ALTERNATE METEOR AND INCOHERENT SCATTER OBSERVATIONS USING MU RADAR

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1. INTRODUCTION

Earth's upper thermosphere and the embedded ionosphere, called thermospheric F-region, have been studied extensively under magnetically quiet and active conditions using different experimental and modeling techniques and theory. These studies have suggested that complete understanding of the behaviour of the thermospheric F-region requires its coupling to the mesosphere-lower thermosphere (MLT) region below and magnetosphere above [1, 2]. Recently, we have started studying the MLT and thermospheric F-regions simultaneously under a project called MTEC-S (mesosphere-thermosphere experiments for coupling studies) [3]. The project uses the MU radar at Shigaraki (35°N, 136°E) in alternate meteor and incoherent scatter (IS) modes for the first time, two MF radars at Yamagawa (31°N, 131°E) and Wakkanai (45°N, 142°E), optical mesosphere-thermosphere imagers (OMTI) located at the MU radar site, and over 1000 GPS receivers spread out in Japan. Four long MTEC-S campaigns, one in each season, have been conducted in 2000-01. The present paper reports the MU radar data from the four MTEC-S campaigns.

2. MU RADRA OPERATION

The MU radar is 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 [4], with an estimated uncertainty of less than 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 four line-of-sight power profiles are combined to obtain the vertical electron density at altitudes 150-600 km. The meteor data are used to derive the zonal and meridional wind velocities at MLT altitudes (80-95 km), with altitude resolution of 1 km [5]. The alternate meteor and IS operations restricted the time resolution of the MU radar data to 1.5 hours. The sign convention used is positive equatorward for all meridional winds and positive eastward for all zonal winds.

3. OBSERVATIONS AND DISCUSSION

Fig. 1a shows the complete MU radar data from the first MTEC-S campaign conducted for eight days during 20-27 October 2000. The panels from top to bottom 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 ionospheric electron density over 200-600 km, with ionospheric peak height in black curve. As shown, at MLT altitudes, the zonal wind varies from east (up to 60 m/s) to west (up to 30 m/s), and meridional wind changes from equatorward (up to 50 m/s) to ploeward (up to 60 m/s). Both winds generally increase with altitude and have downward phase propagation. In the thermospheric F-region, the meridional wind varies from equatorward (up to 75 m/s) to poleward (up to -75 m/s), and ionospheric electron density and peak height repeat usual diurnal variation and follow the wind. Fig. 1b shows the amplitude spectra of the data. As seen, diurnal tide is dominant at all altitudes; weak semi-diurnal and tri-diurnal tides are also present. Waves of period near 18 hours and two day are generally present in all regions. In addition, waves of period near 66 hours are also present at thermospheric F region altitudes.

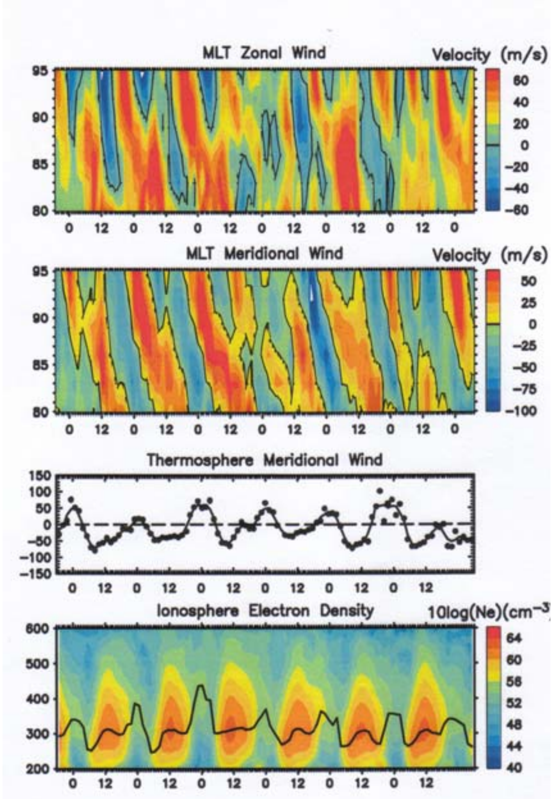

Fig. 1a: MU radar data from the first MTEC-S observations during 20-27 October 2000.

