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Collapse of the equatorial ionosphere during the sunrise period

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ABSTRACT. The paper discusses the phenomenon of abnormally large values of slab thickness of the equatorial ionosphere at presunrise hours. The phenomenon is concurrent with a large ratio of electron content above and below the $F2$ peak and with the occurrence of daily minimum of Nm and Nt. It is shown that the phenomenon is consequent with the collapse of the bottomside $F2$-layer, the maximum electron density reducing to a value of 10^{10} electrons m^{-3} or even less than measurable by normal ionosondes. The whole phenomenon is suggested as being primarily due to electromagnetic effects caused by a large presunrise reversal magnitude of the westward electric field in the equatorial region.

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INTRODUCTION

It has been well understood from the early observations of ionospheric soundings that the minimum ionization occurred in the presunrise period. Immediately after the installation of an automatic ionosonde at the equatorial station, Kodaikanal (dip lat 1.7° N) it was found that on about 60 percent of the days during the period March-July 1952 the ionospheric echoes ceased to be recorded for some time during the predawn period (Bhargava, 1952). Similar features have been reported for Ibadan by Olatunji (1966). Chandra and Rastogi (1971) showed that the solar cycle variation of $foF2$ at the equatorial station Thumba, was most prominent for predawn periods. Thus, with decreasing solar activity, more and more of the nighttime hours prior to sunrise experienced the absence of $F2$ echoes, suggesting the collapse of the ionospheric ionization. At tropical latitudes, Ahmedabad, the phenomenon occurred on only 20 percent of winter days during minimum sunspot years (Rastogi, 1960). Using the Faraday rotation of radio beacons signals from the low orbiting satellite S66, Rastogi *et al.*, (1973) showed that during the no echo conditions at presunrise hours, TEC was abnormally low, of the order of 1×10^{16} electrons m^{-2}. The ratio of topside to bottomside electron content exceeded a value of five. This high ratio was suggested to be due to the low value of $NmF2$ during the presunrise period such that it becomes comparable to the electron densities at heights well above the $F2$ layer. Utilizing the modulation phase delay of the 1 MHz wave on the carrier of 140 MHz, Rastogi *et al.*, (1979) found that the slab thickness $T = Nt/Nm$ or the ratio of topside to bottomside electron content was abnormally high during the presunrise hours for the Ootacamund to ATS-6 path. This paper discusses the early morning phenomenon as deduced from the ionospheric electron content data at the equatorial station Huancayo. First of all, we describe in figure 1,

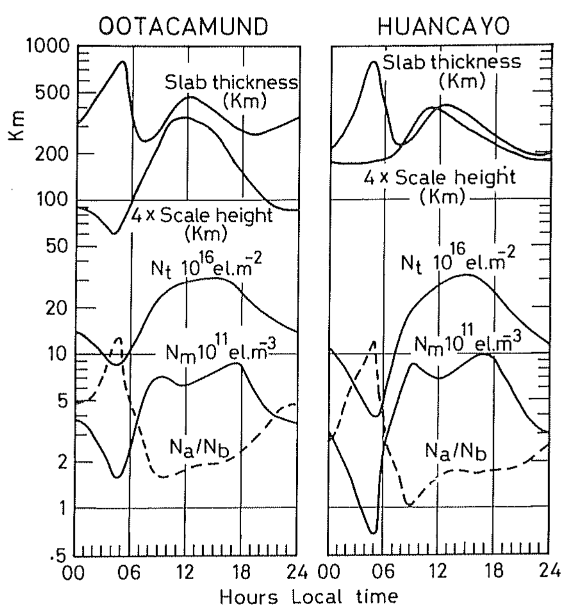


Figure 1
Daily variations of the maximum electron density Nm, scale height of the F2 layer, total content Nt, ratio of the electron content above and below (Na/Nb) of the F2 peak, and the slab thickness Nt/Nm of the ionosphere over the equatorial region in Indian, Ootacamund (October 1975-July 1976) and American zones, Huancayo (December 1974-May 1975).

the mean daily variations of the following parameters of the ionosphere over the magnetic equator in the Indian (Ootacamund) and American (Huancayo) zones.

(i) $NmF2$ = maximum electron density of the $F2$ layer.

(ii) Nt = total electron content of the ionosphere computed from the phase delay of the 1 MHz modulation of 140 MHz with respect to the same on 360 MHz.

