Simultaneous mesosphere-lower thermosphere and thermospheric F region observations using middle and upper atmosphere radar


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[1] Simultaneous MLT (mesosphere-lower thermosphere) and thermospheric F region observations conducted using the middle and upper atmosphere (MU) radar (35°N, 136°E) in alternate meteor and incoherent scatter modes in October 2000 and March 2001 are presented. The continuous observations, each lasting more than a week, provide simultaneous zonal and meridional wind velocities at MLT altitudes (80–95 km), meridional wind velocity in the upper thermosphere (220–450 km), and electron density and peak height in the ionosphere with a time resolution of 1.5 hours. The data seem to suggest that the upper atmospheric regions could be dynamically coupled through mean winds, tides, and waves. Diurnal (24-hour) and semidiurnal (12-hour) tides and waves of periods 16–20 hours and 35–55 hours coexist at MLT and upper thermosphere altitudes, and the waves become stronger than tides at mesopause (∼88 km) in both October and March. The data in these equinoctial months also show large differences in mean winds, tides, and waves in the MLT region. The amplitudes and phases of the 24-hour and 12-hour tides at MLT altitudes are compared with those predicted by the global scale wave model (GSWM). The model qualitatively predicts the observed growth of the tides with altitude but does not predict the 12-hour tide becoming stronger than the 24-hour tide at altitudes above mesopause in October.


1. Introduction

[2] The mesosphere-lower thermosphere (MLT) region and thermospheric F region (upper thermosphere and the embedded ionosphere) at midlatitudes have been studied independently using different experimental and modeling techniques and theory in numerous publications. The MLT region (70–130 km altitudes), a region of complicated dynamics, has been studied using medium frequency (MF) and Meteor radars that cover altitudes of 70–100 km [e.g., Alleyne and Scholefield, 1975; Vincent et al., 1998; Manson et al., 2002], incoherent scatter (IS) radars that cover altitudes of 95–130 km [e.g., Amayenc and Vasseur, 1972; Salah, 1994], and rockets that reach different MLT altitudes [e.g., Larsen et al., 1997]. The radar and rocket observations have significantly broadened our understanding of the neutral dynamics in the MLT region [e.g., Mitchell et al., 2002; Zhang et al., 2003; Nozawa et al., 2003; Gurubaran et al., 2005]. Recently, the space-based instruments like the Wind Imaging Interferometer (WINDII) [Shepherd et al., 1993] and High Resolution Doppler Imager (HRDI) [Hays et al., 1992] on board the Upper Atmosphere Research Satellite (UARS), and TIMED Doppler Interferometer (TIDI) on board the Thermosphere Ionosphere-Mesosphere Energetic and Dynamics (TIMED) satellite [Killeen et al., 1999] have revealed a wealth of information on the global structures, seasonal, annual, and interannual variations of the winds, tides, and waves in the MLT region. Manson et al. [2002] have presented the diurnal and semidiurnal tides from six MF radars at locations from 2°N to 70°N, and compared the amplitudes, phases, and wavelengths with the global scale wave model (GSWM). Recently, they have shown significant similarities...
in the tides in the MF radar and WINDII data [Manson et al., 2003].

[3] Thermospheric F region is the most extensively studied region of the Earth’s upper atmosphere, for reviews see Rishbeth [1996] and Rodger [2000]. Recent studies of the thermospheric F region have suggested that complete understanding of the behavior of this region requires its coupling to the magnetosphere above and MLT region below [e.g., Cowley, 1996; Thomas, 1996; Aruliah et al., 1996; Balan et al., 1997]. Modeling studies have also indicated that the MLT and thermospheric F regions could be dynamically coupled through mean winds, tides, and waves [e.g., Forbes and Garrett, 1979]. However, except for a few studies [Fesen et al., 1993], observations of the two regions have usually been carried out independently. Fesen et al. [1993] measured the neutral winds, temperatures, and electron density simultaneously at lower and upper thermosphere altitudes over Arecibo (18°N) and Millstone Hill (42.6°N) in September 1987. The data showed large day-to-day variability possibly due to the geomagnetic storms that occurred during the period.

