THE HADLEY CELL IN CLIMATE-CHANGE SIMULATIONS, 1870-2100

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The Hadley Cell is a prominent feature of atmospheric circulations at low latitudes, credited with transporting tropical heat polewards and setting the stage for many tropical-extratropical climate interactions. Using recent Accelerated Climate Prediction Initiative simulations by the coupled ocean-atmosphere Parallel Climate Model (PCM), the strength and location of the Hadley Cell are being evaluated in simulated historical and future climates responding to historical and business-as-usual future greenhouse-gas and aerosol concentrations in the atmosphere.

The historical simulation by PCM yields a pronounced and realistic Hadley Cell mean-zonal circulation as indicated in Figure 1. During Northern Winter, rising motions around 15ºS define the rising limb of the Hadley Cell while sinking motions in the atmosphere about about 30ºS and, especially, about 20ºN define its subsiding limbs. At upper levels, southerly winds over the Equator and into the winter hemisphere (in these global-zonal means), and an enhanced northern subtropical jet are signatures of the Hadley Cell connections of tropics and subtropics. Near the surface, trades winds blow from near the northern subtropics to the Hadley Cell's rising limb. In Northern Summer, the situation is largely reversed (reflected around the Equator). These various features compare quite well with the Hadley Cell, represented in this way, in the NCEP/NCAR Reanalysis fields, 1968-1996, and thus the fate of the Hadley Cell under the greenhouse-warming trends simulated by this model is of interest.

Under the influence of business-as-usual increases in greenhouse-gas and aerosol concentrations during the 21st Century, global temperatures warm moderately in PCM, by about +3ºC/century. Warming is most pronounced over the North Pole and, indeed, over the Northern Hemisphere, but generally, in both Northern and Southern Hemisphere, the warming pattern is relatively simple, with strong poleward enhancement of warming and notable enhancements over the continents. Precipitation rates increase globally at the same time, but the global increase is more spatially complex. Importantly, warming in the PCM simulations (in all ensemble members analyzed thus far) does not take the form of enhanced El Nino-Southern Oscillation (ENSO) patterns, either within or outside the Tropics. Indeed, the 21st Century climate trends seem almost orthogonal to the well developed ENSO process in the PCM. There are strong hints of abrupt reductions in deep convection of North Atlantic Ocean, which appear to affect (at least) North Hemisphere atmospheric heat and moisture fluxes. These abrupt changes are presaged by notable surface-heat flux trends through much of the 21st Century, but are expressed in sea-surface temperatures abruptly near the mid-21st Century in several ensemble members, decades after the global warming trends have been established.

In the midst of these other changes, PCM projects a relatively complex change in the Hadley Cell, as indicated by Fig. 2. In Northern winter, we currently interpret the dipole of decreased uplift (anomalous subsidence) and increased uplift south of the Equator as an Equatorward shift of the rising limb of the climatological Hadley Cell

(centered about 15ºS in the DJF frame of Fig. 1). Meanwhile, projected changes in the broader zone of subsidence at the northern edge of the tropics in the DJF panel of Fig. 1 are also characterized by a dipole of changes that appear to represent a northward displacement of the (winterward) sinking arm of the Hadley Cell (Fig. 2). A similar pattern of (southern) winterward displacement appears to characterize the JJA Hadley cell under global warming in PCM. In both seasons and in both hemispheres, the subtropical jets extend further upward in the atmosphere in response to these changes in the Hadley Cell. Throughout the Tropics, static stabilities are enhanced (more stable) in the projections. Frankly, we are still sorting out the meaning of the changes in all three winds shown in Fig. 2: Are these indeed shifts? Do they imply a poleward retreat or even diminishment of the subtropics? We hope to have a better sense of their implications by the time of the Workshop.

Not shown here, but also of considerable importance, is the fact that, in map view, the changes in the Hadley Cell shown in Fig. 2 are probably derived mostly from the Atlantic and Indian Ocean basins. In those basins, the projected patterns of 21st Century change of precipitation, subisidence, and atmospheric stability in and around the Tropics are notably zonal, symmetric around the Equator, and clearly would reflect directly in the zonal-average changes of Fig. 2. In the Pacific Ocean basin (and over the tropical land masses), patterns of change are much less zonally symmetric. We will also be investigating the nature of this difference before the Workshop, with an eye towards possible implications for the Walker Cell, the longitudinal counterpart of the Hadley Cell.