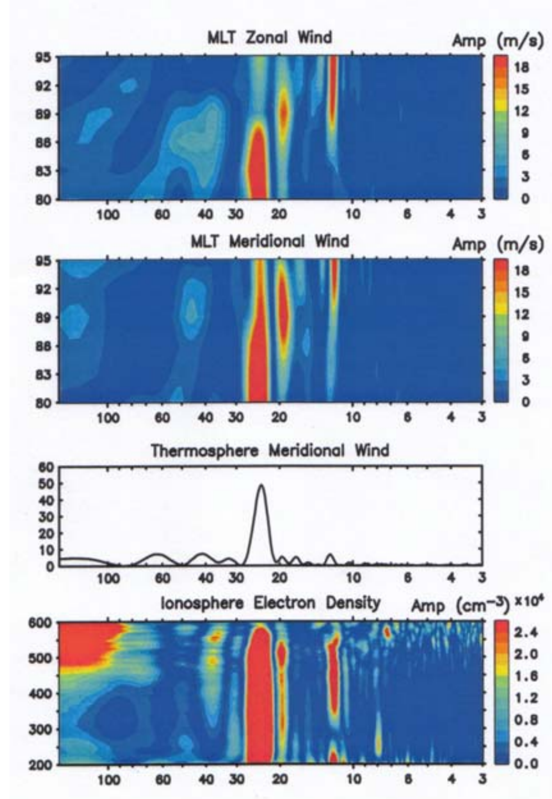

Fig. 1b: Amplitude spectra of the MU radar data (left) from the first MTEC-S observations during 20-27 October 2000.

The second MTEC-S campaign was conducted for 10 days during 23 March - 02 April 2001 when two geomagnetic storms occurred; solar activity was also high (Fig. 2); the solid vertical line shows the end of the campaign. The data from the second TEC-S campaign (Fig. 3a) should, therefore, contain the effects of high levels of solar and magnetic activities. The vertical lines in the data (Fig. 3a) show the times of SC. Under magnetically quiet conditions, the meridional wind in the upper thermosphere (panel 3) is poleward during daytime and equatorward at night. In the lower thermosphere (panel 2 and above about 88 km), the wind seems to be generally equatorward during daytime and poleward at night. The directions of these meridional wind flows can be understood in terms of the quiet-time thermospheric meridional circulation, which under equinoctial daytime conditions could be closed by vertical upward winds at equatorial latitudes and downward winds at latitudes just equatorward of the auroral oval [6]. However, the magnitudes of the velocities in the lower and upper thermospheres are comparable. That seems to suggest that only a small fraction of the air in the lower thermosphere may be involved in the meridional flow.

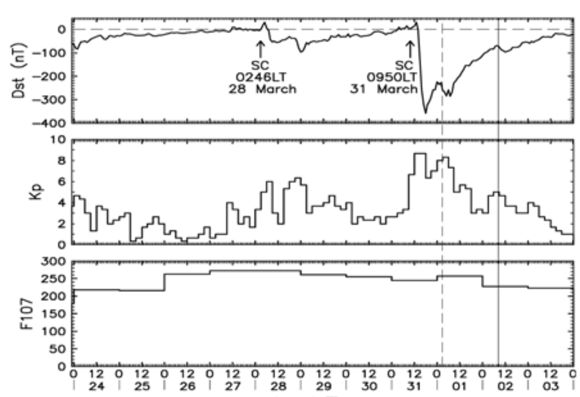

Fig. 2: Dst, Kp and F10.7 during second MTEC-S.

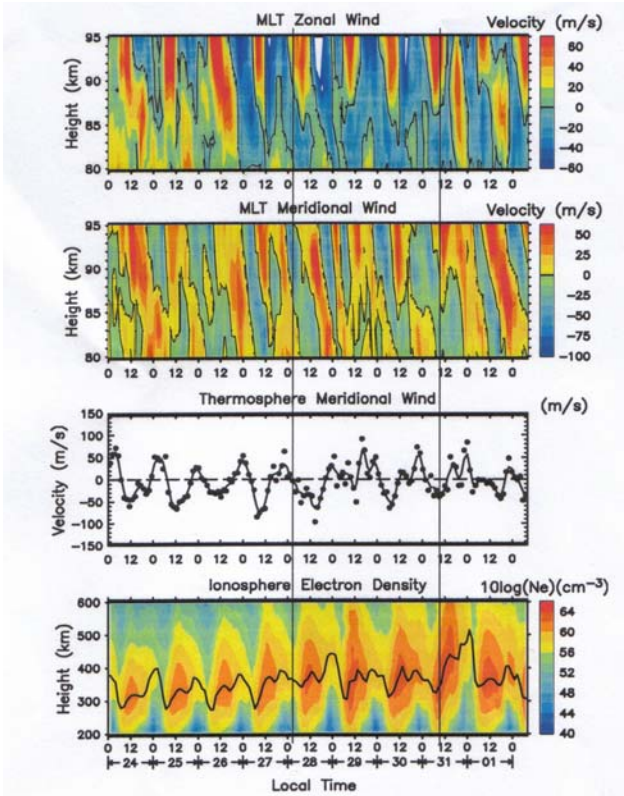

Fig. 3a:
observations during 24 March-02 April 2001, when two geomagnetic storms occurred (Fig. 2).

