

Comparative study of MLT mean winds using MF radars located at 16.8°N and 8.7°N

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The main aim of the paper is to describe mesosphere and lower thermosphere (MLT) wind field observed between June 2000 and May 2002 by medium frequency (MF) radars at two locations near the equatorial region and at tropical latitude. We have presented and compared observations of mean horizontal winds in the mesosphere and lower thermosphere (MLT) region over Kolhapur (16.8°N, 74.2°E) and Tirunelveli (8.7°N, 77.8°E). Our analysis reveals annual oscillation in the zonal wind and semi-annual oscillation in the meridional wind over Kolhapur. On the other hand, results over Tirunelveli reveal semi-annual oscillation (SAO) in the zonal wind and annual oscillation in the meridional wind. Also we have observed enhanced magnitude of wind speed in spring equinox period of 2002 exhibiting the signatures of the quasi-biennial oscillation (QBO) over Tirunelveli.

1. Introduction

In recent years much attention has been paid to study the dynamics of the equatorial and low-latitude mesosphere and lower thermosphere (MLT) region. Number of medium frequency (MF) radars have been working at several places, and they are very useful in deriving numerous useful information about this less understood region (Vincent and Lesicar 1991; Fritts and Isler 1994; Rajaram and Gurubaran 1998). Atmospheric radars along with Lidars, are therefore, required at low and equatorial latitudes to continuously monitor the winds in these regions. These radars have generated enormous information on the dynamics of the middle atmosphere. Formation of the MLT radar network gave a new twist in co-ordinated studies and helped to make a better global coverage, thus contributing to the generation of global wind and tidal climatology (Kishore *et al* 2000).

Radio-wave probing of the MLT region using MF radars has been carried out by several groups during the last few decades. Due to the close collisional coupling between the neutral and ionized species, the spaced antenna drift measurements at these heights (80–100 km) have been considered to represent the bulk motion of the neutral gas (Gurubaran *et al* 2007; Patil *et al* 2007).

Different dynamical processes occur in the equatorial and low-latitude mesosphere and some of which are confined to this region where the Coriolis frequency becomes small to allow certain long-period wave modes. Waves of this kind are thought to contribute significantly through the complex wave-mean flow interactions to some of the observed variations in dynamical parameters such as the quasi-biennial oscillations (QBO) in the stratosphere (Veryard and Ebdon 1961; Reed *et al* 1965) and the semi-annual oscillations (SAO) (Reed 1965; Hirota 1978) in the middle atmospheric mean zonal wind (Andrews *et al* 1987;

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Rajaram and Gurubaran 1998 and the references therein). The dynamics of the MLT in the equatorial and low-latitude region due to the small Coriolis force is quite different to mid-latitudes, resulting in waves and dynamics which are unique in this region. These unique waves can contribute to QBO and SAO of the MLT winds. The QBO and SAO being related to each other are unique to the equatorial region and are attributed to momentum transport generated by planetary and gravity waves in the troposphere and stratosphere (Dunkerton 1979; Garcia and Sassi 1999; Buriti *et al* 2008). The equatorial MLT zonal winds are characterized by predominant semi-annual variability with westward winds during equinox and eastward winds during solstice (Vincent 1993; Garcia *et al* 1997). Small-scale gravity waves are believed to be responsible for the seasonal reversals of the zonal wind (Dunkerton 1982).

Keeping this in mind, data collected by MF radar in Kolhapur (16.8°N, 74.2°E) are compared with MF radar data in Tirunelveli (8.7°N, 77.8°E) in India. It is interesting to observe winds and waves over these locations since these two radars are aligned on almost same meridian and has small distance of about 800 km. The paper consists of the description of the mesospheric wind field as observed during two years by two different MF radars located near the equatorial region and at tropical latitude. These two radars are located in India and correspond to nearly same longitude but at different latitudes (8.7° and 16.8° North). Hence the comparative analysis would be of great interest giving results in the Indian longitude only. The results are compared, discussed and reported herein.

2. Observations and data analysis

In the present study, we have utilized the data obtained from the MF radars operated at Kolhapur and Tirunelveli. The radar system at Kolhapur is very similar to the one installed at Tirunelveli (8.7°N, 77.8°E), India (Rajaram and Gurubaran 1998). These MF radars are used for measuring horizontal winds in the mesosphere and lower thermosphere through the observations and analysis of D-region partial reflection echoes. The MF radars yield data on winds in the MLT region at heights between 68 and 98 km. The system details and the mode of operation are similar as already been described by Vincent and Lesicar (1991) and will not be repeated here. The system utilizes a full correlation analysis (Briggs 1984; Holdsworth and Reid 1995) to determine the wind field across the range of observation. A total of 730 full or partial days of data recorded at both stations between

June 2000 and May 2002 are considered in this study.