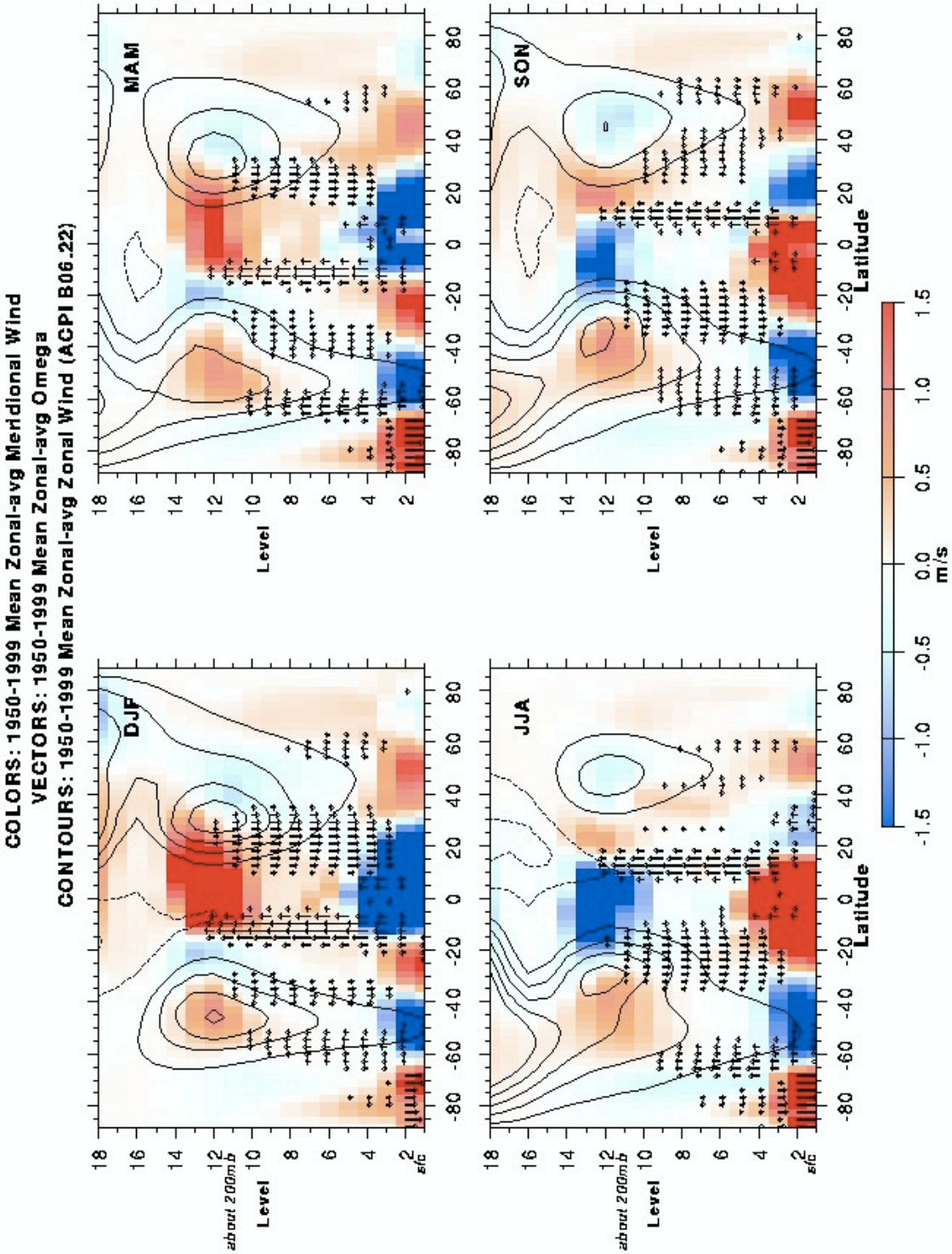

Fig. 1 – Global zonal-mean seasonal wind fields in a PCM historical simulation, 1950-1999. Colors indicate meridional (v) winds as described by color bar; vertical "wind" vectors illustrate negative-omega (-dP/dt), where |dP/dt| is greater than 0.01 Pa/s and with vectors pointing along the direction of the vertical movement; and contours indicate zonal (u) winds, with a 10 m/s contour interval (starting at ±10 m/s) and dashed where negative. The longest omega vectors shown are about 0.04 Pa/s.

