Observations of large scale F-region irregularities using airglow emissions at 7774 Å and 6300 Å

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Received 13/12/82, accepted 28/01/83.

ABSTRACT. Simultaneous scanning measurements of the atomic oxygen 7774 Å and 6300 Å emissions, to study the dynamics of low-latitude large scale F-region irregularities, were carried out at Cachoeira Paulista (geographic coordinates 22.7° S, 45.0° W; geomagnetic latitude 11.95° S), Brazil, during the period October-November, 1980. The measurements were made with a two-channel photometer which permitted scanning observations both along and across the magnetic meridian. Observations at 7774 Å can detect large scale irregularities near the F-region peak height, whereas observations at 6300 Å detect such irregularities at an altitude about 50 km to 100 km lower, depending on the F-region height. On many nights, during spread-F conditions, as indicated by an ionosonde operating at the same location, the presence of large intensity depletions of short duration were detected in both emissions. These depletions were observed to move towards the east in the east-west scans, and apparently towards the south in the north-south scans. Salient features of these observations are presented and discussed.

Key words : F-region, nightglow, ionospheric irregularities.

Annales Geophysicae, 1983, 1, 3, 271-276.

INTRODUCTION

Experimental and theoretical investigations of depleted plasma regions, or ionospheric bubbles, and their associated ionospheric irregularities, in the equatorial ionosphere, have been made in the past few years by a number of workers. Various experimental techniques have been used, including incoherent backscatter radar observations (Woodman and La Hoz, 1976; Tsunoda, 1980), scintillation measurements (Basu and Kelley, 1979), ionosonde measurements (Abdu *et al.*, 1981), *in situ* observations by satellites (McClure *et al.*, 1977), and airglow observations of the atomic oxygen lines at 6300 Å (Weber *et al.*, 1978, 1980; Sobral *et al.*; 1981) and also at 7774 Å (Sahai *et al.*, 1981*a*; Moore and Weber, 1981). Theoretical and computer simulation investigations of equatorial ionospheric irregularities suggest that they are initially generated through a fluid type gradient instability mechanism, such as the Rayleigh-Taylor instability (Ossakow *et al.*, 1979) and that the ionospheric plasma bubbles are actually plasma depleted magnetic flux tubes, so that flux tube integrated quantities of electron content and Pedersen conductivity, instead of local values, should be considered in the theoretical simulations (Anderson and Haerendel, 1979). These combined efforts have shown that plasma depleted regions, or bubbles, aligned along the magnetic field lines, are generated in the bottom side of the F-region just after sunset, when the layer shows a rapid upward movement. These bubbles then buoyantly rise upward and westward with respect to the ambient plasma (McClure *et al.*, 1977). The bubbles may be typically of scale size of the order of 100 km perpendicular to the magnetic meridian plane and break up into smaller scale size irregularities which are associated with VHF backscatter, scintillations and spread-F.

The OI 7774 Å emission, which results from radiative recombination of O^+ ions, with a small contribution from ion-ion recombination (Tinsley *et al.*, 1973) and the [OI] 6300 Å emission, which results from dissociative recombination of O_2^+ ions (e.g. Peterson and Van Zandt, 1969), can be used to remotely monitor the dynamics of transequatorial bubbles and large scale irregularities in the ionospheric F-region. Atomic oxygen emissions arising mainly from radiative recombination of O^+ ions in the F-region provide an indirect measurement of the F-region peak electron density $n_m(e)$, and simultaneous measurements of an OI radiative recombination emission and the 6300 Å emission can be used to infer the $F2$-peak height, $h_m F2$, as described by Tinsley and Bittencourt (1975; see, also, Sahai *et al.*, 1981*b*). It may be pointed out that the peak height, $h_m F2$, estimated from the ratio $(J_{7774})^{1/2}/$

(J_{6300}), where J_{7774} and J_{6300} are the column emission rates for the OI 7774 Å and 6300 Å, respectively, depends on the assumed F-layer electron density profile. As discussed by Moore and Weber (1981), the F-layer profile may change from outside to inside the depletion making this ratio unsuitable for layer height determination, but this ratio can still be used to infer qualitatively the height region of maximum fractional decrease in electron density.

Remote airglow measurements are an effective means to assess the magnitude, structure and drift motion of equatorial ionospheric plasma depletions. The development of large-scale processes, believed responsible for triggering F-region irregularities at medium and small-scale sizes can be monitored from ground-based 6300/7774 diagnostic techniques from suitable sites. This can provide coarse resolution in altitude, latitude, longitude and time of the large-scale processes and thus are complementary to the *in situ* plasma diagnostics.

In an earlier paper (Sahai *et al.*, 1981*a*) we have presented simultaneous zenith observations of the OI 7774 Å and 6300 Å emissions, in which both emissions showed short-term simultaneous large intensity depletions due to the presence of large-scale irregularities in the F-region. In this paper we present results from scanning observations of the OI 7774 Å and 6300 Å emissions carried out at Cachoeira Paulista (geog. 22.7° S; 45.0° W; geomag. lat. 12.0° S), Brazil. Scanning measurements were made along and across the magnetic meridian, during the period October-November, 1980, to study the dynamics of low-latitude large scale F-region irregularities or transequatorial ionospheric bubbles. Simultaneous ionospheric data obtained from an ionosonde, operating at the same station, are also presented. The depletions seen in the optical measurements constitute a signature of the ionospheric bubbles in the height range from where the emissions are originated. The main features of the dynamic processes associated with the large-scale ionospheric irregularities, as they manifest themselves in the airglow observations, are discussed.

