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Intraseasonal oscillation (ISO) in the MLT zonal wind over Kolhapur (16.8° N) and Tirunelveli (8.7° N)

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Abstract. Simultaneous observations of the mean zonal winds at 88 km obtained by the medium-frequency (MF) radars at Kolhapur (16.8° N, 74.2° E) and Tirunelveli (8.7° N, 77.8° E) have been used to study the intraseasonal oscillation (ISO) in the MLT region. The influences of the intraseasonal variations in the lower tropospheric convective activity associated with the Madden-Julian oscillations on the latitudinal behavior of intraseasonal oscillations (ISO) of the zonal winds in the equatorial mesosphere and lower thermosphere (MLT) have been studied. The ISO activity in the lower tropospheric convective activity is examined by employing outgoing long wave radiation (OLR) as a proxy for deep convective activity occurring in the tropical lower atmosphere. The ISO activity in the zonal wind over TIR is more correlated with that in the convective activity compared to the ISO over KOL. The latitudinal and temporal variabilities of the ISO in MLT zonal winds are explained in terms of the intraseasonal variabilities in the convective activity.

Keywords. Meteorology and atmospheric dynamics (Middle atmosphere dynamics)

1 Introduction

The equatorial/low latitude region is the source region of many unique atmospheric processes that couple the entire atmosphere vertically. The circulation of the equatorial middle atmosphere is known to be dominated by a semi-annual oscillation (SAO) and a quasi-biennial oscillation (QBO) (Ebdon, 1960; Reed et al., 1961; Hirota, 1978; Hamilton, 1982; Garcia et al., 1997; Baldwin et al., 2001). Convectively generated waves such as Kelvin, Rossby-gravity and gravity waves play a crucial role in driving the QBO in the lower stratosphere and the stratospheric SAO (SSAO) (Lindzen and Holton, 1968; Dunkerton, 1979, 1997; Garcia, 2000), whereas Kelvin waves and gravity waves are considered to be important for driving the mesospheric SAO (MSAO) (Hirota, 1978; Dunkerton, 1982).

Zonal winds in the equatorial mesosphere and lower thermosphere (MLT) region are characterized by long-term variations such as the annual oscillation (AO) and the semiannual oscillation (SAO) (e.g., Vincent, 1993). In addition, the SAO amplitudes show biennial variations (e.g., Burrage et al., 1996). Wind oscillations caused by the ultrafast Kelvin waves (UFK) with 3–4 day period and quasi 2-, 5-, and 16-day wind oscillations have also been investigated (Tsutsumi et al., 1996; Riggin et al., 1997; Kovalam et al., 1999; Yoshida et al., 1999; Isoda et al., 2002; Sridharan et al., 2003; Mota Lima et al., 2008). Besides these oscillations, the MLT zonal winds also undergo variations with periods between the seasonal cycle and planetary-scale wave periods (periods ranging from 20 to 100 days), which have been termed as the intraseasonal oscillation (ISO), first reported by Eckermann and Vincent (1994) from Christmas Island (2° N, 150° W).

In the equatorial troposphere, intraseasonal variabilities in the zonal wind velocity and tropical rainfall are observed. The Madden-Julian oscillation (MJO) of this kind is characterized by large-scale convective anomalies that are mostly confined in the region between the Indian Ocean and the western and central Pacific (Madden and Julian, 1971, 1972; Zhang, 2005). The MJO has been studied extensively

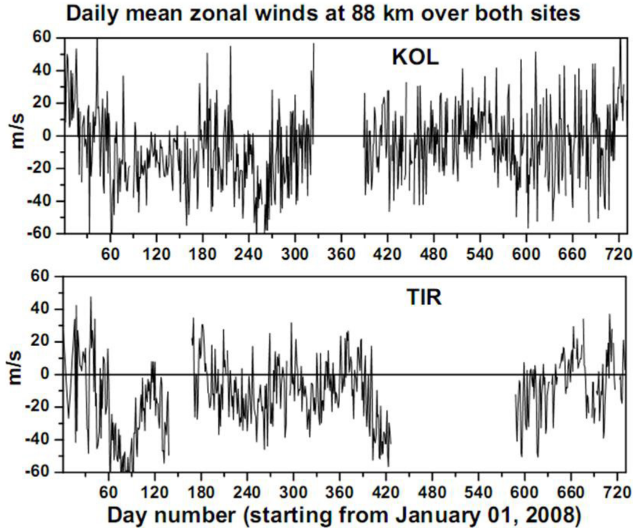

Fig. 1. Time series of daily mean zonal winds at 88 km altitude over Kolhapur (KOL) (top plot) and Tirunelveli (TIR) (bottom plot) for the observational period 1 January 2008–31 December 2009.

because of its role in influencing the weather and climate system (Lau and Chan, 1985; Nakazawa, 1986; Knutson and Kutzbach, 1986; Hendon and Salby, 1994; Madden and Julian, 1994; Matthews, 2000; Lau and Waliser, 2004; Zhang, 2005, and references therein). The studies of ISO over tropical Indian stations showed that the wind variabilities in the intraseasonal time period are diminished above tropopause and reintensified at the upper stratospheric heights (Nagpal and Raghavarao, 1991; Ziemke and Stanford, 1991; Nagpal et al., 1994; Kumar and Jain, 1994). Ziemke and Stanford (1991) explained this behavior of ISO activity in terms of tropical Rossby waves that refract to mid-latitudes near the tropopause then back to tropical latitudes near the stratopause.

