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Upper mesosphere and lower thermospheric wind response to a severe storm in the equatorial latitudes

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ABSTRACT

Wind variation in the equatorial latitudes during the October 2003 severe storms has been investigated in the equatorial latitudes using data from the TIMED Doppler Interferometer (TIMED). Zonal winds are observed to be generally eastwards during storm and non-storm nighttime and daytime local time sectors. Daytime and nighttime local time sector meridional winds are generally equatorward during the storm days. The winds did not show changes that can be attributed to high geomagnetic activity levels. Winds in the MLT region are strongly influenced by Tides and planetary waves from below. These can overshadow influences from strong geomagnetic activity in the equatorial and low latitudes. TIMED Satellite provides a near global picture of the MLT region but has limited local time sampling and so to obtain variability of MLT data on short (days) time scales, multiple platforms in different orbits would be needed for a complete satellite analysis.

Keywords. Geomagnetic storm, TIMED satellite, winds

INTRODUCTION

The thermosphere is energized by solar UV and EUV energy, energy and momentum from the magnetosphere and tides, gravity and planetary waves from the troposphere and stratosphere. Even before 1950s, many scientists suspected that the sun might be sending corpuscular matter into space with speeds large but much less than that of light [8]. A temperature increase resulting from solar wind energy dissipation at high latitudes leads to expansion of neutral atmospheric gases. Tides and gravity waves propagate upwards from their sources in the troposphere and stratosphere and deposit energy and momentum in the upper mesosphere and thermosphere. The mass and energy from the high latitudes are transported across mid to low- latitudes by means of horizontal winds. Changes in wind patterns and global circulation result from external forcing of the mesosphere and lower thermosphere (MLT). This forcing which is more pronounced in the high latitudes is brought about by geomagnetic disturbances and solar activities. A geomagnetic storm occurs when the solar wind causes deep and intensive circulation of the magnetospheric plasma and this circulation is induced by reconnection of the interplanetary magnetic field and that of the earth [13]. Auroral Joule heating effects on the upper atmosphere that result from geomagnetic storms can extend from high to low latitude in the form of enhanced neutral horizontal winds. During a geomagnetic storm, strong and rapid magnetospheric processes impose changes in the earth's magnetic field. The magnetospheric inputs which are confined to high latitudes only propagate to mid and low latitudes at periods of high geomagnetic activity. Strong aurora and some geomagnetic disturbances seemed to recur in 27days (solar rotation period) and are stronger at the terrestrial poles, indicating some sort of channeling of charged particles by the geomagnetic field [6].

The geomagnetic storm intensity effects on the earth's atmosphere are different at different latitudes and altitudes. The coupling of the magnetosphere to the ionosphere drives ion convection (ion winds) in the Polar Regions and these winds are greatly perturbed during geomagnetic storms [20]. Meanwhile through ion-neutral momentum transfer and through thermospheric heating neutral winds at all thermospheric altitudes strengthen [3]. The response of the upper thermosphere to geomagnetic storms is different from that in the mesosphere and lower thermosphere.

Understanding the characteristics of the neutral wind and temperature in the upper mesosphere/lower thermosphere (ionospheric E-region) is a crucial element in the investigation of thermosphere-ionosphere coupling and in the study of interactions of the lower thermosphere with the upper thermosphere through wave propagation [4]. Observational data of neutral thermosphere to geomagnetic storms below about 180 km is relatively meager. Although ground observations have been carried out using Coherent Scatter Radars and Fabry-Perot interferometers they cannot distinguish between global and local signatures. Geomagnetic Storm time wind variations in the mesosphere and lower thermosphere have been investigated using different observation techniques [15, 5, 11, 14, 22, 21, and 1]. Most of these studies were carried out in the mid- and high latitudes. In this article, we try to investigate wind response in the equatorial MLT region to the severe solar storms that occurred during 29 October to 1 November, 2003 using data from the 'TIMED Doppler interferometer' (TIDI).

2. Data Source

2.1. The TIMED Doppler Interferometer

The TIMED Doppler Interferometer is a wind measuring instrument on the TIMED satellite, which measures horizontal winds in the mesosphere and lower thermosphere from altitudes of about 70 km to 120 km. The TIDI telescopes perform limb scan simultaneously in four orthogonal directions: two at 45^0 forward but on either side of the spacecraft's velocity vector and two at 45^0 rearward of the spacecraft [17] . An image of the TIDI geometry is shown in figure 1 below. The TIMED satellite orbits an altitude of 625 km and the total inclination is 74.1^0; TIDI measures the horizontal vector wind field with an accuracy of 3m/s and a vertical resolution of 2 km [9]. TIDI measures wind by measuring the Doppler shift of the atmospheric emission features. With the data generated at this altitude range it is possible to study MLT wind variation on a global scale.