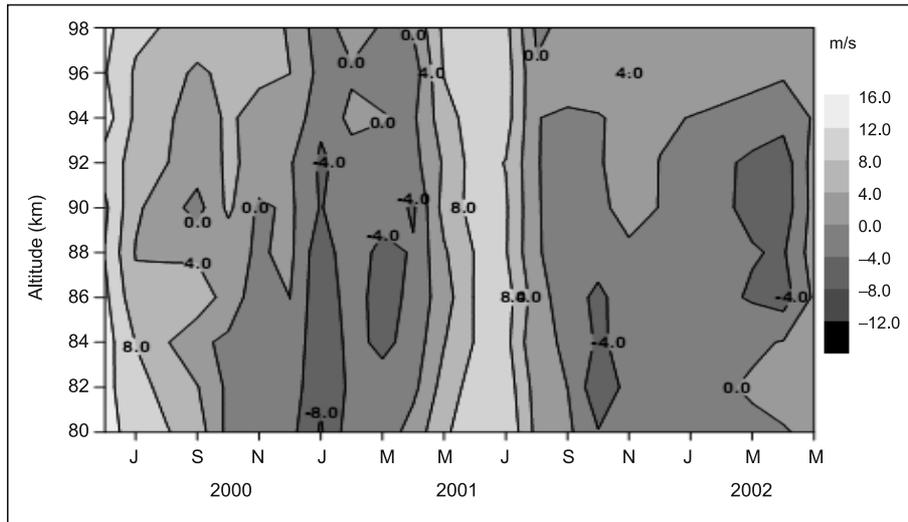
In particular, the two radars located at Kolhapur (16.80°N) and Tirunelveli (8.70°N) provide a valuable dataset for the study of detailed behaviour of seasonal variation of MLT winds in the northern tropical region over India. Although the time resolution of raw data is 2 minutes, we averaged data values for one hour. There are no noticeable numbers of data gaps during the period of observations. The daily mean values were calculated by averaging hourly data for those days having number of data points more than 18 points. The days during which number of hourly data points less than 18 were not considered. The data gaps formed in daily mean data were filled by linear interpolation between the neighbouring data points to calculate the monthly winds. These monthly values have been averaged for winter, summer, spring (March–April) and fall (September–October) equinoxes and the seasonal behaviour of the winds is studied.

3. Results

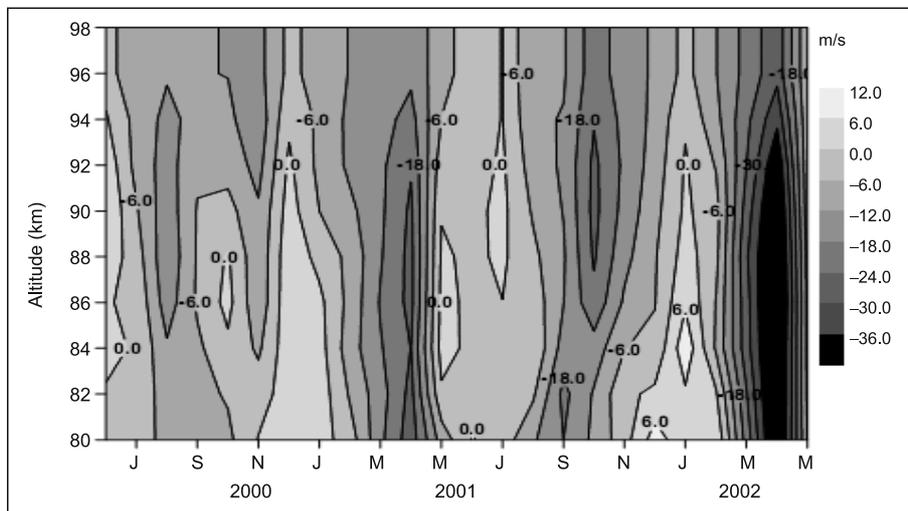
3.1 Zonal wind

The time-height cross-sections of monthly mean zonal winds from 80 to 98 km for 24 consecutive months from June 2000 to May 2002 for Kolhapur and Tirunelveli are shown in figure 1(a and b) respectively. The dark shaded area corresponds to westward winds in both the figures. In figure 1(a), (for Kolhapur) there have been westward flows observed during the winter and eastward flows observed during the summer periods. The flow becomes westward during October and ends at the end of April. There is a tendency for the flow to become eastward during May that ends in September. All these features seem to reveal an annual oscillation in the zonal wind. It is seen in figure 1(a) (Kolhapur) that the eastward flow during the fall equinox appears at higher altitudes above 94 km, whereas major westward flow appears in between ~84 and ~92 km during spring equinox. During the annual variability, an enhanced eastward flow during summer is an important feature revealed by the analysis. Gavrilov *et al* (2003) also observed similar feature. They have observed an additional maximum of eastward wind in summer above ~83 km in the mean zonal wind. Peak eastward flows of 10 ms^{-1} were observed during summers of 2000 and 2001. The westward flow had been relatively weaker during the equinox periods of 2000, 2001 and 2002.

