Is the Hadley Cell an appropriate paradigm for understanding past tropical climate changes?

A.C. Clement [(1)], A. Hall [(2)], A. J. Broccoli [(3)], and C. Jackson [(4)]

(1) *Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149*
(2) *UCLA, 7955 Math Sciences Building, 405 Hilgard Ave., Box 951565, Los Angeles, CA 90095*
(3) *NOAA/Geophysical Fluid Dynamics Laboratory, Princeton University, Forrestal Campus, U.S. Route 1, P.O. Box 308, Princeton, NJ 08542*
(4) *University of Texas at Austin, Institute for Geophysics, 4412 Spicewood Springs Rd., Bldg. 600, Austin, Texas 78759-8500*

Experiments with an atmospheric general circulation model (AGCM) are performed to compare the response of the tropical atmospheric circulation to precessional forcing and Last Glacial Maximum boundary conditions. It is found that the response to the glacial forcing has a significant projection onto the zonal mean circulation, resulting in a strengthening and southward shift of the boreal winter Hadley cell. This appears as a glacial decrease of precipitation in the northern tropics and an increase in the southern tropics. The precessional forcing, on the other hand, induces large zonal asymmetries in atmospheric circulation with little change in the zonal mean Hadley cell. These asymmetries arise primarily through dynamical coupling between heating over land and a remote response over the ocean. Additional experiments with an AGCM of lower resolution are analyzed to evaluate the evolution over the past 150,000 years of the seasonal Hadley cell under varying orbital parameters. It is found that obliquity forcing dominates the time evolution of the austral summer Hadley cell, and that there is a smaller response in the boreal summer Hadley cell that is due to the combined effect of obliquity and precessional forcing. The reason for the different response in austral and boreal summers relates to the land-sea configuration of the two hemispheres. In austral summer, because of the smaller size of the southern hemisphere land masses, a zonally symmetric Hadley circulation is well defined, and responds strongly to obliquity driven changes in the meridional gradient. In boreal summer, the land-sea configuration significantly interrupts the zonally symmetric circulation. Instead, the modification of the Asian monsoon by the orbital forcing dominates the atmospheric response, and although this does project onto the zonal mean, it is clearly not simply Hadley cell physics that are at play. This collection of AGCM results indicates that quite different mechanisms operate in response to different climate forcings, and that the paradigm of the Hadley cell may only useful for understanding climate change on some timescales.