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Meteor radar measurements of MLT winds near the equatorial electro jet region over Thumba (8.5° N, 77° E): comparison with TIDI observations

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Abstract. The All-Sky interferometric meteor (SKYiMET) radar (MR) derived winds in the vicinity of the equatorial electrojet (EEJ) are discussed. As Thumba (8.5° N, 77° E; dip lat. 0.5° N) is under the EEJ belt, there has been some debate on the reliability of the meteor radar derived winds near the EEJ height region. In this regard, the composite diurnal variations of zonal wind profiles in the mesosphere-lower thermosphere (MLT) region derived from TIMED Doppler Interferometer (TIDI) and ground based meteor radar at Thumba are compared. In this study, emphasis is given to verify the meteor radar observations at 98 km height region, especially during the EEJ peaking time (11:00 to 14:00 LT). The composite diurnal cycles of zonal winds over Thumba are constructed during four seasons of the year 2006 using TIDI and meteor radar observations, which showed good agreement especially during the peak EEJ hours, thus assuring the reliability of meteor radar measurements of neutral winds close to the EEJ height region. It is evident from the present study that on seasonal scales, the radar measurements are not biased by the EEJ. The day-time variations of HF radar measured E-region drifts at the EEJ region are also compared with MR measurements to show there are large differences between ionospheric drifts and MR measurements. The significance of the present study lies in validating the meteor radar technique over Thumba located at magnetic equator by comparing with other than the radio technique for the first time.

Keywords. Ionosphere (Equatorial ionosphere) – Meteorology and atmospheric dynamics (Middle atmosphere dynamics) – Radio science (Remote sensing)

1 Introduction

The understanding of Earth's atmosphere to a great extent depends on understanding the energetics and dynamics of the middle and upper atmosphere (McLandress and Ward, 1994; Clemesha, 2002). Most of the energy and momentum transported by tides and waves of various temporal and spatial scales from the lower atmosphere are deposited at mesospheric and lower thermospheric (MLT) heights, thereby influencing this region (Antonita et al., 2008). Tidal variability, evidences for non-linear wave-wave interactions and the signature of lower atmospheric processes are also observed in this region (Beard et al., 1996; Kumar et al., 2008, 2007a; Eckermann and Vincent, 1994). To study these interactions in depth, we need to have reliable long term wind and temperature measurements in the MLT region as most of these phenomena are exhibited in the form of wind/temperature fluctuations. Winds are also very important in understanding circulation patterns, oscillations in the middle atmosphere and in redistributing chemical constituents. Therefore, long term wind observations have been made across the globe and studies have been carried out in this regard using various instruments (Manson et al., 1992; Middleton et al., 2002, Kishore Kumar et al., 2008). Wind measurements in the MLT region are primarily obtained from rocket soundings, radars like MF, MST and meteor wind radars (Vincent, 1984; Manson et al., 1991; Kumar et al., 2007b), and satellites (Huang et al., 2006).

The Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellite by NASA probes the atmosphere from 60 to 180 km with the primary objective of understanding the energetics and dynamics of this region. The TIDI (TIMED Doppler Interferometer), one of the payloads on board TIMED, measures the wind in 60–120 km height region (Killeen et al., 1999). There have been comparisons for the TIDI wind measurements with data from instruments like High resolution Doppler imager (Huang et al., 2006). There

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have also been studies comparing the diurnal and semidiurnal tidal amplitudes and phases obtained from TIDI wind data with those obtained from ground based instruments giving neutral wind measurements in the MLT region such as MF and meteor radars (Killeen et al., 2006; Oberheide et al., 2006).

The meteor radar at Thumba provides wind measurements in the 82–98 km height region. However, in recent years, there has been some debate on the reliability of the winds measured by the meteor radar at the 98 km height region (the maximum height where we obtain continuous data from the meteor radar at Thumba) as Thumba is located in the vicinity of the magnetic dip equator where there is a presence of the equatorial electrojet (EEJ), a strong zonally flowing current system which peaks around 105 km over the magnetic equator (Kumar et al., 2007b, 2009; Dhanya and Gurubaran, 2009). The debate was started by Dhanya and Gurubaran (2009) and the important aspect of their query is the scattering of radio waves by the irregularities that grow on the meteor trail as a result of plasma instabilities induced by EEJ. Kumar et al. (2009) based on earlier studies argued that the echoes from such irregularities are non-specular, which will not have any outstanding implications in MR measurements as reported by Chapin and Kudeki (1994). However, there is always a quantum of doubt about the meteor radar wind estimations over the magnetic equator and till now there were no comparison of these measurements other than with radio techniques.

