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Thermospheric meridional neutral winds associated with equatorial midnight temperature maximum (MTM)

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Abstract. Coordinated measurements were made on two nights in December 1992 of thermospheric temperature with a Fabry-Perot Interferometer (FPI) at Kavalur (dip~ 9.5° N) and of F-layer height with ionosondes at Trivandrum (dip~ 0.6° S), Kodaikanal (dip 3°N), Sriharikota (dip~ 10.5° N) and Ahmedabad (dip 34°N) in India. On both the nights which are geomagnetically quiet (Ap≤9), the FPI measurements revealed a distinct temperature enhancement around midnight over Kavalur. Neutral winds estimated from h'F data of Trivandrum and Sriharikota showed significant poleward winds in association with the temperature increase over Kavalur. At Ahmedabad a clear-cut descent of F-layer followed the temperature enhancement over Kavalur. This pattern is consistently seen on the two nights. The simultaneous thermospheric and ionospheric observations demonstrate for the first time the relationship, in totality, between the equatorial midnight temperature maximum (MTM), poleward reversal of nighttime meridional winds and 'postmidnight collapse' of F-layer at low latitudes.

Introduction

Interactive plasma-neutral coupling is a dominant physical process underlying many characteristic features of the structure and dynamics of the equatorial upper atmosphere. These include the neutral anomaly (NA), the midnight temperature maximum (MTM) and the associated pressure bulge and the equatorial temperature and wind anomaly (ETWA) [Hedin and Mayr, 1973; Spencer et al,1979; Raghava Rao et al, 1991]. One of the established methods of direct measurements of thermospheric temperature and neutral winds is groundbased Fabry-Perot interferometry of O(^{1}D) 630 nm night airglow line emissions. Optical interferometer measurements at equatorial latitudes are however quite limited. In India, remote sensing of the thermosphere using optical techniques is hitherto confined to Mt. Abu (24.6°N)[e.g. Sridharan et al, 1991]. As a step in the direction of realising multipoint monitoring of the thermosphere in India, we have recently commissioned a Fabry-Perot interferometer (FPI) at Kavalur (12.5°N).

Measurements made at Kavalur on 16 nights during March-April 1992 showed that the thermospheric temperature attains, on the average, a maximum around midnight (amplitude 95-155 K), and is followed by an unmistakable decrease in F-layer peak height (descent rate ~ 6.5ms $^{-1}$) at Ahmedabad (dip 34°) in the postmidnight hours (Sastri and Rao, 1993). The temperature enhancement at Kavalur is interpreted as the signature of the equatorial midnight temperature maximum (MTM) and the subsequent 'postmidnight descent' of F-layer at Ahmedabad as the effect of poleward winds set-up by the MTM. This interpretation, though logical, remained unconfirmed due to lack of data (direct or indirect) of meridional winds simultaneous with our temperature measurements at Kavalur. Such a confirmation is warranted because, to our best knowledge, these observations constitute the first evidence of the (expected) relationship between temperature enhancement near the equator and F-layer descent at a higher latitude station in the nocturnal upper atmosphere. Evidence for the relationship between the MTM and consequent abatement/reversal of the normal nighttime equatorward winds and midnight 'collapse' of F region at low latitudes is hitherto limited to either changes in temperature and winds (e.g. Spencer et al, 1979) or changes in winds and F-layer height (e.g. Behnke and Harper, 1973; Burnside et al, 1983).

Krishnamurthy et al (1990) introduced a method of deriving meridional neutral winds for the night time using h'F data of the two equatorial stations, Trivandrum and Sriharikota in India. Their results showed a poleward reversal of the meridional winds in the postmidnight period both in winter and autumn equinox, which feature they attributed to the equatorial MTM. This interpretation also remained unsubstantiated due to lack of simultaneous direct measurements of temperature near the equator and/or of winds at locations away from the equator. In this paper we present the results of case studies which validate our earlier interpretations that the midnight temperature maximum (MTM) near the equator is indeed responsible for the poleward reversal of meridional winds derived from equatorial ionogram data and the 'postmidnight collapse' of F-layer at Ahmedabad in the Indian sector (Krishnamurthy et al, 1990; Sastri and Rao, 1993).

Instrumentation and Data Analysis

The present study is based on the simultaneous measurements of thermospheric temperature with the Fabry-Perot interferometer (FPI) at Kavalur (12.5°N, 78.5°E geographic; dip ~ 9.5°N) and of F-layer height with ionosondes at Trivandrum (8.6°N, 77°E geographic; dip 0.6°), Kodaikanal (10.2°N, 77.5E geographic; dip 3°N), Sriharikota (13.7°N, 80.2°E geographic; dip ~ 10.5°N) and Ahmedabad (23°N, 72°E geographic; dip 34 °N). The locations of the stations are shown in Fig.1.