In figure 1(b), westward flow is seen during each of the equinoxes and eastward flow during



(a)



(b)

Figure 1. Monthly mean zonal wind (a) over Kolhapur and (b) over Tirunelveli from June 2000 to May 2002. The dark shaded area corresponds to westward winds.

each of the solstices for Tirunelveli. An eastward regime begins during the month of May and the flow becomes westward again at the end of July. As stated by Rajaram and Gurubaran (1998), all these features are consistent with the SAO in the zonal wind. The westward flow during the spring equinoxes is larger compared to the flow during the fall equinoxes. Westward speeds in spring equinox 2002 are very much larger than that of 2001. We observed inter-annual variability in the westward flow during spring equinox. The maximum westward flow of $\sim 40 \text{ ms}^{-1}$ was observed in 2002 in contrast to westward flow of $\sim 25 \text{ ms}^{-1}$ in 2001. Burrage *et al* (1996), Rajaram and Gurubaran (1998) and Sridharan *et al* (2007) reported this variability as a manifestation of the QBO in the mesospheric zonal wind.

Altitude profiles of time-mean zonal winds for the four seasons (equinoxes and solstices) recorded from Kolhapur are shown in figure 2(a). Although there is inter-annual variability in the observed winds, the altitude variation of zonal winds for each season is consistent. The summer and winter curves in figure 2(a) reveal similar trend in their respective motions for both the years. During winter a clear transition in mean zonal wind was observed with westward speeds up to 94 km and eastward speeds above. During summer, both curves reveal time-mean eastward flow at all altitudes. During the spring equinox period 2001, the wind remains westward for all altitudes, whereas wind in 2002 had undergone change-over to westward direction between 84 and 95 km altitudes before becoming eastward again. Maximum wind speeds were

