The Hadley and Walker Circulations during Warm Periods of the Past: Coupled Simulations with the NCAR Climate System Model

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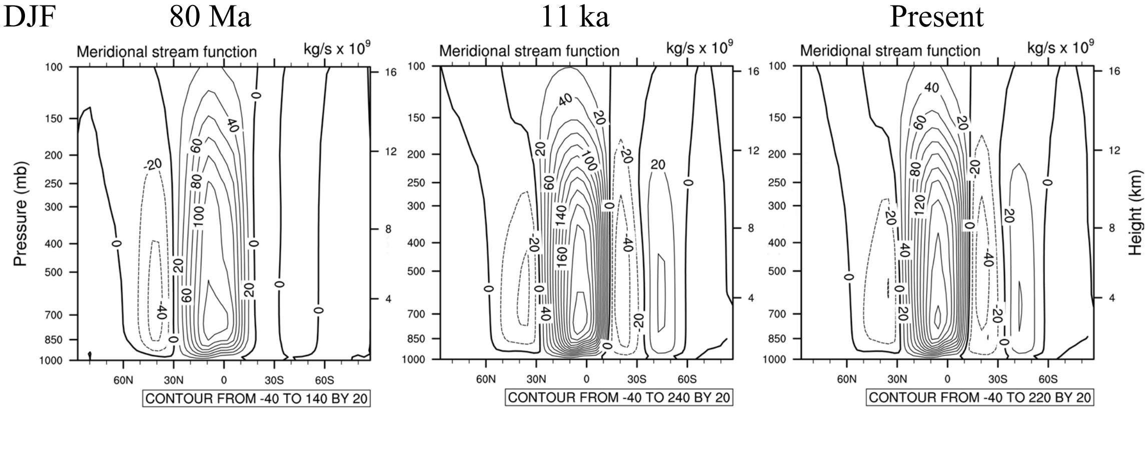
It has been argued that warmer climates at high latitudes during past time periods were associated with strengthened and possibly more latitudinal extensive Hadley cells. In this paper, we will present results from the NCAR Climate System Model (CSM). This model is global in extent with sophisticated models of the atmosphere, ocean, and sea ice and their coupling. Three simulations are compared: Present, late Pleistocene (11 ka), and the late Cretaceous (80 Ma).

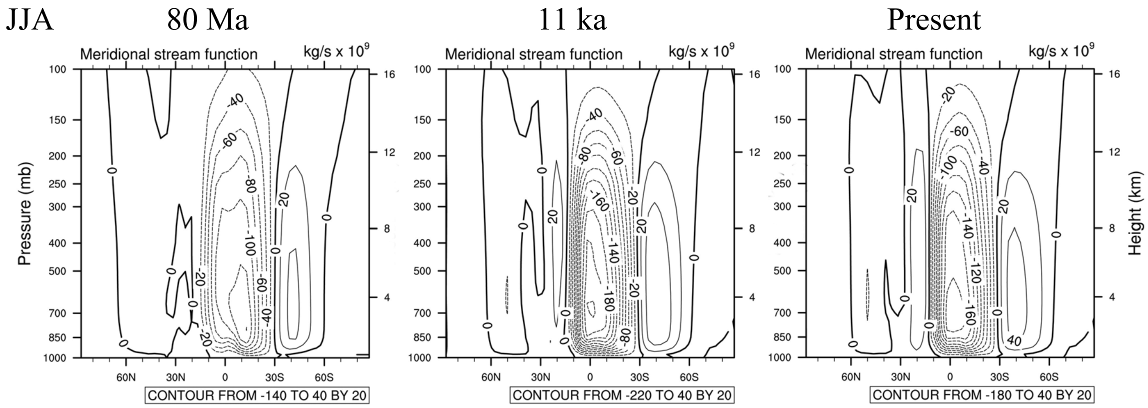
Seasonal plots of the zonal-mean meridional streamfunction simulated by the CSM for present-day show the predominance of the strong winter Hadley cell in both hemispheres with mass fluxes over 190 x 10^9 kg s^{-1}. The center of the circulation is near 700 mb in both seasons, somewhat lower than indicated by observational estimates. The widths of the circulations are 40-45˚ latitude, comparable to observed.

The late Pleistocene (11 ka) simulation includes only the effect of the Milankovitch forcing. This forcing results in a seasonal redistribution of incoming solar radiation with positive top-of-atmosphere anomalies at all latitudes in June-July-August (JJA) and negative anomalies in December-January-February (DJF). Atmospheric trace gas concentrations are set at their pre-industrial values. The residual ice sheet over North America is not considered. Compared to present-day, the winter Hadley cells for 11 ka are stronger by 25-30 x 10^9 kg s^{-1}. Their latitudinal locations and widths remain similar to present-day.

The land-ocean configuration for the late Cretaceous (80 Ma) is very different from present-day. High stand of sea level resulted in global land area 20% less than present. Proxy data and geochemical models suggest Greenhouse conditions, with atmospheric CO_2 levels of 1680 ppm possible. Warming in the tropics is 2.5-3˚C, but is in excess of 30˚C at the winter poles. Compared to present-day, the winter Hadley cells for the late Cretaceous are significantly weaker with mass fluxes less than 155 x 10^9 kg s^{-1}. The width of these circulations increases slightly to 45-50˚ latitude. The summer Hadley cells are quite weak and not well-defined in the late Cretaceous.

DJF 80 Ma 11 ka Present





JJA
80 Ma
11 ka
Present
Meridional stream function
kg/s x 10^9
Pressure (mb)
Height (km)
CONTOUR FROM -140 TO 40 BY 20
CONTOUR FROM -220 TO 40 BY 20
CONTOUR FROM -180 TO 40 BY 20