Eckermann and Vincent (1994), Eckermann et al. (1997), Lieberman (1998), Isoda et al. (2004), Miyoshi and Fujiwara (2006), Kumar et al. (2007), Sridharan et al. (2007) and Rao et al. (2009) reported that the ISO periods observed in the zonal winds of the MLT region are similar to the MJO periods and suggested that the intraseasonal cycles in the tropospheric convection associated with the MJO modulate the intensity of the upward propagating gravity waves, non-migrating diurnal tides and ultra fast Kelvin waves and that these induce intraseasonal variations in the MLT region zonal winds through wave induced driving of the mean flow (when they either dissipate or break).

The above mentioned observational studies on the ISO activity in MLT region are pursued using the data of radars situated in the equatorial region (close to the equator i.e., 10° S–10° N). Simultaneous data obtained from the network of radars situated at the low latitude sites Kolhapur (KOL) (16.8° N, 74.2° E) and Tirunelveli (TIR) (8.7° N, 77.8° E) during the period from January 2008 to December 2009 provide an opportunity to study the latitudinal variation of the ISO of the zonal winds in the low latitude MLT region. The two sites are located almost at the same longitude but at different latitudes. In the present work, we attempt to understand the latitudinal nature of the ISO in low latitude MLT region and its relation to the intraseasonal variability of convective activity associated with the MJO in the troposphere.

2 Data

In the present study we have utilized the data obtained from the MF radars operated at KOL and TIR. The radar system at KOL is very similar to the one installed at TIR (8.7° N, 77.8° E), India (Rajaram and Gurubaran, 1998). Both the MF radars are operating at 1.98 MHz frequency. The MF radar measures wind using the spaced antenna technique in the 68–98 km height range during day time. During night time, it measures wind in the 70–98 km height range. The MF spaced antenna technique provides reliable winds for synoptic studies of neutral air motions in the height range 84–94 km at time scales of greater than 12 h. The data acceptance rate is relatively high at heights above 84 km with largest acceptance rate around 88 km. Winds are recorded every 2 min at 2 km height intervals (for further details, see Vincent and Lesicar, 1991). The wind data with two minutes time interval are averaged to compute hourly mean winds. The daily mean values were calculated by averaging hourly data for those days having number of data points more than 18 points. The days with number of hourly data points less than 18 were not considered.

The outgoing long-wave radiation (OLR) data (obtained from the National Oceanic and Atmospheric Administration – National Centers for Environmental Prediction (NOAA-NCEP)) has been used as a proxy for deep tropical convection (Hendon and Woodberry, 1993), to study the nature of the ISO activity in the lower tropospheric convection. The OLR data are indicators of cloud top heights. Very high and cold clouds (low OLR) at tropical latitudes are presumed to be associated with deep convection.

3 Results and discussion

3.1 Behavior of the ISO in zonal wind at 88 km height

The time series of daily mean zonal winds determined from the observations made by both the radars at a height of 88 km for the period of January 2008–December 2009 are shown in Fig. 1.

The quality of data is very poor during the observation periods, with day numbers in the range 324–387 at KOL and days 139–167 and days 427–587 at TIR and we have shown gaps for those particular periods. In this work, we

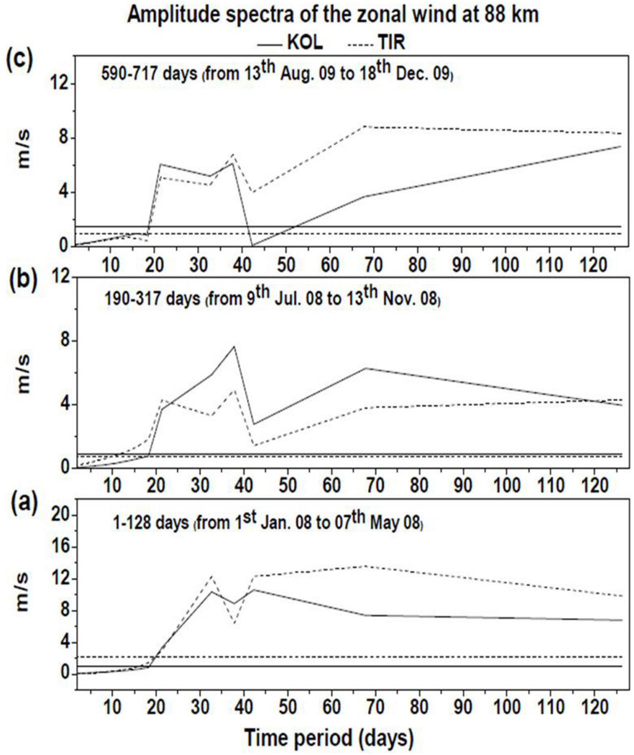

Fig. 2. Amplitude spectra of the daily zonal winds at 88 km over two sites Kolhapur (KOL) and Tirunelveli (TIR) for the three time intervals **(a)** 1–128 days, **(b)** 190–317 days and **(c)** 590–717 days. The horizontal lines represent the 95 % confidence levels.