(iii) Nf = electron content of the ionosphere computed from the Faraday rotation of 140 MHz radio beacon.

(iv) Tt or $Tf = Nt/Nm$ or Nf/Nm respectively, slab thickness of the ionosphere.

(v) Scale height, H = 1/4 the thickness of equivalent parabolic layer approximation of the F-layer.

(vi) Nb = electron content in the bottomside of the ionosphere, up to the $F2$ peak computed from a total height electron density profile derived from a bottomside ionogram.

(vii) $(Na)t$ or $(Na)f = Nt - Nb$ or $Nf - Nb$ electron content in the topside of the ionosphere.

(viii) Na/Nb = the ratio of electron content above and below the $F2$ peak.

We notice that Nm clearly showed a minimum during the sunrise period and a noon biteout at either of the stations. The corresponding Nt curve showed a minimum at sunrise period but a single flat maximum in the afternoon hours. The ratio of Nt/Nm, designated as slab thickness, (T), showed a noontime maximum and an abnormally large maximum during the presunrise hours. The noontime maximum of slab thickness was analogous to the noontime maximum of scale height, but there was no correspondence on the scale height curve of the sunrise maximum of slab thickness. Further, the slab thickness during daytime hours was close to four times the scale height, as expected from the simple theory of ionization due to Chapman (1931). The sunrise peak in slab thickness was concurrent with the peak value of the ratio of topside to bottomside electron content.

In figure 2 are shown the hour-to-hour relations between the scale height of the F layer and the slab thickness of the ionosphere. According to the theory of Wright (1960) if the ionospheric electron density profile is approximated with a Chapman layer, then slab thickness is 4.13 times the scale height. From figure 2 it is seen that the above relation holds well for the hours 0800 to 2300 h, when the change of slab thickness is about four times the corresponding change of the scale height. Only during the period 0000 h to 0700 h the slab thickness changes enormously without any change of the scale height, with a peak slab thickness of about 800 km at 0500 h. Thus the F layer during the postmidnight period departs considerably from a Chapman layer. To test if the above phenomenon is characteristic of equatorial latitudes only, in figure 3 are shown the average daily variations of the Nm, Nt and Nt/Nm at Ahmedabad, a station close to the Appleton anomaly crest region. At this tropical latitude station both Nm or Nt have a

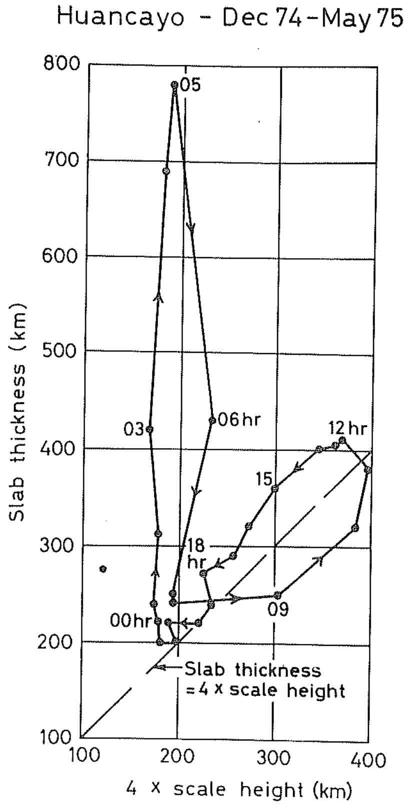


Figure 2
Interrelation between the hour-to-hour values of slab thickness and scale height of the equatorial ionosphere.

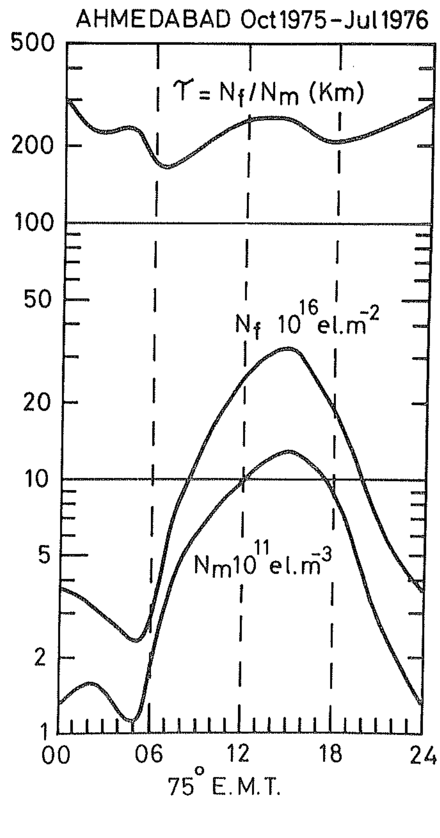


Figure 3
Daily variation of the Nm, Nt and Nt/Nm parameters at tropical station Ahmedabad.

single maximum in the afternoon and a minimum at the sunrise hour. The slab thickness showed a major maximum in the afternoon and another in the nighttime. No abnormal increase of slab thickness was seen around the sunrise period.