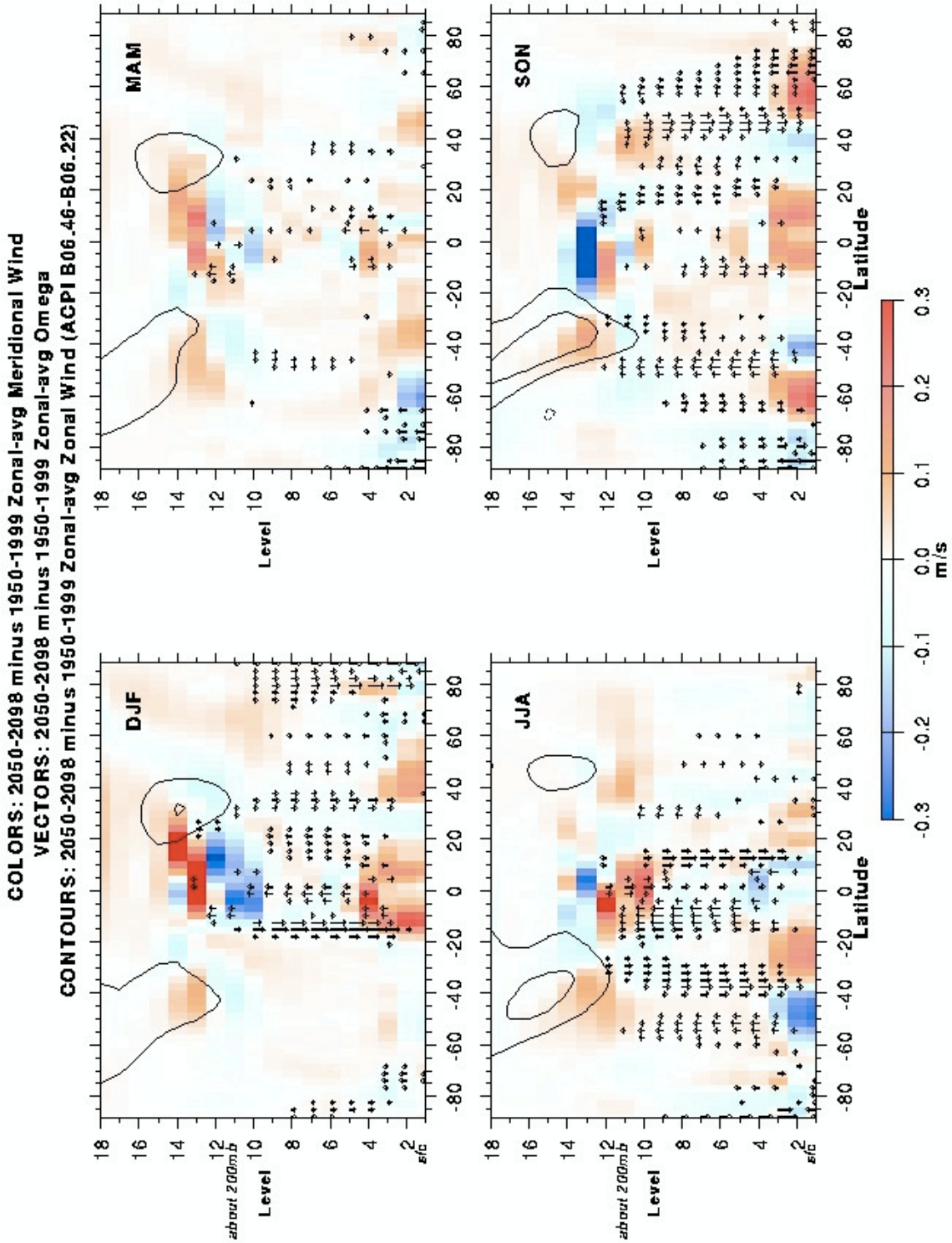

Fig. 2 – Changes in 50-yr means of global zonal-mean wind fields simulated by PCM during 1950-1999 and 2050-2099. Colors indicate meridional-wind changes as described by color bar; vertical "wind" vectors illustrate changes in negative-omega (-dP/dt), where change in omega is greater than 0.001 Pa/s; and contours indicate changes in zonal winds, with a 2 m/s contour interval (starting at ±2 m/s) and dashed where negative. The longest omega vectors shown are about 0.004 Pa/s.