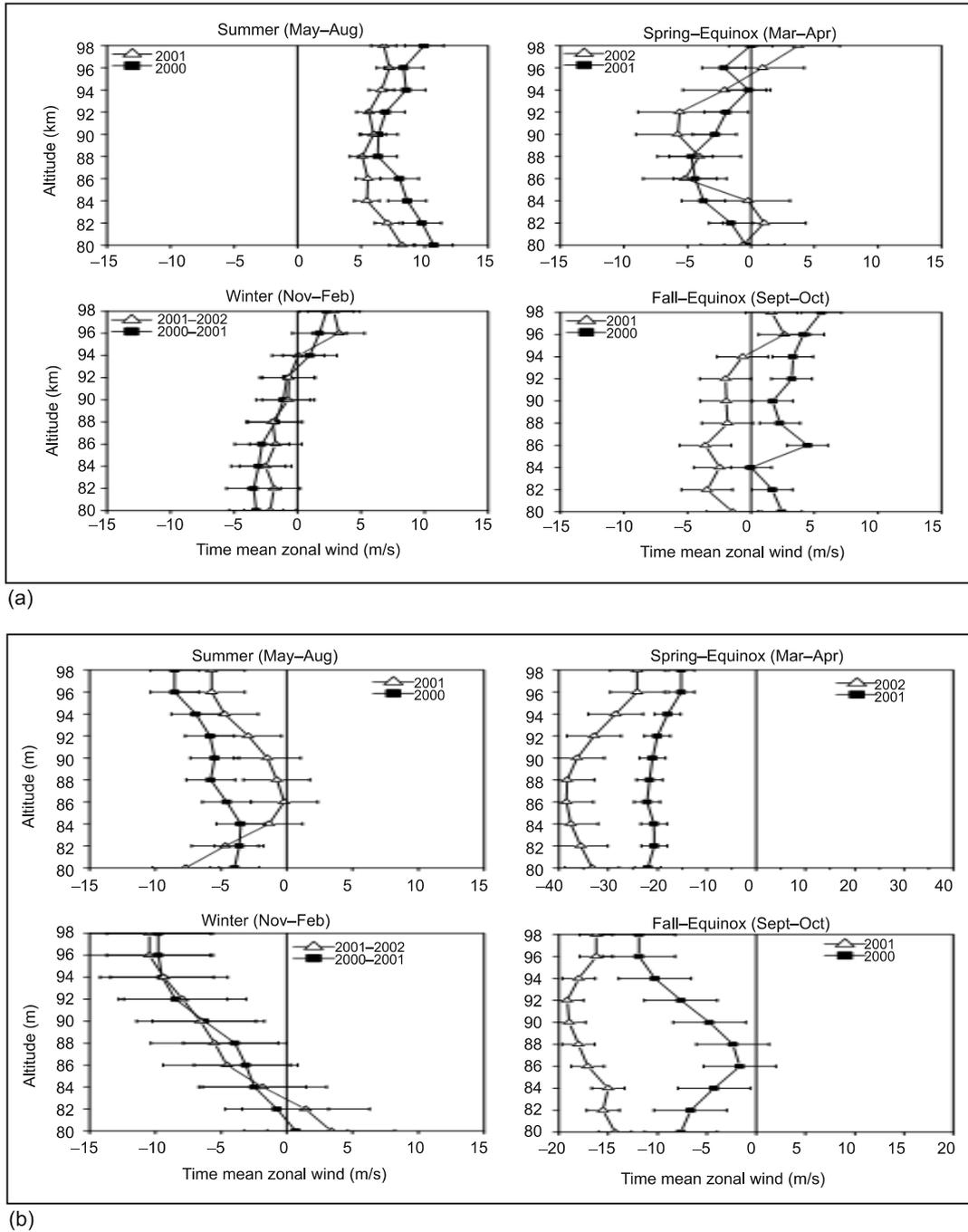


Figure 2. Vertical profiles of mean zonal winds (a) over Kolhapur and (b) over Tirunelveli. Top left: summer, top right: spring equinox, bottom left: winter, bottom right: fall-equinox. The positive velocity indicates an eastward flow.

observed at 88 km and 90 km in the year 2001 and 2002, respectively. The wind profiles for fall equinox period depicted in figure 2(a) show that the wind flows westward up to 94 km and becomes eastward above this in 2001. There has been net eastward motion for all altitudes during fall equinox period of 2000.

On the other hand, altitude profiles of time-mean zonal winds for the four seasons (equinoxes and solstices) recorded from Tirunelveli are shown

in figure 2(b). Large inter-annual variability is observed in the zonal mean winds for all seasons, but altitude dependence in winter is quite consistent. During the summer solstices in both the years, net westward flow was observed for all altitudes. Wind speed in year 2000 is larger than winds in year 2001. For both the years, winds in winter flow towards westward direction above about 82 km. Both the curves in winter are consistent with each other showing the maxima at

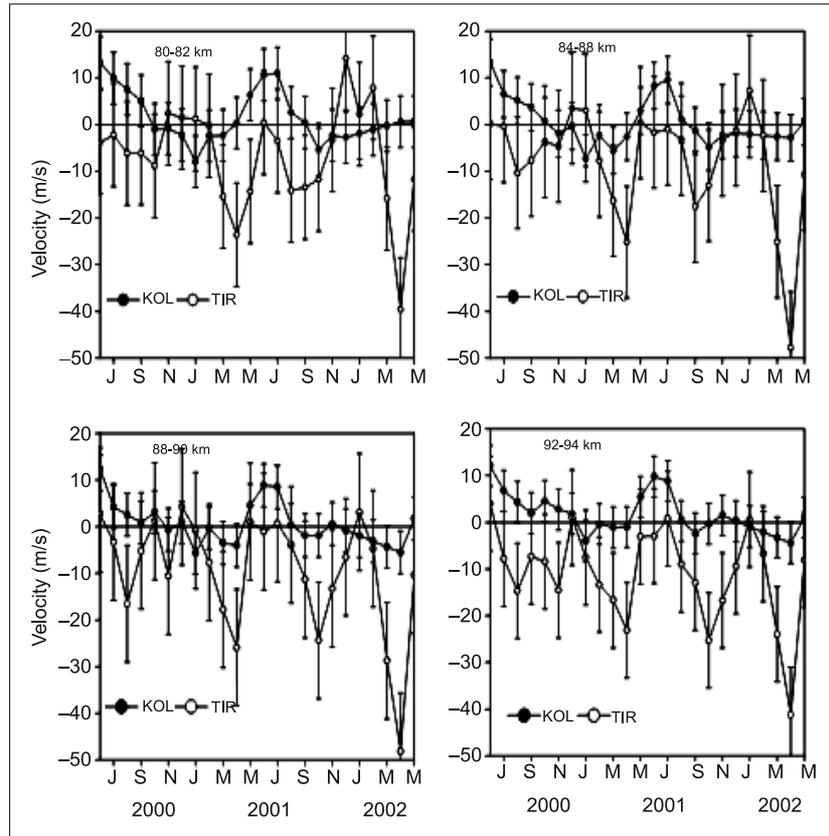


Figure 3. Monthly mean zonal wind averaged for different altitudes for both Kolhapur and Tirunelveli stations.