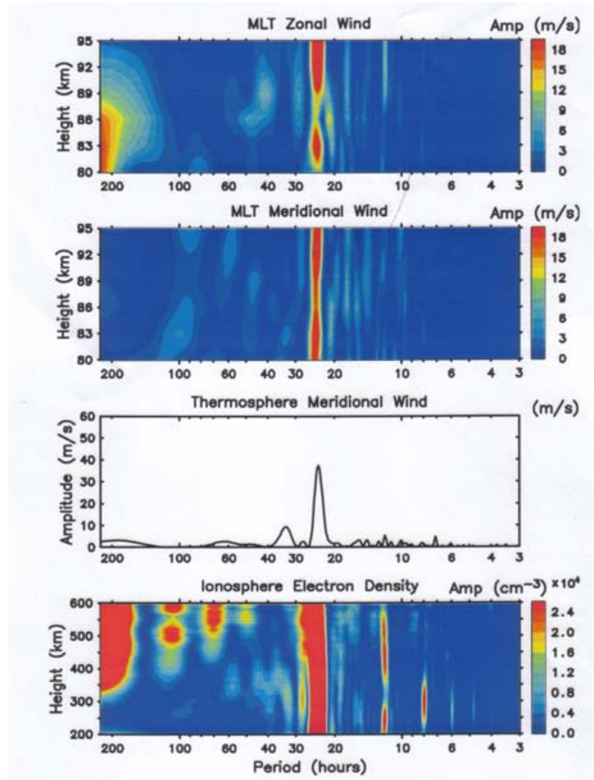

Fig. 3b: Amplitude spectra of the MU radar data (left) from the second MTEC-S observations during 24 March-02 April 2001.

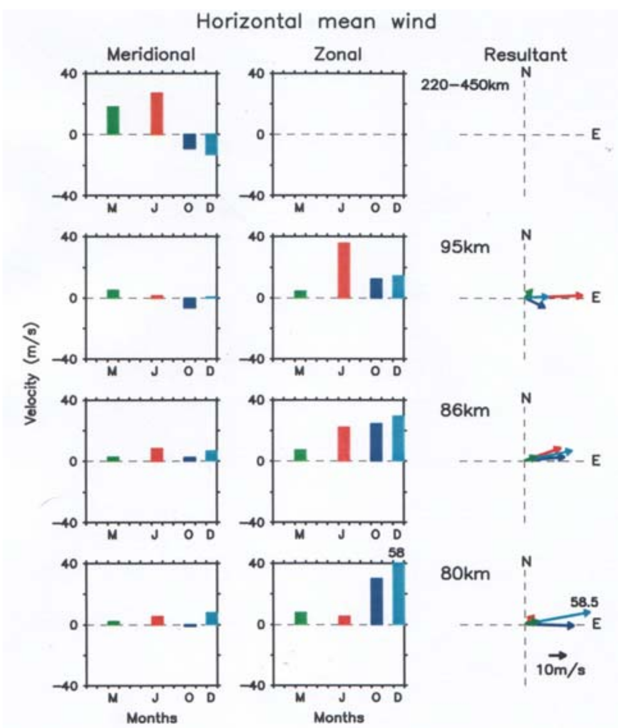

Fig. 4: Comparison of the horizontal mean wind velocities from the four MTEC-S observations. The Data during the active days 28, 29 and 31 March 2001 are not considered. The colour code is same for the histograms and vectors.

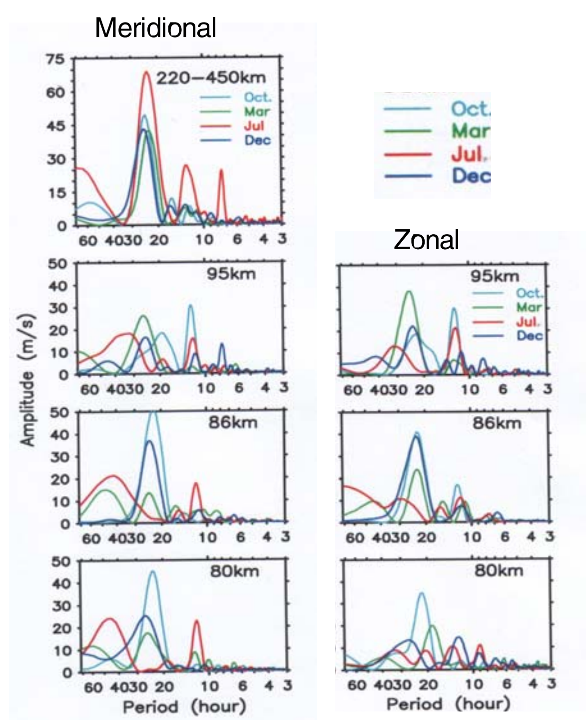

Fig. 5: Comparison of the amplitude spectra from 72-hours of quiettime wind velocity data from the four MTEC-S observations.