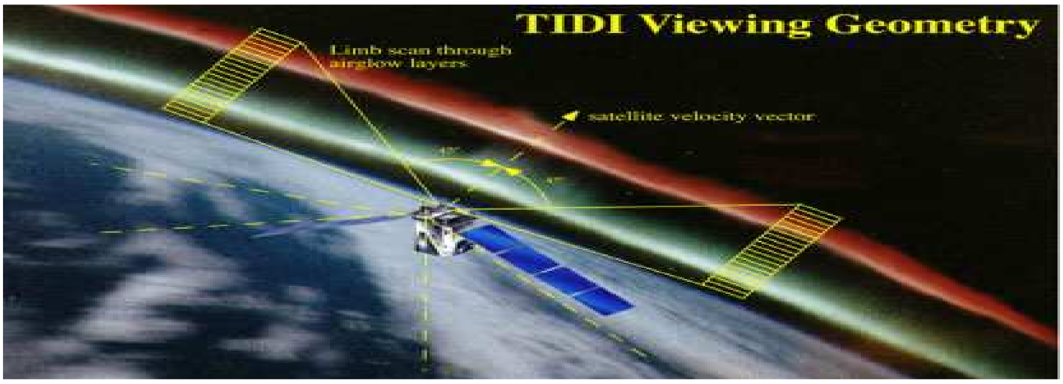


Figure 1. Illustration of TIDI viewing geometry [10]

RESULTS AND DISCUSSION

3.1 Solar-Geophysical Conditions

The Dst index represents the axially symmetric disturbance magnetic field from large-scale magnetospheric current systems observed at the dipole equator on the Earth's surface [12]. The Dst index data is acquired from the World Data Center for Geomagnetism, Kyoto. The global Kp index is obtained as the mean value of the disturbance levels in the two horizontal field components. It is observed at 13 selected mid-latitude stations during three-hour time intervals and covers the range 0 to 9 according to a quasi-logarithmic scale. The Kp index data is provided by GeoForschungsZentrum (GFZ) Potsdam. The solar and geophysical conditions that prevailed during the period of study are shown in figure 2. During this period Dst values of -350 nT and -383 nT were recorded on the 29th and 30th respectively. The interval of study, 27th October to 2ndNovember includes periods of elevated magnetic activity with Kp values varying between 5 and 9. The solar flux index varied between 210 s.f.u and 279.1 s.f.u.

3.2 Data Selection and Results

Measurements in the considered equatorial latitude are available from -10 to +10 geographic latitudes. Zonal and meridional wind data in this latitudinal band is available both day and night at local time sectors from 1400 to 1800 hours and from 0200 to 0600 hours. Figure 3 shows the number of measurements in each local time sector under consideration. Data is not continuous in each of the two local time sectors so for analysis data in each local time sector is further split into two time sectors. Wind speeds are considered at 3 altitude levels of 90 km, 100 km and 110 km.

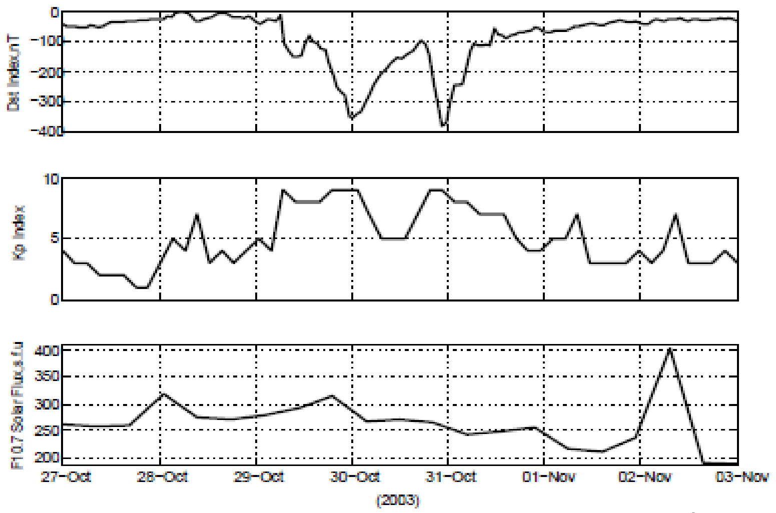


Figure 2. Solar (F10.7) and geomagnetic activity (Dst and Kp) conditions during the period from 27th October to 2nd November, 2003.