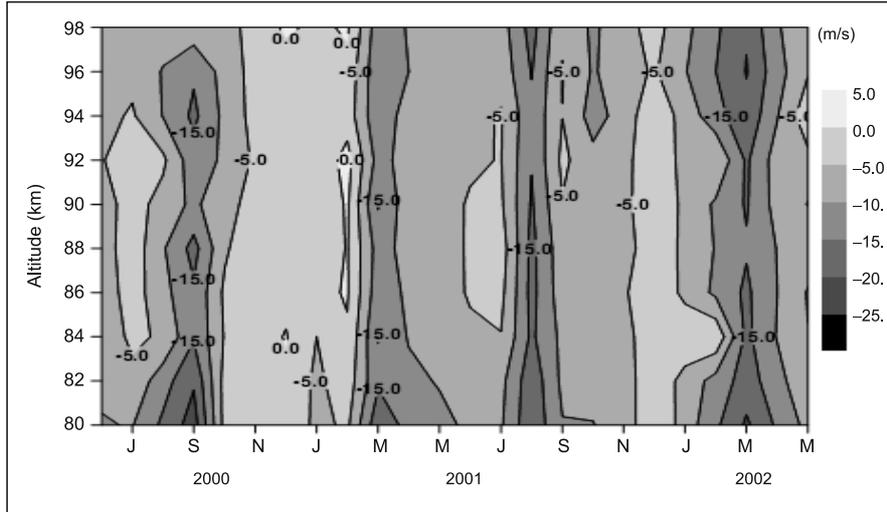
about 96 km. Below 82 km, wind flows in eastward direction in both years. During the spring equinox period, an overall motion was westward in both years. It is seen from the figure that the wind flow in 2002 was much larger than that of 2001. For 2002, maximum speed of $\sim 39 \text{ ms}^{-1}$ was observed at 88 km altitude whereas maximum speed of $\sim 22 \text{ ms}^{-1}$ was observed at 80 km during 2001 which is much smaller compared to 2002. During fall equinox period the wind profiles show net westward flow. Maximum wind speed of $\sim 20 \text{ ms}^{-1}$ was observed at 92 km for the year 2001 whereas maximum wind speed of $\sim 10 \text{ ms}^{-1}$ was observed at 96 km for the year 2000. Wind speeds for 2001 were larger than those for 2000 for all altitudes.

Monthly mean values of the zonal wind field between 80 and 94 km for both stations, Kolhapur and Tirunelveli, are shown in figure 3. Each curve in the figure represents the average value of the wind at heights shown. To facilitate comparison, we have grouped the curves into four separate sets for various altitudes. From the figure we observe two most distinct features namely, the annual variability of the zonal wind field at all heights over Kolhapur and the semi-annual variability over Tirunelveli and the pronounced magnitude of wind speed in spring equinox period of 2002 over

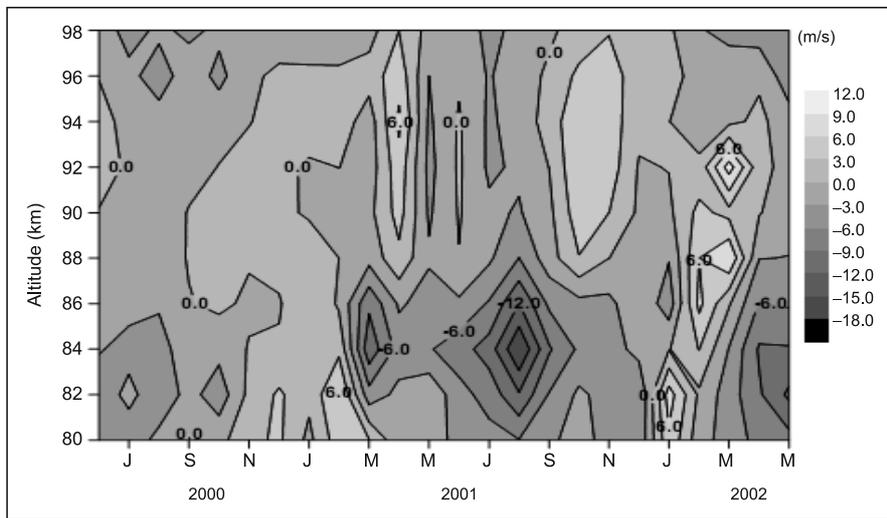
Tirunelveli exhibiting the signatures of the QBO in the mesospheric zonal wind. All the four sets for various altitudes exhibit nearly equal magnitudes of winds for all seasons over Kolhapur showing annual variation for all altitudes. Whereas curves in all sets for Tirunelveli show SAO. The pronounced wind values in spring-equinox of 2002 for all altitudes show signature of QBO for all heights.

