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Variability of Madden Julian Oscillations (MJO) observed over southern India using radiosonde observations

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ABSTRACT

In the present work, characteristics of 30–50 day oscillations (referred to as the MJO) in tropospheric and lower stratospheric wind and temperature have been studied using long-term high resolution radiosonde observations at a tropical station, Gadanki (13.5°N, 79.2°E) for the period 2006–2012. Wind and temperature perturbations showed clear features of the MJO with higher amplitudes between 10 and 18 km altitude. Interestingly, the MJO signal is confined vertically to different altitudes in different seasons. Variability in the perturbations of wind and temperature similar to that of outgoing long-wave radiation (OLR) with a few cases showing an out of phase relation. The amplitudes of these oscillations are larger in the winter and pre-monsoon seasons than in the monsoon season where the largest amplitudes are confined below the Tropical Easterly Jet (~16 km). There also exists a large inter-annual variability in the MJO. Spatio-temporal variability of OLR not only showed the features of the MJO but also northward and eastward propagation in the monsoons and winter seasons, respectively, in a few cases. It is found that convection leads the MJO in the zonal wind by 8–12 days in all the seasons except in winter. One intriguing result observed is the vitiation of the MJO pattern by the presence of strong wind shears during monsoon season. We expect this study would be helpful in representing the MJO features in the vertical in the general circulation models (GCMs) which is still a major challenge.

1. Introduction

It is well known that the dominant atmospheric oscillation observed in tropics is the Intra-seasonal Oscillation (ISO) or the Madden Julian Oscillations (MJO). It was the pioneering study by Madden and Julian (1971, 1972) which first demonstrated the global scale phenomenon (zonal wave-number 1) called the MJO on a time scale of around 40 days (Krishnamurti et al., 1984; Chen 1987). The MJO appears to be confined to within 30° latitude of the equator and is known as large scale coupled patterns of atmospheric circulation and deep convection. This phenomenon influences many other large scale features of the atmosphere such as atmospheric circulations of various spatial and temporal scales (Zeng et al., 2012) and variations in the precipitation in many regions of tropics and sub-tropics (Lau and Chan, 1986; Sui and Lau, 1992; Kayano and Kousky, 1999; Jones and Carvalho, 2014). It also plays a significant role in modulating tropical cyclones especially over the Pacific Ocean and the Caribbean Sea (Zhang, 2005) and in bridging weather and climate (Zhang (2013) and references therein). It is observed from earlier studies that the MJO affects both global medium and extended range weather forecast (Ferranti et al., 1990; Hendon et al., 2000) and also modulates the global angular momentum (Zhang, 2005). All these studies have not only discussed the different atmospheric phenomena that are affected by the MJO but also have investigated the features and evolution of the MJO.

It is well known that the ISO has a periodicity of 30–90 days, and can be categorized into two types based on the season. The MJO is the mode with predominant eastward propagation along the equator, and prevails in the boreal winter. The boreal summer, ISO (BSISO) is the mode with prominent northward propagation and large variability in off-equatorial monsoon trough regions (Wang et al., 2005). These basic features were well explained by Zhang (2005) who illustrated with an example (Figure 1 of Zhang (2005)) showing the eastward moving center of strong deep convection and precipitation (termed as 'active phase') flanked on either side i.e. east and west by convectively suppressed conditions (termed as 'inactive phase'). He suggested that the two phases of the MJO are connected by overturning zonal circulations that extend vertically through the entire troposphere. Note that

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the active phase of the MJO is associated with large scale enhancement of convection with an increase in the occurrence of large and deep cloud clusters and vice versa during the inactive phase (Mapes and Houze, 1993; Chen et al., 1996). It is well known that the large-scale wind structures are often described in terms of equatorial waves coupled to deep convection. Both Kelvin and Rossby wave structures have been considered dynamically essential to the MJO. Based on this, there can be a phase difference between convective center and surface zonal winds. For example when the active phase of the MJO is over the Indian Ocean, its convective center is more likely to be in between the surface westerlies to the west and easterlies to the east. Observational studies (e.g., Knutson and Weickmann, 1987; Rui and Wang, 1990) have also shown that there is a relative phase difference between large scale surface zonal wind and convective center during the MJO life cycle.

Studies have also been carried out on various forcing mechanisms and energy sources of the MJO. One school of thought considered the MJO to be an atmospheric response to a forcing mechanism which exists independently, whereas another thought is that the MJO creates its own energy source through atmospheric instability (Zhang, 2005). There are several independent forcing mechanisms present in the atmosphere such as tropical intraseasonal stationary forcing, lateral forcing, atmospheric instability, moisture convergence, surface evaporation and radiation which can contribute one way or other as an energy source for the MJO.