[4] The middle and upper atmosphere (MU) radar (35°N, 136°E) has been routinely used to study the MLT and thermospheric F regions separately using turbulent reflection, meteor, and incoherent scatter (IS) experiments since 1986 [Fukao et al., 1990; Tsuda et al., 1990; Oliver et al., 1991; Nakamura et al., 1991]. Recently, the radar, together with other experimental facilities, has been used for simultaneous observations of the MLT and thermospheric F regions under a project called MTEC-S (mesosphere-thermosphere experiments for coupling studies). The project has used the MU radar in alternate meteor and IS modes, for the first time. The data and observations from a March equinox operation, when two geomagnetic storms occurred, have been reported recently [Shiokawa et al., 2003; Balan et al., 2004].

[5] In the present paper we report the alternate MLT and thermospheric F region observations conducted in October 2000 and compare the data with that collected in March 2001. The continuous observations, each lasting more than a week, provide simultaneous zonal and meridional wind velocities at MLT altitudes (80–95 km), meridional wind velocity in the upper thermosphere (220–450 km), and electron density, peak height, and plasma drift velocity in the ionosphere with a time resolution of 1.5 hours. The data are used to study the mean winds, tides, and waves at MLT and upper thermosphere altitudes under magnetically quiet conditions in March and October. The observed amplitudes and phases of the diurnal (24-hour) and semidiurnal (12-hour) tides at MLT altitudes are also compared with those obtained from the global-scale wave model (GSWM) [Hagan and Forbes, 2002, 2003]. Section 2 describes the MU radar operation. The data and results are presented and discussed in section 3, with a summary in section 4.

[6] The simultaneous MLT and thermospheric F region data are also being compared with those modeled using a new version of the nonlinear coupled thermosphere ionosphere plasmasphere (CTIP) model [Millward et al., 2001]. The CTIP has lower altitude boundary at 80 km where diurnal and semidiurnal tidal forcing are introduced using the Hough modes (1,1), (2,2), (2,3), (2,4) and (2,5), and also includes a model for the electrodynamic coupling between the ionosphere and thermosphere. The data-model comparisons will be presented in a follow-up paper.

[7] Tides in the atmosphere are known to be produced by solar heating, which generate diurnal (24-hour) tide and its harmonics and subharmonics (12-hour, 8-hour, and 6-hour tides). According to tidal theory [e.g., Harris and Priester, 1962; Champan and Lindzen, 1970; Forbes and Garrett, 1979], there are two types of Sun-synchronous (migrating) diurnal tides. One is the upward propagating diurnal tide, which is produced in the troposphere due to the absorption of solar UV radiation by water vapor. It propagates upward but not above about 110 km due to its short vertical wavelength [see also Hays et al., 1992; McLandress et al., 1996]. The other is produced by in situ EUV heating at higher altitudes and hence dominant in the upper thermosphere. Some modes of the semidiurnal tide are generated at altitudes below about 70 km due to the absorption of solar UV radiation by ozone and water vapor and propagate upward. Other modes are excited via mode coupling owing to mean winds and meridional temperature gradients in the lower thermosphere, and momentum coupling due to mean winds and ion drag in the upper thermosphere. The data presented below show the relative importance of the propagating and in situ tides at different altitudes.

2. MU Radar Operation

[8] As mentioned above, the MU radar (35°N, 136°E) has been operated continuously in alternate meteor and IS modes, with 30 min for meteor mode and 1 hour for IS mode. In IS mode, 45 min was used for plasma drift velocity measurement, with range resolution of 38.4 km, and 15 min was used for power profile measurement, with range resolution of 9.6 km. The IS measurements are carried out sequentially in each interpulse period (11 ms) at four azimuthal directions (355°, 85°, 175°, 265°) at 20° off from zenith. The four line-of-sight plasma drift velocities are combined to determine the plasma drift velocity parallel to and perpendicular to the geomagnetic field direction. The drift velocity parallel to the geomagnetic field lines is used to derive a single weighted average value of the upper thermospheric (220–450 km) meridional wind velocity by removing the contribution of plasma diffusion velocity from the measured plasma drift velocity following a “layer wind” method described by Oliver et al. [1998]. Kawamura et al. [2000] have applied this method to 10 years of MU radar measurements and studied the climatology of the wind velocity at low and high solar activities. The estimated uncertainty of the wind velocity is approximately 20 m s⁻¹. The wind velocity, though in the geomagnetic meridian, is essentially equal to that in the geographic meridian because declination angle is small (5.7°) at MU radar location. The IS mode measurements can be used to infer only the meridional component of the upper thermosphere wind. The four line-of-sight power profiles are combined to obtain the vertical electron density at altitudes 200–600 km.