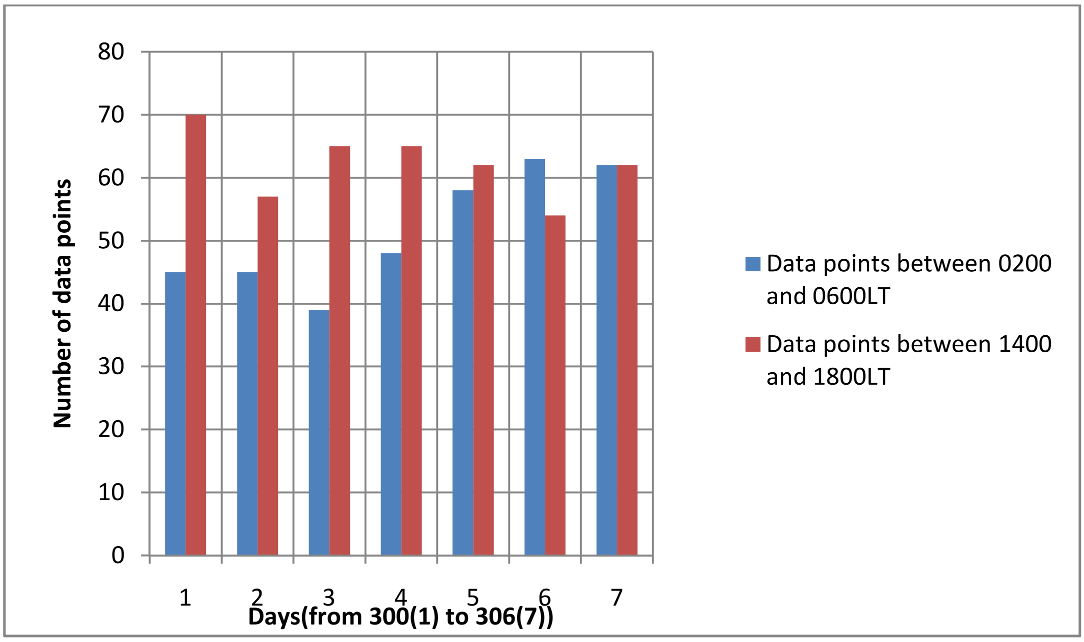


Figure 3. Number of measurements in each local time sector from the 27th October (day 300) to 2nd November (day 306)

Wind variation is considered from 27th October to 2nd November 2003. This includes periods of elevated activity and undisturbed periods which serve to define quiet times. Figures 4, 5, 6 and 7 display the zonal and meridional winds at different Solar Local time sectors from 27th October to 2nd November 2003 at altitudes 90km, 100km and 110km. Under disturbed conditions on the 29th October 2003, during the nighttime time sector the zonal wind at 100 and 110 km altitude is generally eastwards, with maximum speeds going above 200m/s. the zonal wind at 90km altitude is westwards. Meridional wind direction at 100 and 110km is generally equatorwards. On the 30th October, still under disturbed conditions zonal wind direction is generally eastward from 0200 to 0300 LT, while meridional wind is poleward at all the three considered altitudes.

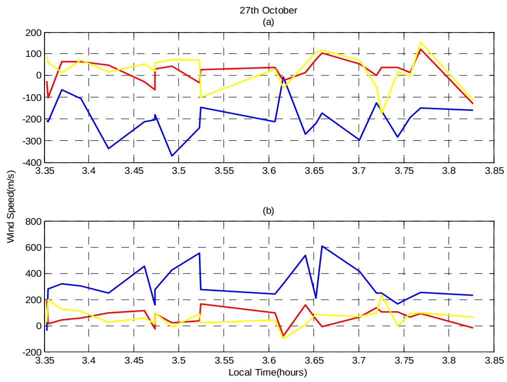
For daytime local time sector under disturbed conditions on the 29th October 2003, the zonal wind direction is generally eastward from 1400-1500LT, while the meridional wind direction is equatorward for all the three altitudes. On the 30th October 2003, zonal wind direction is eastwards, but generally westwards from 1600-1700LT. Meridional wind direction is generally equatorwards with maximum speeds at 100 and 110km going above 100m/s.

