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Investigation on the mesopause energetics and its possible implications on the equatorial MLTI processes through coordinated daytime airglow and radar measurements

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[1] This paper investigates the simultaneous presence of a prominent planetary scale modulations of quasi 16-day period observed in the daytime mean mesopause temperature and in the phase velocity of Type I electrojet irregularities during January–March 2001 over Trivandrum (8.5°N, 76.5°E, 0.5°N diplat.). The temperature was estimated from the Multiwavelength Dayglow Photometer (MWDPM) measurements of OH (8–3) Meinel band dayglow emissions. The radar measured phase velocity of the irregularities is found not only exhibiting $\sim$8 and quasi 16-day modulations, but also exceeding the isothermal ion-acoustic threshold i.e. $\sim$360 m/s for Trivandrum. The modulation in the mesopause temperature is attributed to the presence of planetary wave of quasi 16-day periodicity. Further, it is proposed that the temperature modulations which cause composition changes in the mesopause and equatorial electrojet region manifest as changes in the phase velocity through fluctuations in ion-neutral collisions corroborating with St.-Maurice et al. (2003). **Citation:** Pant, T. K., D. Tiwari, C. Vineeth, S. V. Thampi, S. Sridharan, C. V. Devasia, R. Sridharan, S. Gurubaran, and R. Sekar (2007), Investigation on the mesopause energetics and its possible implications on the equatorial MLTI processes through coordinated daytime airglow and radar measurements, *Geophys. Res. Lett.*, *34*, L15102, doi:10.1029/2007GL030193.

1. Introduction

[2] In the recent years, the importance of the mesosphere, lower thermosphere and ionosphere (MLTI) region has been recognized in addressing complex issues concerning the atmosphere-ionosphere coupling. Various mesospheric processes that couple the MLTI region have been the focus of some of the recent international programs like the Planetary Scale Mesopause Observing System (PSMOS) that have brought out some very important results in this regard (see the *Journal of Atmospheric and Solar-Terrestrial Physics* (*JASTP*), volume *64*(8–11), 2002). The energetics and dynamics of planetary waves in the MLTI region has been one such topic that has been extensively addressed to in these programs.

[3] Various studies have shown that the effects and presence of these planetary waves are not limited only up to mesopause. At times, the variations in the lower ionosphere parameters have also been ascribed to the planetary waves. A broad range of oscillations with periods $\sim$3–35 days in the lower ionosphere have been reported (see *JASTP*, volume *64*(8–11), 2002). The ionospheric absorption data clearly reveal the presence of waves having quasi 16-day period that are traveling upwards from lower atmosphere [*Lastovicka et al.*, 1994, and references therein]. The presence of these waves has also been seen in the low latitude radio-meteor zone [*Pogoreltsev and Sukhanova*, 1993]. In fact, the presence of a quasi 16-day oscillation in the F-region critical plasma frequency had also been reported [*Forbes and Leveroni*, 1992].

[4] As a consequence, the changes in MLTI energetics and dynamics observed at any time, particularly daytime, are an outcome of the variabilities primarily in the neutral atmospheric energetics and dynamics of the mesospheric region, and also the lower ionospheric electrodynamics. In this context, the present paper discusses changes in the dynamics of the daytime Equatorial Electrojet (EEJ) region vis-à-vis energetics of the mesopause that are caused by the presence of planetary waves. As is well established, in the daytime EEJ current, there are two types of plasma instabilities namely the two stream and gradient drift instabilities, also referred to as Type-I and Type-II instability. It is the changes in VHF radar measured phase velocity of the Type-I EEJ irregularities [*Farley*, 1963; *Buneman*, 1963], also known as Farley-Buneman waves that are being investigated in this study along with the mesopause temperatures.