[9] The meteor data collected by the MU radar (35°N) are used to derive the zonal and meridional wind velocities at MLT altitudes (75–95 km), with altitude resolution of 1 km [Nakamura et al., 1991]. The alternate meteor and IS operations restricted the time resolution of the data to 1.5 hours. The uncertainty in the MLT region wind velocity is...
found to depend on altitude and time of the day; the estimated uncertainty is in the range 10–20 m s\(^{-1}\) at altitudes around 90 km [Nakamura et al., 1991]. The sign convention used is positive equatorward for all meridional winds and positive eastward for all zonal winds.

[10] Amplitude spectra of the data are obtained using Lomb-Scargle technique [Scargle, 1982], from which the amplitudes of the 24- and 12-hour tidal components are scaled. Lomb-Scargle technique is best suited for the spectral analysis of evenly and unevenly spaced data, and it does not require interpolation for missing data. The present data are complete and evenly spaced. The neutral wind data sets are also used to determine the phases of the tidal components by least squares fitting between the wind velocity \(U\) and the basis functions for the mean wind velocity \((U_0)\) and 10 strongest oscillating components using

\[
U = U_0 + \sum_n U_n \cos[2\pi(t - \phi_n)/24]
\]

where \(U_n\) and \(\phi_n\) (\(n = 1, 2, 3, \ldots 10\)) are the amplitude and phase of the oscillating components. As mentioned above, the study compares the “relative values” of the mean wind velocities \((U_0)\), and amplitudes \((U_n)\) of the tides and waves in March and October. The estimated uncertainties in \(U_0\) and \(U_n\) are of the order of 2.5 m s\(^{-1}\) and 3.5 m s\(^{-1}\), respectively, for the data used (minimum 4 days) though the uncertainties of the individual data points are up to 20 m s\(^{-1}\). Though single station radar studies do not have the advantages of distinguishing various tidal modes, they do provide a wealth of information on the temporal and height behavior of the tidal fields.

3. Results and Discussion

3.1. Data

[11] The data from the two MTEC-S observations are presented in Figures 1a–1d for October data and Figures 1e–1h for March data; color plot is provided at the end. The figures from top show the time variations of the zonal and meridional wind velocities at MLT altitudes (80–95 km), height average (220–450 km) upper thermospheric meridional wind velocity and electron density in the ionosphere (200–600 km). The ionospheric peak height is also shown in the bottom figures (black curves).

[12] The first alternate MLT and thermospheric \(F\) region observations were conducted for nearly 7.5 days during 1900 LT on 20 October to 0800 LT on 27 October 2000 when solar activity was high (\(F10.7 = 170–180\)) and magnetic activity was quiet (\(Kp < 4\)). As shown by the data in Figures 1a–1d, at MLT altitudes, the zonal wind (Figure 1a) in October varies from about 70 m s\(^{-1}\) to −40 m s\(^{-1}\) and is mainly eastward, meridional wind (Figure 1b) varies from about 60 m s\(^{-1}\) to −60 m s\(^{-1}\), and both winds show the presence of tides with downward phase propagation. In the upper thermosphere the meridional wind (Figure 1c) follows the usual September equinox pattern, with poleward flow during daytime and equatorward flow at night [Kawamura et al., 2000]. Though the velocity varies from about 80 m s\(^{-1}\) to −80 m s\(^{-1}\), the flow is mainly poleward (negative). The ionospheric electron density and peak height (Figure 1d) repeat the usual diurnal variations at equinox. The density becomes maximum around midday due to the predominance of the production of ionization, and peak height becomes maximum around midnight due to the equatorward neutral wind.

[13] The second observation was conducted for 10 days during 23 March to 2 April 2001 when two geomagnetic storms occurred, and the data have been used to study the storm-time changes in mean winds and tidal amplitudes at MLT and upper thermosphere altitudes [Balan et al., 2004]. Figures 1e–1h reproduces the MU radar data for the first 4 magnetically quiet (\(Kp < 4\)) days (24–27 March 2001) under high solar activity (\(F10.7 = 210–250\)), for comparison with the data in October (Figures 1a–1d). As Figure 1 shows, the zonal wind in March (Figure 1e) is mainly eastward as in October (Figure 1a). However, the eastward flow in October is faster than that in March. The IS radar and WINDII data over Millstone Hill (42.6°N, 288.5°E) studied by Zhang et al. [2003] have also shown stronger eastward flows at September equinox compared to March equinox at altitudes of 84–95 km.

