A New Perspective to the Daytime h'F variations and its Role in Modulating the Mesopause Energetics over Equatorial latitudes

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Abstract

This study reports unique observations, illustrating the vertical coupling between the daytime mesopause and F region of the ionosphere over a magnetic dip equatorial station Trivandrum in India. For the 'first time', it has been shown that the temporal variations in the mean daytime mesopause temperatures (MPT), during geomagnetically quiet days corroborate well with that of the base height changes (h'F) of the ionosphere. However, there exist some characteristic time delays between these two, which vary from 0 to 90 minutes. The observed time delays are attributed to the role of chemistry/dynamics in modulating atomic oxygen at these altitudes.

1. Introduction

In recent years, the atmosphere – ionosphere coupling has emerged as an important area of research globally. Comprehension of the nature of this coupling requires an understanding of various neutral and plasma processes. As is known, the mesopause is a crucial transition region that facilitates the coupling between the neutral dynamics dominated atmosphere and the electro-dynamically controlled ionosphere above. In general, the day-to-day variability in this atmosphere-ionosphere system during geomagnetically quite times are believed to be governed primarily by the dynamical forcings from below like the tides, gravity and planetary waves, and their interactions. It has been shown that the aforesaid forcings induce significant changes in the mesopause energetics and dynamics [14]. At the same time, the mesopause energetics itself was found to exhibit substantial changes in conjunction with the ionospheric process like equatorial Counter Electrojet [16]. By now it is well understood that the investigation of the variability in the mesopause region vis-à-vis changes in the ionosphere can lead to a better understanding of the prevailing atmosphere-ionosphere coupling at any given time.

However, it had been difficult to measure the neutral parameters like the temperature in the mesopause, more so during daytime, due to the relative inaccessibility of this region to the existing ground-based techniques. In this context, the unique dayglow photometer developed in India had been successfully used for making daytime mesopause temperature measurements over the Indian longitudes in recent years [10, 16]. Presently, this dayglow photometer is operated from Trivandrum (8.5^{o}N; 77^{o}E; dip lat. 0.5^{o} N), India to get the estimate and, also the temporal variability of the mesopause temperature over the dip equator. Simultaneous, co-located ionospheric measurements are also made using a ground-based digital ionosonde.

These simultaneous measurements indicate that during geomagnetically quiet days the variability in the mean trends of the daytime mesopause temperature (MPT) significantly corroborate with those of the simultaneously measured bottomside ionospheric height (h'F), but after a time delay.. The present paper aims at reporting these first observations and exploring plausible physical mechanisms for explaining the same.

2. Dataset

The daytime mesopause temperatures were estimated from the OH Meinel (8-3) band dayglow intensities of rotational lines at 731.6 and 740.2 nm following the method of Meriwether [7]. The characteristics of the photometer and data analysis procedure had been published elsewhere [15]. The measurements at every ~7 minute intervals typically span ~7-8 hours during daytime between 0900 to 1700 hrs for the zenith sky. For the present study, the MWDPM observations of magnetically quiet days (Ap<7) for the period 2005-2007 are considered, Ap being the index representing planetary level of geomagnetic disturbance. Simultaneous measurements on the F region height variations (h'F) as scaled from the quarter hourly ionograms from the collocated digital ionosonde have been used for representing the ionospheric variability.

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3. Observation

To highlight these observations, the mean trends for both i.e. MPT and h'F were estimated for eight months during the period 2005-2007 and are presented here. Figure 1 shows the mean trends of temporal variations in the h'F and MPT, time delayed. The corresponding time-delays, as obtained from the cross correlation analysis are mentioned in each panel.time delays are estimated by carrying out the cross correlation analysis.

