On the role of photo-chemisty vis-a-vis- electrodynamics in controlling sunrise undulation of the F region peak altitude at the dip – equator

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1. Abstract

This paper shows that, contrary to previous explanations, the apparent undulating motion of the equatorial F region peak at sunrise is produced mainly by photochemistry rather than dynamics. Our study is based on an investigation of the behavior of the early morning ionosphere observed by a Digital Ionosonde at Trivandrum, India, and an In-coherent backscatter radar measurements at Jicamarca, Peru. Electrodynamics is not responsible for the sunrise undulation, but plays an indirect role in the detection of the sunrise effect by simultaneously lowering during the night the peak height and decreasing the density.

2. Introduction

The equatorial region is rich in ionospheric phenomena observed exclusively at low latitudes. A primary example is the steep climb in the peak height of the F-region during local sunset hours at the dip equator [1]. Studies based on incoherent scatter radar observations have shown the PRE phenomenon to be clearly related to a reversal in the sign of the zonal electric field [2,3] . A less documented but similar undulation in the altitude of the F region peak has also been reported shortly after sunrise. Given the similarities of the F peak motion with the evening PRE undulation and the fact that the zonal electric field changes sign around sunrise, it has been assumed that the sunrise undulation is also the result of an electrodynamic phenomenon [2,4,5] .

Here we have used observations from Digisonde systems, and incoherent backscatter radar located at the dip-equator to perform a more detailed study of the F region undulation at sunrise. We have focused on data obtained in March 2010 at a time when the sunrise undulation in the F region was particularly clear and repeatable. We show that chemistry explains not only the sudden increase in the F region peak altitude after sunrise, but also a previously unnoticed F peak density increase during the undulation. The main role played by the electrodynamics is to remove, prior to sunrise, F region plasma produced on the previous day.

3. Data and Method of Analysis

F region electron density information was retrieved from Digisondes installed at Trivandrum (8.47^0 N, 76.92^0E, 0.17^0S dip-latitude) and Jicamarca (12.0^0 S, 75.2^0 W, 0.17^0S dip-latitude) and electron density profiles obtained from an incoherent backscatter radar at Jicamarca. We compared measurements from these instruments with calculations from a time-dependent one-dimensional numerical ionospheric model that solved the ions and electron continuity equations. The model was limited to a computation of O^+, NO^+, $N2^+$ and $O2^+$ densities based on the photo-ionization of O, O2, and N2, the conversion of O+ to molecular ions via charge exchange reactions, and the subsequent dissociative recombination reactions of molecular ions. Details on model used in this study can be found in *Ambili et al, 2012 [6*]. The model also incorporates the effects of vertical electrodynamic drifts resulting from zonal electric fields. It does not, however, include diffusion as the altitudes of interest are well below 400 km, where the magnetic field lines are horizontal, the time scale for diffusion to operate was assumed to be long compared to the time scales of interest.

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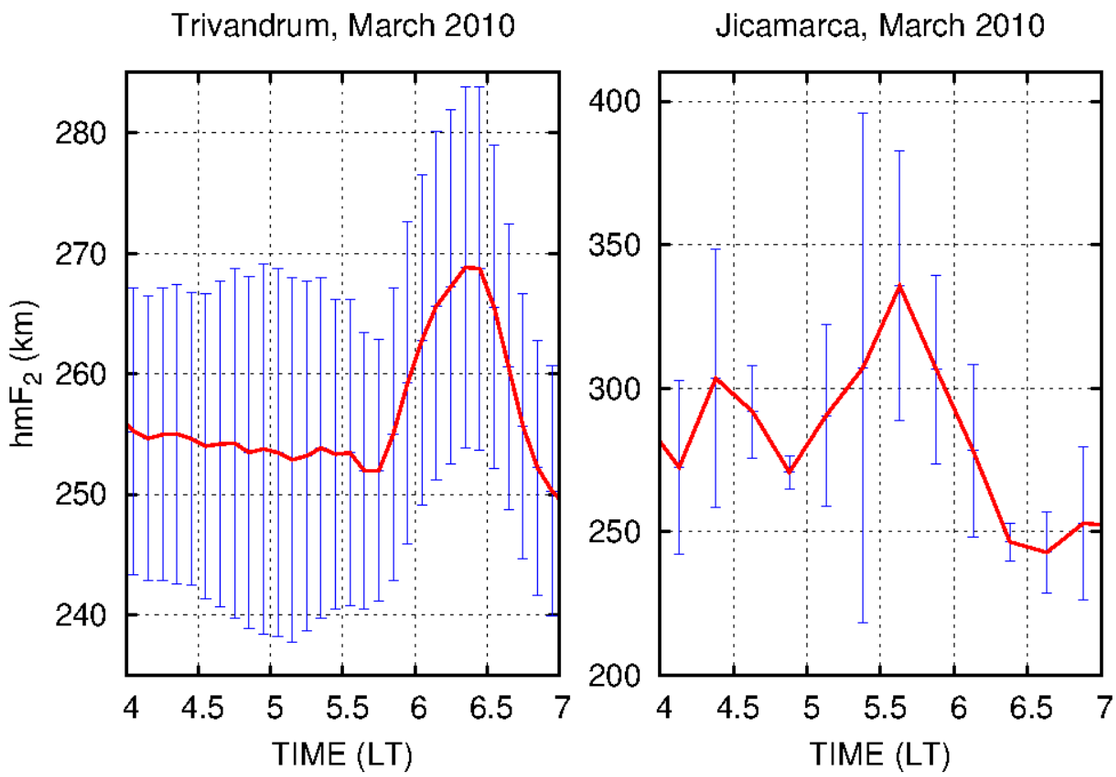