[14] The meridional wind in the upper thermosphere in March (Figure 1g) is poleward during daytime and equatorward at night as in October (Figure 1g), which agrees with the theory of winds in the upper thermosphere [Roble et al., 1977; Rishbeth, 1998]. However, the wind in March is more equatorward than that in October as reported earlier and suggested to arise from the possible equinoctial differences in the magnetosphere-ionosphere coupling and/or MLT-upper thermosphere coupling [Aruliah et al., 1996; Balan et al., 1998]. In the lower thermosphere, the meridional wind in March is generally opposite to that in October (Figure 1b and above about 86 km, see also Figure 3). It and the faster zonal wind at MLT altitudes in October compared to March (described above) could be related to the physical processes that control the winds. The winds at MLT altitudes are basically governed by the semidiurnal and diurnal tides that originate in the lower atmosphere and propagate into the MLT region [Forbes and Garrett, 1979]. The observed differences seem to suggest that the propagation and coupling of the tides from lower to upper atmospheres may have differences in the two equinoctial months, which needs to be investigated.

[15] The ionospheric electron density and peak height in March (Figure 1d) undergo similar variations as in October (Figure 1d). However, the ionosphere in March is broader and denser in the topside (see the yellow color extending to 600 km) compared to the ionosphere in October. This is consistent with the direct effect of the meridional neutral wind on the ionosphere [Kawamura et al., 2002]. The comparatively less poleward daytime meridional wind in March (compare Figure 1c, and also see Figure 3) raises and expands the ionosphere to higher altitudes (compare the daytime peak heights in Figures 1d and 1h) of reduced chemical loss, which can cause the topside ionosphere broader and denser in March compared to October as has been shown by model calculations [Balan et al., 1998]. In effect, the less poleward wind in March partially relaxes the wind’s forcing of the ionosphere to low altitudes compared to the forcing of the more poleward wind in October. The density at the ionospheric peak in March is nearly the same or a bit smaller compared to the density in October. This, though, seems to contradict the solar activity differences.
between the 2 months, is also consistent with the wider expansion of the ionosphere in March and the fact that the ionospheric peak density remains more or less constant when F10.7 exceeds above about 180 [Balan et al., 1993].

### 3.2. Amplitude Spectra

[16] The amplitude spectra of the data in Figure 1 are shown in Figures 2a–2d for October and Figures 2e–2h for March; color plot is provided at the end. The red color of the spectra is made saturated for easy comparison of the spectral features, and absolute magnitudes of the tides and waves are compared in Tables 1 and 2. As shown by the spectra, the diurnal (24-hour) and semidiurnal (12-hour) tides and waves of periods 16–20 hours and 35–55 hours coexist at MLT and upper thermospheric altitudes. These tides and waves are discussed. Other weak tides and waves are not discussed. As shown by the spectra (Figure 2), the diurnal (24-hour) tide is generally dominant at MLT and thermospheric F region altitudes and in both zonal and meridional directions. However, in October (Figures 2a–2d), the diurnal tide (Figures 2a and 2b) becomes weak and semidiurnal tide grows strong with altitude in the MLT region so that the semidiurnal tide becomes stronger than the diurnal tide at altitudes above mesopause (>88 km). In March, on the other hand, the diurnal tide remains strong and semidiurnal tide remains weak at all MLT altitudes (Figures 2e and 2f).

[17] In both months (Figure 2), the waves (16–20 hours and 35–55 hours) are strong at mesopause (>≈88 km). The short period wave (16–20 hours) is stronger than tides in October (Figures 2a and 2b) and long period (35–55 hours) wave is stronger than tides in March (Figure 2e). Also, the short period wave has period around 18 hours in October.