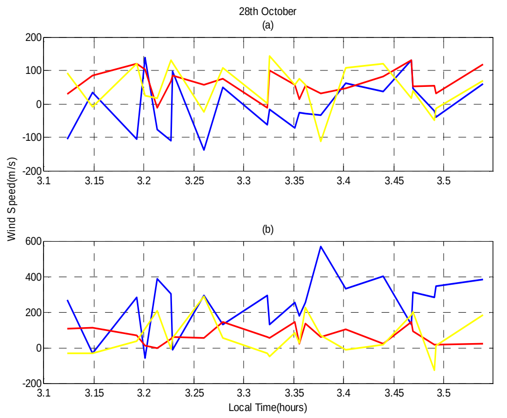
DISCUSSION

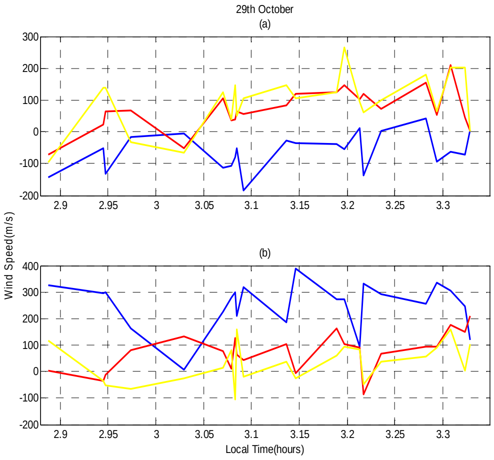
The winds at the considered MLT altitudes did not show any significant changes in direction and magnitude to the wind behavior during the non-storm days of 27th and 28th October. Zonal winds are generally eastwards during storm and non-storm nighttime and daytime local time sectors. Winds at low and equatorial latitudes may respond slowly to sources from Polar regions because propagation speeds are limited in the cooler dense lower thermosphere. Internal atmospheric processes such as stratospheric warming events, seasonal transitions, planetary waves and local magnetic fluctuations may also mask the response of the MLT region to geomagnetic activity since winds at MLT altitudes are governed by the semidiurnal and diurnal tides that originate in the lower atmosphere and propagate into the MLT region.

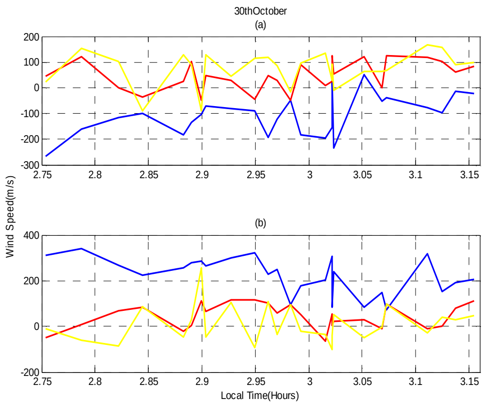
The National Center for Atmospheric Research Thermosphere-Ionopsphere General Circulation Model (NCAR TIGCM) predicts that effects of varying geomagnetic activity are larger at solar minimum than at solar maximum and increase with increasing latitude and altitude well above 100km [7]. The October 2003 storms did not occur during the declining phase of cycle 23. The tidal zonal winds generally decrease at low and middle latitudes and increase at high latitudes, the diurnal and semidiurnal meridional winds generally increase [2]. In their study of horizontal winds over Eastern Siberia region near 95km, [18], showed that effects of geomagnetic storms(Ap>100) are manifested in the decrease in the prevailing wind and increase in the semidiurnal tide amplitude. As reported by [1], the response of thermospheric winds at heights above 90km in the mid and high latitudes has been found to be significant during intense storms (Kp exceeding 6). This is expected as effects of geomagnetic storms are strongly felt in the auroral zone. During propagation their amplitudes weakens as they propagate through the middle to low latitudes. Effects are felt but in the low latitude and equatorial F-regions.

As of now, there is not enough information to determine definitively how much variability of MLT region is internal and how much is externally forced [16].






29th October
(a)
(b)
Wind Speed(m/s)
Local Time(hours)


30thOctober
(a)
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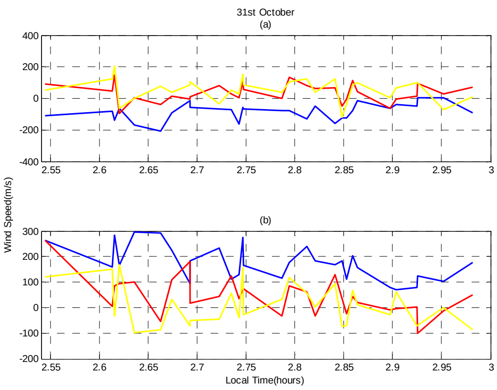
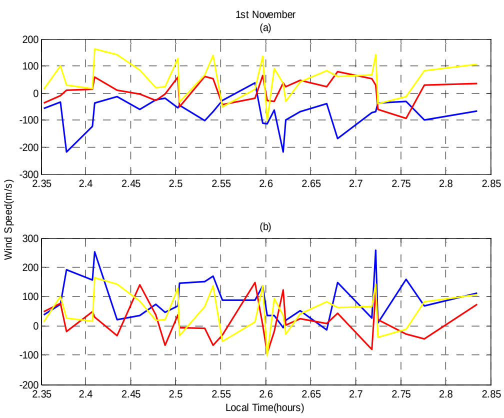
Wind Speed(m/s)
Local Time(Hours)


31st October
(a)
(b)
Wind Speed(m/s)
Local Time(hours)


1st November
(a)
(b)
Wind Speed(m/s)
Local Time(hours)