The FPI at Kavalur is built around an optically-contacted etalon of 100 mm effective diameter made-up of FP plates of λ/100 flatness with R=0.85 at 630 nm and spaced 10mm apart. The etalon is housed in an air-tight chamber and the

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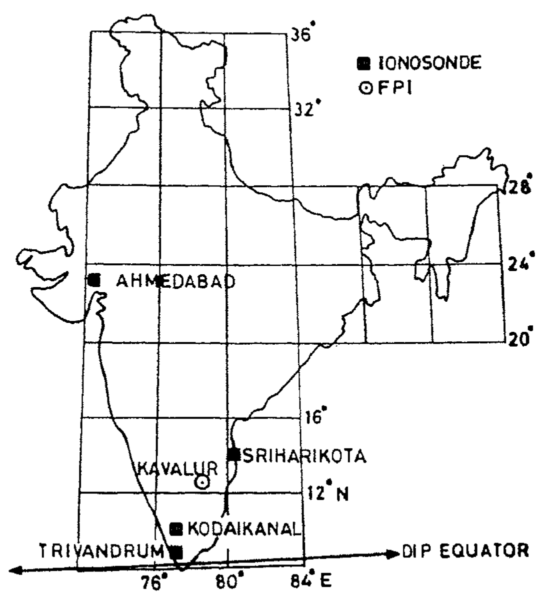

Fig. 1. Map showing the geographic locations of the FPI station at Kavalur and the ionosonde stations in India.

concentric-ring FP pattern is imaged at the exit plane on an on-axis central aperture (dia. 3mm, finesse 7) plate. A narrow-band (0.3nm) temperature-tuned interference filter is used to isolate the $O(^1D)$ 630 emission line. An EMI photomultiplier (9863A/350) thermoelectrically cooled to -15° C and operated in a photon counting mode is used as the detector. The wavelength scan is made by changing the air pressure inside the etalon chamber by a stepper-motor driven piston. The pressure inside the chamber is measured by a high-precision pressure transducer (Datametrics). The scanning process as well as the data acquisition is controlled by a IBM compatible PC-AT through appropriate interface hardware and software written in Turbo-Pascal. Two orders of interference are usually scanned at a time and the number of steps used for the scan over a free spectral range (FSR) is 70-80. The typical integration time is 8 sec per channel which gave a total signal at the peak of the profile of at least 50 counts/sec (more when the emission layer is at lower altitudes). A He-Ne laser is used to obtain the instrument profile.

At present only Doppler-width measurements of the 630 nm line are made in the zenith direction for determining the neutral temperature. We have used the method of Sridharan et al (1991) to derive the source line profile from the experimental data for determining the temperature. The key elements of the method are the use of the actual instrumental profile for deconvolution and the application of non-linear least-squares technique to the observed profile to arrive at the best set of parameters to describe the source profile. The sky background is evaluated and subtracted from the experimental profile while deducing the source line profile. Further details can be found in Sridharan et al (1991). The estimated error in the temperature determined from the 630 nm line widths varied in the range ± 53-199 K in the data presented here.

We have derived the nocturnal pattern of meridional winds from the quarter-hourly h'F data of Trivandrum and Sriharikota following the method of Krishnamurthy et al (1990). The method is based on the logical assumption that the F-region vertical drift at Trivandrum very close to the dip equator is affected solely by electric fields, while that at Sriharikota is controlled by electric fields, meridional winds and plasma diffusion. The winds are calculated at 15-min intervals from the time derivatives of h'F at the two stations making allowance for chemical loss and plasma diffusion effects, and are smoothed for random fluctuations (if any) with a five-point running mean filter. The overall uncertainty in the estimated winds is ± 25 ms $^{-1}$.

