

Orbital forcing and the Ice Ages

This reading list was developed for the UChicago Climate journal club. Each paper was the basis of an hour-long discussion. The goal of the list is to provide a basic overview of the evidence we have for glacial cycles, and then give an introduction into Milankovitch cycles and more modern discussions of the problem.

Main goals

- What is the basic orbital theory & evidence for it? [Weeks 1-3]
- Outstanding problems, i.e. missing 20kyr cycle and strong 100kyr cycle.
- Can we differentiate between multiple explanations?

Introduction:

[1] Milankovitch, M., 1941: *Canon of Insolation and the Ice-Age Problem*. Chapters 122, 124-125.

[1] Raymo, M. E., and P. Huybers, 2008: Unlocking the mysteries of the ice ages. *Nature*, **451**, 284–285, doi:10.1038/nature06589.

Evidence – ocean cores:

[2] Hays, J. D., J. Imbrie, and N. J. Shackleton, 1976: Variations in the Earth's Orbit: Pacemaker of the Ice Ages. *Science*, **194**, 1121–1132, doi:10.1126/science.194.4270.1121.

[2] *Optional reading (presenter summarizes):*

Mix, A. C., 1987: The oxygen-isotope record of glaciation. *North America and adjacent oceans during the last deglaciation*, W.F. Ruddiman and H.E. Wright Jr., Eds., Geological Society of America, Boulder, Colorado, 111–135.

Evidence – ice cores:

[3] Shackleton, N. J., 2000: The 100,000-Year Ice-Age Cycle Identified and Found to Lag Temperature, Carbon Dioxide, and Orbital Eccentricity. *Science*, **289**, 1897–1902, doi:10.1126/science.289.5486.1897.

An updated view of the orbital forcing hypothesis:

[4] Roe, G., 2006: In defense of Milankovitch. *Geophys. Res. Lett.*, **33**, L24703, doi:10.1029/2006GL027817.

Outstanding questions

Multiple equilibria might explain non-linear response to eccentricity forcing

[5] Paillard, D., 1998: The timing of Pleistocene glaciations from a simple multiple-state climate model. *Nature*, **391**, 378–381, doi:10.1038/34891.

Role of obliquity

[6] Huybers, P., and C. Wunsch, 2005: Obliquity pacing of the late Pleistocene glacial terminations. *Nature*, **434**, 491–494, doi:10.1038/nature03401.

Role of eccentricity

[7] Lisiecki, L. E., 2010: Links between eccentricity forcing and the 100,000-year glacial cycle. *Nature Geoscience*, **3**, 349–352, doi:10.1038/NGEO828.

Role of precession

[8] Huybers, P., 2006: Early Pleistocene Glacial Cycles and the Integrated Summer Insolation Forcing. *Science*, **313**, 508–511, doi:10.1126/science.1125249.

Role of obliquity and precession

[9] Huybers, P., 2011: Combined obliquity and precession pacing of late Pleistocene deglaciations. *Nature*, **480**, 229–232, doi:10.1038/nature10626.