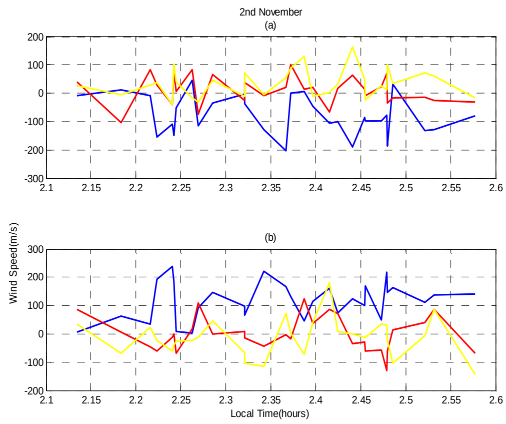
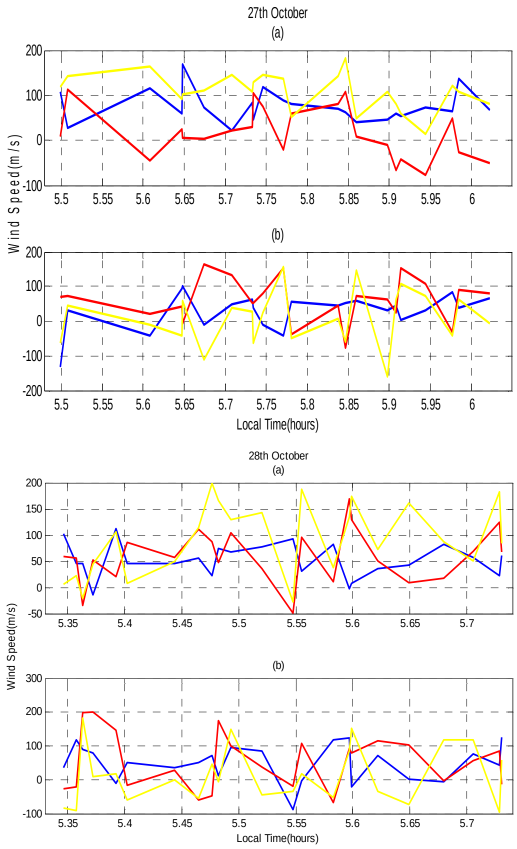
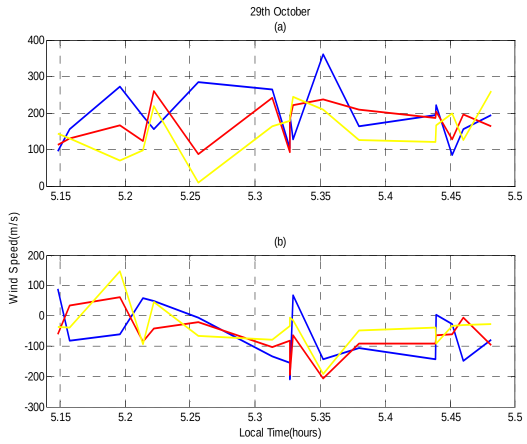


Figure 4. Zonal and meridional winds in the mesosophere/lower thermosphere at 90, 100 and 110 km from 27th October to 2nd November, 2003 (LT~2.3 to 3.9). Blue represents winds at 90km; red, winds at 100km and yellow, winds at 110km.

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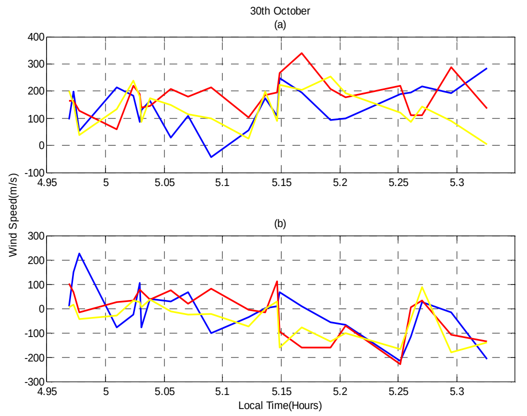
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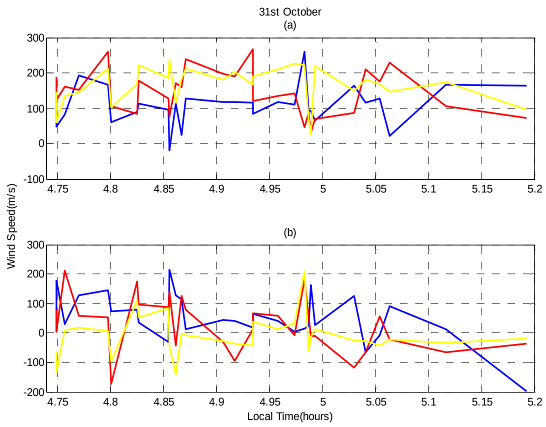
Wind Speed(m/s)
Local Time(Hours)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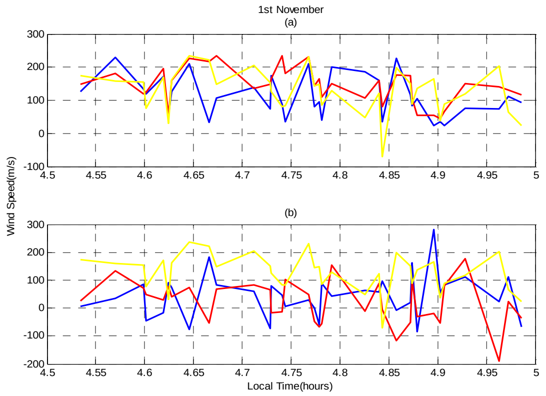
1st November
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Wind Speed(m/s)
Local Time(hours)