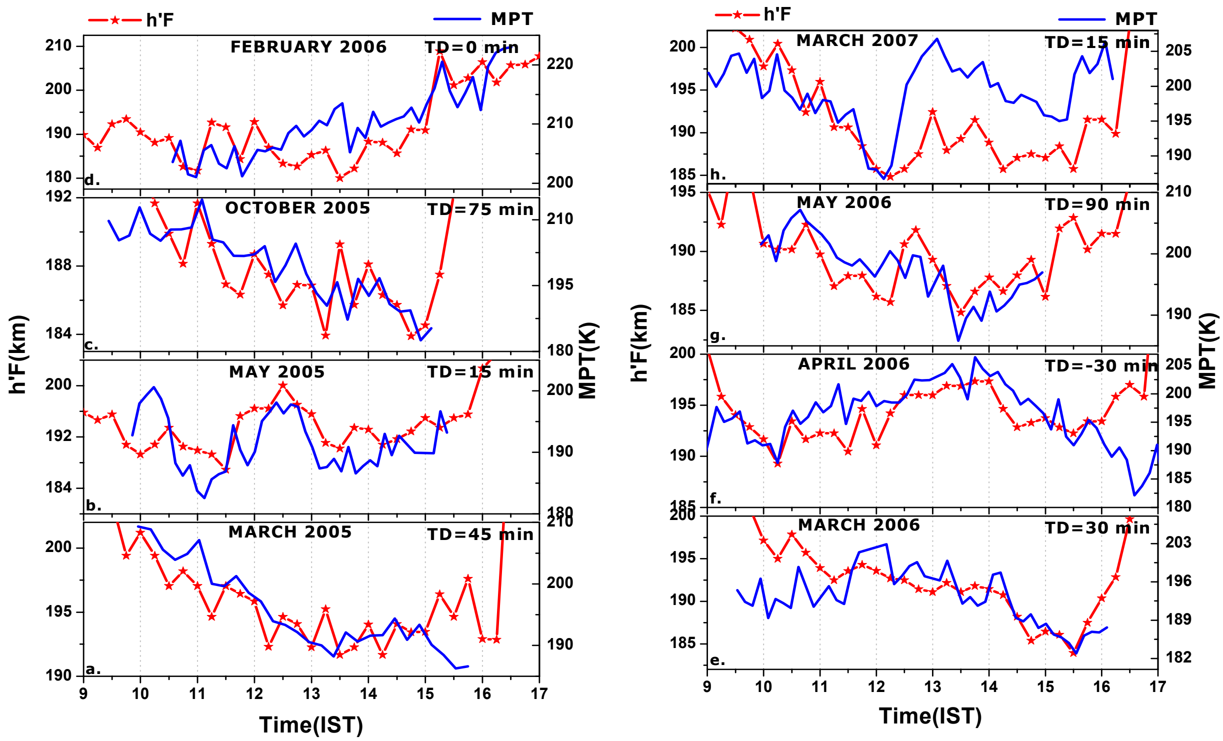

Figure 1: *Time variation of monthly mean h'F variations and time delayed equatorial mesopause temperature (MPT) for different months during the year 2005-2007. The corresponding time delays (TD) are also shown.*

The solid lines represent the MPT variability, while those with star symbols indicate the h'F variations. Each panel represents the mean picture of the quiet time variability of these parameters during different months. The scales of both MPT and h'F are kept varying for different months, primarily to highlight the variability. As mentioned earlier, the main observation presented here is the time-delayed positive correlations (corr.coeff.>0.6) between the MPT and h'F. Here the variability in h'F precedes those in MPT (i.e., time delay is positive) for all the cases except April 2006. It is worthwhile to mention that these time-delays vary from month to month. The time delay obtained for April 2006 is intriguing, where MPT precedes the h'F, with a delay of ~30 minutes. The plausible mechanisms for these observations are discussed in the following section.

4. Discussion

The observations showing the corroboration between the MPT and h'F are highly interesting. Since a very good correlation exists in the monthly mean trends, one can attribute these to the changes in the background variability which is not induced by the short period wave dynamics. In this context, we conjecture that the vertical transport of the chemical species induced by the photochemistry at these altitudes is responsible for the observed coupling between the equatorial mesopause and F region of the ionosphere.

It is known that during daytime the bottomside of the ionosphere (130-200 km) is 'photochemically' governed, where photo dissociation of molecular oxygen in the Schumann-Runge continuum (135 -175 nm) leads to the generation of atomic oxygen, which in turn leads to the formation of ionization. At the same time, the ionization loss processes are mainly controlled by the molecular Nitrogen through chemistry. As a result, the ratio [O]/ [N_2] at any time is taken as a measure of the net ionization in the lower F region [3]. Therefore, the modulations of the h'F, specifically during daytime, are taken to be the direct indicator of the ratio [O]/[N_2] in the bottom side ionosphere, since these measurements are actually the representative of the group retardation of the radio waves due to the presence of fresh ionization.