Kumar et al. (2007b) compared the present meteor and MF radar wind measurements, which employ interferometry and spaced antenna drift techniques respectively. The MF radar is located at Tirunelveli (8.7° N, 77.8° E) which is also in the vicinity of the magnetic dip equator. The wind comparison was excellent below 90 km and was poor above 90 km. The authors attributed the poor agreement between MF and meteor radar above 90 km to the influence of EEJ on the MF radar measurements as reported by Gurubaran and Rajaram (2000). However, Kumar et al. (2007b) could not convincingly show that the meteor radar measurements at 98 km are not affected by the EEJ as MF radar measurements were also affected by the ionospheric drifts at this height region. Thus, so far there were no independent measurements to compare the MR measurements other than MF radar. TIDI is a space-borne optical method and completely different from the MR and MF radar technique. Ward et al. (2010) established the validity of TIDI measurements by comparing tidal fields from ground based MR and TIDI. It is thus a timely effort (as we now know that MR and TIDI tides agree in non-EEJ regions) to use such comparisons for investigating MR winds measured around EEJ. Thus, the central objective of the present study is to discuss the meteor radar and TIDI derived composite diurnal variations of zonal winds at 98 km height region. Sections 2 and 3 provide a brief description of TIDI and meteor radar at Thumba respectively as these are the two instruments used for comparison in this study. Section 4 presents the comparison of TIDI and radar derived composite diurnal variation of zonal winds and Sect. 5 provides the concluding remarks.

2 TIDI

The TIMED spacecraft was launched in December 2001 and it has been providing observations from January 2002. The satellite is placed into a 74.1° inclined orbit at an altitude of 625 km. TIDI is a limb viewing instrument that carries out remote sensing measurements of the temperature and vector winds by observing the Doppler line and band characteristics of atmospheric emissions in the MLT region. It is a Fabry-Perot interferometer that measures neutral horizontal wind vectors with a vertical resolution of $\sim$2.5 km, mainly in the 70–120 km altitudinal range. TIDI consists of four telescopes which are orthogonal to each other. This allows the instrument to measure neutral winds on both sides of the satellite track with two telescopes looking at the same location in a short time period within which the change in the wind speed and direction is negligible. It takes about 60 days to sample the full range of local times, providing global coverage of the wind field. A detailed description of TIDI geometry as well as the limb viewing details and specifications can be found in Niciejewski et al. (2006). TIDI views emissions from several atmospheric species, among which emissions from OI 557.7 nm and rotational lines in the O_2 (0-0) band at 762 nm are used to determine the Doppler shift and thus the wind. More details of the specific channels used for day and night time observations for each parameter and the filters employed are explained by Killeen et al. (1999). The neutral wind data used for the present study are obtained by using the preliminary O_2 P9 filter data processed at NCAR/HAO. The O_2 band P9 line measurement covers the 70 to 110 km altitude range during the day and 80 to 105 km during the night with 2.5 km height resolution.

3 Meteor radar at Thumba

The All-Sky interferometric meteor (SKYiMET) radar (MR) is a multi channel coherent receiver pulsed radar system that provides wind measurements from 82 to 98 km, deriving information from meteor entrance events in the Earth's atmosphere. A detailed description of this commercialized radar and the meteor detection algorithm is explained in Hocking et al. (2001). This radar system operates at 35.25 MHz with a peak power of 40 kW. Four antennas (three-element crossed Yagi) at the corners of a square transmit the circularly polarized beam and five antennas (two-element crossed Yagi) in the form of an asymmetric cross receive back the signal. In order to avoid the effect of echoes from the EEJ region which can interfere with the neutral wind derivations, one pair of transmitting antennas will be transmitting out of phase with the other such that a null field is formed at the overlapping region of the beams, thus avoiding echoes from EEJ region (Kumar et al., 2007b). Additional caution is taken in the analyzing software to ensure that EEJ influenced echoes are completely avoided as described by Kumar et al. (2009). Once the meteor enters the Earth's atmosphere, it forms a plasma trail that is carried along with the neutral winds of the atmosphere. By detecting these meteor trail drifts in time, we can deduce the background atmospheric wind speed and direction at the altitude where the meteor is observed. The complex correlation method is adopted to measure the phase differences between the receiving antennas in order to determine the echo arrival angle, and both the complex auto and cross correlation methods are used to measure the rate of change of the relative phase in order to determine the radial velocity of the meteor trail. Thus the meteor wind radar provides hourly zonal and meridional winds, angular and height distribution of meteors, meteor entrance velocity in real time.

