Atmospheric Research 137 (2014) 80–90

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Observational relations between potential vorticity intrusions and pre-monsoon rainfall over Indian sector

M. Sandhya, S. Sridharan *

National Atmospheric Research Laboratory, Gadanki 517 112, Pakala Mandal, Chittoor District, India

ARTICLE INFO

Article history:
Received 10 June 2013
Received in revised form 6 September 2013
Accepted 16 September 2013

Keywords:
Potential vorticity
Deep convection
Pre-monsoon rainfall

ABSTRACT

The climatology of potential vorticity (PV) intrusion events to low latitudes, identified from the ECMWF (European Centre for Medium Range Weather Forecasting) reanalysis (ERA) interim data for the years 1982–2012, shows that the intrusion events occur, though less in number, over African and Indian sectors (0°–90°E) also, in addition to the well known intrusions over Eastern Pacific and Atlantic sectors. The seasonal variation of the PV intrusion events over Indian sector (50°E–90°E) shows that the intrusion events are more during pre-monsoon months, in particular during March and April contrary to the case over Eastern Pacific and Atlantic sectors, where the intrusions are more during winter. It is interesting to note that no intrusion events occur during the Indian monsoon months (June–September) due probably to the presence of tropical easterly jet. Though the number of PV intrusions is less, it plays a profound role in triggering deep convection and associated precipitation over Indian sector. Four cases are presented to show that these PV intrusions are clearly associated with deep convection and precipitation over Indian sector during the pre-monsoon months.

1. Introduction

Deep convection and associated latent heat release drive the general circulation of the tropical atmosphere. Over tropics, deep convection is often influenced by changes in heat and moisture surface fluxes in the boundary layer. The tropical convection may also be influenced by lateral forcing. In particular during Northern Hemispheric (NH) winter, the presence of upper tropospheric eastward winds provides a path for the Rossby waves to propagate cross equatorially (Webster and Holton, 1982). When the wave amplitudes are larger, the wave breaking occurs producing stratospheric air with high potential vorticity (PV) into the tropical upper troposphere (Waugh and Polvani, 2000). The PV intrusions are nearly always accompanied by deep convection. Hoskins et al. (1985) and Thorpe (1985) showed that a positive (cyclonic) upper-level PV has a less stable potential temperature distribution within and immediately below the anomaly. This decrease in the static stability, together with the translational motion of the anomaly itself, results in a vertical motion in low levels. The upper level PV triggers convection by destabilizing lower troposphere and by causing upward and poleward motions ahead of the PV tongues and the poleward motion transports tropical moist air to northern higher latitudes (Kiladis, 1998). Waugh (2005) using space based upper tropospheric humidity measurements and trajectory-based simulations showed high relative humidity (RH > 80%) ahead (east) of potential vorticity intrusions into the northern subtropics. This is consistent with the known deep convection and poleward flow ahead of these intrusions (Kiladis, 1998; Waugh and Funatsu, 2003). Ryoo et al. (2008) also showed that upper level humidity during the NH wintertime is controlled by PV intrusions over the eastern Pacific and Atlantic Ocean. During the period of 6–8 January 2009 western Washington experienced a rainfall of about 3–8 in., which led to flood (Neiman et al., 2011). Associated with this event there was reported an intrusion of subtropical air with PV ~ 7 PVU (1 PVU, potential vorticity unit is 10^{-6} Ks^2/kg). Earlier, Martín et al. (2006) linked a heavy rainfall event of November

* Corresponding author. Tel.: +91 8585 272124; fax: +91 8585 272018.
E-mail address: susridharan@narl.gov.in (S. Sridharan).

0169-8095/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.atmosres.2013.09.013

2011 in the Western Mediterranean sea with the PV intrusion. Shuai et al. (2009) attributed a heavy rainfall event over Northern China to non-uniformly saturated instability induced by a dry intrusion. Graf et al. (2011) observed the formation of most European tornadoes within 200 km of a distinct upper-level PV anomaly.

