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Observations of the intraseasonal oscillations over two Brazilian low latitude stations: A comparative study

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ABSTRACT

A comparative study of intraseasonal oscillations (ISO) in the period range 20–110 days is carried out in the mesosphere and lower thermosphere (MLT) zonal wind at two low latitude stations, Cariri (7.4°S, 36.5°W) and Cachoeira Paulista (22.7°S, 45°W) located far from the convective anomaly region. Considerable seasonal and interannual variability is observed. The ISO in the MLT and lower atmosphere are found to be well correlated during winter and spring indicating a coupling of the atmospheric regions through the ISO. On the other hand, relatively less correlation during summer and fall may suggest a dominance of the in situ excitation of the ISO in the MLT relative to the lower atmospheric contribution. The correlation between the MLT and lower atmosphere is found to be a little higher at Cachoeira Paulista than Cariri. The ISO in the MLT shows good correlation between the two stations, but correlation is insignificant in the case of lower atmosphere. The ISO is most prominent in the upper troposphere, upper stratosphere and MLT. The waves responsible for communicating the ISO signature from the troposphere to the middle atmosphere in the tropics are believed to refract through mid-latitudes in course of their propagation. An evident height variation of the high amplitude ISO in the upper troposphere is observed with a clear annual oscillation at Cariri. The observed behaviors of the ISO at the present sites are discussed in the light of plausible physical mechanisms.

1. Introduction

The equatorial middle atmosphere exhibits a number of long period oscillations, e.g. semiannual oscillations (SAO), annual oscillation (AO), quasi-biennial oscillations (QBO) which control the propagation of various atmospheric waves by modifying the dynamical condition of the ambient atmosphere (Burrage et al., 1996; Guharay et al., 2009, 2014a). Intraseasonal oscillations (ISO) constitute another class of relatively lower period oscillations first observed in the mesosphere and lower thermosphere (MLT) by Eckermann and Vincent (1994) within the period band 10–100 days using medium frequency (MF) radar observations at Christmas Island (2°N, 157°W). As the ISO are actually a manifestation of the large scale zonal circulations they control the dynamics of the zonally propagating waves in the middle atmosphere by influencing the mean background state.

Eckermann and Vincent (1994) noted remarkable similarity between the ISO and the lower atmospheric Madden–Julian Oscillation (MJO) as reported by earlier investigators (Madden and Julian, 1971, 1972). They also suggested that the intraseasonally modulated lower atmospheric gravity waves reaching the mesosphere might cause MLT-ISO in the zonal wind due to dissipation indicating a strong linkage of the lower and middle atmosphere through the ISO. Later, Eckermann et al. (1997) argued that convectively generated gravity waves and nonmigrating diurnal tides are modulated by the convective ISO and carry the ISO signature to the MLT from the lower atmosphere. A dominant role of the diurnal tide in causing the MLT-ISO was also supported by other investigators (Lieberman, 1998; Isoda et al., 2004; Kumar et al., 2007). With the help of general circulation model simulations Miyoshi and Fujiwara (2006) explained that interaction of Kelvin waves and diurnal tides (migrating and nonmigrating) with the background wind can drive the MLT-ISO in the zonal wind.

The MJO (consists of symmetric zonal circulation about the equator) in the equatorial troposphere is caused by enhanced convective activity near the Indian Ocean-western Pacific region (Madden and Julian, 1971). The equatorial dominant convective anomaly over the Indian Ocean propagates eastwards towards western Pacific and central Pacific Ocean with diminishing strength and ends near the eastern Pacific Ocean (Madden and Julian, 1972). The MJO can be considered as a mixed mode of Rossby and Kelvin waves near source region and an eastward

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propagating Kelvin wave away from the source (Madden and Julian, 1994).

The tropospheric ISO (consists of symmetric, asymmetric and off-equatorial zonal circulation) cannot propagate directly to the MLT region owing to small phase speed rather they modulate the lower atmospheric waves which communicate the ISO to the MLT from the troposphere on dissipation in the MLT (Eckermann et al., 1997). There are two possible ways described in the literatures through which the ISO modulated waves can reach the middle atmosphere. Kumar and Jain (1994) argued that westward propagating Rossby waves can propagate directly to the upper stratosphere to cause the ISO signature over the Indian sector. On the other hand, Ziemke and Stanford (1991) suggested that the tropospheric Rossby waves associated with the ISO propagate towards mid-latitudes and reach the stratopause at equatorial latitudes in the Indian Ocean-western Pacific Ocean indicating a refraction of the waves. Using a modeling study Salby et al. (1994) demonstrated refraction of Rossby waves between low and mid-latitudes similar to the previous study.