In figure 4 we have shown detailed variations of the parameters derived from ionosonde and radio beacon data at Huancayo on a typical day, 24 January 1975. The maximum electron density, Nm, showed a consistent decrease during the night reaching a minimum at 0500 h, after which it again started increasing rapidly. Nm had decreased from a value of $8.0 \times 10^{11}\ m^{-3}$ at 0000 h to less than $0.4 \times 10^{11}\ m^{-3}$ at 0500 h, thus decreasing by a factor of 20 within five hours. The bottomside electron content Nm showed very similar change during the night as did Nm. The total electron content, Nt, also reached a minimum at 0500 h but rate of decrease of Nt during the night was much slower than that of Nm. The topside electron content $Na = Nt - Nb$ also showed a very slow decrease during the nighttime in a manner very similar to that of Nt. Thus, both the ratio of the topside to bottomside electron content Na/Nb, as well as the slab thickness $T = Nt/Nm$, showed a gradual increase reaching a maximum at the predawn period around 0500 h. It can be seen that the height of the peak ionization of the F layer and, therefore the semithickness of the layer, remained practically constant during the nighttime hours. The abnormally high value of Na/Nb and T around the sunrise period thus seems to be due to a very fast decrease of the bottomside ionization in the nighttime F layer.

To further check the role of Nm and Nt in the abnormally large value of slab thickness T, in figure 5 are shown the daily variations of the percent standard deviations of Nm, Nt and T at Huancayo for the month of April 1975. The total electron content showed a small standard deviation during the daytime hours ranging between 10 % to 15 %, rising after sunset to a maximum of 40 % during predawn hours. The slab thickness had a standard deviation of 15 % to 20 % between 0700 to 2400 h after which it increased to a maximum of 90 % at 0500 h. The maximum electron density, Nm, had a standard deviation of 10 % to 20 % between 0700 h to 2200 h after which it started increasing with a maximum of 96 % at predawn hours. This too confirms that the large day-to-day variation of the abnormal values of slab thickness of the $F2$ layer at predawn hours had a significant contribution from the large day-to-day fluctuation of Nm rather than that of Nt.

A final test could be made by plotting the individual values of slab thickness (Nt/Nm) against Nt and Nm on separate diagrams as shown in figure 6 for Huancayo for the period January to May 1975. It is

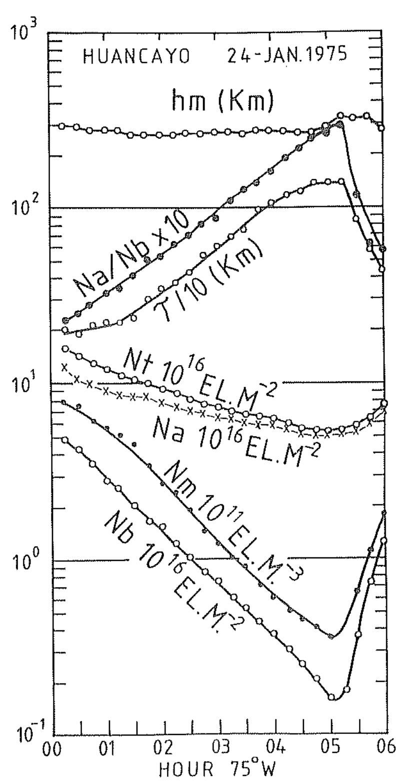


Figure 4
Temporal variation of bottomside and topside parameters of the ionosphere over Huancayo on the postmidnight period on 24 January 1975.