Since, the molecular diffusion coefficient grows rapidly with decreasing pressure and increasing temperature in thermosphere; its net effect in the lower thermosphere is always to increase the mixing ratio of [O]. As a consequence, in the lower thermosphere, always there is a significant downward diffusion of atomic oxygen [14]. A part of this [O] diffuses into mesopause altitudes from its source region above. Near mesopause, atomic oxygen has a mixing ratio that reaches 10^{-2}. The chemical lifetime for atomic oxygen increases with increasing altitude reaching 24 hours near 85 km. As a result, below this altitude the concentration has a strong diurnal variation whereas above it, primarily the dynamics, rather than the chemistry, induces variability in the profile [12]. In this backdrop, it is suggested that during daytime the downward motion of [O] in ionosphere reduces [O]/[N_2] ratio at F region altitudes (i.e., net F region bottom side ionization) which in turn manifests as a change (increase) in the ionosphere base height (h'F) as observed using the ground based ionosonde. At the mesopause, this downward diffusion of [O] creates ozone maximum through three body recombination and subsequently increases the mesopause temperature through exothermic OH chemistry [8]. In this process, there would be a time-delay involved between the h'F changes and the MPT modulations. While such a mechanism is plausible and consistent with the time-delays in the lower F region, we realize that the time constants associated with such a transport process between the bottom side F region and mesopause in terms of molecular diffusion would be very large and is of the order of hours to days [4]. However, one factor which can help in the fast transport of [O] to the mesopause is the location of the turbopause. Below the turbopause altitude which is typically around ~90-120 km [2, 9], the diffusion time scales are very large as mentioned above [4]. Nevertheless, the eddy diffusion of the air parcels, which have large vertical sizes can create thorough mixing of species like atomic oxygen down to the mesopause. Apart from these, it must be kept in mind that the h'F measurements described here correspond to the virtual height. The real heights will correspond to about 20-30 km lower than the virtual heights.

In view of the above, it is proposed the downward transport of [O] from bottomside F-region to the turbopause is facilitated through the molecular diffusion and below eddy diffusion. Such a scenario only can create perturbations in MPT within the limits of the time delays observed here. Though the importance of eddy diffusion at lower thermosphere altitudes (90-130 km) had been reiterated in literature, it is largely uncertain (45-90 m^2/s) and important to compute it correctly [11]. In view of this uncertainty in the Eddy diffusion coefficient (K), the Eddy diffusion time scale which is given by H^2/K (where H is the scale height) can vary from one day to few hours. Eddy diffusion plays a large part in controlling the neutral gas composition- in particular the [O]/ [N_2] ratio, by influencing the vertical motions (upwelling and down welling) of the neutral air. Increasing the eddy diffusion coefficient causes more [O] to be transported downward and more N_2 upward, thereby decreasing the ratio of [O] to [N_2] [11]. The transport processes induced by these turbulent motions produce fluxes of minor atmospheric constituents, heat and momentum and influence the atmospheric properties at and the above these altitudes [2]. Recently, two dimension turbulence mechanism was proposed to explain the transport of energy to large scales in the lower thermosphere [5]. They suggested that the molecular diffusion is too slow to account for the spreading of plumes as observed by them. In fact, the observations [6] have shown that atomic hydrogen, and by inference water vapor can transport over hemispherical-scale distances with speeds much faster than expected from models of thermosphere wind motions. In addition to this, processes such as heating of the upper mesosphere/lower thermosphere as well as upwelling can carry N_2 rich air to higher altitudes. This can also modulate the diffusive equilibrium state of the thermosphere, thereby influencing the [O]/ [N_2] ratio especially in the lower ionosphere [3].

Further, the height variation of turbopause as well as the upward dynamical forcing like waves and tides can have a profound role in altering time scales of downward molecular diffusion/eddy mixing. The upward propagating waves and tides which have large vertical and horizontal velocity lead to advective transport of [O], thereby making its downward diffusion a slower process. It has also been shown that tidal impact is large at low latitudes and varies day to day, where the vertical velocity due to the diurnal tide is largest, though it also depends on time of year [1]. During the month of March, the impact of tides is found to be significantly smaller than the impact of diffusion, where as calculations for April indicated greater role of tides [13]. It must be noted here that present observations also showed negative time delay (MPT precede h'F) during April 2006. It is due to this day-to-day variability in the lower atmospheric forcing like the tides and waves, and their competing roles in influencing the transport of [O], that the observed time-delays are found to be different for different months.

In this context, the trend of MPT preceding the trend for h'F for the month of April 2006 could be due to the dominance of upward propagating tides/waves over the downward diffusion of [O] through molecular diffusion and eddy mixing. Larger vertical velocity can slow down the downward diffusion and even lead to accumulation of [O] at higher altitudes. In our view, in such scenario the MPT may precede the changes in h'F that could be the reason for the negative time delay observed during April 2006. However, it can't be said unambiguously. At this juncture, it must mentioned that the interplay between the diffusion and the dynamical processes still remains an aspect needing better clarity, and our proposition here is only qualitative at present. However, the observations presented are new and unique, and in our view as discussed above have significant implications in the present understanding about the equatorial Mesosphere-Ionosphere-Thermosphere system.

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6. References

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