![Figure 1. Simultaneous mesosphere-lower thermosphere (MLT) and thermospheric F region observations conducted using the middle and upper atmosphere (MU) radar in alternate meteor and incoherent scatter modes in October 2000 (left) and March 2001 (right) when magnetic activity was quiet (Kp < 4) and solar activity was high. The October data (left) are for nearly 7.5 days from 1900 LT on 20 October to 0800 LT on 27 October when the solar activity index F10.7 was 170–180. The March data (right) are for 4 days from 0000 LT on 24 March to 2400 LT on 27 March when F10.7 was 210–250. In both cases, the panels from top show the zonal and meridional wind velocities at MLT altitudes (80–95 km), height average (220–450 km) upper thermospheric meridional wind velocity, and electron density in the ionosphere (200–600 km). Ionospheric peak height is also shown in the bottom panel (black curve). The sign convention is positive equatorward for all meridional winds and positive eastward for all zonal winds.](A10S17.png)
while the long period wave is centered around 48 hours in both months. A long wave of period 4–5 days also seem to coexist at all altitudes in October (Figures 2a–2d). The quiet-time data in March are not long enough to check the existence of this wave. The spectra of the height average upper thermosphere wind (Figure 2c) and ionospheric density (Figure 2d) seem to contain more short-period gravity wave components than the spectra of the winds in the MLT region (Figures 2a and 2b).

3.3. Mean Winds, Tides, and Waves

The data and spectra presented above for the equinoctial months of March and October (Figures 1 and 2) have indicated similarities and differences in winds, tides, and waves. Figures 3 and 4 bring out the similarities and differences in the mean wind velocities. Figure 3 compares the diurnal variations of the zonal (right) and meridional (left) mean wind velocities at different altitudes (220–450, 95, 86, and 80 km); solid curves correspond to October and dashed curves to March. The diurnal mean velocities are obtained by averaging 6 magnetically quiet days data each in the 2 months; standard deviations are not shown for clarity. Figure 4 compares the net zonal (middle) and net meridional (left) wind velocities at different altitudes in the form of histograms obtained by averaging the data in Figure 3. As Figures 3 and 4 show, the zonal wind is eastward at all altitudes and in both months, and the wind in October is more than three times faster compared to the wind in March, especially at altitudes below mesopause (~88 km). The meridional wind, on the other hand, is equatorward in March and poleward in October at lower and upper thermosphere altitudes (95 and 220–450 km). At mesosphere altitudes (86 and 80 km), the meridional wind is weak.
Figure 4 also compares the resultant horizontal mean winds (resultant of the net zonal and net meridional winds) at different altitudes as vectors (right); dark vectors for October and light vectors for March. As shown by the vectors, the resultant horizontal mean wind, as expected, is also predominantly eastward in both months, and the wind in October is more than three times faster compared to the wind in March at altitudes below mesopause (≈88 km). At higher altitudes, the resultant wind in October is southeastward and twice as fast as the northeastward wind in March.

### 3.4. Comparison With GSWM

Tables 1 and 2 list the amplitudes and phases of the tides (24-hour and 12-hour) and waves (16–20 and 35–55 hours) at MLT and upper thermosphere altitudes in October and March, respectively. The amplitudes are scaled from the spectra in Figure 2, and phases are computed using equation (1); the values are listed outside the brackets. The tables reproduce the similarities and differences in the tides and waves observed in the spectra (Figure 2). For example, in October (Table 1) the 12-hour tide becomes stronger than 24-hour tide at altitudes above mesopause; the 12-hour tide at lower thermosphere altitudes (95 km) has amplitudes of about 30 m s⁻¹ in the zonal direction and 26 m s⁻¹ in the meridional direction compared to the 24-hour amplitudes of about 12 m s⁻¹ and 16 m s⁻¹. The short-period (16–20 hours) wave in October (Table 1) becomes stronger than the tides around mesopause where the wave has amplitudes of about 19 m s⁻¹ in the zonal direction and 27 m s⁻¹ in the meridional direction compared to the average (24- and 12-hour) tides.

<table>
<thead>
<tr>
<th>Alt, km</th>
<th>24-Hour</th>
<th>12-Hour</th>
<th>16–20 Hour</th>
<th>35–55 Hour</th>
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<td></td>
<td>Amp, m/s</td>
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<td>Amp, m/s</td>
<td>Phase, hours</td>
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<tr>
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</table>

aThe radar measurements cannot provide the zonal wind in the upper thermosphere (220–450 km). The values in brackets are the amplitudes and phases of the tides obtained from the Global Scale Wave Model (GSWM-02).
12-hour) tidal amplitudes of 12 m s\(^{-1}\) and 16 m s\(^{-1}\). In March (Table 2), it is the long-period (35–55 hour) wave that becomes stronger than the tides around mesopause; the short-period wave has amplitudes of about 24 m s\(^{-1}\) and 12 m s\(^{-1}\) respectively in the zonal and meridional directions compared to the respective average tidal amplitudes of 9 m s\(^{-1}\) and 11 m s\(^{-1}\).