[5] As is known, the maximum phase velocity of Type-I waves almost always saturate at the isothermal ion-acoustic speed of the medium, which in turn, is determined by the ambient neutral temperature thereof. Therefore, it would be intriguing that the phase velocity of the Type-I wave is measured to be significantly higher, as in this case, than the ion-acoustic speed of the medium both over equatorial and polar latitudes [*Ravindran and Murthy*, 1997; *St.-Maurice et al.*, 2003, and references therein]. Various mechanisms based on linear, nonlinear, kinetic and generalized fluid formulations have been given in the last two decades to explain these higher phase velocities. All these theories and formulations basically invoke the electron heating resulting in higher velocities. Apart from the electron thermal fluctuations, it has also been shown that the other factor that strongly influences the phase velocity is the aspect angle. While investigating the effect of electron temperature feed-

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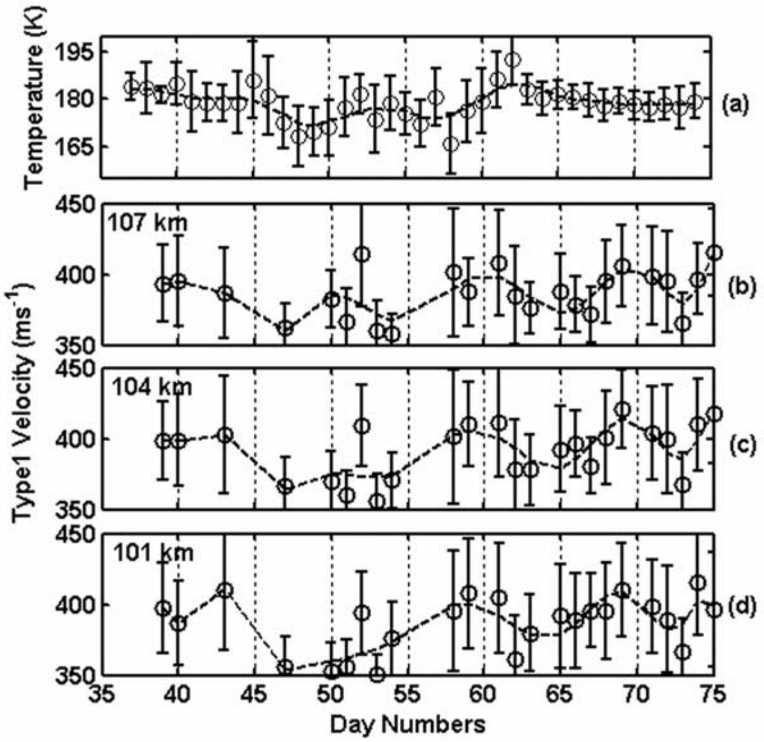

Figure 1. Variation of (a) the daymean mesopause temperature and the mean Type-I phase velocity at (b) 107, (c) 104, and (d) 101 km altitudes in the electrojet region during February–March 2001.

back on the phase velocity at non-zero aspect angles, the maximum phase velocity is found to be associated with zero aspect angle [*Kagan and St.-Maurice*, 2004].

[6] However, due to the lack of daytime temperature measurements in the MLTI region, it has never been investigated whether the mesopause temperatures can also have an effect in the phase velocities. The development of MWDPM enables the measurements of the mesopause temperature and airglow intensity during daytime, and important results have been reported from Indian longitudes recently [*Vineeth et al.*, 2005, and references therein]. This paper, in this context, presents the 'first evidence' for the variabilities in the mesopause temperature to indirectly affect the phase velocities.

2. Experiments

[7] The mesopause temperatures were estimated using daytime measurements on the OH (8-3) airglow emission intensity of rotational lines at 731.6 and 740.2 nm in the OH Meinel (8-3) band. The Krassovsky ratios estimated using the emission intensities of these two lines at any given time provide the mesopause temperatures [*Krassovsky*, 1972]. These emissions are measured using the Multiwavelength Dayglow Photometer (MWDPM) at Trivandrum (8.5°N, 76.5°E, 0.5°N diplat.), a dip equatorial station in India. The dayglow intensity measurements were made during February–March 2001. The measurements at every 20 sec typically span ~8–10 hours everyday between 0800 to 1800 hrs for the zenith sky. The details of MWDPM and method of estimation of the temperature have been described earlier [*Vineeth et al.*, 2005, and references therein].