3.2 Meridional wind

The time-height cross-sections of monthly mean meridional winds from 80 to 98 km for 24 consecutive months from June 2000 to May 2002 for Kolhapur and Tirunelveli are shown in figure 4(a and b) respectively. The dark shaded area corresponds to southward winds in both the figures. The contours in figure 4(a) for Kolhapur reveal that most of the time wind flows towards equator except in February 2001 where wind flows poleward from about 83 to 93 km. The mean equatorward wind speeds during spring were larger at all altitudes. The contours provided for Tirunelveli in figure (4b) shows equatorward flow during summer and poleward flow during winter. During winter the mean poleward wind speed in 2001 is smaller than poleward wind speed in 2002.



(a)



(b)

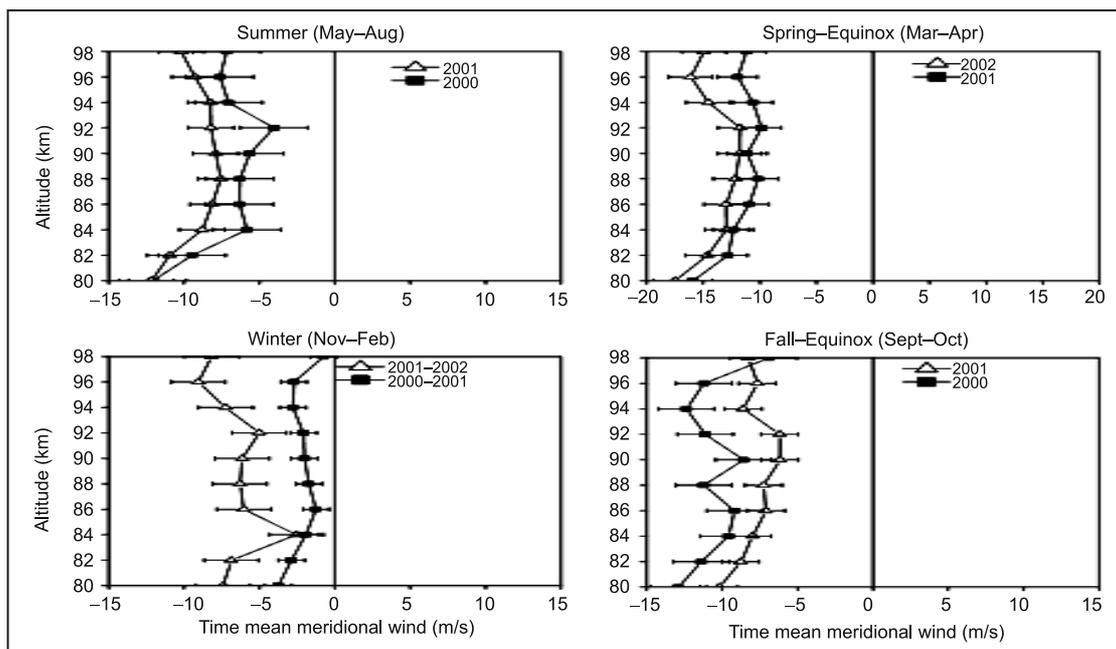
Figure 4. Monthly mean meridional wind (a) over Kolhapur and (b) over Tirunelveli from June 2000 to May 2002. The dark shaded area corresponds to southward winds.

Altitude profiles of time-mean meridional winds for the four seasons over Kolhapur are depicted in figure 5(a). There is small inter-annual variability throughout the year and altitude dependence of the observed winds during all seasons is consistent. Figure 5(a) reveals equatorward motion of the winds throughout the year in all seasons. Figure depicts larger wind speeds during spring equinox as compared to solstices and fall equinox.

