The Influence of Orbital Forcing on Past Climate Change

Michael P. Erb¹, Anthony J. Broccoli¹, Amy C. Clement², Andrew T. Wittenberg², and Gabriel A. Vecchi³
¹Rutgers University, ²University of Miami, ³Geophysical Fluid Dynamics Laboratory

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.

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.

- Lo-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.

- Lo: Obliquity is set to its low (~22.1°).
- Hi: Obliquity is set to its high (~24.5°).
- AE: Perihelion is set to the NH autumnal equinox.
- WS: Perihelion is set to the NH winter solstice.
- VE: Perihelion is set to the NH vernal equinox.
- SS: Perihelion is set to the NH summer solstice.
- Lo: Obliquity is set to its low (~22.1°).
- Hi: Obliquity is set to its high (~24.5°).
- AE: Perihelion is set to the NH autumnal equinox.
- WS: Perihelion is set to the NH winter solstice.
- VE: Perihelion is set to the NH vernal equinox.
- SS: Perihelion is set to the NH summer solstice.

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.

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.

<table>
<thead>
<tr>
<th>Feedback</th>
<th>Lo-Hi</th>
<th>WS-SS</th>
<th>Double-d ń CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Albedo</td>
<td>-0.27</td>
<td>0.31</td>
<td>0.61</td>
</tr>
<tr>
<td>Water Vapor</td>
<td>-0.20</td>
<td>0.19</td>
<td>4.02</td>
</tr>
<tr>
<td>Lapse Rate</td>
<td>-0.90</td>
<td>0.47</td>
<td>-0.70</td>
</tr>
<tr>
<td>Cloud</td>
<td>-0.67</td>
<td>0.74</td>
<td>1.06</td>
</tr>
<tr>
<td>Total</td>
<td>-2.03</td>
<td>1.72</td>
<td>6.99</td>
</tr>
</tbody>
</table>

Table 1: Global-mean effect of each feedback in net downward TOA radiation, ΔE = (Wm⁻²). Double-d ń CO₂ experiment for comparison. Values calculated using the turbulent method of Saltzmann et al. (1998).

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 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?

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-preced experiment, eastern equatorial Pacific seasonality is significantly reduced (Fig. 4).
- This is the result of thermodynamic and dynamic processes.

- 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.

- **Implications 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:


Contact information: Michael P. Erb, mperb@rutgers.edu. Website: envsci.rutgers.edu/mperb.