Changes of The Hadley Circulation Since 1950

Xiao-Wei Quan, Henry F. Diaz, Martin P. Hoerling
(NOAA-CIRES CDC, 325 Broadway, Boulder, CO 80305)

Abstract

The Hadley circulation is changing in response to a warming in the tropical Indian Ocean and Pacific Ocean during the past 50 years. The oceanic warming has two manifestations: the increased amplitude of warm sea surface temperature (SST) anomalies during El Nino in the central and eastern Pacific Ocean; and the slow monotonic increase of the SST in the tropical Indian and western Pacific Oceans. Evidence for the changes in the Hadley Circulation comes from ensemble simulations of an atmospheric general circulation model (AGCM) forced with the observed evolution of SST for the period from 1950 to 1999, station observations of precipitation, and the NCEP reanalysis data.

We measure the Hadley Circulation by the zonal average of the 200mb meridional velocity minus the zonal average of the 850mb meridional velocity, which contrasts the opposite flows of the upper and lower tropospheric mass translation. Measured as such, the climatological Hadley Circulation has a strong annual cycle typified by upper level mass transport into the Northern Hemisphere during boreal winter and into the Southern Hemisphere during boreal summer. The changes in the Hadley Circulation appear to be also strongly seasonal dependent. As shown in Figure 1, the simulated Hadley Circulation is intensified during the northern winter (e.g. December-January-February, or DJF) since 1950 while no long-term trend exists for the northern summer (e.g. June-July-August, or JJA). The DJF intensification of the Hadley Circulation can be further partitioned into El Nino-related and non-El Nino-related portions. Figure 2 shows the linear regression between the Hadley Circulation and the spatial average of SST anomalies for the region (10ºS-10ºN, 160ºW-80ºW) (Fig.2 left column) and the residual from the linear regression (i.e. total value minus regressed value) (Fig.2 right column). About half of the DJF intensification of the Hadley Circulation can be explained by the linear response to the increased amplitude of El Nino in the central and eastern tropical Pacific Ocean. The remaining part is attributed to the warming in the tropical Indian and western Pacific Oceans, which is more interdecadal trend rather than increase in the magnitude of interannual variability.

The seasonal dependence of the change in the Hadley Circulation since 1950 reflects different impacts of the SST warming on the oceanic-dominated monsoons during boreal winter versus the continental-dominated monsoons during boreal summer. During winter, a warming of the oceans throughout the deep tropics yields an increase in zonal averaged rainfall (not shown), and hence an intensification of the zonally symmetric meridional over turning. The summertime response of the monsoon is more regional, and lacks a zonally symmetric component.

The regional patterns of the simulated interdecadal changes in winter and summer 200mb divergent mass circulations are shown in Figure 3a and 3b respectively. The oceanic warming enhances the ocean-land thermal contrast during the northern winter, therefore intensifies winter monsoon circulation over the Indian Ocean and Asian Monsoon region. The intensified winter monsoon circulation, together with the enhanced convections over the southeastern tropical Pacific Ocean makes the Hadley Circulation intensified during the northern winter (Fig.3 top panel). During the northern summer, the oceanic warming forces intensification of convection over the tropical Indian and western Pacific Ocean, which in turn causes the intensification of descending motions over North Africa and helps the development of persistent summertime drought over that region during the past several decades. The intensification of convection over the tropical Indian and western Pacific Ocean is also accompanied by stronger subsidence over the northern tropical American monsoon area during the northern summer (Fig .3, bottom panel). In addition, stronger convection over the ocean weakens the monsoon circulation in the tropical monsoon regions and is associated with a general trend of reduced precipitation over land in the tropical region of Asian Monsoon and the marine land of Philippine and Indonesia (not shown). In the extratropics, the enhanced Hadley Circulation is linked to the summer monsoons over Northeast Asia and North America by the intensification of subtropical high and the strengthening and southward shift of the westerly jet over the Northern Hemisphere.