[8] Simultaneous measurements on the drift velocity of the Type I waves, were made using a collocated VHF radar operating at 54.95 MHz. This is a coherent pulsed radar with peak-power aperture product of $\sim 2.2 \times 10^7$ Wm^{-2}, pulse-repetition-frequency of 250 Hz and it had a phased antenna array with beam oriented 30° west from zenith. The Fast Fourier Transform of the complex amplitude samples of the backscattered signal provides the spectral parameters including the velocity at different altitudes i.e. every 3 km in 91–110 km region. The system details of this radar are available in the literature [*Reddy et al.*, 1987].

3. Observations

[9] The observed temperature variability is discussed in terms of the mean temperature of the day i.e. daymean temperature. The variation of estimated daymean temperatures as a function of day number is shown in Figure 1a. Figures 1b, 1c, and 1d show the variation of mean phase velocity of Type I wave as a function of day number at three EEJ altitudes 101, 104 and 107 km respectively. The dashed lines in all panels represent the best-fit curves.

[10] As is known, at 3 m scale size the Type-I echoes appear only for some time during the day, the period of their occurrence ranging from minutes to hours. Therefore, the phase velocities presented here, were taken only for the period where the Doppler shifts and returned echo power reveal the presence of pure Type-I wave i.e. phase velocity $\geq$360 m/s. Each velocity point shown in Figure 1 represents the mean of the phase velocity for the period of its

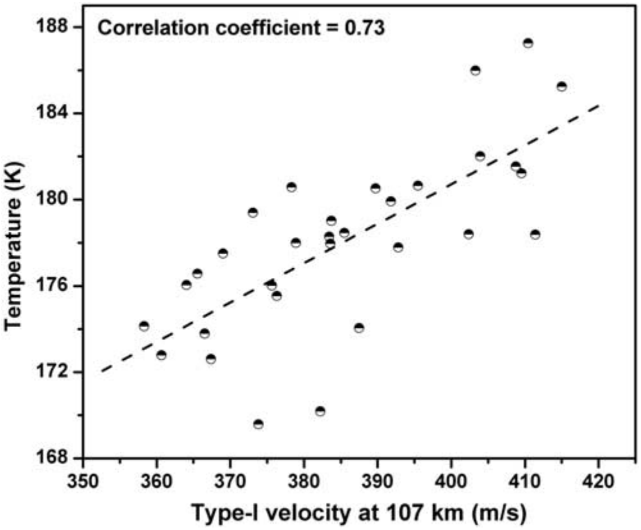

Figure 2. The time delayed correlation between temperature and the Type-I velocity at 107 km. The modulation in temperature lags the Type-I velocity changes by 4 days indicating upward propagation of wave and downward propagation of phase.

occurrence during the day. The maximum occurrence of Type-I echoes was found to be mostly around noon hours. The standard deviation associated with each data point is also shown in Figure 1.

[11] It is clear from Figure 1 that the measured phase velocity at each altitude exceeds the ion-acoustic speed of the medium (~360 m/s for Trivandrum) by ~20–30 m/s on an average. The absence of data points in Figures 1b, 1c, and 1d on certain days shows the absence of Type-I echoes. On day numbers 52, 59 and 61 the phase velocity seems to be ~400 m/s or beyond at all the three heights. Though one notices small differences in the phase velocities from one height to another, the overall trend remains grossly unchanged.

