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Mesospheric winds from 70 to 98 km altitude over low latitude station Kolhapur by a partial reflection radar

P. T. Patil[1*], S. Gurubaran[2], R. Rajaram[1], A. K. Sharma[3] and R. V. Bhonsle[3]

[1]*Indian Institute of Geomagnetism, New Panvel, Navi Mumbai 410 218, India*
[2]*Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Tirunelveli 627 011, India*
[3]*Department of Physics, Shivaji University, Kolhapur 416 004, India*

Abstract. Temporal variations of daily winds in the altitude region 70 – 98 km from the data collected during June 2000 to April 2003 using partial reflection radar at Kolhapur (16.40°N, 74.15°E), India, are presented in this study. Sequential wind profiles are obtained using partial reflections. The horizontal component of mesospheric mean winds and their monthly variations are presented in detail. The motions implied by mesospheric drifts closely resemble movements of the neutral air. Detailed study of the seasonal variations of the zonal and meridional winds is presented.

Keywords : wind profiles – radio aeronomy – data analysis

1. Introduction

Motion of the neutral air is caused by the differential heating between the equator and the poles and the rotation of the earth from west to east that would lead to an equator-to-pole flow in the upper atmosphere and pole-to-equator flow at lower levels with slight westward shift due to the coriolis force (Humphreys 1964). At the low latitude region in the northern hemisphere, it is observed that the meridional component of the wind flows towards northward direction during daytime and it reverses to the southward direction during night hours. Wind blows across from the day to night side at the earth with westward and eastward components in the morning and evening sectors at middle and

*email: iigkop@unishivaji.ac.in

low latitudes. The prevailing wind is predominantly zonal and varies throughout the course of a year. Strong eastward winds in winter give way to moderate westward winds in summer 60 - 80 km altitude (Beer 1974). There are also meridional (north-south) components at prevailing wind leading to a net latitudinal flow. In short, neutral wind flow at mesospheric altitudes is a three-dimensional vector with zonal and meridional components, which can be measured by a medium frequency (MF) radar echoes from mesospheric electrons which are dragged by the neutral air flow due to their high collision frequency.

The low latitude mesosphere is characterized by a variety of dynamical processes, some of which are confined only to this region (latitude as well as altitude). The global circulation at these heights is not well understood at low latitudes. The ground-based radar measurements play a unique role in understanding the dynamics of the mesosphere with better temporal and altitude resolution (Woodman & Guillen 1974; Vincent & Lesicar 1991; Harris & Vincent 1993; Fritts & Isler 1992; Palo & Avery 1996). Medium frequency (MF) radars have been widely used to measure the mesospheric and lower thermospheric motions. MF radars have the capability to monitor the mesospheric and lower thermosphere (MLT) winds on a continuous basis but are more reliable above 80 km (Ratnam et al. 2001). The partial reflection radar operating in the medium frequencies (MF) yields useful information on mean winds, planetary waves, tides and gravity waves, in the mesosphere and lower thermosphere (60-100 km) region (Gurubaran & Rajaram 2000, for example).

The partial reflection radar at Kolhapur (16.40°N, 74.15°E), India, was installed by the Indian Institute of Geomagnetism, Mumbai, during the middle of 1999. Data obtained from the partial reflection radar operated at Kolhapur were utilized in the present study. The radar system operation on 1.98 MHz is identical to the one placed at Tirunelveli (8.7°N, 77.8°E), India (Rajaram & Gurubaran, 1998). The system details and the mode of operation are the same as described by Vincent & Lesicar (1991). The full correlation analysis developed by Briggs (1984) has been adopted in the present work for determining neutral winds in the sampling region. The main objective of this study is to study mean motions in the low-latitude MLT region and examine their seasonal and altitude dependence.

The emphasis in the present study has been to examine the temporal variability in the mesospheric winds. Because of the collisional coupling of neutral gas and the ionized species, the drift measurements at heights below 100 km have been considered to represent the bulk motion of the neutral gas. The knowledge of the wind field at various height levels in the atmosphere is important for understanding the atmospheric dynamical processes of various temporal and spatial scales.

2. Observations and data analysis

The hourly zonal and meridional wind speeds derived from the partial reflection radar observations on each day have been averaged in order to obtain the daily values which have been further averaged to get the monthly values, which in turn, have been averaged for the group of three months keeping December, March, June, and September in the middle for the estimation of the seasonal winds for three years. The long-term behavior of the two components of the winds is studied in detail and the results are presented in the following sections.