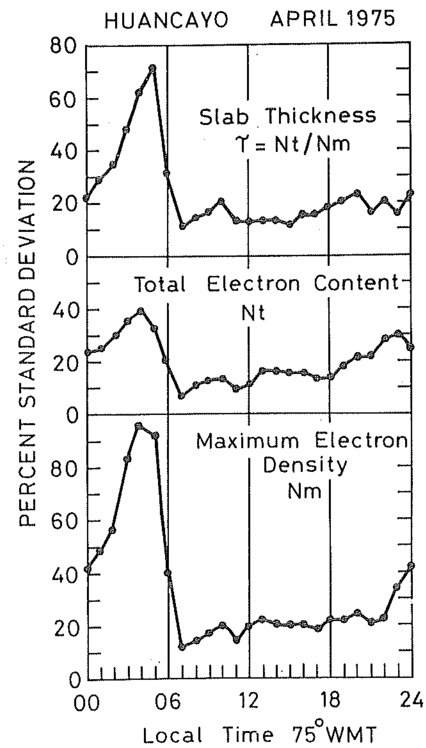


Figure 5
Daily variation of the percent standard deviations of Nm, Nt and $\tau = Nt/Nm$ at Huancayo for the month of April 1975.

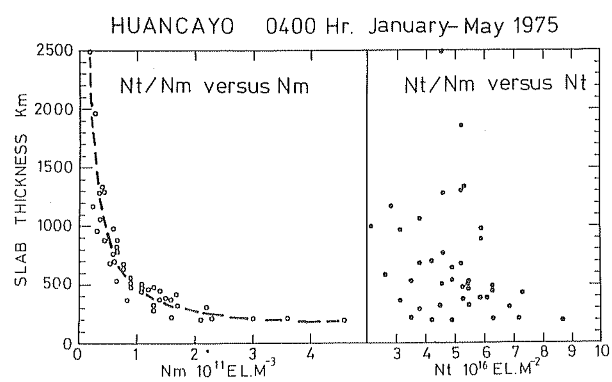


Figure 6
The dependence of individual values of slab thickness of the ionosphere on the corresponding value of Nt and Nm for Huancayo.

seen that the points are randomly distributed in the T *versus* Nt diagram, suggesting that the fluctuations of T are not related to fluctuations of Nt. The same data points when plotted on a T *versus* Nm diagram indicate a very smooth curve indicating that with the decreasing value of Nm, the corresponding value of T increases very rapidly. Thus the abnormal value of the predawn slab thickness is due to the collapse of ionization near the $F2$ peak.

To show that the abnormality in the slab thickness occurs on days when Nm (or $foF2$) decreases to a very low value around predawn hours we show the variations of ionosonde and radio beacon data on 10 and 30 April 1975 at Huancayo. Figure 7*a* shows the series of ionograms at Huancayo on the morning hours of 10 and 30 April 1975, while figure 7*b* shows the variations of maximum electron density (Nm, $foF2$) electron content (Nt and Nf) and the slab thickness (Tt and Tf). On 10 April 1975 the $foF2$ was 6.1 MHz at 0300 h and decreased to a minimum value of 4.2 MHz at 0545 h after which it started increasing due to sunrise. On 30 April 1975, $foF2$ at 0300 h was only 2.6 MHz, it started decreasing fast to a value of 1.2 MHz at 0500 h. No echoes were recorded at 0530 h on the ionogram. The temporal variations Nm, Nt, Nf on 10 April 1975, shown on a logarithmic scale, run practically parallel to each other indicating similar rates of change of the three parameters. The slab thickness Tt and Tf were practically constant at a value of about 200 km and 175 km respectively throughout the night. No large values of Tt or Tf were found at predawn period. On 30 April 1975 Nt decreased after midnight almost at the same rate as on 10 April 1975, while Nf decreased faster and Nm showed a sharp decrease between 0000 h and 0500 h. The value of slab thickness increased very rapidly after 0300 h reaching a value exceeding 2000 km for Tt and 700 km for Tf after 0000 h.