4 Results and discussion

The primary aim of the present study, as stated earlier, is to investigate the reliability of meteor radar wind measurements at 98 km height region especially during the local noon time, when EEJ strength is maximum. This study is of utmost significance as there have been many studies showing the meteor trail velocities being influenced by E-region phenomena. Oppenheim et al. (2000) have discussed extensively the evolution of meteor trail to form plasma turbulences. They have used 1-D and 2-D models to show that meteor trails in the equatorial E-region ionosphere will be structured by the growth of a gradient drift/Farley-Buneman instability which rapidly develops into plasma turbulence through three distinct stages. The E-region electric fields can cause the drift of these trails/plasma turbulences and affect meteor trail dynamics perpendicular to the geomagnetic field in all parts of the E-region. This can ultimately result in a situation where meteor trail motions may not accurately reflect atmospheric wind speeds and directions during the early stages of trail evolution. So it is extremely important to check the reliability of the MR data at Thumba, located at the geomagnetic equator. The details of EEJ can be found in Forbes (1981). Meteor radar obtains hourly horizontal winds from a fit of the radial velocities measured within one hour. Thus the meteor radar observations over Thumba are available round the clock. TIDI and meteor radar observations during the year 2006 covering all the four seasons [winter (December-January-February) vernal equinox (March-April-May), summer (June-July-August), autumnal equinox (September-October-November)] are used in the present analysis. TIDI wind observations are grouped within a 5° × 15° (latitude × longitude) grid over Thumba. This grid is used to have sufficient number of observations to construct the composite diurnal winds.

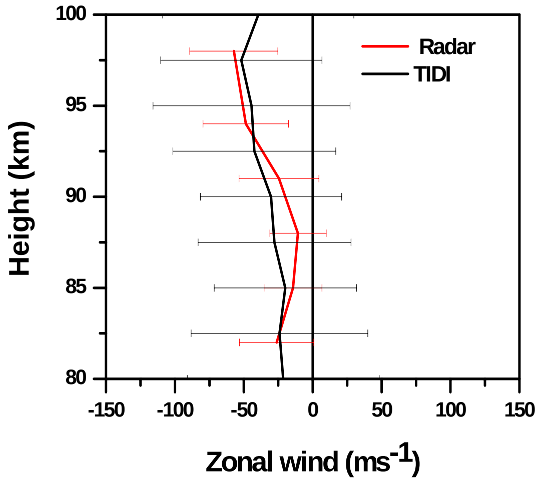

Fig. 1. Comparison of radar and TIDI measured mean zonal wind profiles in the afternoon hours (11:00–14:00) during the observational period.

Individual TIDI wind profiles above 85 km altitude have an error of about 30 m s^{-1} during the day and double that during the night (Oberheide et al., 2005). On the other hand, radial velocity can be measured with an accuracy of 5 % or better by meteor wind radar (Hocking et al., 2001). However, the accuracy of the all sky fit as described by Hocking shows a statistical dependence with the number of meteors. Further, MR observes a measurement volume of 600 km in diameter, which means that there are natural variations in this volume caused by gravity waves, and it becomes very challenging to derive an absolute error for the wind. The same is true for the satellite observations also. The wave activity leads to huge variability in the measurements, which does not mean that the measuring technique has a large inaccuracy. Therefore it is envisaged that the comparison of mean profiles over a month or two may provide better agreement between the two measurements. Earlier studies by Huang et al. (2006) reported that the relative variations in the amplitude of the meridional and zonal winds for diurnal tide derived from TIDI compared well with those from HRDI. Killeen et al. (2006) compared the diurnal and semidiurnal tide amplitudes and phases derived from TIDI and that from ground based meteor radars located at several sites. This comparison showed very good consistency between the radar and TIDI measurements. Guo and Lehmacher (2009) also compared the meteor radar and TIDI derived tides over Jicamarca. Very recently, Ward et al. (2010) compared the diurnal and semidiurnal tide amplitudes derived from TIDI and ground based meteor radar observations from various geographical locations, which showed very good agreement. All these studies thus validated the TIDI observations of composite diurnal variations of zonal and meridional winds. We take the advantage of these studies to compare the TIDI derived composite diurnal variation of zonal and meridional