FIGURE 1. Temporal variations in monthly averaged hmF_2 during sunrise period at Trivandrum (left) and Jicamarca (right) during March 2010.

4. Results and Discussion

FIGURE 1 presents the temporal evolution of the F-region peak height hmF2 derived from the Digisonde observations during March 2010 at Trivandrum, and Jicamarca. The plots represent the monthly averaged value in 5 minutes intervals (at Trivandrum, left panel), and in 15 min intervals (at Jicamarca, right panel), along with the standard deviations at each bins during sunrise (0400 to 0700 LT) periods. The peak height of the F region shows uplift and then a descending motion (more clearly at Trivandrum than at Jicamarca) during morning hours. As discussed in the introduction, such undulation in the F region is frequently seen during evening hours and is well known as the Pre Reversal Enhancement (PRE) associated with a reversal in the sign of the zonal electric field. It should be clear from FIGURE 1 that there is a strong trend at Trivandrum around 0630 LT for a descending F peak that becomes detectable around 300 km altitude. Within a half hour the peak comes down to 250 km only to move back after 0730 LT. A similar undulation in hmF_2 at Jicamarca can also be identified from FIGURE 1 where the F-region peak appears to jump from 260 km at 4:45 LT to 335 km at 5:45 LT and thereafter moves swiftly down to 240 km by 6:30 LT. *Ambili et al,* [6] have shown that the apparent jump in the F-region altitude is a result of two separate factors: an erratic remnant from the night before, which is typically found below 260 km altitude, and a fast descending component that starts at an altitude far in excess of the `remnants' mean altitude.