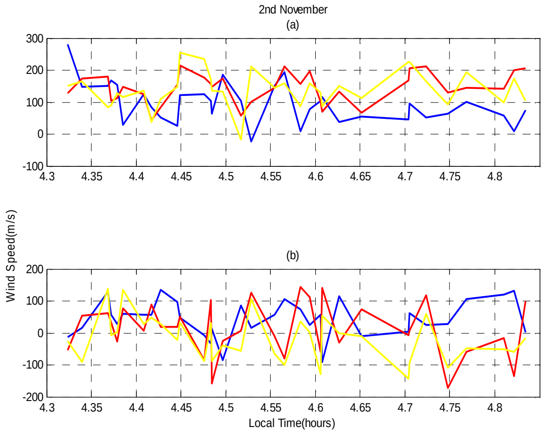
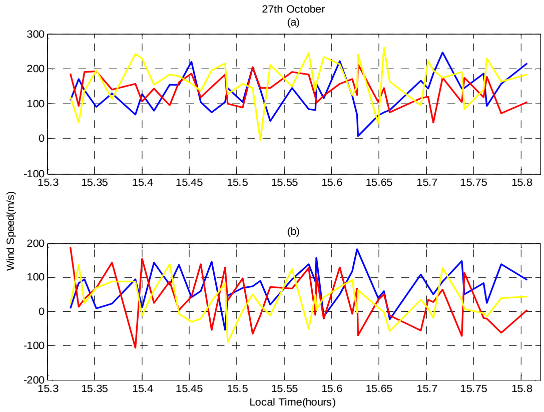
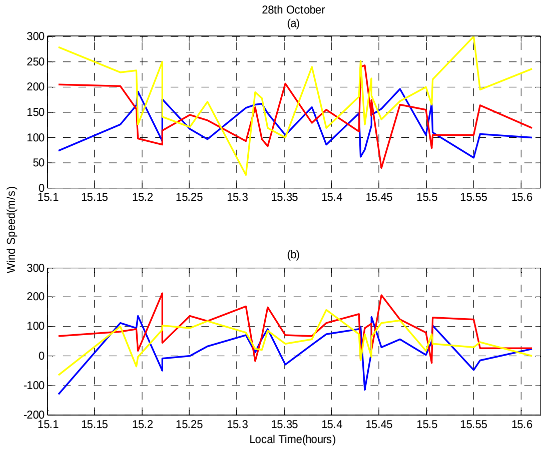
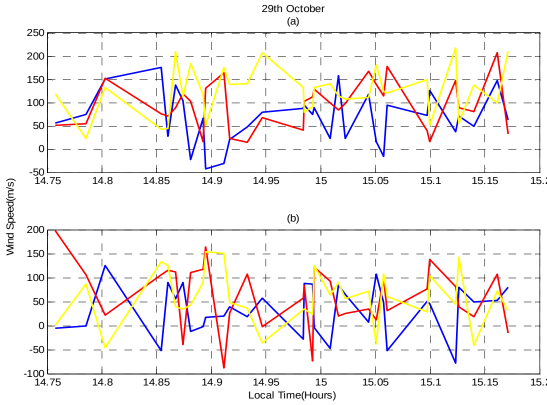


Figure 5. Zonal and meridional winds in the mesosophere/lower thermosphere at 90, 100 and 110 km from 27th October to 2nd November, 2003 (LT~4.3 to 6.5). Blue represents winds at 90km; red, winds at 100km and yellow, winds at 110km.