Using the Faraday rotation of the back-scatter signals over Jicamarca, McClure (1965) has published electron profiles for Jicamarca during the night of 2-3 February 1965. Contours of $\log_{10} Ne$ for the same night have been published by Farley (1966). Combining these data in figure 8*a* we have redrawn electron density profiles for afternoon hours (1544 h) and nighttime hours (2448 h to 0430 h). From these curves various parameters viz. Nm, Nb, Na, $Nt = Na + Nb$, Na/Nb and $T = Nt/Nm$ were computed. Temporal variations of these parameters over Jicamarca on 2-3 February 1965 are shown in figure 8*b*. It is seen that the electron densities at 1544 h were quite high for any altitude of the ionosphere. During the period 2248 h-0150 h the maximum electron density did not change appreciably, but the height of the $F2$ peak decreased continuously from about 450 km to 240 km. Afterwards the electron densities below 800 km decreased very rapidly. During the course of the night the electron density at any height above 800 km did not change with time. Thus, around the predawn hours the electron density near the peak of the F layer had decreased practically to value at heights above about 1000 km. Referring to figure 8*b* the rapid decrease of Nb after midnight caused a rapid increase of Na/Nb. Similarly, a very rapid decrease of Nm after 0200 h had caused a very rapid increase of slab thickness from a value of 250 km to 850 km. Thus the results derived from the radio beacon Faraday rotation and group delay measurements are consistent with those from incoherent backscatter radar measurements.

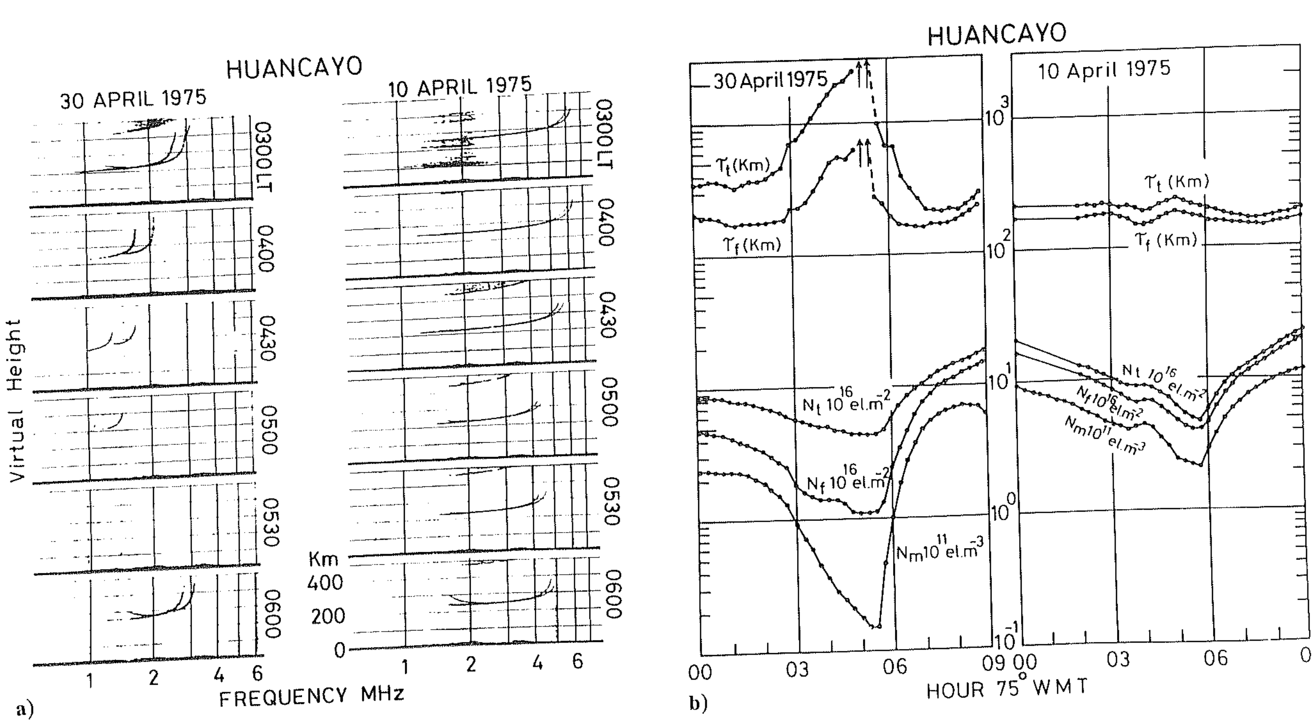
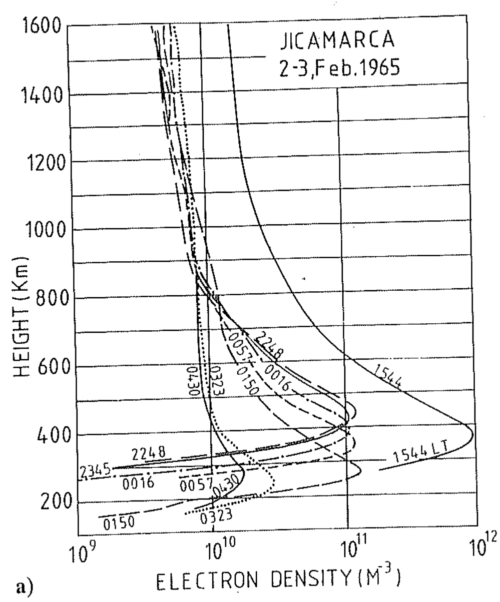