There are also differences in the ascent of moist, boundary layer air ahead of the PV tongues in mid-latitudes and tropics. In mid-latitude systems, this ascending air is typically part of a warm conveyor belt (Browning, 1990), where advection aids in the ascent up a frontal surface and the upward transport can occur over large distances (e.g., 30° latitude) (e.g., Wernli, 1997). However over tropics, the ascent ahead of the PV intrusions results in deep convection within a localized region. The intrusions are strongly dependent on the background flow. The presence of equatorial westerly ducts over Pacific and Atlantic during northern fall through spring favours the wave-like disturbances to propagate. These disturbances compress zonally and amplify meridionally generating a thin tongue of high PV air to intrude into the tropical eastern Pacific predominantly during winter. The PV intrusions to tropics have been linked with transient deep convection in the tropical eastern Pacific and Atlantic (e.g., Kiladis and Weickmann, 1992; Kiladis, 1998; Waugh and Funatsu, 2003). Though the influence of these intrusions on the weather of Eastern Pacific and Atlantic has been studied in detail, less attention has been paid to the intrusion events in other sectors due to the less number of events. Over tropics, Roca et al. (2005) showed the modulation of extra-tropical dry-air intrusions on the occurrence and duration of convective systems and hence the mode of variability of rainfall over West Africa during the African monsoon. Vialard et al. (2011) studied a rainfall event over India during March 2008. However, they related the rainfall with the equatorial eastward propagation, characteristic of the Madden Julian Oscillation (MJO). Recently, Ullah and Shouting (2013) observed that high mid-tropospheric potential vorticity anomaly was conducive for the development of strong mesoscale convective vortex and large-scale cyclonic circulation over Pakistan during summer monsoon of 2010.

In this paper, the climatology of PV intrusions is studied over Indian sector (50°E–90°E) and a few cases are shown relating clearly these intrusion events with deep convection and precipitation.

2. Data sets

2.1. Potential vorticity

For this study European Centre for Medium Range Weather Forecasting (ECMWF) reanalysis (ERA) interim potential vorticity and zonal wind data are used. The first real-time medium-range forecasts through this centre were made in June 1979 and the centre has been producing operational medium-range weather forecasts since 01 August 1979. The data sets are currently available for the period January 1979 to January 2013 in the website data-portal.ecmwf.int/data/d/interim_daily/for 15 isentropic levels. These data were prepared by ECMWF using their variational data assimilation system (Berrisford et al., 2009). The ERA-interim data set consists of results from analysis conducted at 6-h intervals available for a 1.5° latitude–longitude grid.

In the present study, potential vorticity at 350 K isentropic level is used and the value of PV > 1.5 PVU (represents stratospheric air) is used to identify the intrusion events. Each event is manually checked and identified in the time-longitude cross section of PV at particular latitude, as it varies spatially and temporally from case to case.

2.2. Outgoing Long-wave Radiation (OLR)

OLR data for this study is obtained from National Oceanic and Atmospheric Administration-National Centres for Environmental Prediction (NOAA-NCEP). The data are interpolated in time and space from NOAA twice-daily OLR values and averaged to once daily. The data sets are available in 2.5° × 2.5° latitude–longitude grid since 01 June 1974. Low value of OLR represents high cloud top heights and it has been used as an indicator for deep convection (Liebmann and Hartmann, 1982).

2.3. Precipitation

Daily precipitation data has been taken from Global Precipitation Climatology Project (GPCP). At present, the data set contains daily global gridded values of precipitations for the period October1996 to April 2009 in 1° × 1° latitude–longitude grid. The GPCP daily precipitation is produced at the NASA Goddard Space Flight Centre. The GPCP data are satellite derived precipitation products with higher temporal and spatial scales and different methods are used for deriving precipitation in the tropics and the extra-tropics. It is a component of the Global Energy and Water Cycle Experiment of the World Climate Research Program (Gebremichael et al., 2005).

2.4. MJO indices

MJO indices are obtained from the website of NOAA climate Prediction Center (http://www.cpc.noaa.gov). These indices are computed by applying an extended empirical orthogonal function analysis to the 200 hPa velocity potential. The first function consists of ten time-lagged patterns with each pattern separated by 5 days and ten MJO indices are formed through regression analysis of daily data on to these patterns. Each index is associated with the phase when the equatorial velocity potential anomalies have propagated to a particular longitude. More details about the MJO indices can be found in the website.

3. Results

Fig. 1 shows longitude–time cross section of PV intrusions at 10.5°N, 12°N, 13.5°N and 15°N for the years 2000–2012. At 10°N, the intrusion events are more in the longitude bands 180°–270°E and 300–360°E. The longitude of more intrusions is around 250°E during winter and it gradually shifts to around 180°E during summer and it again proceeds towards 250°E during fall equinox and winter. There is a large interannual variability in the number of intrusions with more events occurring during winter and spring equinoxes of 2000, 2006, 2008, 2009, 2011 and 2012. As latitude increases, intrusion events are noticed in the African and Indian sectors (0°E–90°E) also, though the number of intrusion events increase largely