The continuous ground-based measurements of mesospheric winds made by spaced antenna partial reflection radar, commenced at Kolhapur in June 1999. During 1000-1500 hours local time, large absorption of the transmitted radar signal has been observed every day. At latitudes like that of Kolhapur, the radio wave undergoes birefringence due to the presence of the geomagnetic field. The transmitted wave is thus circularly polarized wave by suitable phasing of the antenna signals. It is quite probable that the left hand and right hand circularly polarized modes are reversed and the transmitted mode during daytime is possibly absorbed at lower mesospheric heights. The polarization aspect will be thoroughly examined when the experiment gets revived during late 2007. For the observations presented herein, the quality of the data is thus low around noon and early afternoon hours due to diminished signal-to-noise ratio.

Data accumulated every two minutes on a daily basis are used for analysis. In the standard operation of the MF radar at Kolhapur, information regarding the received signal strength is not stored. It is the strength of the fluctuations in the signal that is stored for the analysis after removing the mean signal level.

As stated earlier, the full correlation analysis of Briggs (1984) is being used to determine several dynamical and spaced antenna parameters. Valuable results on zonal and meridional mean winds are reported in this paper. For the present work, the radar measurements made during June 2000 to April 2003 are utilized. Hourly values were obtained for each height in the sampling region (70-98 km), which was then examined for meaningful statistics before subjecting the data to further analysis. The averaging procedure adopted for the present work yielded monthly mean values of wind velocities and directions over selected period. The overall mean at each height is computed from the mean of the monthly values.

3. Results

3.1 Zonal wind

The monthly variation of the mean zonal winds from 70 to 98 km altitude for the three consecutive years - 2000, 2001 and 2002 and up to March 2003 is shown in Fig. 1. The contours with positive values (faint shading) represent the eastward component in the

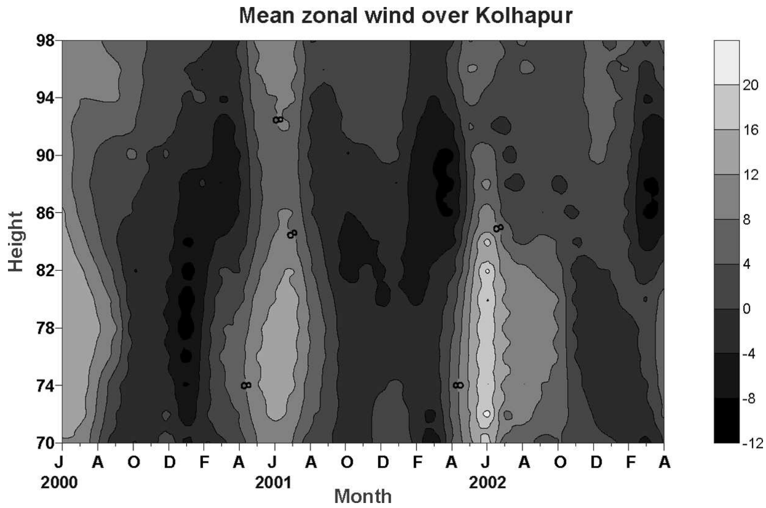

Figure 1. Monthly mean zonal winds observed over Kolhapur from June 2000 to April 2003. The dark shaded area corresponds to westward winds.

zonal winds. The eastward regime begins during the month of May and the flow becomes westward during the month of November.

The inter-annual variations of the mean zonal winds for the four seasons (Spring and Fall Equinoxes, Winter and Summer Solstices) are shown in Fig. 2.

From this it is clear that the altitude dependence of the zonal winds for all seasons is consistent although there is large inter-annual variability in the observed wind, altitude dependence of zonal winds for each season is quite consistent. These figures show that a positive zonal wind is eastward. As can be seen from the figure, there has been a westward flow observed during winter below the 90 km height regions and during the spring equinox above 80 km height regions. Moreover, the eastward flow during the summer is stronger than that observed during the fall equinox.

During the spring equinox period every year, the motion was eastward at heights below 80 km and westward above, the exception being westward flow which persisted at all heights above 70 km in the year 2001. It may be noticed that westward speeds as large as 7.5 ms^{-1} at 88 km during 2001, 5 ms^{-1} at 86 km and 88 km during 2000 and 2002 respectively. The wind motion again reversed towards eastward above the heights 94 km during 2000 and 2002. The maximum eastward speed is 2.5 ms^{-1} at 76 and 78 km during 2000 and 2002 respectively.