All the above mentioned features of the MJO and its forcing mechanisms have been investigated following the pioneering study of Madden and Julian. Most of these studies are based on modeling and deal with global reanalysis products or satellite observations. There are very few studies using in-situ observational data from the Indian region (e.g. Kumar and Jain, 1992; Narayana Rao et al., 2000; Guharay et al., 2012; Mohammad et al., 2014). Despite many studies, the MJO phenomenon still remains as one of the topics under debate and challenging in tropical atmospheric dynamics. This is mainly due to the lack of enough observations to delineate its characteristics vertically and globally (Zhang, 2005). A recent study by Yoneyama et al. (2013) using DYNAMO (Dynamics of the MJO) field observations showed that several MJO events were captured by ground-based, airborne and oceanic instruments. This campaign was conducted in and around the tropical Indian Ocean mainly to study the atmospheric and oceanic processes associated with the MJO. This study also emphasized the use of in-situ field observations to advance the understanding of the MJO. For better simulation of the MJO features, we need all the properties of the MJO including its vertical structure by considering each episode which can be provided mainly from observations. It is well known that ground based observations can provide information on the MJO characteristics temporally and vertically. A few studies on these oscillations have been reported from the present study site using MST (Mesosphere–Stratosphere–Troposphere) radar, Radiosonde observations, reanalysis data products etc. Among these, the study using MST radar at Gadanki (13.5°N, 79.2°E) by Narayana Rao et al. (2000) has shown that there are some interesting features of 30–40 and 50–70 day period waves in zonal and meridional winds which suggested that the origin of these oscillations is in the lower troposphere. Using radiosonde observations Guharay et al. (2012) has observed the tropical ISO in the lower atmosphere, and found there is good correlation between convection and zonal wind during all seasons within ISO scale of variability. It is noted that the results by Guharay et al. (2012) mainly concentrated on zonal wind observations from 2006 to 2009.

In the present study, we have investigated the vertical and temporal characteristics of the MJO during different seasons using the wind and temperature information obtained at Gadanki (13.5°N, 79.2°E, $\sim$375 m AMSL) using long-term high resolution radiosonde observations from 2006 to 2012. Possible forcing mechanisms of these oscillations and their association with atmospheric convection are examined. The topography of the study region is shown in Fig. 1a. Gadanki lies in the southern part of India. Fig. 1(b) shows the climatology of rainfall observed using rain gauge over Gadanki. It is clear from this figure that this region receives rainfall from both southwest (SW) (June, July and August) monsoon (also refereed as monsoon) as well as northeast (NE) (September, October and November) monsoon (also referred as post-monsoon). Note that rainfall amount is higher during NE monsoon compared to the SW monsoon over Gadanki location. It is worth to mention that the NE monsoon peak is in part due to orographic uplift on the upstream side of the high terrain. In other months such as pre-monsoon (March–April–May) the rainfall activity is mainly due to localized convective events like thunderstorms or passing of cyclones.

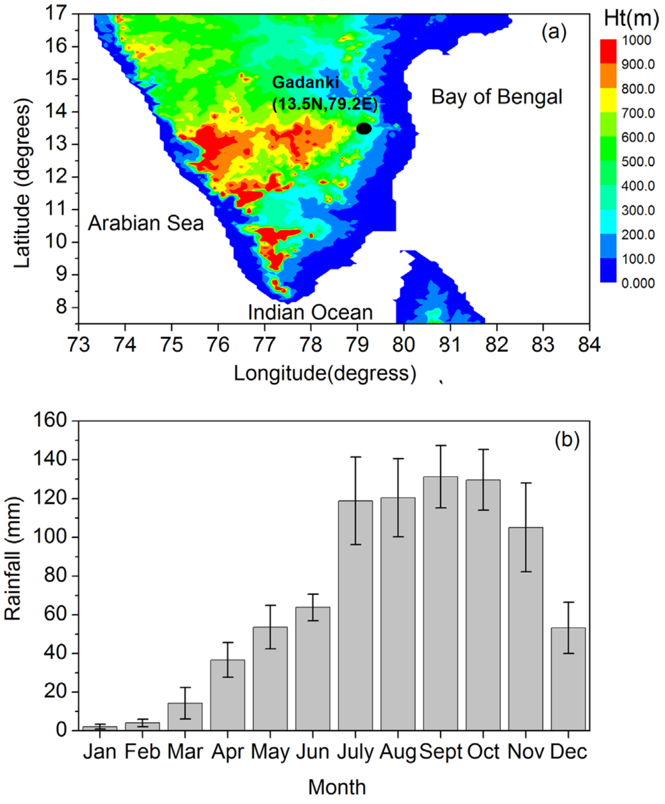

Fig. 1. (a) Topography map showing the location of Gadanki. (b) Climatological mean rainfall along with standard deviation (vertical bars) observed using rain gauge located at Gadanki.

2. Data

2.1. Radiosonde

GPS radiosonde balloon flights were carried out with Väisälä RS-80 (April 2006 to March 2007), RS-92 (from 17 July 2006 to 31 August 2006) and Meisei (May 2007 to November 2012) on each day over Gadanki from April 2006 to November 2012 around 1730 h IST (IST=UT+0530 h). Note that we have used three different sondes, initially Väisälä RS80, later for short period Väisälä RS-92 and then Meisei. However, note that there is no difference in the wind and temperature measurements between these three different sondes though some differences are noted in water vapor measurements. Since we are using only wind and temperature