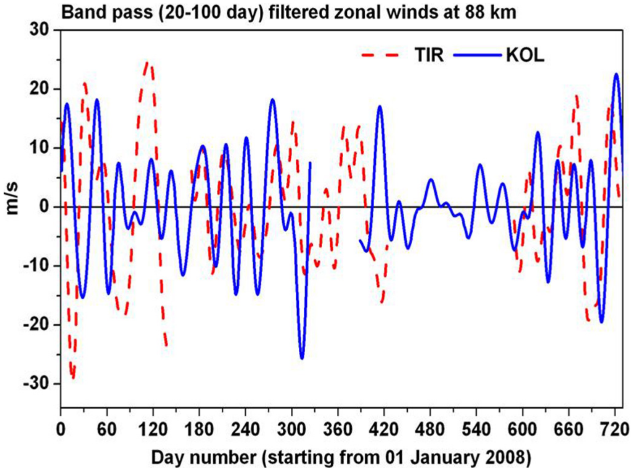

Fig. 3. Band pass (20–100 days) filtered daily zonal winds at 88 km observed at Kolhapur (KOL) and Tirunelveli (TIR) for the observational period 1 January 2008–31 December 2009.

have chosen to consider the daily mean zonal winds at 88 km for studying the ISO.

The mesospheric semiannual oscillation (MSAO) is clearly evident over both the sites, with westward flow during the equinoxes and eastward flow during the solstices. Also wind variabilities in intraseasonal time scale can be seen clearly. In order to examine dominant periods of time variations of the zonal winds in the intraseasonal time scale, a spectral analysis of zonal winds at 88 km was performed whose results are shown in Fig. 2a–c. From the whole data set, three data segments have been chosen corresponding to different time intervals in which data from both the stations are available, namely, days 1–128 (1 January 2008–7 May 2008) (128 data points), days 190–317 (9 July 2008–13 November 2008) (128 data points) and days 590–717 (13 August 2009–18 December 2009) (128 data points), and a Fast Fourier transform (FFT) is applied to each data segment to check the presence of dominant periodicities in different time intervals. The 95 % confidence levels for both the stations are shown. To test the statistical significance of the spectral amplitude (Rk), we have used a method in which the probability “p” that the ratio $\mathrm{Rk}^2/\sum \mathrm{Rk}^2$ exceeds a parameter “g” is given by $p = [m(1-g)^{m-1} +$ higher order terms] (here, $\sum \mathrm{Rk}^2 = 2/N \sum (\mathrm{Xi} - \mathrm{X\ mean})^2$), the summation on the left hand side runs from $k = 1$ to m and that on the right hand side runs from $i = 1$, N, the number of points; $m = N/2$. The error introduced in neglecting the higher order terms is only 0.1 % for $p = 0.05$ (95 % confidence level). Therefore, the parameter g (for $p = 0.05$) can be calculated from the relationship, $p = m(1-g)^{m-1}$. The parameter gk is given by $gk = \mathrm{Rk}^2/\{t2/N \sum (\mathrm{Xi} - \mathrm{X\ mean})^2\}$. If $gk > gp = 0.05$ (for 95 % confidence level), the amplitude is 95 % significant.

Since our main interest is to study intraseasonal oscillations, we now concentrate on the oscillations in the period range 20–100 days. During the time interval 1–128 days (Fig. 2a), dominant peaks around day number 32 and 42 are observed over both the stations KOL and TIR. A peak around the 67 day is also observed over TIR. The 32 and 42 day oscillations are relatively strong over TIR compared to KOL during this interval. During the interval 190–317 days (Fig. 2b), oscillations with the time period around 37 and 67 days are observed over both the stations and are dominant over KOL compared to TIR. A weak oscillation of time period around 21 days is also observed over TIR. During the interval 590–717 days (Fig. 2c), again a dominant peak is observed around 37 days and a peak around 21 days is also evident over both the stations. In addition to this, a peak around the 67 day is observed over TIR. The 37 and 67 day oscillations are strong over TIR and 21 day oscillation is relatively strong over KOL during this interval. From Fig. 2a–c, it can be noticed that the ISO activity with time period around 67 days is observed during all the time intervals i.e., 1–128 days and 190–317 days and 590–717 days, whereas a 37-day and 21-day activities are dominant during the intervals 190–317 days and 590–717 days and oscillation with 42 and 32 days are observed during the interval 1–128 days.