Figure 7
(a) *The series of ionograms at Huancayo on 10 and 30 April 1975.*
(b) *The variations of maximum electron density, electron content and slab thickness of the ionosphere over Huancayo on 10 and 30 April 1975.*



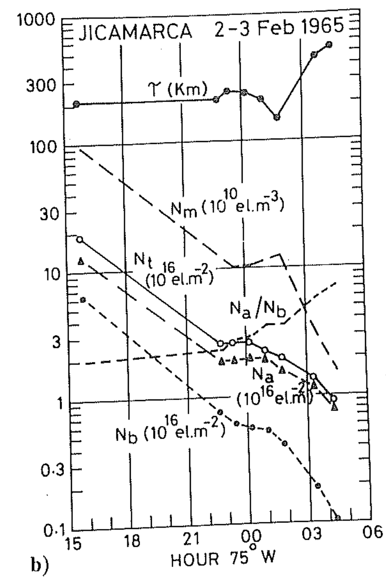


Figure 8
(a) *Electron density profiles over Jicamarca during the course of time during nighttime on* 2-3 *February* 1965.
(b) *Temporal variations of* Nm, Na, Nb, Nt, Na/Nb *and* τ *on* 2-3 *February* 1965.

DISCUSSION

The disappearance of the $F2$ layer in the morning hours is clearly a phenomenon of increasing probability with decreasing solar activity, but the various causes for its day-to-day variability have still to be investigated. Chandra and Rastogi (1970) had shown that, although the average ionospheric drift speed of F region at the equatorial station Thumba was eastward during the night reversing to westward at 0600-0700 h, there were a number of occasions when a significant increase of eastward drift speed was noticed about an hour before the morning reversal. This unusually large eastward drift (or westward electric field) would push down the F ionization causing the collapse of the layer on some occasions.

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REFERENCES

Bhargava, B. N., A new early morning ionosphere phenomenon, *Nature,* **170**, 983-984, 1952.

Chandra, H., and R. G. Rastogi, Daily variation of F region drifts at Thumba, *J. Atmos. Terr. Phys.,* **32,** 1309-1311, 1970.

Chandra, H., and R. G. Rastogi, General features of the ionosphere at Thumba, *J. Inst. Telecom. Eng.,* **17,** 207-216, 1971.

Chapman, S., The absorption and dissociative or ionizing effect of monochromatic radiation in an atmosphere on a rotating earth, *Proc. Phys. Soc.,* **43,** 26-45, 1931.

Farley, D. T., Observations at the equatorial ionosphere using incoherent backscatter, in *Electron Density Profiles in Ionosphere and Exosphere,* J. Frihagen ed., North-Holland, Amsterdam, Netherlands, 446-469, 1966.

McClure, J. P., Electron density studies at Jicamarca, in *Report on Equatorial Aeronomy,* ed. F. de Mendonca, Brazil, 170-177, 1965.

Olatunji, E. O., Some features of equatorial ionospheric storms, *Ann. Géophys.,* **22,** 485-491, 1966.

Rastogi, R. G., Synoptic study of the $F2$ region of the ionospheric in the Asian zone, *J. Atmos. Terr. Phys.,* **18,** 315-331, 1960.

Rastogi, R. G., R. P. Sharma, and V. Shodhan, Total electron content of the equatorial ionosphere, *Planet. Space Sci.,* **21,** 713-720, 1973.

Rastogi, R. G., G. Sethia, H. Chandra, M. R. Deshpande, K. Davies, and B. S. Murthy, Total electron content and F region electron density distribution near the magnetic equator in India, *J. Atmos. Terr. Phys.,* **41,** 561-564, 1979.

Wright, J. W., A model of the F layer above h_{max} $F2$, *J. Geophys. Res.,* **65,** 185-191, 1960.