The wind profiles for fall equinox period depicted in the figure all have maxima at 78 km. similar to the curves for spring equinox. The wind speeds for 2001 were systematically smaller than those for 2000 and 2002. The wind motion was eastward at all heights above

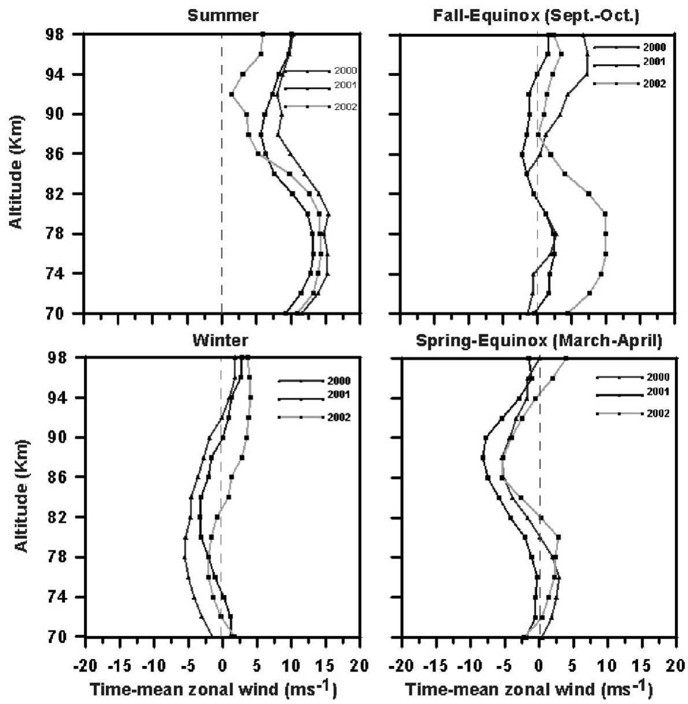

Figure 2. Vertical profiles of mean zonal winds over Kolhapur during four seasons from years 2000 to 2003. The positive velocities correspond to an eastward flow.

70 km in 2002. One may notice eastward speeds as large as 10 ms^{-1} at 76-80 km during 2002. During the year 2000, the wind was flowing towards westward below 74 km and above it was flowing towards eastward, the exception being westward at heights between 82-84 km. One interesting thing to note here is that for every year below 78 km, the wind pattern (direction) is reversed for fall and spring equinoxes. The entire altitude region in the fall equinox, winter and spring equinox during consecutive years 2000-2001, 2001-2002 and 2002-2003 respectively shows a reversal in the wind direction. This feature might be due to the presence of the quasi-biennial oscillation (QBO) in the mesospheric zonal wind which is not seen in summer. The zonal winds during the summer show only eastward propagation with a smooth inter-annual variability.

3.2 Meridional winds

The monthly variation of the mean meridional winds from 70 to 98 km for the three consecutive years 2000, 2001 and 2002 and up to April 2003 are shown in Fig. 3. The contours with positive values (faint shading) represent the northward flow in the meridional component. The contours reveal a flow with southward motion during summer and during each equinox and northward motion during the winter.

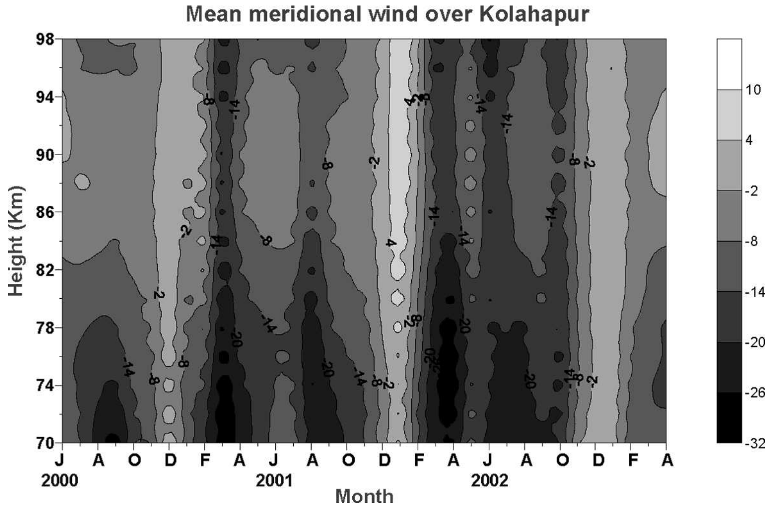

Figure 3. Monthly mean meridional wind observed over Kolhapur from June 2000 to April 2003. The dark shaded area corresponds to the southward winds.

The annual variation of the mean meridional wind obtained by the partial reflection radar from 70 to 98 km is shown in Fig. 4. The vertical profiles of the mean meridional winds for the four seasons (Spring and Fall Equinoxes, Winter and Summer solstices) are shown. It is clear that the altitude dependence of the meridional winds is consistent for all seasons except during the year 2001 for winter and there is a smooth inter-annual variability during all the seasons.