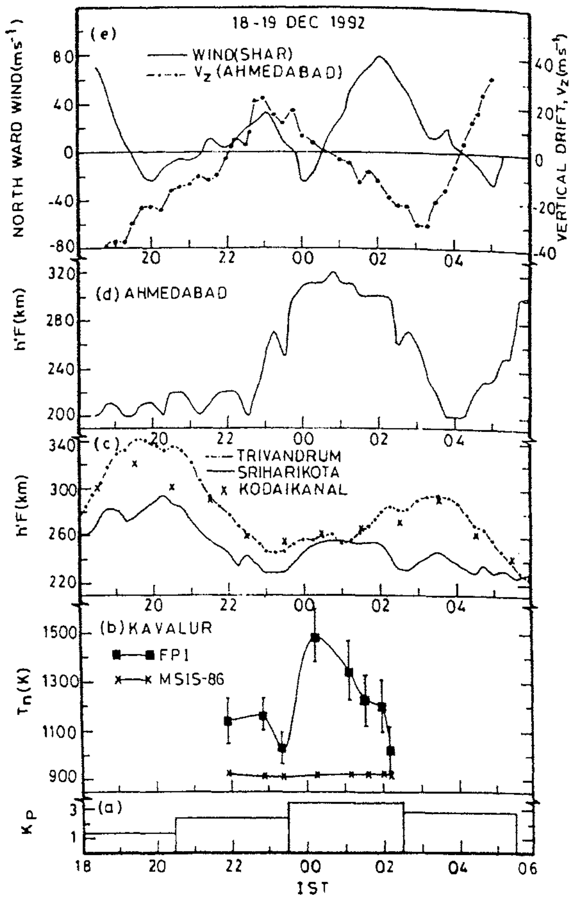

Fig. 2. Temporal variation of (a) the 3-hr geomagnetic Kp index, (b) thermospheric temperature at Kavalur and (c-d) h'F at Trivandrum (TRV), Kodaikanal (KKL), Sriharikota and Ahmedabad on the night of 18/19 December 1992 (Ap = 9). The topmost panel (e) shows the time histories of the meridional neutral winds derived from h'F data of Trivandrum and Sriharikota and the F-region vertical drift (Vz) at Ahmedabad derived from h'F data - see text for further details.

Results and Discussion

In Figures 2 and 3 we present the evidence obtained on the two nights of coordinated measurements for the effect of neutral gas temperature variation near the equator on neutral and plasma dynamics in the nocturnal equatorial F-region. The figures, drawn in the same format, show the time histories of geomagnetic Kp index, neutral temperature over Kavalur, and height of bottomside F-region (h'F) at the various stations on the nights of 18-19 December and 23-24 December 1992. The ambient geomagnetic conditions are quiet on both the nights as judged from Kp (see bottom panel of Figures. 2 and 3) and Ap ($\leq$ 9) indices. The local time coverage of our FPI measurements is typically from 2130 to 0430 IST (IST = UT + 5.5 hrs). The lack of data in the post-sunset hours is primarily due to the low intensity of the 630 nm line emission because of the well-known enhancement of F-region vertical drift, Vz in the vicinity of dip equator at such times and also the fact that

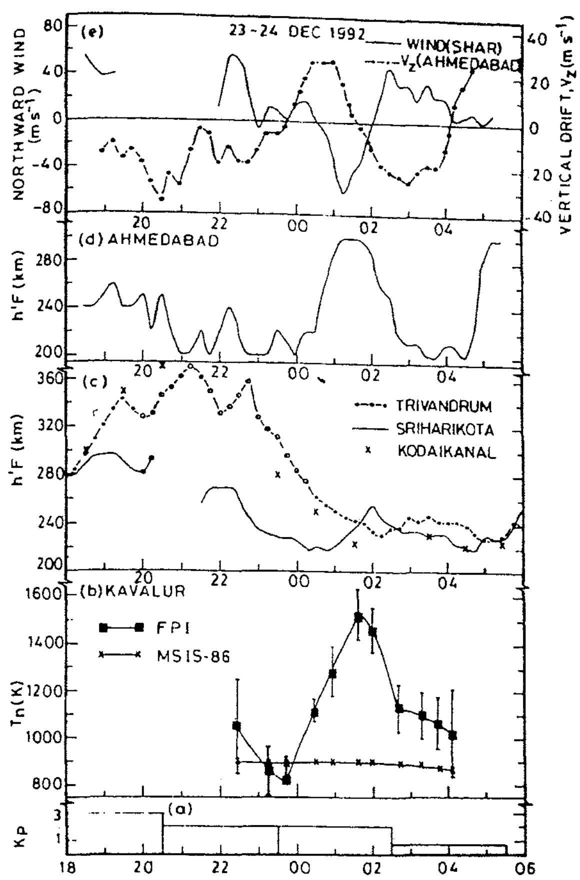

Fig. 3. same as in Fig.2 but for the night of 23-24 December 1992 (Ap = 8). Open circles on h'F plots of Trivandrum and Sriharikota indicate times when spread-F is present on ionograms.

we operate our FPI in the central aperture scanning mode.