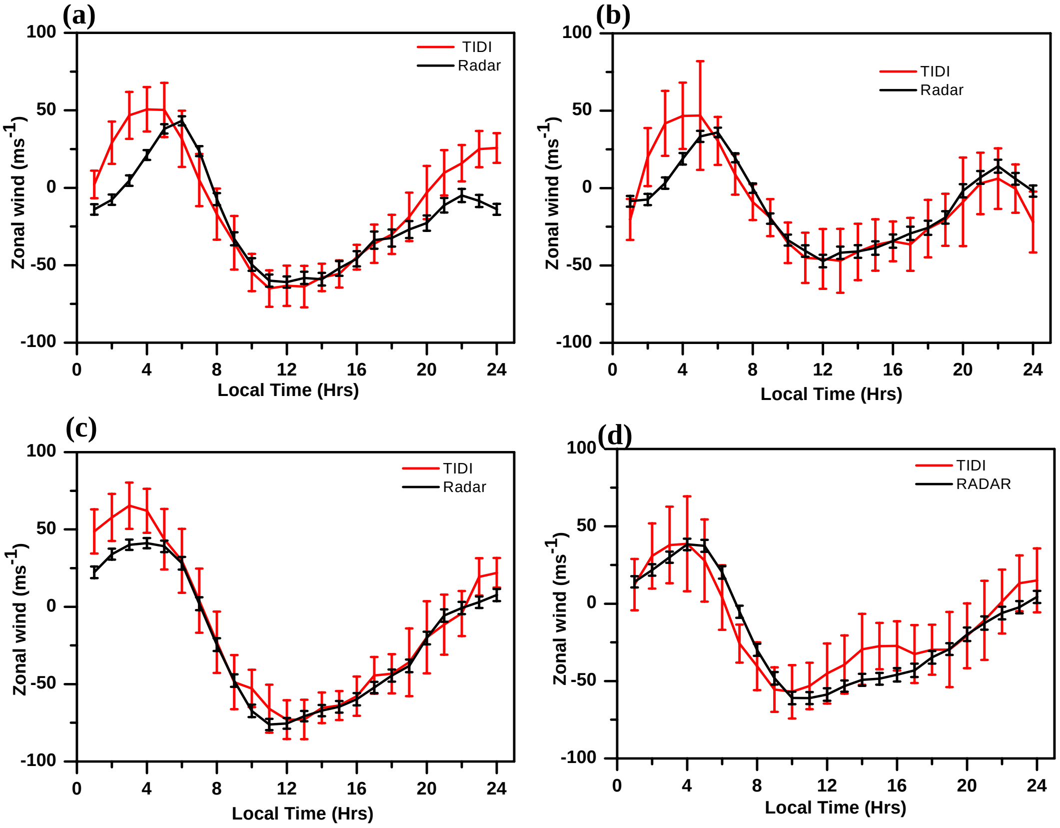

Fig. 2. Composite diurnal variations of zonal winds derived from TIDI and MR for **(a)** winter, **(b)** vernal equinox, **(c)** summer and **(d)** autumn equinox.

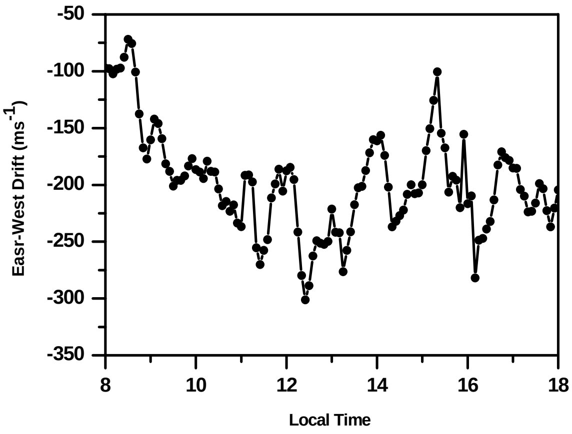

Fig. 3. Typical day-time variation of E-region drifts at EEJ region as observed by HF radar over Thumba on 26 December 1991.

winds with meteor radar observations. We limit to compare the diurnal pattern in zonal winds as these measurements were recently debated (Dhanya and Gurubaran, 2009). As mentioned earlier our aim is to justify the MR observed westward motions at 98 km during local noon time.

Before comparing the composite diurnal variations of zonal winds, we compare the mean height profile of radar measured zonal wind profiles during the entire observational period in the local afternoon hours (11:00–14:00 LST) when the EEJ is at its peak. Figure 1 shows the comparison of radar and TIDI measured mean zonal wind profiles in the afternoon hours during the observational period. From this figure, it is evident that both the measurements show westward winds at 98 km during the peak hours of EEJ and exhibit very good agreement between the two. As we use the mean profile of TIDI, it is envisaged that its errors also reduce. However, the TIDI mean profile shows large standard deviations as compared to meteor radar profile. It is to be remembered that TIDI winds are averaged over a large area around the meteor radar site, which can in turn incorporate some anomalies. Thus, Fig. 1 confirms that the reliability of westward winds measured by meteor radar at 98 km during the local noon hours.