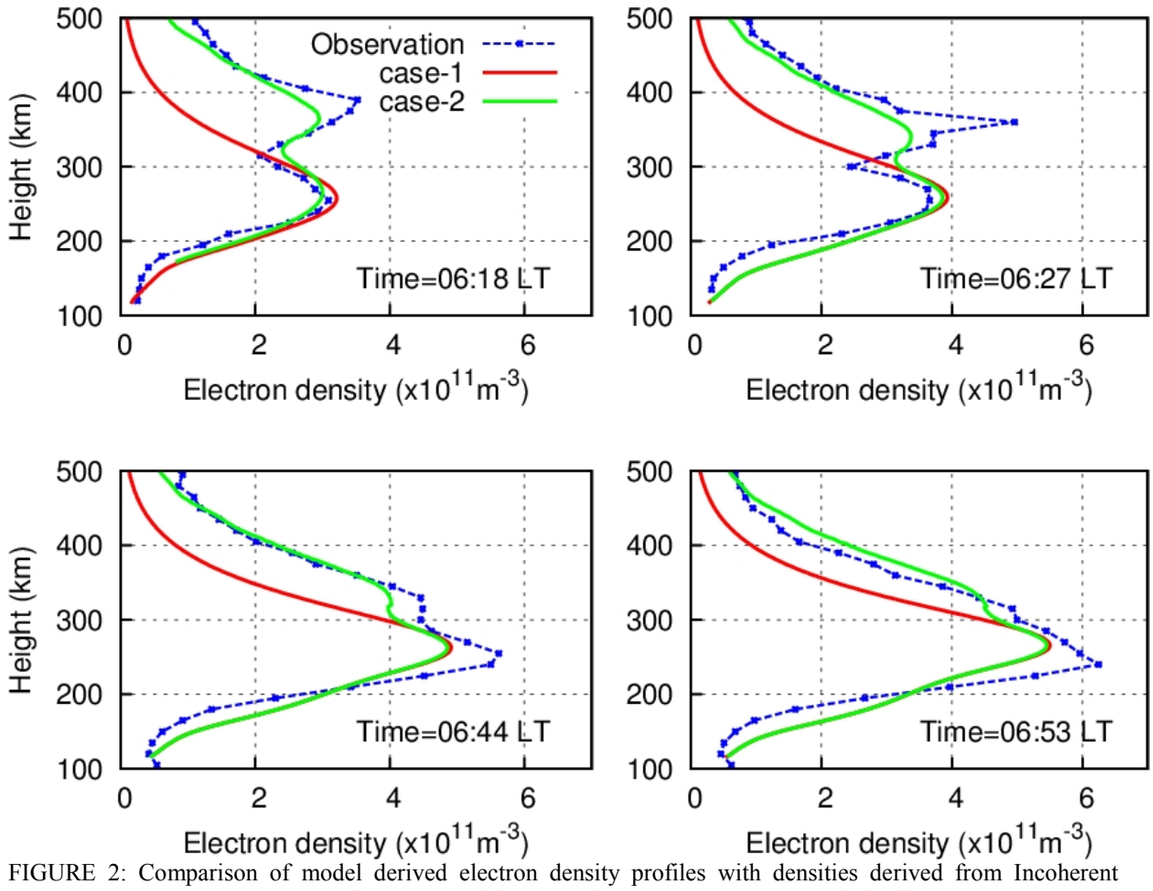

FIGURE 2: Comparison of model derived electron density profiles with densities derived from Incoherent backscatter radar measurements at Jicamarca on March 11, 2011 (after *Ambili et al., 2013* [7])

In order to study the roles of residual ions from the prior night on the observations of sunrise undulations, we compare in FIGURE 2 the observations on March 11, 2011 (blue curves) with the numerical model results by initializing the model under two different set of conditions, namely, [Case 1, red curves] with negligible density so that only the newly produced plasma and hence the evolution of the ionosphere with time could be tracked, and [Case 2, green curves] with the plasma density matching the ISR observations at the pre sunrise time. March 12 was a special day a moderate geomagnetic storm with Dst ~ -90 nT had started on 11 March 2011 at 0300 UT, and was in its recovery phase on March 12. A double hump structure was observed in the electron density profile which had remained unexplained till date. As the Fejer model output could not represent actual electric field conditions prevailing during March 12, in our model run for Case 2, we initialized the model with ISR- measured plasma density at 03:00 AM and applied a modest updrift of 5 m/s till 06:15 LT (there was no drift data from the ISR itself). Afterwards, we used the Fejer drift in the calculations. While the agreement with observations may not be perfect, our model calculations can clearly be used to emphasize that the lower peak in the density profile was associated with the SU effect while the other peak came from remnant plasma that had been lifted up to unusually high altitudes and had undergone little, if any, recombination. This upper peak descended near dawn because of the downward motion seen after 0615 LT. The motion of the upper peak therefore had nothing to do with the chemical processes associated with the plasma produced through the SU mechanism. It just so happened that the remnant plasma was high enough and had a large enough density to be seen in tandem with the photochemically produced plasma, even as late as 0653 LT. Therefore, even though there was an initial rise in altitude followed by a downslide after sunrise, the temporal variations in hmF2 on March 12, 2011 was entirely due to an unusual electrodynamical effect.

5. Conclusions

The behavior of the ionosphere shortly after sunrise has been characterized using high time resolution observations from a Digital Ionosonde (Digisonde) at Trivandrum, India and incoherent backscatter measurements at Jicamarca. Our study makes it clear that the hmF2 jump after the upper F region sunrise, and its

subsequent downward excursion afterwards is entirely explicable by chemical effects associated with the production of new plasma after sunrise. Our chemical calculations not only predict the right altitudes at the right time for the F peak, but also, very near the right densities. The up and down oscillations that follow sunrise are therefore not due to an oscillating vertical drift. Using incoherent backscatter measurements we have also shown that the peak in plasma density due to its fresh production during morning hours can be easily identified even in the case when background density is high. A double hump structure in the electron density in the morning of a geomagnetically disturbed day was also explained with the upper peak due to remnant plasma and lower due to pure chemistry.

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7. References

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