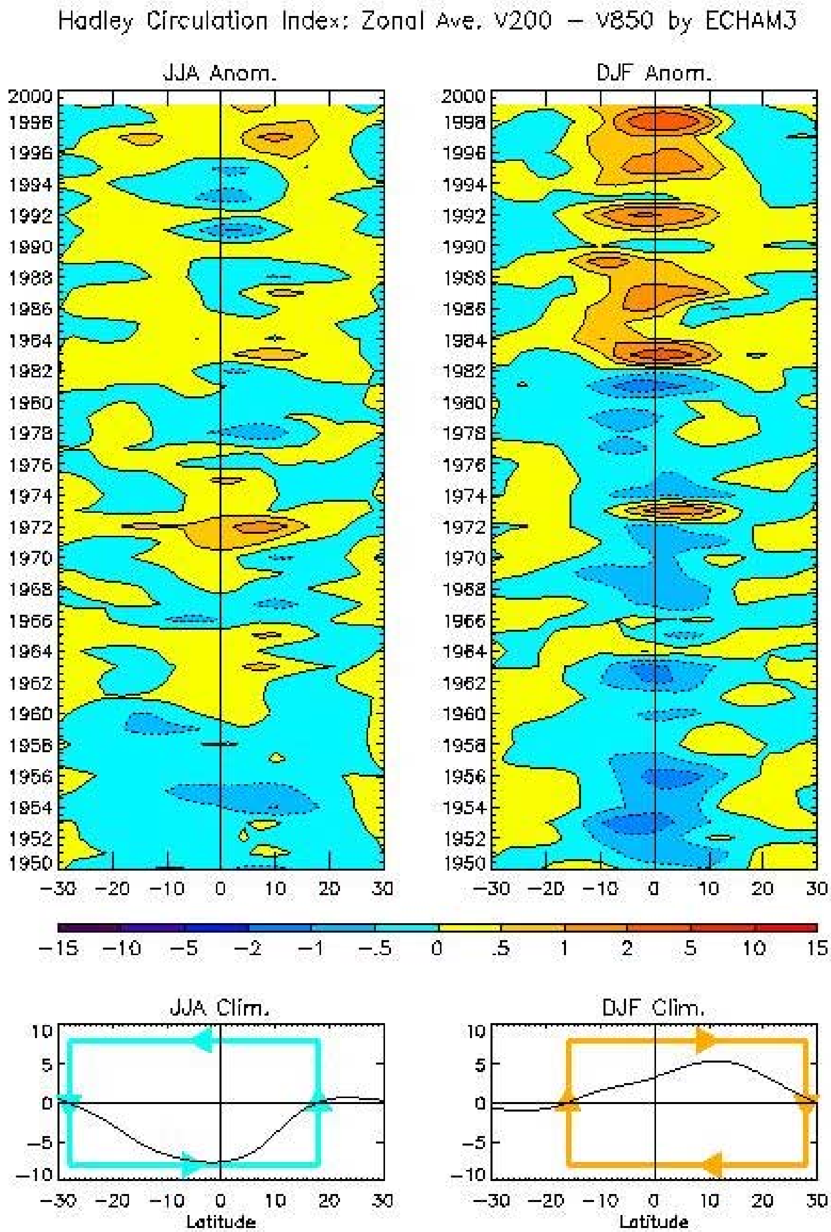
Hadley Circulation Index: Zonal Ave. V200 – V850 by ECHAM3
JJA Anom.
DJF Anom.
JJA Clim.
DJF Clim.
Latitude
Latitude

