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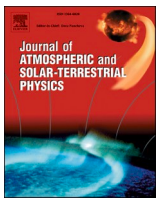

Short Communication

A rare episode of minor circulation embedded in the northern hemispheric zonal mean hadley cell

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ABSTRACT

A rare episode of minor circulation embedded in the Hadley circulation (HC) and processes responsible for its formation is discussed. Using 34 years (1979–2012) of HC climatology derived from reanalysis datasets, a minor circulation centered on ~35°N and embedded within the northern hemispheric zonal mean HC is observed during the month of July 1993. A longitudinally resolved vertical velocity observations centered on 35°N latitudinal belt revealed that there is an anomalous upwelling over the North American sector possibly associated with "Great Floods of 1993" thus emphasizing the prominence of a regional feature and its impact on the zonally averaged circulation.

1. Introduction

The large-scale circulations in the Earth's lower atmosphere are primarily driven by the differential heating of the Earth's surface by the Sun. This differential heating sets up a large-scale ascent over the equator, a meridional transport at upper troposphere towards poles on either side of the equator and a large-scale descent over subtropics. This giant circulation from the equator to sub-tropics, is known as the Hadley cell. There are two more circulation cells in mid- and high-latitudes *viz.*, the Ferrel and Polar Cells in the Earth's lower atmosphere. Broadly defined on the basis of the influence of these three circulation cells are the major climatic zones of the earth, which includes the arid, semi-arid and wet regions.

One of the most influential cells of the general circulation is the HC which is primal in determining the warm, moist climate of the tropics and the relatively dry climate of the subtropics. In the recent decade, focus of the atmospheric scientific community has been on the descending limbs of the HC and the regions beneath it. Researchers have shown that the descending limb has shifted its location poleward (Hu et al., 2018; Liu et al., 2012; Staten et al., 2020), leading to a crisis in the existence of the ecosystem of these regions, most importantly through the constraint on water reserves. The extent of the expansion of the HC (Grise and Davis, 2020; Hu et al., 2013; Nguyen et al., 2013; Reichler, 2009), its implications (Issac and Turton, 2014; Seidel et al., 2007), as well as the factors contributing to it (Xian et al., 2021) have been discussed in several studies. These studies used a variety of metrics to quantify the expansion of HC, which include the outgoing long-wave radiation (OLR), precipitation, subtropical jet, tropopause, difference between precipitation and evaporation, ozone and meridional mass stream function (MSF) (Lucas et al., 2014; Reichler, 2009; Xian et al., 2021). Majority of these studies relied on the reanalysis data during the satellite era (1979-present). Owing to the metrics used, methods followed and the uncertainties in reanalysis datasets, there have been significant discrepancies in the observed trends in the expansion of the HC. Zonal mean of a chosen metric has been used by several of these studies in order to quantify the rate of HC expansion. For instance, Johanson and Fu (2009) have used zonal mean MSF to identify a total expansion of 3.2° latitude in the past 25 years for the zonal mean HC. Davis and Rosenlof (2012) have used latitude of mean 850 hPa wind maximum to identify an expansion of 0.3° latitude per decade in the Northern Hemisphere (NH) alone. However, it is envisaged that the amount of widening may vary from region to region. For example, the expansion rate will be more over land than over ocean because of the faster response of the land surface to sensible heating than oceans.

The process of zonal averaging of metrics may, however, mask many important physical processes and hence, cannot be a complete description of the meridional circulation (Holton, 2004). This demand studies on a regional scale, which are relatively rare. Chen et al. (2014)

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longitudinal sector and 25° N–40° N latitudinal sector (figure not shown). The MSF estimated by excluding the data over the above-mentioned sector does not show any anomalous HC during the month of July 1993, and corroborates with the climatological mean MSF. This analysis thus indicates that the circulation features associated with the Great floods of 1993 during the month of July may be responsible for the observed anomalous features of the HC shown in Fig. 2(b) and (d). The consequence of this anomalous HC on other atmospheric processes shall be studied further; so will be the climate model reproduction of this anomalous feature of HC. Thus, the present results ascertain that though rare, the minor circulations embedded in the NH zonal mean HC do exist.

4. Concluding remarks

The present study discussed an anomalous HC observed during the month of July 1993. The mean meridional mass steam function analysis showed that northern hemispheric HC during July 1993 was very much different from their 34-year mean climatology obtained using MERRA and JRA-55 reanalysis. A minor circulation, which is embedded within the northern hemispheric HC and centered on ~35° N, was identified during July 1993. Though this feature is thought to be the artifact of not considering the orography, it is noted that it appears even after account for the orography during the month of July 1993. In an attempt to divulge the possible reasons for the observed anomalous HC, the vertical wind observations during July 1993 have been analyzed and compared with their mean climatology. This analysis revealed an anomalous upwelling in the 35° N–40° N latitudinal belt during July 1993. A longitudinal cross section of the of the vertical velocities over the 35° N latitude showed upwelling in the 70° W–110° W longitudinal belt, thus pointing towards the fact that the anomalous structure of the HC for July 1993 is because of the anomalous upwelling in the 20° N–35° N and 70° W–110° W sector. This, in fact, is observed to be coincident with the region affected by "Great floods of 1993" in the North America. The circulation features associated with the Great floods during the summer of 1993, and the persistent trough maintained throughout the region during the July of 1993 is presumed to be the major reason for the anomalous circulation pattern of HC. The current observation upholds the impact which a prominent localized feature can make on a zonal mean pattern of the HC. Taking into consideration the manifestation of regional features on a zonal mean HC, it is time for focusing on the HC studies on regional scales in order to estimate zonally resolved rate of expansion of the HC.

Credit author statement

All the authors contributed to conceptualization of the study, development of methodology, data analysis and writing of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data is publically available.

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