[12] A comparison of trends in the radar measured phase velocity with the daymean mesopause temperatures reveals similarity (Figure 1). The days of larger phase velocities are followed by days of higher temperatures with a time delay of ~4 days. Figure 2 shows that the time-delayed correlation between this two is indeed significant (0.73) for velocity at 107 km altitude. The powers of the dominant periodicities in the daymean temperature and phase velocity are shown in Figures 3a, 3b, 3c, and 3d as a function of day number. These periodograms are obtained after performing the wavelet analysis using the daymean temperature and phase velocities data at each height. The ‘Morlet’ function is used as the mother wavelet [*Strang and Nguyen*, 1996]. Figure 3 clearly exhibits the quasi-16 and 25–30 days are most dominant in these measurements. While the origin of ~25–30 days could be ascribed to the solar rotation (~27 days) affect, the presence of quasi 16 day period is a definite indicator of the presence of planetary wave in the mesopause and electrojet region. The quasi 16-day oscillation is dominant on almost all the days and is significant in both, temperature as well as the phase velocity.

[13] It must also be mentioned that an investigation of the variation of the phase velocity associated with Type-II waves vis-à-vis the mesopause temperatures was also conducted during the course of this study. It was found that the short-term (<2–3 hrs) variations dominate both Type-II phase velocity as well as the temperature. In addition, the variations in these two parameters do not always correlate positively. At times, negative correlations were observed. On the whole, the daymean variations of the Type-II phase velocity and the mesopause temperature did not reveal any systematic correlation. However, it appeared that the changes induced by short-period gravity waves, in the mesopause energetics and E-region electrodynamics could be important in context of Type-II. This aspect is a subject matter of an ongoing study and is beyond the scope of this paper. Nevertheless, the main point of this paper is that the modulations seen in the mesopause temperature and the Type-I phase velocities appear correlated.

4. Discussion

[14] Recent photochemical–dynamical models for the OH Meinel airglow suggest that alterations in the energetics are brought about by the advection of excited hydroxyl population by gravity waves, collisional quenching of OH* and a secondary reaction involving perhydroxyl radical (HO_2) and O during daytime [*Makhlouf et al.*, 1995, and references therein]. All these factors affect the vibrational yield of OH, manifesting as the dayglow intensity changes. This in turn is seen as the variations in the mesopause temperature.

[15] In the present analysis, the short-period (~2–3 hrs) variabilities in temperature that could be due to the above mentioned factors, especially gravity waves, are somewhat smoothed out as only the daymean temperatures are considered. However, variability in temperature with periods larger than ~4–5 hrs would affect the daymean temperatures and could be attributed to chemistry, solar, tidal or planetary wave effects. While the effects due to sun or chemistry on the temperature are more systematic and gradual on a long-time scale; the presence of waves and tides, and their interaction can modulate the temperature on a day-to-day basis. It has been shown that the nonlinear interactions of gravity waves with tides and planetary waves may lead to significant alterations in the mean mesospheric energetics [*Manson and Meek*, 1990].

[16] In a recent study using the mean OH dayglow intensities derived from the same dayglow data as presented in this paper and simultaneous radar measured zonal wind at ~87 km along with F10.7 cm solar flux indices, it had been shown that a ~16 day planetary wave have been generated in the lower atmosphere through modulations of the absorbed solar radiation there [*Pant et al.*, 2004]. The same study showed that this ~16 day wave had an eastward momentum as systematic decelerations were measured in the prevailing zonal wind at mesopause altitudes. The prevailing mesospheric background wind was westward under the influence of Mesospheric Semi Annual Oscillation (MSAO) during February–March period of the year. As a consequence, the energy associated with this wave got dissipated in the mesopause region. Therefore, the wave amplitudes at higher heights would decrease substantially