Figure 1

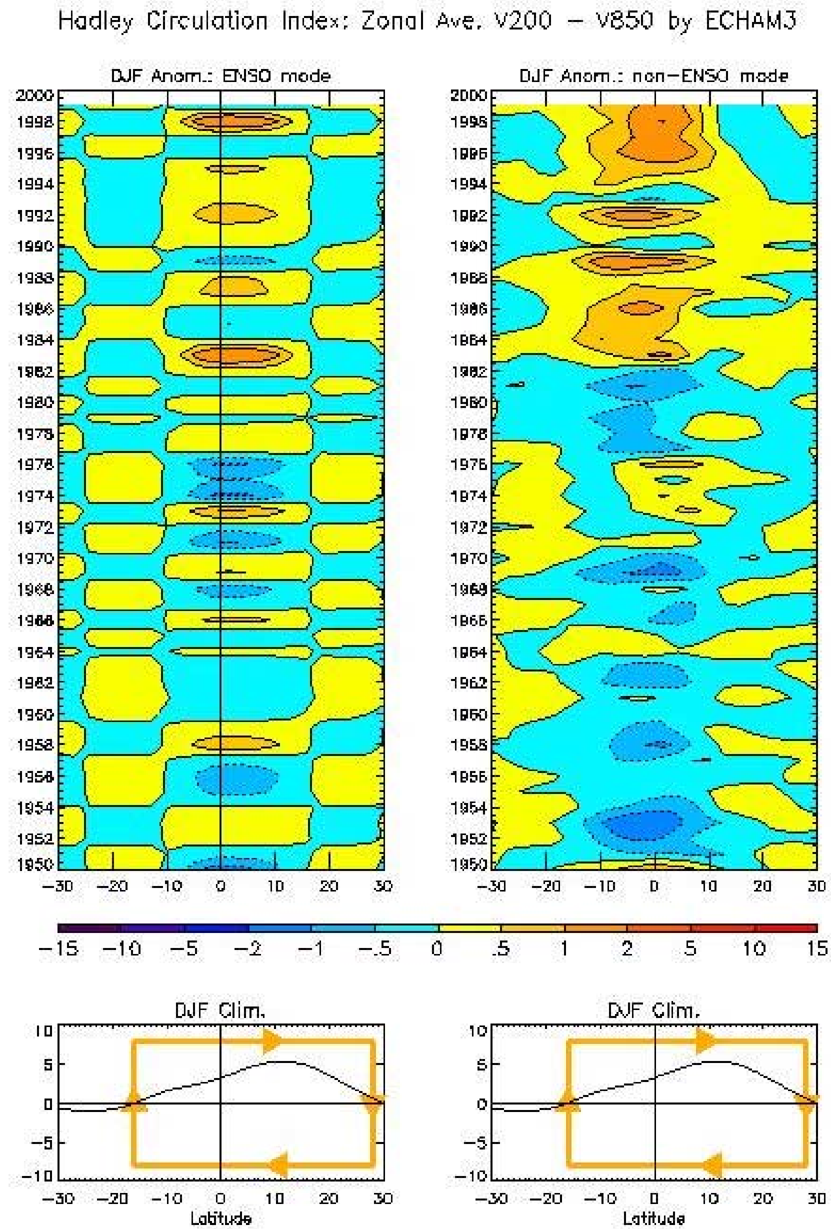
Hadley Circulation Index: Zonal Ave. V200 − V850 by ECHAM3
DJF Anom.: ENSO mode
DJF Anom.: non-ENSO mode
2000
1998
1996
1994
1992
1990
1988
1986
1984
1982
1980
1978
1976
1974
1972
1970
1968
1966
1964
1962
1960
1958
1956
1954
1952
1950
−30 −20 −10 0 10 20 30
−15 −10 −5 −2 −1 −.5 0 .5 1 2 5 10 15
DJF Clim.
DJF Clim.
10
5
0
−5
−10
Latitude
Latitude

Figure 2

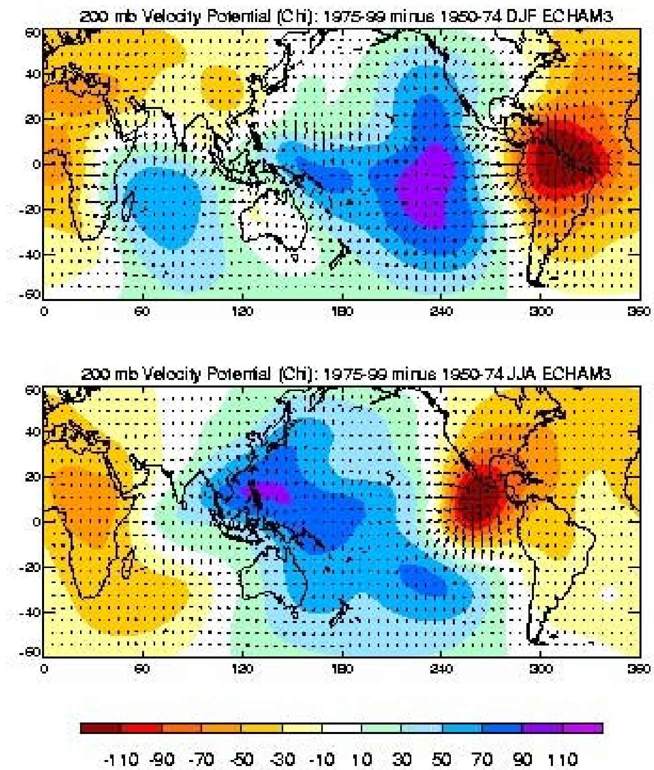
200 mb Velocity Potential (Chi): 1975-99 minus 1950-74 DJF ECHAM3
60
40
20
0
-20
-40
-60
0
60
120
180
240
300
360
200 mb Velocity Potential (Chi): 1975-99 minus 1950-74 JJA ECHAM3
-110 -90 -70 -50 -30 -10 10 30 50 70 90 110

Figure 3