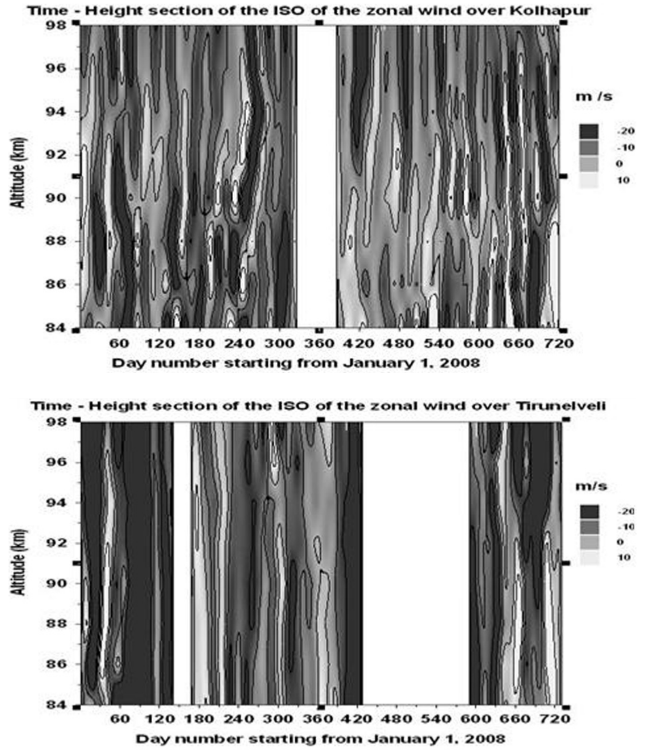

Fig. 4. Time-height sections of the ISO of the zonal winds ($\mathrm{m\,s^{-1}}$) over Kolhapur (KOL) and Tirunelveli (TIR) for the observational period 1 January 2008–31 December 2009.

By applying a filter with band-pass of 20–100 days, fluctuations in the period range 20–100 days in the daily mean zonal winds at 88 km height were extracted and are shown in Fig. 3. As can be seen in Fig. 3, during the observational period days 1–128 (January 2008 to May 2008), the ISO activity in the 60–70 day period band is dominant over TIR and 30–40 day oscillation are dominant at both sites. The observation period days 190–317 (June 2008 to February 2009) is dominated by both 30–40 day and weak 60–70 day ISO activity at both sites and for the period 590–717 (August 2009 to December 2009), 60–70 day activity is dominant at TIR. Also, 20–30 days and 30–40 days activities are dominant over both the stations. The results from this exercise reveal the similarity of 20–30 day and 30–40 day ISO variations over both sites during the observational period days 190–317 and days 590–717, whereas 60–70 day ISO activity is not similar during the observational period days 1–128 and 590–717. The ISO activity at MLT heights is relatively more prominent over TIR as compared to other station KOL and ISO over TIR and KOL is not correlated well during most of the time in all time periods except few occasions.

Figure 4 shows the height-time contours of the ISO amplitudes (20–100 day filtered zonal winds) of the zonal winds over KOL and TIR. It can be observed from the Fig. 5 that the ISO over both the stations are not correlated well.

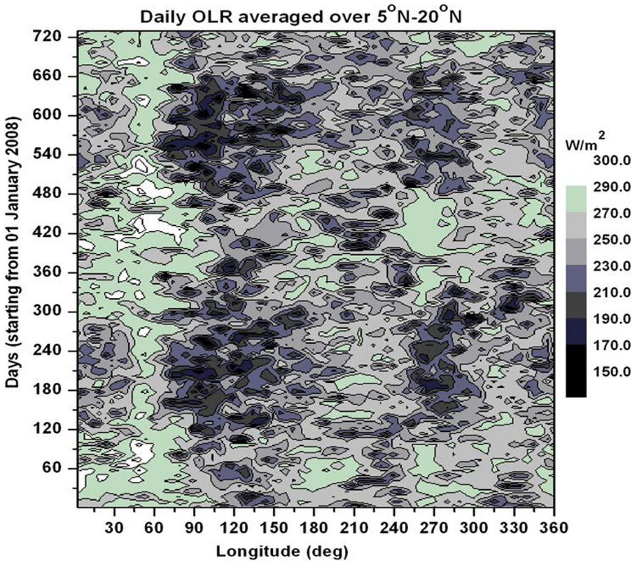

Fig. 5. Time–longitude cross sections of the OLR ($\mathrm{W\,m^{-2}}$) averaged over 5° N–20° N for the observational period 1 January 2008–31 December 2009.

3.2 ISO in the lower tropospheric convective activity

Figure 5 depicts the time-longitude behavior of OLR averaged over 5° N–20° N. OLR values less than 190 $\mathrm{W\,m^{-2}}$ represent deep convective activity. The deep and broad convective clusters are present mainly over the 70° E–180° E longitude sector and relatively weak convective activity is observed around 20° E and 270° E regions and the remaining regions are convectively quiescent. The contours over the 70° E–180° E longitude sector tilt slightly towards the right or towards the left during certain times with increasing or decreasing longitude indicating an eastward or a westward motion of the convective clusters.