We constructed composite diurnal variations of zonal winds at 98 km using TIDI and Meteor wind radar observations over Thumba for four seasons. In each season, the TIDI observations are grouped in time and as mentioned earlier, TIDI takes 60 days to complete one diurnal variation in local time. For the present study, the TIDI observations binned in time (0–23 h) during a season are used for obtaining the diurnal variations and similar procedure is used to obtain the composite diurnal variations of meteor radar derived winds. Figure 2a–d shows the composite diurnal cycle of zonal winds derived from TIDI and meteor radar observations at 98 km height region during the four seasons along with standard errors. The data points at each hour are relatively numerous for meteor radar as compared to TIDI observations and thus we estimate the standard errors to account for the number of observational points. Further, a three-point running mean is performed over TIDI observations. From this figure, it is evident that the TIDI and meteor wind measurements show relatively more discrepancies during the local night time as compared to daytime; this is probably due to larger errors of TIDI night time measurements (Oberheide et al., 2005). However, the composite diurnal variations in zonal wind show remarkable agreement between the two measurements during the peak EEJ hours (11:00–14:00 h), confirming the neutrality of the meteor radar wind measurements at 98 km height region. Both the measurements show westward motion during the local noon time consistently for all the four seasons. Thus we can ensure that at least on seasonal scales, the radar measurements are not biased by EEJ. It is to be remembered that TIDI employs optical technique to retrieve the wind fields thus free from ionospheric electric fields unlike radio techniques. However, both TIDI and MR winds show peak at the same local time as that of EEJ, which makes it difficult to ascertain whether MR echoes are contaminated with EEJ induced plasma instabilities around meteor trails or not. To verify this aspect, one should have measurements of velocity of these irregularities. Manju et al. (2005) reported the day-time variation of ionospheric drifts using HF radar measurements over Thumba. The measured drifts were in the range of 200–400 $\mathrm{m\,s^{-1}}$ in the 95–110 km height region and the motions were predominantly westwards. Chapin and Kudeki (1994) also reported that the Doppler shifts of the non-specular echoes from meteor trails of the order of $\sim$400 $\mathrm{m\,s^{-1}}$. Figure 3 shows a typical day-time variation of HF radar measured ionospheric drift at the EEJ region during the year 1991. However, we don't have simultaneous measurements of HF radar and MR as HF radar is not operating for quite some time and it is under renovation. One can find details of HF radar and day-time variation of E-region drifts in Manju et al. (2005). Nevertheless the day-time variation of E-region drifts around EEJ region shown in Fig. 3 and the magnitudes are very much different from that shown in Fig. 2. If MR measures the non-specular echoes, the wind magnitudes may compare with those shown in Fig. 3. However, MR uses only specular echoes and thus the composite diurnal variations in zonal winds in the proximity of EEJ show remarkable agreement with TIDI measured neutral winds. Given the two entirely different techniques of wind measurements (one ground based radio technique and another space based optical technique), the comparison shown in the Fig. 2 is very good. However, there are discrepancies in magnitudes of TIDI and MR derived winds, which are attributed to the measuring inaccuracy of TIDI and its average area of observation around the MR site. Nevertheless, the present study showed good agreement between TIDI and MR measurements within the error bars assuring the reliability of MR derived winds at 98 km height region.

5 Concluding remarks

The TIDI and ground based meteor wind radar measured composite diurnal variations of zonal winds at 98 km region over Thumba are compared during the year 2006. The comparison is carried out during all the four seasons, viz., winter, vernal equinox, summer and autumn equinox. The composite diurnal variation of MR measured zonal winds at 98 km, which is the focus of the present study, show remarkably good agreement with TIDI measurements. So we can conclude that on seasonal scales, the radar measurements are not biased by EEJ. Even though, there is good agreement in overall features of diurnal variations, there are discrepancies in observed magnitudes of winds, which are attributed to the measuring inaccuracy of TIDI. The mean zonal wind profile obtained during the peak EEJ hours also showed very good agreement, thus confirming the reliability of the meteor radar derived winds at 98 km height region, which was in debate recently. Further, HF radar measured day-time variations of E-region drifts over the present observational site are compared with the MR measurements. The HF radar measurements are very large as compared to MR measurements. Thus the present study by comparing the radio and optical techniques for wind measurements show the reliability of MR measurements of neutral winds over Thumba. However, these results cannot be generalized to other magnetic equator locations as EEJ show considerable longitudinal variation along the magnetic equator and the present exercise should be carried out to confirm this aspect.

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