Using radar wind observations at Jakarta (6°S, 107°E), Pontianak (0°N, 109°E) and Christmas Island, Isoda et al. (2004) concluded that the mesospheric ISO is actually a variation of the zonal mean flow which was supported by other studies (Pancheva et al., 2003; Rao et al., 2009). Of late, using MF radar observations at Tirunelveli (8.7°N, 77.8°E), Kumar et al. (2007) reported ISO feature in two period bands, i.e. 50–70 days and 20–40 days indicating a potential contribution of the atmospheric tides to the ISO. Recently, Rao et al. (2009) studied the MLT-ISO with wind observations using radars distributed over various equatorial locations around the globe and reported a significant role of convection on the longitudinal variability of the ISO. Using meteor radar wind observations at Tirunelveli (8.7°N, 77.8°E) and Kolhapur (16.8°N, 74.2°E), Rokade et al. (2012) observed a decrease of the correlation of the MLT-ISO and convective ISO with latitude.

Most of the earlier studies related to the ISO described above were carried out near the convective anomaly source region, i.e. the Indian Ocean-western Pacific sector. Until now observations of the simultaneous ISO in the lower and middle atmosphere from the South American sector are very rare. Also latitudinal behavior of the MLT-ISO has not been investigated at all extensively. In the present work we have carried out a comparative study of the MLT-ISO between two Brazilian stations, i.e. São João do Cariri (7.4°S, 36.5°W) (hereafter referred to as CA) and Cachoeira Paulista (22.7°S, 45°W) (hereafter referred to as CP) with more than two years of simultaneous observations using meteor radar zonal wind. Behavior of the lower atmospheric ISO and its relationship with the MLT-ISO are also looked into with respect to convection and zonal wind variability.

2. Observational database

The present study is carried out using the following database covering the period 31st May, 2004 to 4th August, 2006 when data gaps in the meteor winds are minimum at the two observational stations, i.e. CA and CP.

2.1. Meteor radar

The meteor radar systems installed at CA and CP are SKiYMET type radars operating at a frequency ~35.24 MHz. They transmit peak power of ~12 kW and pulse width ~13 μs. For transmission they use one three-element Yagi antenna. For receiving the meteor backscattered signal they utilize five two-element Yagi antennas aligned along two orthogonal baselines with one center antenna common to both. Received echoes from the meteor trails are used to estimate the echo range, angular position and horizontal wind components. Details of the analysis procedure for estimating the wind velocity components from the obtained echoes can be found in the available literature (Hocking et al., 2001). We have used zonal and meridional winds with temporal and vertical resolutions of 1 h and 3 km, respectively in the vertical range 81–99 km for the present work during aforementioned total period of 796 days. Small data gaps are filled by linear interpolation.

2.2. ERA-Interim data

Daily ERA-Interim reanalysis data is provided by the European Center for Medium-range Weather Forecasts (ECMWF) on a latitude–longitude grid of $0.5 \times 0.5^{\circ}$ which is utilized for the two observational stations. The zonal wind data available at 37 pressure levels within 1–1000 mb, i.e. 0–48 km approximately, is used for studying the ISO in the Troposphere–Stratosphere (TS) region.

2.3. Outgoing longwave radiation (OLR)

OLR data obtained from the National Center for Environmental Prediction (NCEP) is used as a proxy for convective activity. Low OLR values are considered to be due to deep convective clouds. The OLR data available on a latitude–longitude grid of $2.5 \times 2.5^{\circ}$ is chosen at closest grid point to the observing sites.

We have utilized daily mean values of the available database for studying the ISO characteristics in this paper.

3. Results

Seasonal scale oscillations may cause unwanted aliasing in the ISO band (20–110 days) because of their large amplitude at various times. Therefore to verify their influence we have first determined the first six harmonics of the AO components, i.e. 365, 182.5, 121.6, 91.2, 73 and 60.8 days using superposed epoch analysis as described by earlier investigators (Pancheva et al., 2003; Guharay et al., 2012) and removed them from the original data to obtain the residual data free from annual harmonics.

In order to compare the dominant components in the original and residual winds in the MLT we have carried out a Lomb–Scargle analysis over the observational span at CA and CP. The normalized power spectra in the zonal and meridional components are shown in Fig. 1a–h. A dominant component of period ~60 days in the original zonal wind at CA is found, but it is not observed in the residual wind implying 6th annual harmonic. Another oscillation of period ~120 days is very evident in the original zonal and meridional winds spectra at CP which is absent in the residual wind spectra suggesting 3rd annual harmonic. It is noteworthy to mention that both (3rd and 6th) annual harmonics are significantly stronger than the rest of the existing components. In the residual zonal wind more oscillation components are observed in the band 20–70 days. Another oscillation in the residual zonal spectra peaking near the period of ~100 days in the lower and upper MLT is prominent. In general, oscillation components are found to be prominent at low and mid-MLT. It should be noted that the meridional wind spectra in the residual wind over both stations do not reveal any notable peak unlike the zonal wind spectra consistent with the ISO characteristics. Therefore in the following sections we will only consider the zonal wind. Furthermore, since we have found considerable influence of the annual harmonics in the horizontal wind spectra subsequent analyses in this paper are carried out with the residual wind to consider only intraseasonal oscillations in the period band 20–110 days.