It can be noticed clearly in Fig. 5 that there is a variation in the convective activity on the intraseasonal time scale over the 70° E–180° E longitude region that is evident without any filtering of OLR data. The convective clusters with nearly 60–70 day variability can be observed during the observation periods 1–180 days, 300–480 days and 600–730 days (the convective centers are separated by specified number of days) and 30–50 day variability can be observed during the observational period 180–320 days. Convective clusters with 20–35 day variability are also observed during the period 480–640 days.

In order to know the exact dominant periods of time variations of the OLR in the intraseasonal time scale, the daily OLR data at 7.5° N and 17.5° N are averaged over the 70° E–80° E longitude region and spectral analysis is performed on the averaged OLR data in the same three time intervals (days 1–128, days 190–317 and days 590–717) for which a spectral analysis was earlier performed on the daily mean zonal wind (Fig. 2a–c) and results are shown in Fig. 6. The

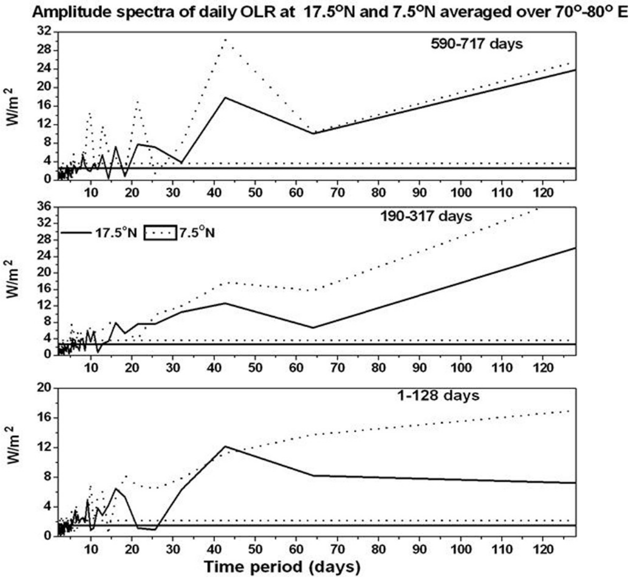

Fig. 6. Amplitude spectra of the daily OLR averaged over 70° E–80° E and 5° N–20° N region for the three time intervals: **(a)** 1–128 days, **(b)** 190–317 days and **(c)** 590–717 days. The horizontal lines represent the 95 % confidence levels.

95 % confidence levels are also indicated in each of the panels. A dominant peak at 42 days over 17.5° N latitude region is observed during the time interval days 1–128, whereas the spectrum increases from a period of 25 days to higher periods continuously over 7.5° N latitude region. A strong ISO activity with a 42 day period is observed during the period 190–317 days over 7.5° N latitude region and the 42 wave activity is relatively weak over 17.5° N latitude region during the same period. During the remaining time interval 590–717 days, peaks around the period 42 day and 21 day are observed over both the latitude regions but the ISO over 7.5° N latitude region is relatively strong and ISO activity with time period above 60 days is also observed over both the latitude regions. From this exercise, we can infer that the convective activity and its ISO variability over 7.5° N region are relatively stronger compared to that over 17.5° N region. Now, we shall proceed to examine the influence of latitudinal variability in convective activity on the latitudinal nature of the ISO in MLT zonal winds by comparing the ISO in convective activity at the latitudes corresponding to respective radar locations with the ISO in zonal winds at 88 km.

3.3 Comparison of ISO in zonal winds at 88 km height with ISO in lower tropospheric convective activity at the respective radar locations

In Figs. 7 and 8, the OLR at 17.5° N latitude (over longitude sector 60° E–140° E) is compared with the ISO in zonal wind at 88 km over KOL (16.8° N, 74.2° E) and the OLR at 7.5° N latitude (over longitude sector 60° E–140° E) is compared with the ISO in zonal wind at 88 km over TIR (8.7° N, 77.8° E), respectively. The convective activity at 17.5° N latitude is strong only during the time intervals 150–300 days and 450–650 days and is weak during remaining periods, whereas convective activity is strong with dominant ISO activity at 7.5° N latitude during the entire observational period. During the observational periods days 1–128 and days 590–717, when convective clusters with 50–70 day variability are observed over the 7.5° N latitude region, the zonal winds over TIR also show strong 60–70 day variability, whereas ISO in zonal winds over KOL exhibit weak 50–70 day variability. It

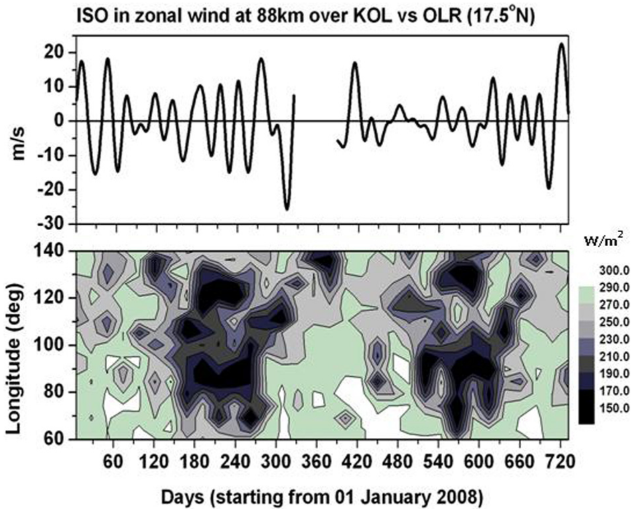

Fig. 7. Bottom panel shows OLR at 17.5° N latitude (over 60° E–140° E longitude) and top panel shows the ISO in zonal wind at 88 km over Kolhapur (KOL).