29th October
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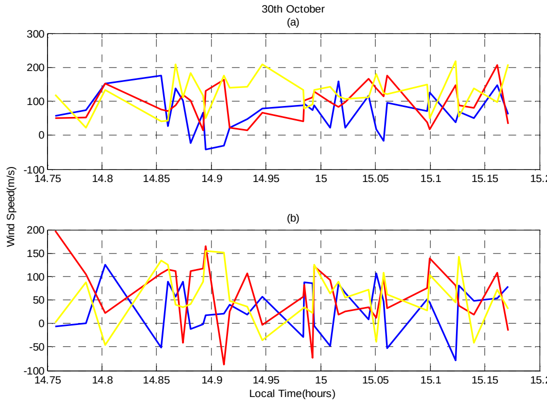
Wind Speed(m/s)
Local Time(Hours)


30th October
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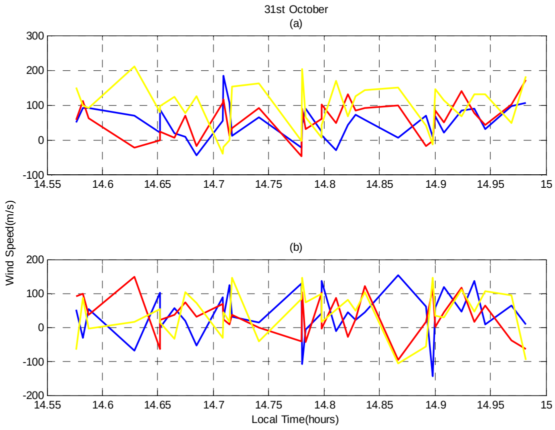
Wind Speed(m/s)
Local Time(hours)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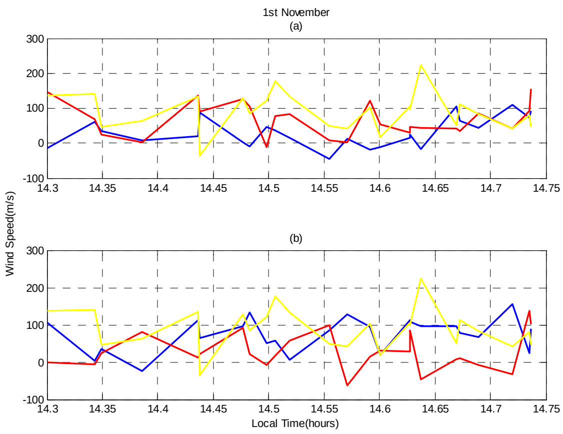
Wind Speed(m/s)
Local Time(hours)


1st November
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Wind Speed(m/s)
Local Time(hours)

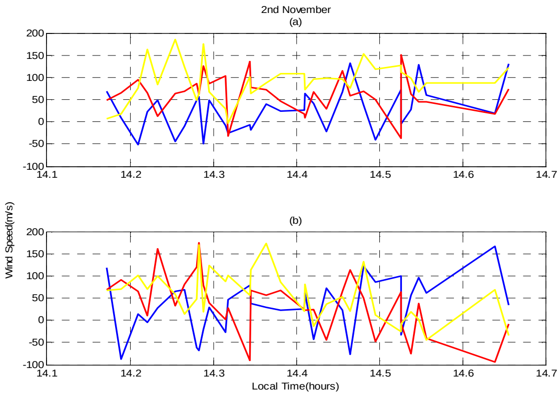
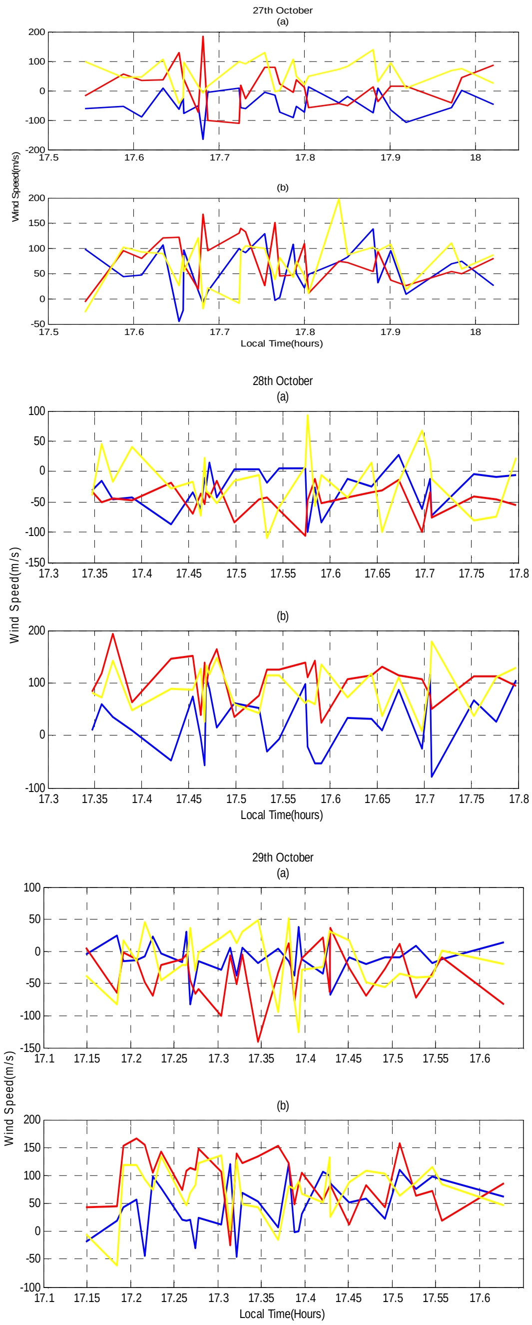
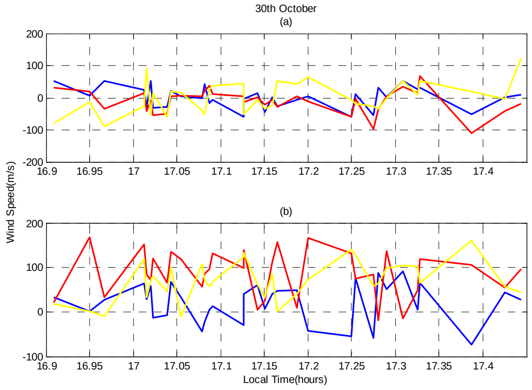


