OBSERVATIONS OF THE LOCAL AND ZONALLY-SYMMETRIC HADLEY CIRCULATION AND ITS DEPENDENCE ON TROPICAL CONVECTION

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1. INTRODUCTION

The Hadley Circulation (HC) is most commonly defined as the zonally symmetric meridional mass circulation between the tropics and subtropics. The upward branch of the HC is generally assumed to be tied to the net mean upward motion due to deep tropical convection, while the subsidence branches within the subtropics arise through somewhat more complicated mechanisms, including effects of radiative cooling along with momentum and mass flux convergence, driven in part from the extratropical circulation. The strength and latitudinal location of at least the upward branch of the HC should in principle be related to the strength and location of tropical convection. This relationship is certainly seen with regards to the seasonal cycle, where the upward branch moves from one hemisphere to the other depending on the declination of the sun and the latitude of maximum sea surface temperature (SST). One can also discuss a "local HC", which is here defined as the meridional mass flux due to the meridional divergent wind combined with the vertical motion along a given longitude range. Here we examine interannual and intraseasonal variations in the both the zonally symmetric and local HC that are linked to variations in the strength of tropical convection in the upward branch. This analysis shows that variations in the HC are related to location and intensity of tropical convection on a wide variety of timescales.

2. APPROACH

Satellite-derived Outgoing Longwave Radiation (OLR) is utilized as an index of tropical convection, and either ECMWF or NCEP reanalysis products are used to represent the circulation in this study. The qualitative conclusions are the same regardless of which analyses are used, although results differ in some important details with regards to the strength of HC between ECMWF and NCEP. In all cases, the circulation indices are regressed against either the "Niño 3.4" index to represent ENSO conditions, or filtered OLR on intraseasonal timescales, as discussed in Kiladis and Weickmann (1997).

3. RESULTS

Fig. 1 shows the zonally symmetric perturbation OLR, vertical motion, and HC for a one standard deviation in Niño 3.4 SST for June-August (JJA) and DJF using data from 1974-2001. During JJA anomalous convection is maximized at 5ºN, while the maximum perturbation in upward motion is slightly poleward than this (7.5ºN) at the 200 hPa level. The anomalous subsidence in the downward branch maximizes at 10ºS. Since the latitude of the climatological upward and downward branches are at 10ºN and 17.5 ºS, respectively (not shown), this implies that during a warm ENSO event the HC is stronger but also contracted equatorward due to the effect of anomalous SST in the tropics. During DJF the situation is similar except that the anomalous upward motion is now south of the equator in the summer hemisphere, also leading to a strengthening and equatorward contraction of the HC when compared to the mean.

Large fluctuations in tropic-wide convection are also observed on subseasonal time scales, independent of SST perturbations and instead tied to organized convective disturbances. The most important of these disturbances is the Madden-Julian Oscillation (MJO), which consists of an eastward propagating envelope of convection with a scale of around 80º in longitude. The MJO is generally initiated in the Indian Ocean and propagates eastward into the Pacific sector with a phase speed of around 5 m s^{-1}. Fig. 2 shows the perturbation OLR and flow at 200 hPa for a time during DJF when MJO convection is active in the Indian sector. The MJO index used is based on space-time filtered OLR at the point 10ºS, 110ºE and retains fluctuations in the 30-96 day range. This plot shows that MJO convection is associated with anomalous anticyclonic flow in both hemispheres over the Indian sector, and cyclones over the Pacific. Although the total flow is directed westward along the equator in the vicinity of the convection, the divergent flow, or local HC (not shown), is directed away from the convection and has a strong component into both hemispheres. The anomalous anticyclones are consistent with the barotropic generation of "Rossby wave sources" by this local mass circulation. Likewise, a similar result is obtained for <30 day filtered OLR in the same region (Fig. 3). In this case, however, both the total and divergent flow are directed primarily towards the winter hemisphere, as was shown for other locations and seasons by Kiladis and Weickmann (1997) to be true in general. While the MJO does have a substantial impact on the zonal mean HC and angular momentum balance, convection on submonthly time scales is found to be significant for local mass circulations only.

4. REFERENCE

Kiladis, G.N., and K.M. Weickmann, 1997: Horizontal structure and seasonality of large-scale circulations associated with submonthly tropical convection. Mon. Wea. Rev., 125, 1997-2013.