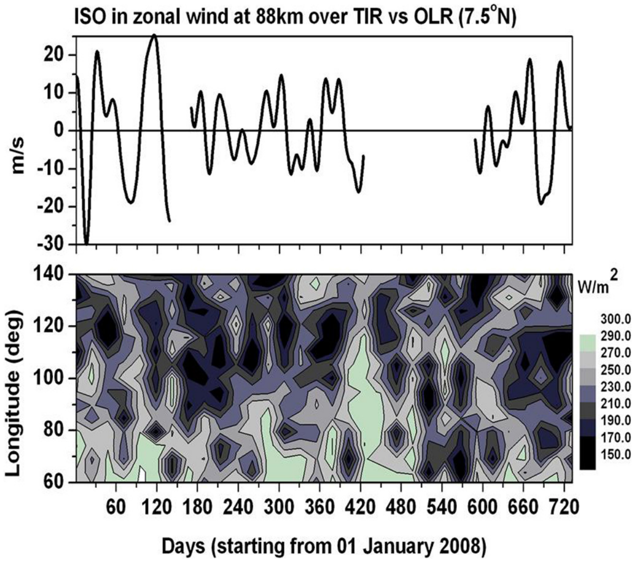

Fig. 8. Bottom panel shows OLR at 7.5° N latitude (over 60° E–140° E longitude) and top panel shows ISO in zonal wind at 88 km over Tirunelveli (TIR).

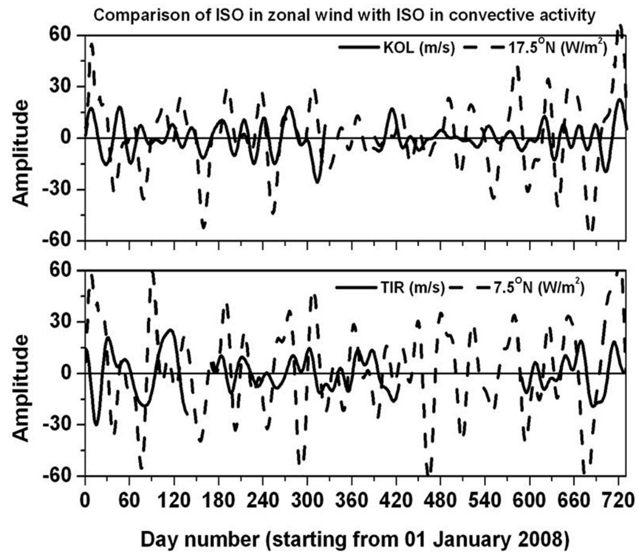

Fig. 9. Bottom panel compares the ISO in OLR at 7.5° N latitude (averaged over 70° E–80° E longitude) with ISO in zonal wind over TIR and top panel compares the ISO in OLR at 7.5° N latitude (averaged over 70° E–80° E longitude) with ISO in zonal wind at 88 km over KOL.

seems that the zonal winds over TIR, as compared with those over KOL, are influenced more by the 50–70 day convective activity. During the observational period 150–300 days, 20–30 and 30–40 day ISO variations in MLT zonal winds over both the stations are similar. One important thing to be noticed is that the ISO in MLT zonal winds over KOL is similar to ISO in MLT zonal winds over TIR during the observational periods 150–300 days (see Fig. 3) during which the convective activity at 17.5° N latitude region is also strong.

In Fig. 9, ISO in OLR at 17.5° N latitude (averaged over longitude sector 70° E–80° E) is compared with the ISO in zonal wind at 88 km over KOL (16.8° N, 74.2° E) and the ISO in OLR at 7.5° N latitude (averaged over longitude sector 70° E–80° E) is compared with the ISO in zonal wind at 88 km over TIR (8.7° N, 77.8° E). It can be observed from the Fig. 9 that the phases of the correlation between the ISO in zonal winds over KOL and ISO in OLR at 17.5° N latitude region are very poor but the ISO in zonal wind over TIR and ISO in OLR at 7.5° N latitude region are correlated well. It seems the eastward zonal wind tends to correspond to the lower OLR during some periods. But, the eastward phase of the ISO need not always be linked with lower convective activity because the westward phase of the ISO was also associated with the deeper convective activity during certain periods as reported in earlier works (Sridharan et al., 2007; Rao et al., 2009) on ISO. In addition, the direction of zonal mean winds in the MLT region depends on the phase of the SAO. So, the response of the zonal wind to forcing caused by the convectively modulated wave dissipation on the intraseasonal time scale might then depend on the phase of the SAO at those altitudes. The study of long-term variability of MLT winds by Sridharan et al. (2007) revealed the times of enhancement of the ISO amplitudes in zonal wind coincided with the times of large westward winds and this suggests that the ISO in zonal wind at least partly depends on the phase of the SAO. Even though the MLT zonal wind responds quite promptly to the ISO in the convective activity, the present observations indicate slight enhancement of ISO amplitudes (as seen in Figs. 1 and 3) during the westward phase of the MSAO.