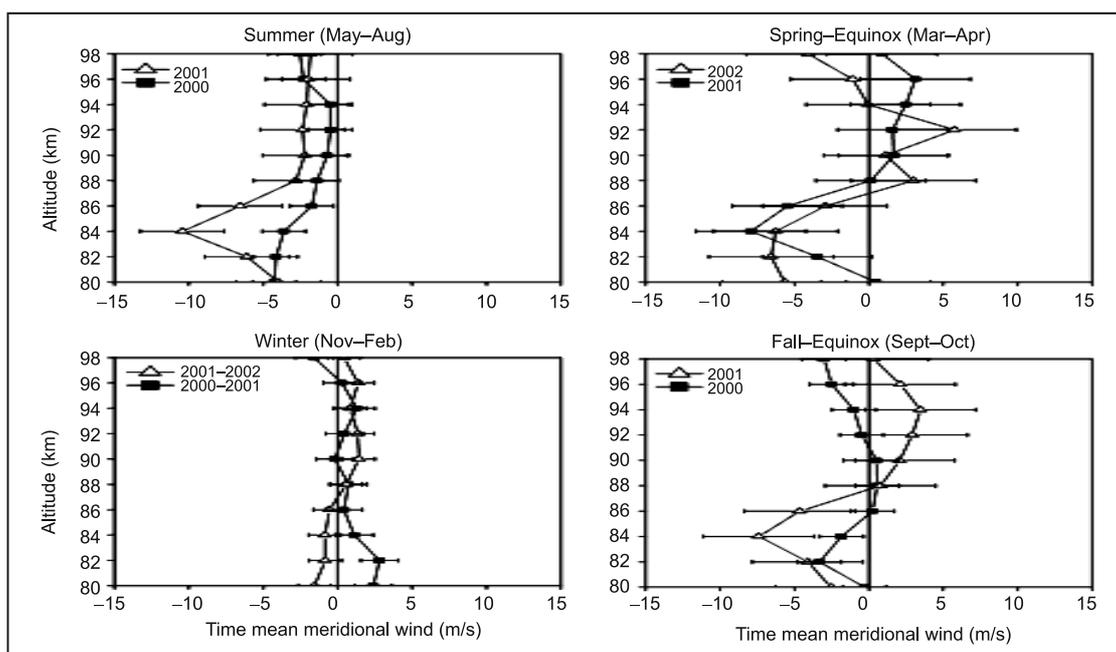
The altitude profiles of time-mean meridional winds for the four seasons over Tirunelveli are shown in figure (5b). Though there is small inter-annual variability throughout the year, the altitude dependence of the observed winds during all the seasons is quite consistent. During summer solstice there is equatorward motion for all altitudes. In winter solstice, in both the years wind flow had

gone change over in both directions. Wind speeds during winter were smaller compared to summer. During spring equinox period a clear transition in wind flow from equatorward to poleward in 2001 can be seen. Winds in the year 2002 had undergone brief change over to poleward in between 86 and 94 km before coming to equatorward again. There is overall consistency for all altitudes. For fall equinox period there was net poleward flow during year 2001 above 88 km and equatorward below this. Wind flows equatorward up to 86 km for the year 2000 and changed its direction to poleward from 86 to 90 km and again flows equatorward above 90 km.

In figure (6), monthly mean values of the meridional wind field between 80 and 98 km for both the stations Kolhapur and Tirunelveli are shown. Each curve in figure represents the average value



(a)



(b)

Figure 5. Vertical profiles of mean meridional winds (a) over Kolhapur, and (b) over Tirunelveli. Top left: summer, top right: spring equinox, bottom left: winter, bottom right: fall equinox. The positive velocity indicates northward flow.

of the wind at indicated heights. We have grouped the curves into four separate sets to facilitate comparison. Figure 6 reveals that most of the time wind flows equatorward for all heights over Kolhapur. On the other hand, wind flows in both directions for Tirunelveli. From all the four sets SAO is observed in the meridional wind over Kolhapur for all the altitudes. Whereas, annual oscillation seems to occur in the meridional wind

over Tirunelveli. Wind magnitude for Kolhapur in any given month is greater than the wind magnitude for Tirunelveli.

4. Discussion and conclusion

We have presented observations of MLT mean winds over Kolhapur and Tirunelveli from June