The tidal phases (Tables 1 and 2) show large fluctuations, especially the 24-hour phase. The 12-hour phase, though fluctuates, shows a general downward propagation in both months as indicated by the data (Figure 1). The phases of the waves also fluctuate with altitude. However, in October (Table 1) the phase of the short-period (16–20 hours) wave, which is stronger than the tides around mesopause, occurs earlier around mesopause and later at higher altitudes. Such a phase variation with altitude is not seen for this short-period wave in March (Table 2) when the wave is weaker than the long-period (35–55 hours) wave. No clear downward or upward phase propagation can be noted for the long-period wave in either month.

Tables 1 and 2 also list the amplitudes and phases of the 24- and 12-hour tides at MLT altitudes (in brackets) obtained from the global scale wave model (GSWM-02) for the months of October and March [Hagan and Forbes, 2002, 2003]. The model amplitudes of both tides increase with altitude in both months, which qualitatively agrees with the observations in March (Table 2) though the model amplitudes are larger than the observed amplitudes by a maximum of about 20 m s\(^{-1}\) for 24-hour tide and 8 m s\(^{-1}\) for 12-hour tide in the meridional direction; however, in the zonal direction, the model 24-hour amplitude becomes smaller than the observed amplitude by a maximum of
12 m s\(^{-1}\) in the lower thermosphere (95 km). In October (Table 1), the model does not predict the 12-hour amplitude exceeding the 24-hour amplitude at altitudes above mesopause. The observed decay of the 24-hour tide makes its amplitude smaller than the model amplitude by a maximum of about 40 m s\(^{-1}\) and the growth of the 12-hour tide makes its amplitude larger than the model amplitude by a maximum of about 18 m s\(^{-1}\) at lower thermosphere altitudes (95 km). The model also predicts downward phase propagation for both tides at all altitudes, which qualitatively agrees with the observed behavior of the 12-hour phase.

[23] The observed tidal parameters are also compared with the GSWM-00 model (not shown), which shows similar model-data agreements and disagreements as GSWM-02. However, GSWM-00 amplitudes are smaller than GSWM-02 amplitudes at all altitudes, by a maximum of about 17 m s\(^{-1}\) for the 24-hour tide at lower thermosphere altitudes (95 km); the 12-hour amplitude is less by only a maximum of 3 m s\(^{-1}\). The model-data differences need to be studied in detail. The differences could be due to the uncertainty of measurements, and the day-to-day, seasonal (equinoctial), and regional differences of the forces.