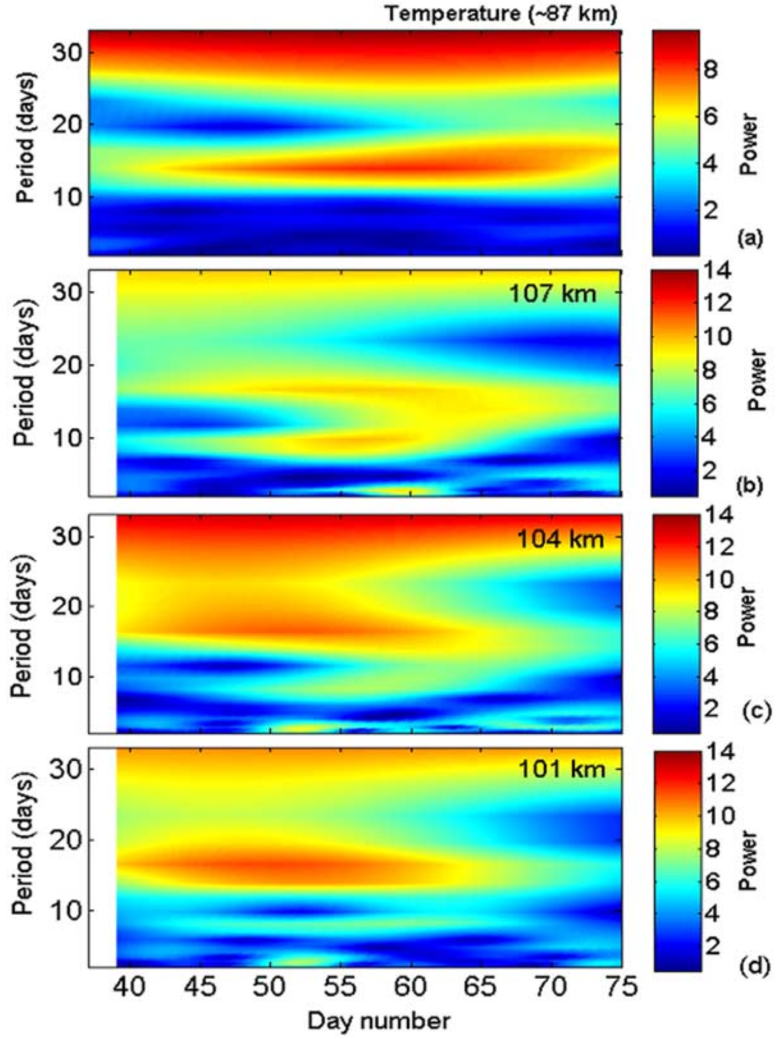

Figure 3. The dominant periods present in the mesopause temperature and in Type-I phase velocity at three different altitudes in the electrojet region.

limiting the propagation of the wave up to mesopause and lower ionosphere only. The changes in the mesopause energetics as a result, are manifested as modulations in mesopause temperatures. The mesopause temperature variability presented in this case is believed to be the consequence of this wave energy dissipation.

[17] Further, as is known the planetary waves themselves are not believed to penetrate to ionospheric heights, therefore an indirect mechanism must be responsible for its presence in E-region in the present case. In general, their presence in the lower ionosphere has been attributed to (1) planetary wave influence on the generation of electric fields via the modulation of tidal fluxes; and (2) a similar influence arising from planetary waves excited in situ at E-region heights by the deposition of momentum from a flux of gravity waves which is itself modulated at planetary-wave frequencies following interaction with planetary waves at lower heights [*Forbes et al.*, 1995]. The signatures of these waves and its role in the vertical coupling with suitable time delays at the equatorial region have been reported recently [*Abdu et al.*, 2006].

[18] As is known, during daytime, both the zonal wind and electric field in the equatorial electrojet region are global in nature. However, the presence of waves can alter their altitude and spatial distribution locally through the neutral wind changes [e.g., *Kudeki et al.*, 1987]. Though it is known that the ion-acoustic speed itself depends on the ambient electric field, the possibility that this field over equator leads to electron heating causing the electrons to stream at phase velocity exceeding the ion-acoustic threshold does not also seem feasible. For, over high latitudes there are enough evidences of the phase velocity saturation at the ion-acoustic speed despite the electric field in general, being significantly stronger than that over the equator [*Nielsen and Schlegel*, 1983, and references therein].

