low obliquity (Lo-Hi) and NH winter solstice perihelion (WS-SS) encourage glaciation by reducing NH summer insolation.
- Consistent with this, high-latitude summer ΔT at 2m is mostly negative in both experiments (Fig. 3).
- However, cloud feedbacks damp or reverse the cooling in some regions (Fig. 3, contours) making glaciation more difficult.
- The CM2.1 lacks dynamic ice sheets. Would the sign of cloud feedback change as ice sheets grow?

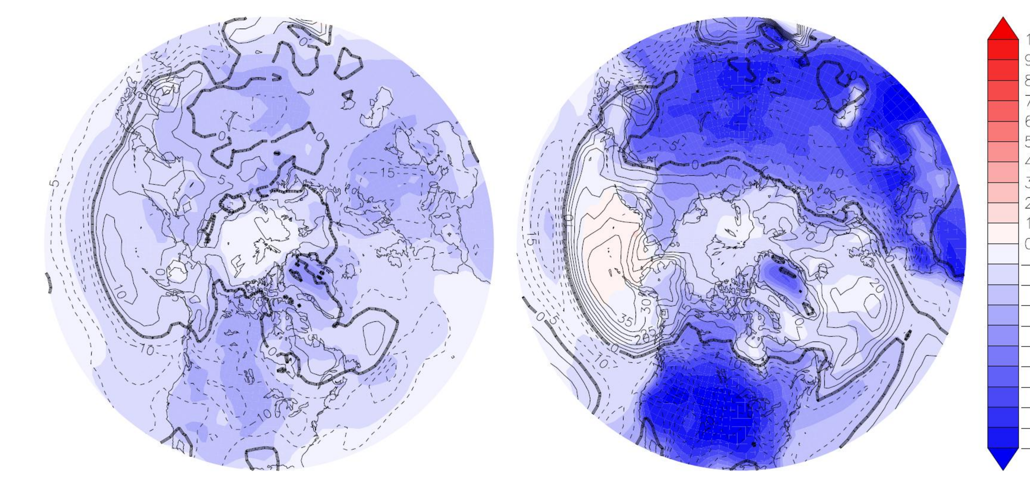

Fig. 3. Mean JJA ΔT at 2m (°C, shaded) and ΔR_{net} from mean JJA cloud feedback (Wm^{-2}, contours).

5. Precession strongly affects the equatorial Pacific seasonal cycle.

- Each precession simulation (AE, WS, VE, and SS) shows large changes in eastern equatorial Pacific seasonality, while obliquity simulations show little change.
- In the AE-preind experiment, eastern equatorial Pacific seasonality is significantly reduced (Fig. 4).
- This is the result of thermodynamic and dynamic processes.

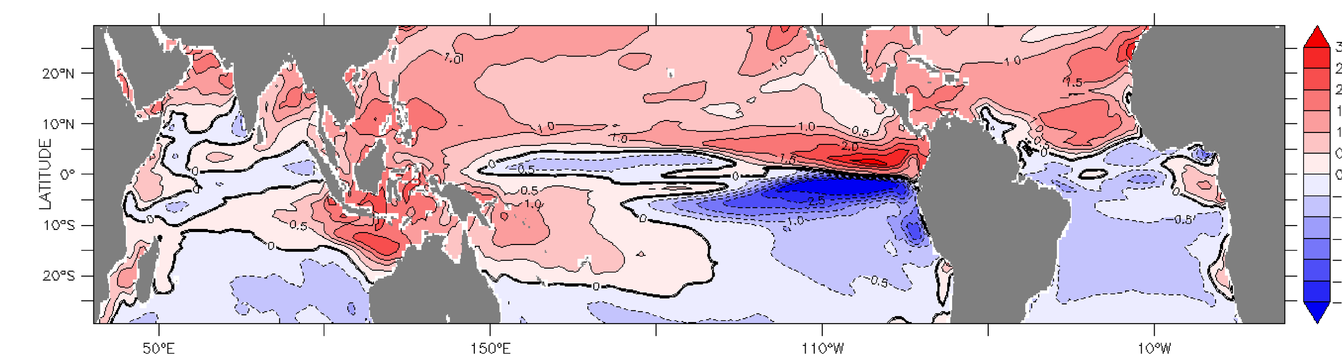

Fig. 4. Change in annual temperature range (K) for the AE-preind experiment.

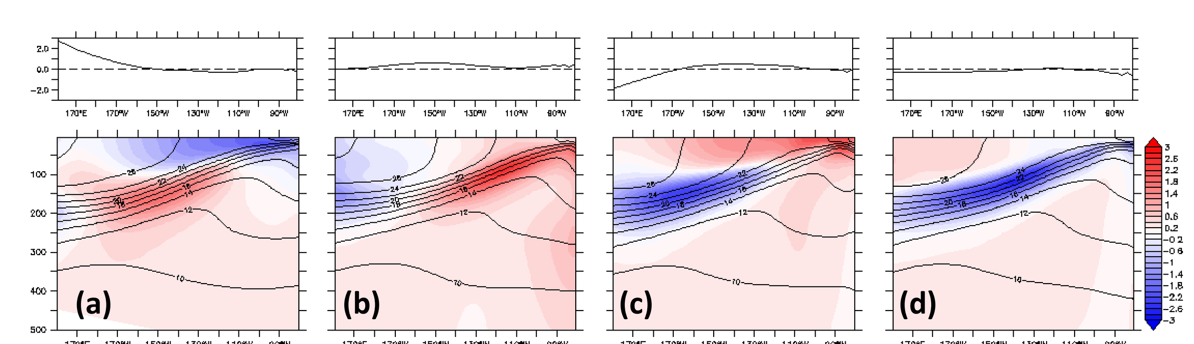

Fig. 5. Change in mean 5°S-5°N zonal wind (top, m s^{-1}) and ocean temperature (bottom, shaded, K) for the AE-preind experiment for MAM (a), JJA (b), SON (c), and DJF (d).

- NH Spring: Reduced insolation → Maritime Continent cools more than western Pacific → anomalous westerly winds → convergence of surface water and downwelling in the west Pacific → warm temperature anomaly propagates eastward at depth (Fig. 5).
- A complementary cold response begins in NH fall.
- These temperature fluxes, reinforced by local insolation change, alter eastern equatorial Pacific seasonality.

- Implication for paleo-ENSO studies: Because precession affects equatorial Pacific seasonality, it may be difficult to discern past ENSO variations from proxy records which reveal changes in extreme temperature events but lack the time-resolution necessary to show year to year variations.

For more information, please see:

Erb, M. P., A. J. Broccoli, and A. C. Clement, 2012: The contribution of radiative feedbacks to orbitally-driven climate change. *J. Clim.* Accepted pending minor revisions.

Mantsis, D. F., A. C. Clement, A. J. Broccoli, and M. P. Erb, 2011: Climate feedbacks in response to changes in obliquity. *J. Clim.*, **24**, 2830-2845, doi: 10.1175/2010JCLI3986.1.

Soden, B. J., I. Held, R. Colman, K. M. Shell, J. T. Kiehl, and C. A. Shields, 2008: Quantifying climate feedbacks using radiative kernels. *J. Clim.*, **21**, 3504-3520, doi:10.1175/2007JCLI2110.1.

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