During all seasons, there was southward flow, except during the winter season, the meridional flow was southward for all the years except 2001, where a directional variability is seen i.e. it was southward below 82 km and above the height it was northward during winter season.

During all seasons the meridional wind speed reached a minimum near 90 km height regions. The wind pattern was constant. The meridional wind reached maximum southward flow of 24 ms^{-1}. There has been a large inter-annual variability during equinoxes while solstice curves reveal transequatorial flow from the summer to winter hemisphere. During winter the meridional wind speed was smaller than the other three seasons and the wind was almost steady during the year 2002 above 84 km height region.

4. Discussions and conclusions

We have presented observations of mean horizontal mesospheric winds over Kolhapur using the (MF) partial reflection radar from June 2000 to April 2003.

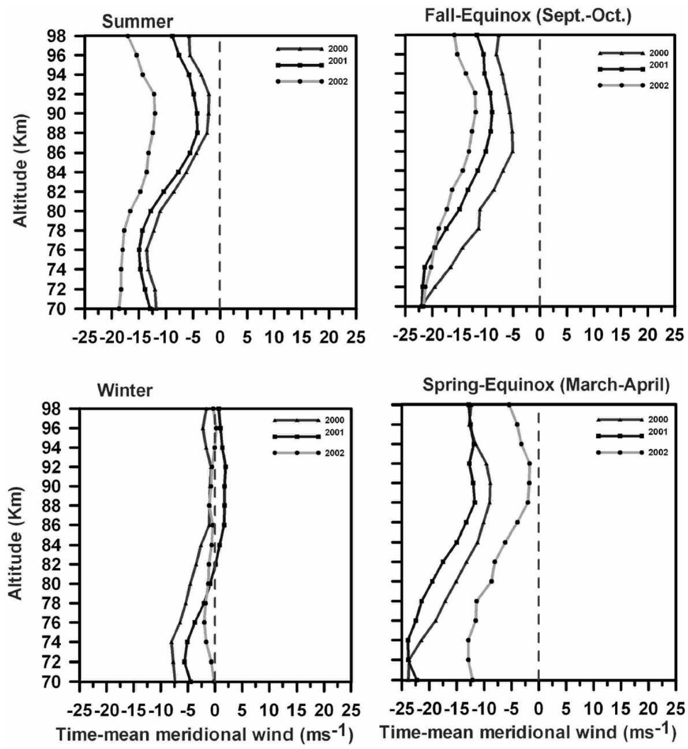

Figure 4. Vertical profiles of mean meridional winds over Kolhapur during four seasons from years 2000 to 2003. The positive velocities correspond to an northward flow.

A comparison of our results with those obtained from MF radar wind measurements at the equatorial station Tirunelveli (8.7°N, 77.8°E) (Rajaram & Gurubaran 1998) will be in order. Furthermore, studies of mean wind profiles have also been carried out (Ratnam et al. 2001) using the data collected with the Indian MST radar facility at Gadanki (13.5°N, 79.2°E). It should, however, be noted that these results are not for the same epoch and some differences could result from that.

The typical zonal wind pattern is characterized by an eastward flow in the late winter in the mesopause region turning strongly westward during the spring equinox. As a general rule the flows tend to be more eastward during the solstices and more westward during equinox. These patterns that were brought out by analysis of the Indian station data (Rajaram & Gurubarn 1998; Ratnam et al. 2001) are also seen in our data except that in our case the westward flows in the fall equinox are very weak in general and almost negligible in 2002. There is also an indication of a slight downward trend in the contour patterns in late winter, a feature noticeable in the corresponding patterns drawn for the other two Indian stations. Stronger westward flows in the spring equinox compared to the fall-equinox that characterized the Tirunelveli flows are also evident in our data. But, in contrast, the winds at Gadanki appeared to have stronger flows in the fall equinox.

In the meridional component the wind flow exhibits southward motion during summer, fall and spring-equinoxes and northward motion during winter. The meridional flows show a weak northward flow during northern hemisphere summer and larger southward flows during northern hemisphere winter. This is consistent with the earlier results reported for Tirunelveli (Rajaram & Gurubarn 1998) and Gadanki (Ratnam et al. 2001). However, meridional winds at Kolhapur exhibit much less of inter-annual variability compared to the other two Indian stations. This could be entirely because the two results are for different epochs.

In conclusion, there is an overall consistency in the wind patterns observed by us and the results of earlier studies conducted for the Indian region. One characteristic difference lies in the much smaller inter- annual variability in the meridional wind flows.

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