Under magnetically active conditions, the meridional wind in the upper thermosphere (panel 3) becomes less poleward, and the effect is quicker for the major storm than for the moderate storm. At MLT altitudes, the winds (panels 1-2) show changes during both non-storm times and storm times. However, during the major storm (31 March and 1st April), the meridional wind (panel 2) seems to become slightly further equatorward and zonal wind (panel 1) seems to become slightly more eastward (or less westward) in the lower thermosphere (above about 88 km). The changes in the meridional wind can be qualitatively understood in terms of the interactions between the solar driven thermospheric quiet-time circulation (described above) and auroral driven disturbed-time winds. The auroral driven winds are equatorward at all thermospheric altitudes and, therefore, can reduce the daytime poleward wind in the upper thermosphere and enhance the equatorward wind in the lower thermosphere. The electron density and peak height (panel 4) repeat almost regular daily variations and respond to the increase in solar activity before the onset of the storms. After the onset of the storms, the ionosphere becomes denser and broad, especially during the daytime (31 March) after the intense storm. Ionospheric peak height rises above 400 km on the first night after the moderate storm and above 500 km on the first night after the intense storm. Fig. 3b shows the amplitude spectra of the data in Fig. 3a. As shown, diurnal amplitude is dominant at MLT and upper thermosphere altitudes and in both zonal and meridional directions. Waves of periods near 18 hours and 2 days are also present, in general, around mesopause and upper thermosphere altitudes.

Fig. 4 compares the horizontal mean wind velocities obtained from the four MTEC-S observations (see figure caption). At MLT altitudes, the zonal mean wind is eastward and is much stronger than the meridional mean wind. The resultant horizontal mean wind therefore flows almost eastward. In the upper thermosphere, the meridional mean wind is equatorward during spring-summer and poleward during fall-winter. A comparison of the amplitude spectra obtained from 72-hours of quiettime wind velocity data from the four MTEC-S observations are shown in Fig. 5. As shown, diurnal tide is dominant at all altitudes and in all seasons except in summer. In summer, semi-diurnal tide and a wave near 36-48 hours seem to be stronger than the diurnal tide. Waves of period near 18 hours and 2 days are also present in general.

4. SUMMARY

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 (150-600 km) and peak height in the ionosphere obtained by operating the MU radar (35N, 136E) in alternate meteor and incoherent scatter modes, for the first time, under a project called MTEC-S are presented for the four seasons in 2000-01 when solar activity varied from medium to high. The amplitude spectra of the data, and the mean winds, tides and waves through which the upper atmospheric regions can be dynamically coupled are also compared.

At MLT altitudes, the resultant horizontal mean wind flows almost eastward, and is found to have yearly mean values (average of the four MTEC-S observations) of about 18 m/s at 80 km, 21 m/s at 86 km and 26 m/s at 95 km. In the upper thermosphere, the meridional mean wind is equatorward during spring-summer and poleward during fall-winter. Diurnal tide is dominant at all altitudes and in all seasons except in summer when semi-diurnal tide and a wave near 36-48 hours become strong at MLT latitudes. Waves of period near 18, 48 and 66 hours are also present in general.

Acknowledgments: The MU radar belongs to and is operated by RISH of Kyoto University. N. Balan thanks Kyoto University for providing a visiting professor position during which this study has started.

References

[1] Balan, N., Y. Otsuka, and S. Fukao, New aspects in the annual variations of the ionosphere observed by the MU radar, *Geophys. Res. Lett., 24*, 2287, 1997.

[2] Rishbeth, H., I. C. F. Muller-Wodarg, L. Zou, T. J. Fuller-Rowell, G. H. Millward, R. J. Moffett, D. W. Idenden, and A. D. Aylward, Annual and semiannual variations in the ionospheric F2-layer: II. Physical discussion, *Ann. Geophys., 18*, 945, 2000.

[3] Balan, N., et al., Simultaneous mesosphere/lower thermosphere and thermospheric F region observations during geomagnetic storms, *J. Geophys. Res. 109*, A04308, doi:10.1029/2003JA009982.

[4] Oliver, W. L., Y. Otsuka, and S. Fukao, MST radar measurement of ionospheric F region winds: The "layer-wind" technique, *Radio Sci., 33,* 941, 1998.

[5] Nakamura, T., T. Tsuda, M. Tsusumi, K. Kita, T. Uehara, S. Kato, and S. Fukao, Meteor wind observations with the MU radar, *Radio Sci., 26*, 857, 1991.