Figure 6. Zonal and meridional winds in the mesosophere/lower thermosphere at 90, 100 and 110 km from 27th October to 2nd November, 2003 (LT~14.1 to 15.9). Blue represents winds at 90km; red, winds at 100km and yellow, winds at 110km.




30th October
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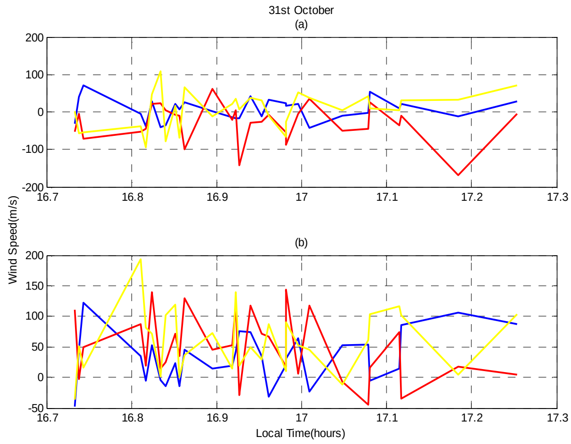
Wind Speed(m/s)
Local Time(hours)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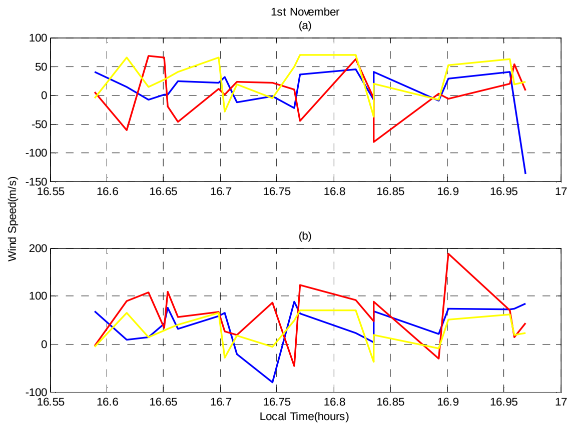
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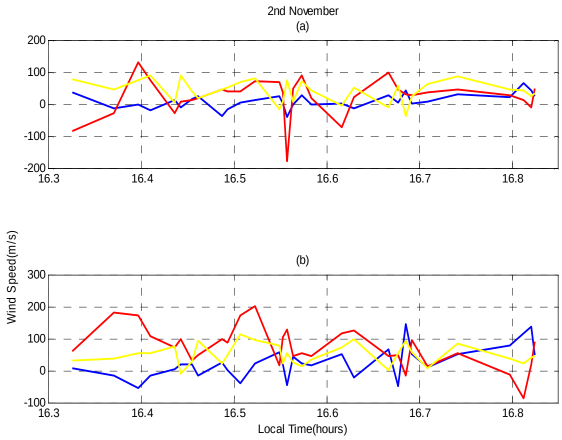

Figure 7. Zonal and meridional winds in the mesosophere/lower thermosphere at 90, 100 and 110 km from 27th October to 2nd November, 2003 (LT~16.3 to 18.5). Blue represents winds at 90km; red, winds at 100km and yellow, winds at 110km

CONCLUSION

There is need for simultaneous measurements to be carried in space at different locations to minimize the errors associated with single satellite measurements. Satellite instruments provide a global or near global picture of the MLT region but have limited local time sampling, and many also have limited spatial resolution [16].

TIMED, like other satellites in high inclination precessing orbits, takes a number of weeks to observe all local times, and so to obtain variability of global tides on short(days) time scales, multiple platforms in different orbits would be needed[19]. The results presented in this study suffer from limited local time sampling.

Acknowledgment
We are indebted to the TIMED team for the TIDI wind dataset.

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