[19] In the past, it has been discussed through theoretical studies that the adiabatic effects could become important in the treatment of Farley-Buneman waves. The adiabatic heating of the electrons through an increase in the electron collision i.e., anomalous collision frequency leading to modified frictional heating rate for the electrons had also been estimated to be important [*Primdahl and Bahnsen*,

1985; *Robinson*, 1986]. It had been shown that a lowering of electron cooling rate, along with increased anomalous collision frequency, is required to explain the phase velocities [*St.-Maurice et al.*, 1986].

[20] However recently, *St.-Maurice et al.* [2003] presented and discussed in detail the Type-I waves moving faster than isothermal ion-acoustic limit as measured by the 49.8 MHz Pohnpei radar over equator (0.7° magnetic dip). They clearly showed that the estimation of the threshold speed needs to be corrected for thermal effects from 'isothermal' to 'non-isothermal' ion-acoustic speed 'Cs'. Based on the non-isothermal ion acoustic speed estimation at 3 m wavelength, they demonstrated that the threshold speed could get enhanced by a factor of about 1.46 times of the isothermal ion acoustic speed thereby explaining the measurements at Pohnpei [*St.-Maurice et al.*, 2003]. It is important to mention here that the non-isothermal Cs, as described by them, forms the envelope for the maximum Type-I phase speed that could be observed at Pohnpei. The exact mechanism is the result of an adiabatic electron heating taking place when the ion-collision frequency exceeds the product of the wave number with the isothermal ion-acoustic speed [*St.-Maurice et al.*, 2003].

[21] In other words, the ion-collision frequency among various other factors discussed by *St.-Maurice et al.* [2003] plays an important role in controlling the observed phase velocity of Type-I waves over equator. In this context, it is proposed here that through the planetary wave modulation the mesopause temperature as well as the density and composition would get altered locally and above at the electrojet region. In fact, it has been shown that the wave interactions at this altitude would not only modify the dynamics of the region, but also its composition [*Akmaev and Shved*, 1980]. Further, this composition change either through change in the mean neutral molecular mass or the total neutral number density can lead to alterations in the local ion-neutral collision frequency in the lower ionosphere. However the atmosphere below ~90 km being well mixed, the modulation in the overall neutral density only can bring about changes in the local ion-neutral collision frequency that, in turn, can explain fluctuation in the phase velocity of Type-I waves observed at equatorial electrojet region. In recent studies the effect of planetary wave is found to be time delayed between the mesosphere and electrojet region [*Abdu et al.*, 2006, and references therein]. In this context, the apparent time delay of ~4 days observed between the mesopause temperature and the Type-I velocity at 107 km could be accounted for. Using the model (MSIS) temperature, collision frequencies and the expression for the "non-isothermal ion-acoustic speed" assuming zero aspect angle, it was found that fluctuations in the phase velocity by as much as ±50 m/s could be seen with ±20% variation in ion-neutral collision frequencies. In this context, an increase of 50 m/s, as can be seen from Figure 1, would satisfactorily explain the present observations.

[22] Further, it has also been shown that most of the Type-I waves do not propagate at perfect zero aspect angle and departure from perpendicularity can result in significant reduction in the phase velocity of propagating waves [*Kagan and St.-Maurice*, 2004]. The maximum phase velocity is shown to be associated with zero aspect angle. Nevertheless, to investigate all these effects in detail, longer time series of radar and optical measurements are required.

5. Conclusion

[23] The long period ~16 day oscillation seen simultaneously in the radar measured Type-I phase velocity in the EEJ region and the daytime mesopause temperature, is a direct evidence of the coupling between the mesopause and the lower thermosphere ionosphere. It is envisaged in this paper that the enhanced Type-I phase velocity is due to the increase in the ion-neutral collisions through the changes in the molecular abundance within EEJ altitudes driven mainly by the planetary wave induced mesopause temperature variations. As discussed by *St.-Maurice et al.* [2003], the measured Type I phase velocity in the present case follow non-isothermal ion-acoustic speed threshold rather than the isothermal threshold. In view of the MTI coupling, this first cut result is of extreme importance and further verification based on an even larger database is called for.

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