An S-transform method (Stockwell et al., 1996) is also applied to both daily mean zonal winds at 88 km over TIR and KOL and to the OLR averaged over 70° E–80° E longitude region at 7.5° N and 17.5° N (at respective radar locations) latitudes to find out the temporal behavior of the ISO in both zonal wind and OLR. In Fig. 10, S-transform spectra of the zonal winds at 88 km over TIR and KOL are compared with that of the OLR. The ISO in zonal wind and OLR over TIR are strong with 20–40 day oscillations and oscillations with a period around 60 day and above, whereas the ISO activity in zonal wind and in OLR is relatively weak over KOL. The S-transform spectra of the zonal winds and OLR over TIR are not similar to that over KOL. The correlation between the ISO in zonal winds and the ISO in OLR over TIR is not evident clearly in S-transform spectra.

We have calculated cross-correlation functions (CCF) between ISO of the zonal wind and ISO of the OLR at the respective radar locations to understand the latitudinal dependency of the correlation between the zonal winds and OLR. In Fig. 11, the cross-correlation functions between the ISO in zonal wind and OLR at both the locations have been shown for the three time periods 1–128 days, 190–317 days, and 590–717 days. It can be observed from Fig. 10 that the maximum values of CCF between ISO in zonal wind and ISO in OLR over TIR during the observational periods 1–128 days, 190–317 days and 590–717 days are 0.4, 0.2 and 0.5 with lag in phase of about −12 days, −5 days and −12 days, respectively. On the other hand, the maximum values of CCF between ISO in zonal wind and ISO in OLR over KOL during the observational periods 1–128 days, 190–317 days and 590–717 days are 0.3, 0.1 and 0.6 with lag in phase of about 12 days, −1 day and 3 days, respectively. It can be understood from these observations is that the ISO in zonal winds and ISO in OLR over KOL are relatively less coherent (with CCF values around 0.3 and 0.1 during the periods 1–128 days and 190–317 days) except during the period 590–717 days (with CCF value around 0.6). The lag in phase is also not consistent during different observational periods. The common feature that can be understood is that the relation between the ISO in zonal wind and ISO in OLR over TIR are relatively more consistent compared to that over KOL.

The earlier results (Isoda et al., 2004; Rao et al., 2009) on longitudinal variability of ISO in MLT zonal winds showed that ISO in convective activity induce similar (same phase) ISO variations in MLT zonal winds in the longitudinal

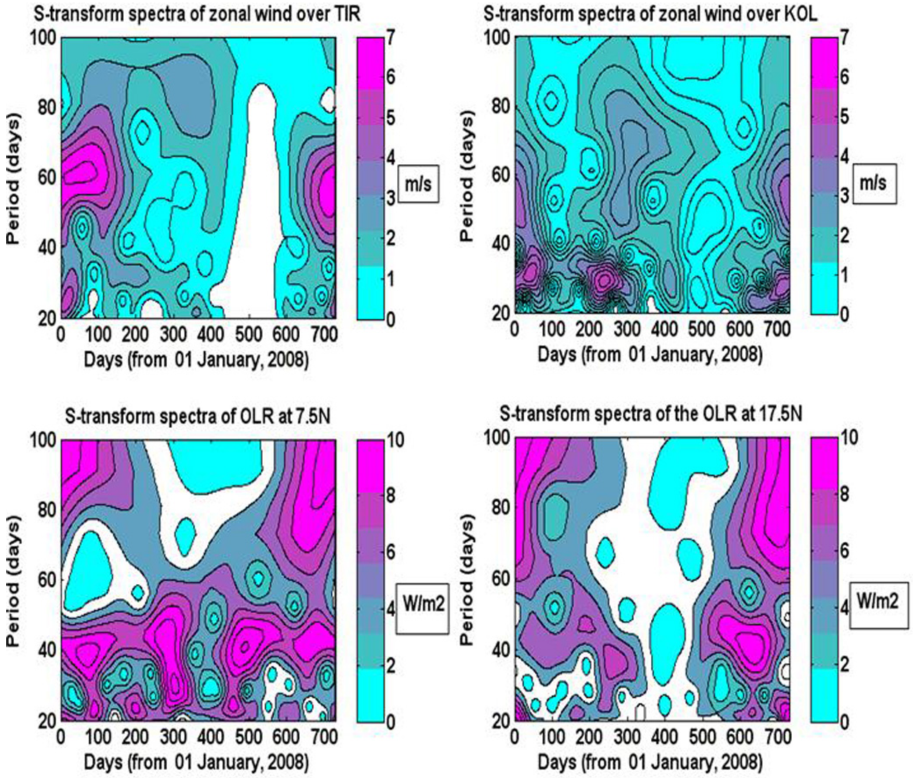

Fig. 10. Comparison of the ISO in zonal wind with ISO in convective activity.