Figure 4. Histograms comparing the net zonal (middle) and net meridional (left) wind velocities at different altitudes at March and September equinoxes obtained by averaging the data in Figure 3. The sign convention is positive equatorward for meridional winds and positive eastward for zonal winds. The vectors on the right compare the resultant horizontal mean winds (resultant of the net zonal and net meridional mean winds) at different altitudes at September equinox (dark vectors) and March equinox.
and coupling mechanisms that control the wind speed and tidal parameters. The model is longitude invariant while observations are for the MU radar longitude (135°E). Also, the observed data are for high levels of solar activity while the model data are for medium level of solar activity. [24] The generation and propagation of the tides [e.g., Forbes and Garrett, 1979], described briefly in the introduction, can make the mesosphere dominated by the upward propagating diurnal tide produced in the troposphere, lower thermosphere dominated by upward propagating semidiurnal tide produced in the mesosphere, and upper thermosphere dominated again by diurnal tide produced in situ. The observed altitude variation of the diurnal tide at all altitudes and semidiurnal tide in the MLT region (Figure 2 and Tables 1 and 2) agree with the above theoretical predictions. The semidiurnal tide in the upper thermosphere could be propagated from below or produced in situ by momentum coupling due to mean winds and ion drag. [e.g., Forbes and Garrett, 1979]. However, the observed semidiurnal tide and waves in the upper thermosphere (Figure 2c and Tables 1 and 2) are unlikely to be propagated from below. That is because the tides and waves in the upper thermosphere are obtained from the height-averaged (220–450 km, 230 km coverage) wind velocity and therefore the upward propagating tides and waves with vertical wavelength shorter than the height coverage (230 km) are filtered out. The semidiurnal tides and waves in the upper thermosphere and ionosphere require further investigation for their origin, which is planned in later studies. [25] The quasi 2-day wave (period 35–55 hours) that becomes strong at mesopause altitudes (Figures 2a and 2b) has been observed earlier [e.g., Muller and Nelson, 1978; Nozawa et al., 2003]. It is interpreted as a manifestation of the westward propagating mixed Rossby-gravity normal mode with period near 2 days and zonal wave number 3 [Salby, 1984]. The simulations of the QTD wave by Hagan et al. [1993] indicate that these oscillations do not penetrate above about 100 km. However, it has been observed in the upper thermosphere and ionosphere, for which Forbes et al. [1997] have suggested some possible explanations. [26] The simultaneous MLT and thermospheric $F$ region observations presented above have shown the existence of similar tides and waves at all altitudes, growth and decay of tides with altitude, possible transfer of energy from tides to waves at mesopause as evidenced by the waves becoming stronger than tides at this altitude, and strong mainly eastward horizontal mean wind. These observations seem to suggest that the upper atmospheric regions could be dynamically coupled through mean winds, tides, and waves. [27] In addition, the study has shown strong differences between March and October in mean winds, tides, and waves in the MLT region. No explanation is given for the differences except suggesting that the differences could be due to the equinoctial differences in the energy and momentum transmitted from altitudes below the MLT region, which needs to be investigated. The observation period in October (20–27 October) is about a month off from September equinox toward December solstice while the period in March (24–27 March) is close to March equinox. The offset of the observation period in October from September equinox may or may not have effects on the observed differences. However, the simultaneous MLT and thermospheric $F$ region observations conducted in December 2001 (not shown) do not show any significant similarities with the MLT region data in October. The random changes and slower trends happening in the MLT region [e.g., Kohseik et al., 1998] may have some effects on the observed differences between March and October. The difference in the solar activity level between the two observation periods (F10.7 = 170–180 in October and 210–250 in March) may not have any significant effect on the observed differences. Zhang and Shepherd [2005] checked the solar activity dependence of the mean winds and 24-hour tides in the MLT region using WINDII data for 5 February months during 1992–1996, and found an irregular solar activity dependence at tropical latitudes. 4. Summary [28] The mesosphere lower-thermosphere (MLT) region and thermospheric $F$ region (upper thermosphere and ionosphere together) at mid latitudes are observed simultaneously by operating the MU radar (35°N, 136°E) in alternate meteor and incoherent scatter (IS) modes. The continuous observations provide simultaneous zonal and meridional wind velocities at MLT altitudes (80–95 km), meridional wind velocity in the upper thermosphere (220–450 km), and electron density, peak height, and plasma drift velocity in the ionosphere, with a time resolution of 1.5 hours. The data collected in the equinoctial months in October 2000 and March 2001, each lasting more than a week, are used to study the similarities and differences in mean winds, tides and waves at MLT and upper thermosphere altitudes. The amplitudes and phases of the diurnal (24-hour) and semidiurnal (12-hour) tides at MLT altitudes are compared with those obtained from the global scale wave model (GSWM). [29] The data seem to suggest that the upper atmospheric regions could be dynamically coupled through mean winds, tides, and waves. The resultant horizontal mean wind (resultant of the strong zonal mean wind and weak meridional mean wind) in the MLT region is predominantly eastward, with the wind in October being more than three times faster compared to the wind in March, especially in the mesosphere (80–86 km). The meridional mean wind in the lower and upper thermospheres is equatorward in March and poleward in October. Diurnal and semidiurnal tides and waves of periods 16–20 hours and 35–55 hours coexist at MLT and upper thermosphere altitudes in both months. The waves are stronger than tides at mesopause, with the 16–20 hour wave becoming stronger in October and 35–55 hours wave becoming stronger in March. The model (GSWM) qualitatively predicts the observed growth of diurnal and semidiurnal tides with altitude but does not predict the semidiurnal tide becoming stronger than diurnal tide at altitudes above mesopause in October. [30] Acknowledgments. 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