It is evident from Figure. 2(b) that on the night of 18-19 December 1992, there is a distinct enhancement in the neutral temperature just after midnight (MTM) over Kavalur with an amplitude of about 280 K. Such a feature is not predicted by empirical global thermospheric models such as MSIS-86 as can be seen from the MSIS model temperatures plotted in the figure. The peak temperature is 24 per cent above the mean temperature for the entire period of observations from 2200 to 0230 IST on the night. Prominent changes in the F-region height accompanied the MTM over Kavalur. At Sriharikota there is a distinct decrease in h'F beginning at 0200 IST while both at Trivandrum and Kodaikanal h'F increased starting from 0130 IST. This feature indicates that while the F-region height at Sriharikota is under the influence of poleward winds, that at Trivandrum and Kodaikanal is under that of an eastward electric field. The electric field is, however, likely to be small because a part of the observed increase in h'F at Trivandrum and Kodaikanal is apparent due to layer decay as the layer is well below 300 km at the time (see Fig.2 c). The pattern of meridional wind derived from the ionosonde data of Trivandrum and Sriharikota (see Figure. 2e) shows short-term variations in the direction and amplitude of wind in the premidnight period. These changes are, however, not very significant (the exception is the strong poleward wind in evening hours) keeping in view the fact that the overall error in the estimated wind is $\pm$ 25ms^{-1}. In contrast the meridional wind turned poleward at 0030 IST and remained in that direction till 0400 IST attaining a peak value of $\approx$ 80ms^{-1} at 0200 IST. The magnitude of the poleward wind averaged over the period of its manifestation (0045-0345 IST) is 44.1 $\pm$ 23.4 ms $^{-1}$ which agrees well with the satellite measurements (Spencer et al, 1979). The data of Figure. 2 thus demonstrate the unambiguous relationship of the poleward winds after midnight derived from the ionosonde data of Trivandrum and Sriharikota with the MTM over Kavalur.

The presence of persistent poleward winds of large magnitude in the postmidnight period near the equator on the night of 18-19 December is to have a significant effect on F-region height at locations like Ahmedabad (dip 34° N). As can be seen from Figure. 2(d), there is indeed a decrease in h'F at Ahmedabad over the period 0045-0345 IST-the layer descent is small to start with but became prominent from 0215 to 0345 IST when h'F decreased from 300 km to 200 km, i.e, a gross descent rate of 18.5ms^{-1}. The very fact that such a large layer descent prevailed in the altitude range 200-300 km where chemical loss effects could be important indicates the presence of a significant downward drift of F-region plasma and hence sizeable poleward winds. With a view to ascertain this, the pattern of F-region Vz at Ahmedabad is derived from the time derivates of h'F. To arrive at Vz solely due to meridional winds,the time derivatives of h'F are to be corrected for the effects of chemical loss,electric fields and plasma diffusion. The corrections due to chemical loss and diffusion are done following standard procedures the details of which are given in Krishnamurthy et al (1990). Vz at Trivandrum as corrected for layer decay is taken to represent purely the electrodynamic drift due to the electric fields and is scaled down to the latitude of Ahmedabad by the cosI term where I is the dip angle. The implicit assumption here is that the zonal electric field is spatially uniform in the equatorial region, which is reasonable particularly for the midnight-dawn period. Latitudinal gradients in equatorial electric fields are known to be present in evening twilight period (e.g.Raghava Rao et al, 1984), but we are not aware of any reports of non-uniform electric fields for the postmidnight interval of specific interest here. The corrected values of Vz are calculated at 15-min intervals and are smoothed with a 5-point running mean filter to smooth out random fluctuations if any (as in the case of the neutral winds).

The temporal pattern of Vz at Ahmedabad thus derived and graphed in Figure. 2(e) is consistent with the meridional wind pattern derived from the ionosonde data of Trivandrum and Sriharikota. This is particularly so in the post-midnight period when a large downward Vz prevailed at the time of poleward winds associated with the MTM over Kavalur. The average value of downward Vz is 15.1 $\pm$ 9.4 ms^{-1} over the period 0045-0400 IST which corresponds to poleward winds of 32.7 $\pm$ 20.4 ms^{-1}. This is consistent with the average value of 44.1 $\pm$ 23.4 ms^{-1} for the poleward winds derived from the h'F data of Trivandrum and Sriharikota and attributed to the MTM over Kavalur. The F-region is known to take a certain time to respond to an imposed neutral wind field, and this time constant for Ahmedabad is about 2 hrs (Sridharan et al, 1991). We consider the time delay (about 3 hrs)between the temperature maximum at Kavalur and the minimum height reached at Ahmedabad as representative of the response time of F-region to the poleward winds set up by the MTM.