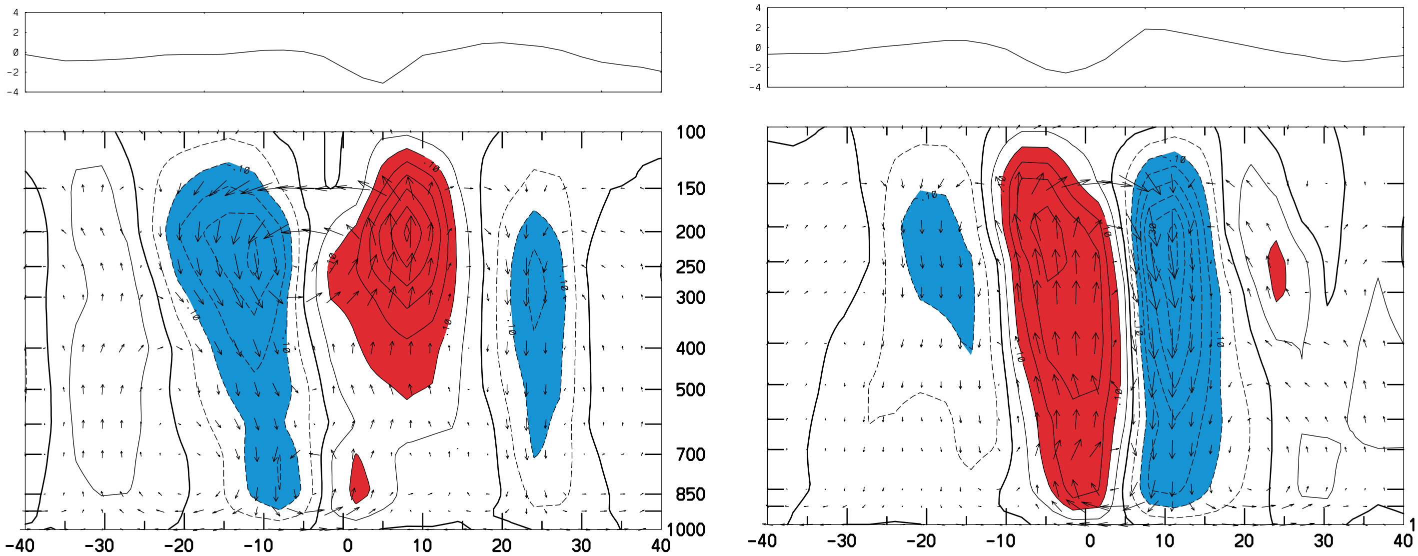

Fig. 1. Meridional-pressure cross sections of zonal mean perturbation vertical wind (contours) and meridional circulation (vectors) from NCEP reanalysis during JJA (left) and DJF (right), regressed onto Nino 3.4 SST, using data for 1957-2001. Also shown on top are zonal mean OLR perturbations (1974-2001, in W m^{-2}). Values are plotted for a +1 standard deviation in SST (around 1ºC). Contour interval is 0.1 cm s^{-1}. Red (blue) shading denotes positive (negative) upward motion. The vertical component of the vectors has been multiplied by 500 to account for the aspect ratio of the plot.

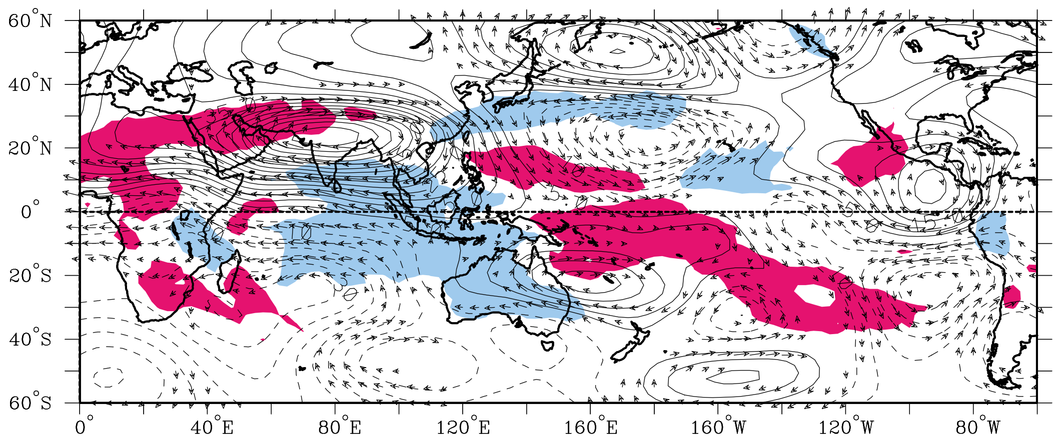

Fig. 2. Perturbation OLR (shading, blue negative) and 200 hPa streamfunction (contours) and total wind (vectors) from NCEP reanalysis during DJF, regressed onto the MJO index (see text). Contour interval is $5X10^6$ m^2 s^{-1}. The largest vectors represent a wind speed of about 5 m s^{-1}. Red (blue) shading denotes positive (negative) OLR, with anomalous convection associated with the negative regions.

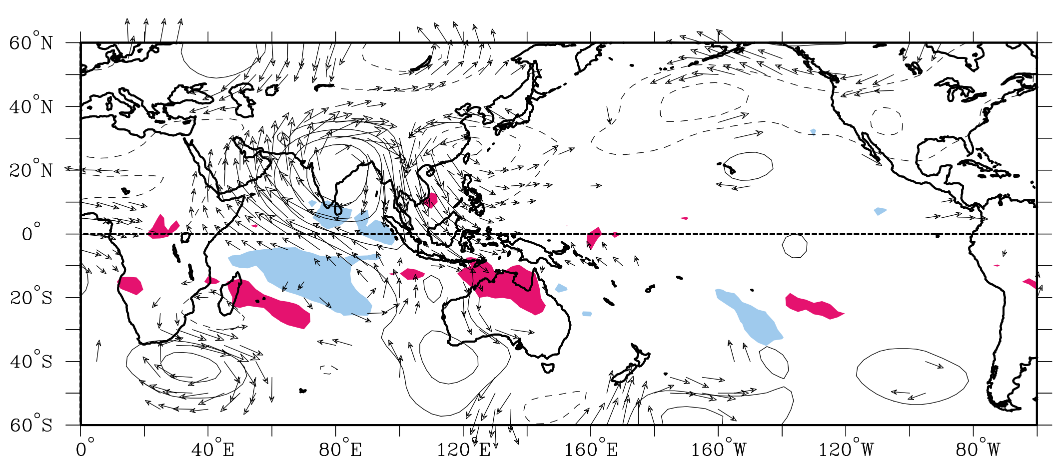

Fig. 3. As in Fig. 2, except for <30 day filtered OLR in the region 15ºS-5ºS, 70ºE-80ºE during DJF.