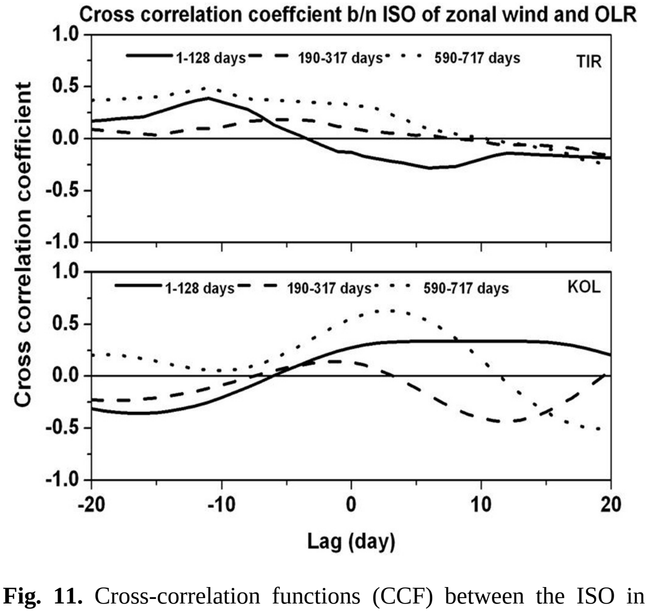

Fig. 11. Cross-correlation functions (CCF) between the ISO in zonal winds and the ISO in OLR, for three different time periods: **(a)** 1–128 days, **(b)** 190–317 days, **(c)** 590–717 days.

direction though the amplitudes of the ISO are different. In the present case, the ISO in zonal winds do not exhibit coherency in the latitudinal direction during certain time intervals. The following could be a plausible explanation for this latitudinal behavior of ISO in the MLT zonal winds. The zonal winds at tropospheric heights are expected to promptly respond to the local convective perturbations associated with the MJO. As the tropospheric ISO is a large scale wave disturbance with a small zonal propagation speed, it cannot propagate upward directly into the middle atmosphere. A spectrum of atmospheric waves is generated in the tropical troposphere owing to deep convection. Waves with slow phase velocities (slow Kelvin wave, Rossby-gravity waves) damp at lower heights while waves with high phase velocities (tides, UFK waves, gravity waves) could propagate up to high altitudes. As convection varies on the intraseasonal scale, the forcing caused by the wave dissipation/breaking varies with similar periods. The nature and amount of forcing at a particular altitude over a particular location depends on the background wind conditions, the strength of the lower tropospheric convective activity and the type and strength of the waves generated by the convective activity and their propagation directions. The atmospheric waves with different phase velocities break/dissipate at different altitudes and could cause similar ISO variations at different altitudes. Even though the MJO related convective signals are dominant only over the Indian ocean and western and central Pacific, the waves (especially non-migrating diurnal tides, planetary and equatorial waves) generated by this deep convective activity are of planetary scale and they could propagate zonally and vertically and could show their effect on the zonal mean circulation globally. But, the equatorial waves and small scale gravity waves decay rapidly away from the equator and could not propagate in the latitudinal direction (Matsuno, 1966; Yang et al., 2006; Garcia et al., 2005). That means the spectrum of waves that could cause for driving the ISO in MLT zonal winds are stronger close to the equator. So, we may expect a stronger ISO in MLT zonal winds at the locations close to the equator. The measurement sites are not many enough in latitudinal direction to make better assessment of the distribution of ISO and the distribution of waves participating in driving the ISO.

4 Summary and conclusions

The present work is focused on studying the latitudinal behavior of intraseasonal oscillations of the zonal wind in the low latitude MLT region, and its relation to the lower tropospheric convective activity, using data on zonal winds obtained by two low latitude MF radars at KOL (16.8° N, 74.2° E) and TIR (8.7° N, 77.8° E). The zonal winds at 88 km over both the sites i.e., KOL and TIR do not exhibit similar ISO in different time period bands (around at 20–30 day, 30–40 day) except few times and 60–70 day ISO activity is stronger over TIR as compared to KOL. The convective activity over 7.5° N latitude region and the zonal winds over TIR exhibit similar ISO variations, whereas convective activity over 17.5° N latitude region is weak and do not show any similarity with the ISO in zonal winds over KOL during some periods. The reason for this could be the confinement of the convectively generated equatorial waves in the region close to the equator.

The latitudinal dependency of the ISO at MLT heights revealed stronger ISO activity in the regions where convective activity is strong. In order to estimate the role of equatorial waves, gravity waves and tides in the excitation of intraseasonal oscillation of the zonal wind, the intraseasonal variabilities of the waves and tides, and their latitudinal variabilities, need to be studied extensively using long-term data provided by satellites and a network of radars. This will be the subject of our future study.

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