The gross features of the temporal variation of the thermospheric and ionospheric parameters on the night of 23/24 December are similar to those on the night of 18/19 December. But there are distinct differences in the details of the behaviour of the parameters between the two nights. As can be seen from Figure. 3(b), the amplitude of the MTM over Kavalur on the night of 23/24 December is larger (about 450 K), peaked later (around 0140 IST) and persisted longer than on the night of 18/19 December. The peak temperature is 34 percent above the average temperature for the entire period of observations from 2230 to 0415 IST. The presence of spread-F conditions at Sriharikota and / or Trivan drum (see Figure. 3 c) did not permit unambiguous derivation of meridional neutral winds from h'F data for the premidnight period. Strong equatorward winds are, however, seen for an hour and half beginning at 0030 IST with a maximum of 62 ms^{-1} at 0115 IST. Around the same time h'F at Ahmedabad experienced a significant increase and Vz (corrected for layer decay, electric field and diffusion effects) is upward with a peak value of 25.5 ms^{-1} [see Figure. 3(c),(e)]. But starting at 0200 IST, i.e. just after the temperature reached its maximum over Kavalur, h'F at Sriharikota underwent a decrease rather rapidly initially but slower afterwards, while h'F at Trivandrum showed an opposite trend till 0430 IST. This implies the presence of poleward winds during the period of subsidence of the MTM over Kavalur. Figure.3 (e) shows that the strong equatorward winds indeed turned sharply poleward by 0200 IST and maintained that direction till 0445 IST. The average value of the poleward winds over the interval 0215-0400 IST is 28 ± 8.9 ms^{-1}. More or less in consonance with the polward reversal of the meridional winds, the F-layer at Ahmedabad underwent a typical 'postmidnight descent' with h'F decreasing by 100 km over the period 0145-0330 IST. Vz at Ahmedabad is accordingly downward during this time with an average value of 17.6 $\pm$ 6.6 ms^{-1} for the period 0145-0400 IST, which corresponds to poleward winds of 38.0 ± 14.2 ms^{-1}. The mean magnitude of the poleward winds at Ahmedabad is in agreement with the value (28 ± 8.9 ms^{-1}) derived from h'F data of Trivandrum and Sriharikota.

It is to be noted that although the amplitude of the MTM is larger on this night compared to that on 18/19 December, the magnitude of the poleward winds is smaller at Sriharikota. This could be due to the difference in the latitudinal position and spatial structure of the midnight pressure bulge which determine the local wind pattern between the two nights. This remains a conjecture for the moment as we do not have any information on the temperature variation at locations north or south of Kavalur for the present campaign. In forthcoming campiagns we plan to coordinate FPI measurements of temperature and winds at Kavalur with those at Mt. Abu to derive a (first-order) picture of the two-dimensional (latitude-time) distribution of MTM. The radar observations at Jicamarca (11.95°S, 76.87°W geographic) show that the MTM assumes amplitudes in the range 40-200K and occurs, on the average, about one hour after midnight in the local winter (Bamgboye and McClure, 1982). The time of the temperature enhancement over Kavalur on 18/19 and 23/24 December 1992 is thus consistent with the MTM at Jicamarca, but the amplitude (280 K and 450 K) is much higher. It remains to be ascertained whether the seemingly larger amplitude at Kavalur compared to Jicamarca is a longitudinal effect in the manifestation of the equatorial MTM.

Conclusions

The simultaneous multistation observations carried out in India on two nights in December 1992 with optical interferometer and ionosonde techniques confirm the prevailing view that the equatorial midnight temperature maximum (MTM) is responsible for the midnight poleward reversal of meridional winds there which, in turn, leads to the 'postmidnight collapse' of the F-layer at low latitude locations on the same meridian. Though this facet of neutral-plasma coupling in the nocturnal upper atmosphere at equatorial/low latitudes is known from earlier studies, a demonstration of the entire sequence of cause-and-effect does not seem to have made before. The method introduced by Krishnamurthy et al (1990) for deriving the nighttime meridional wind pattern from h'F data of two equatorial stations nearly on the same magnetic meridian has served to demonstrate the cause-and-effect relationship. The demonstration opens up the possibility of obtaining indirect but reliable information on nighttime winds for the Indian sector more or less on a routine basis.

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