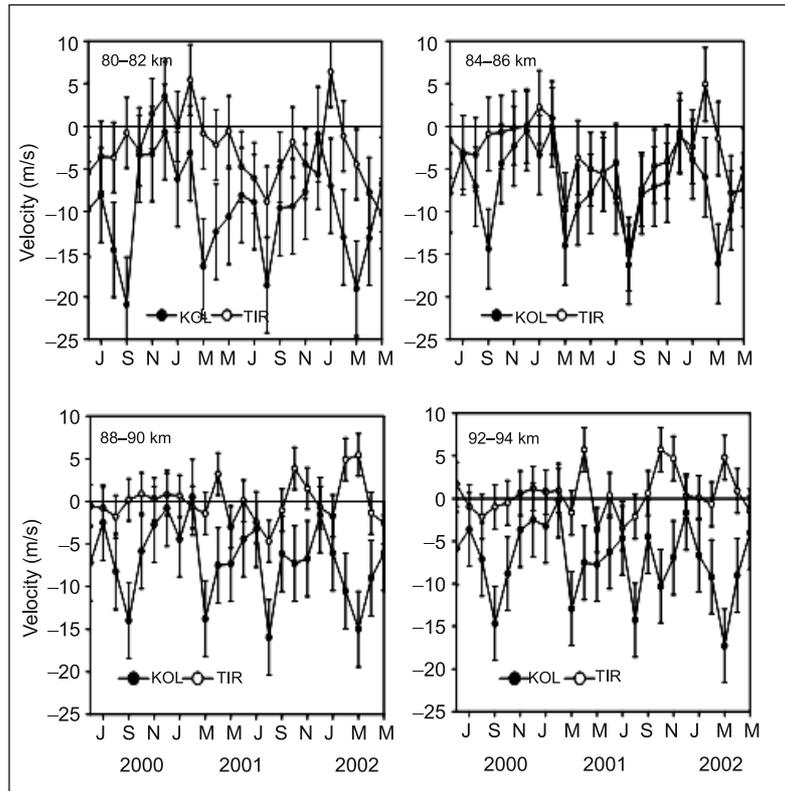


Figure 6. Monthly mean meridional wind averaged for different altitudes for both Kolhapur and Tirunelveli stations.

2000 to May 2002 and compared the results. Our results over Kolhapur seem to be in better agreement with the URAP climatology presented by Swinbank and Orland (2003). In the URAP climatology (figure 5 of Swinbank and Orland 2003), wind field for MLT region shows a clear eastward flow during summer, wind in winter flows westward in February and eastward for other months up to 90 km, during fall equinox overall wind is towards eastward and in spring equinox overall wind flow is towards westward. Our analysis over Kolhapur (figure 2a) reveals eastward flow during summer and westward flow during winter up to ~ 93 km. During fall equinox period 2000, wind flow is towards eastward or nearly zero and overall westward flow is observed during spring equinox. Thus our results over Kolhapur strongly matches with URAP climatology. On the other hand, our analysis over Tirunelveli (figure 2b) reveals westward wind flow during summer, winter and fall equinox which is exactly opposite to URAP climatology in which overall wind is towards eastward. URAP climatology and our results over Tirunelveli both reveal westward wind flow during spring equinox. Thus our results over Tirunelveli matches with URAP climatology only during spring equinox.

In the prevailing wind model presented by Portnyagin *et al* (2004), the zonal wind field (figure 2 of Portnyagin *et al* 2004) shows overall

wind is towards eastward in the summer solstice and westward during spring equinox which exactly matches with our results over Kolhapur (figure 2a). Model shows westward flow during fall equinox which fairly matches with our results. During winter solstice, model shows overall eastward wind and we observed westward wind over Kolhapur. In the meridional wind field (figure 3 of Portnyagin *et al* 2004) model shows southward wind during summer solstice and spring equinox periods which exactly matches with our results over Kolhapur (figure 5a). During winter solstice and fall equinox periods we have observed southward wind whereas model shows overall northward wind during this period.

Sridharan *et al* (2007) reported the mean wind field of MLT region over Tirunelveli. They have observed SAO, with large westward wind during equinox months and nearly zero or eastward winds during solstice months. Also they have observed larger wind values during spring equinox than during fall equinox and the signatures of the QBO with enhanced westward wind in spring equinox period of year 2002. Our analysis over Tirunelveli reveals SAO with westward winds during equinox months and eastward winds during solstice months (figure 1b). We have also observed the signatures of the QBO with enhanced westward wind in spring equinox period of year 2002. In the monthly mean

meridional wind field, they have observed annual variation with southward flow during summer months and northward flow during winter months and the direction reversal of winds occur during equinoctial months. Our analysis for meridional wind reveals southward wind during summer months and northward wind during winter months (figure 4b). Thus our analysis over Tirunelveli gives same results as that of Sridharan *et al* (2007).

One of the interesting features of our analysis over Kolhapur is the SAO in the meridional wind field. Gavrilov *et al* (2004) reported superposition of annual and semi-annual harmonics in the meridional wind in the MLT region over Hawaii (22°N, 160°W) which is very near to Kolhapur latitudes (16.8°N, 74.2°E). In the zonal wind pattern, they have reported annual oscillation with maximum eastward wind in winter and westward wind in summer below 82–85 km and SAO with an additional maximum of eastward wind in summer above. Thus there is quite similarity in meridional mean wind field between these two stations Kolhapur and Hawaii.

In summery, considering the relatively small distance of about 800 km between both the radars, the derived differences are very surprising indicating a strong latitudinal variability of the wind field in the MLT region. Our analysis reveals annual oscillation in the zonal wind and SAO in the meridional wind over Kolhapur. On the other hand, results over Tirunelveli reveal SAO in the zonal wind and annual oscillation in the meridional wind. In spring equinox period of 2002 over Tirunelveli, we have observed enhanced magnitude of wind speed exhibiting the signatures of the QBO in the MLT zonal wind. The results are of great interest for future investigations. Further comparative studies are currently underway to investigate the nature of latitudinal difference in tidal variability between two stations, Kolhapur and Tirunelveli, along with model and/or satellite comparisons.

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