INSTRUMENTATION

Scanning observations of the 7774 Å and 6300 Å emissions were made with a two-channel photometer, which was placed horizontally and looked into two coupled mirrors inclined at 45° to the horizon. The two coupled mirrors were then rotated by a synchronous motor, to allow east-west or north-south meridional scans up to 70° zenith distance on either side. The 6300 Å photometer used a 2″ interference filter with a 10 Å bandwidth. Details for the 7774 Å photometer are given in Sahai *et al.* (1981*a*). The east-west 6300 Å scanning observations, presented for October 2-3, 1980, were obtained from another meridional scanning photometer operating simultaneously at the same location (see Sobral *et al.*, 1980), scanning up to 75° on either side of the zenith.

The zenith 6300 Å observations, obtained simultaneously with the scanning data, were made with a six-channel filter wheel type photometer, using the tilting filter technique, with 2″ interference filter of 10 Å bandwidth, having a field of view of 5° diameter. The ionograms were obtained from an ionosonde operating on a routine basis at Cachoeira Paulista.

RESULTS AND DISCUSSION

During the period October-November, 1980, good weather permitted airglow observations on ten nights around the new-moon period. On most of these nights, during the presence of spread-F as indicated in the ionograms, large intensity drop-outs of short duration were observed in the zenith 6300 Å airglow emission. These depletions seen at the zenith are associated with the drift motion of the large scale irregularities which were observed in the successive scanning measurements as depletions moving from west to east and apparently from north to south, as discussed later. To investigate the F-region dynamical effects during spread-F conditions, we have chosen to present here and discuss in some detail the data obtained on the night of October 2-3, 1980, whose behavior can be considered to be typical of the nights when these observations under spread-F conditions were made. Figure 1 shows the 6300 Å zenith intensity in Rayleighs, and the $h'F$ determined from the ionograms, as a function of local time, for this night. It can be seen that a rapid upward movement of the F-layer, just after sunset, precedes the onset of spread-F and the development of large-scale irregularities, which appear in the 6300 Å emission as short duration large

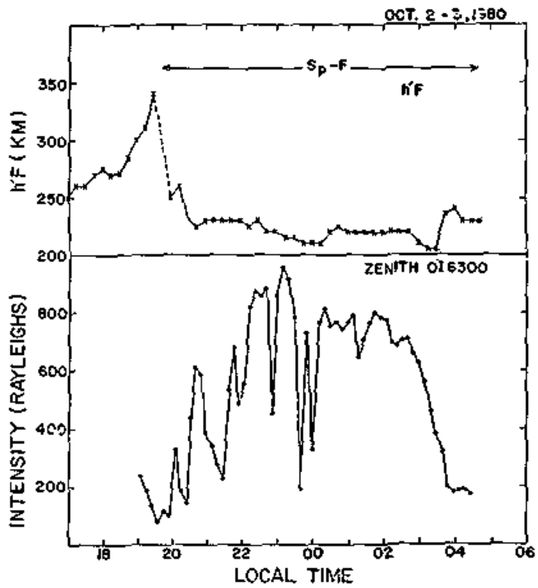

Figure 1
Ionospheric parameter h′F taken from ionosonde measurements, and the observed 6300 Å zenith intensities as a function of local time, for the night of October 2-3, 1980, at Cachoeira Paulista, during spread-F conditions.

intensity depletions. This rapid post-sunset rise of the F-layer is generally known to be accompanied by an evening enhancement of the equatorial anomaly (Tsunoda, 1980). The OI 6300 Å and 7774 Å observations, at this low-latitude station, on nights with strong spread-F, usually show large intensities up to late night hours (up to 03 : 00 L.T. in the case of fig. 1). However, this is not the case on nights with no spread-F (see e.g. Sahai *et al.*, 1981*a*). This seems to indicate the presence of a well-developed equatorial anomaly till late hours on the nights with strong spread-F.

According to the results presented in Sahai *et al.* (1981*b*), we obtain the following expression for the F-layer critical frequency ($f_0\,F_2$) in terms of J_{7774},

$$f_0\,F_2\,(\mathrm{MHz}) = [430\,J_{7774}\,(\mathrm{Rayleighs})]^{1/4}. \quad (1)$$

The $n_m(e)$ is related to the $f_0\,F_2$ according to the well-known expression

$$n_m(e)\,\mathrm{cm}^{-3} = 1.24\times10^4\,[f_0\,F_2\,(\mathrm{MHz})]^2. \quad (2)$$

Equation (1) has been obtained on the basis of the observational data presented in figures 1 and 5 of Sahai *et al.* (1981*b*), and differs only slightly from a similar equation given by Moore and Weber (1981).

Figure 2 shows the local time variation of $f_0\,F_2$, determined from the observed J_{7774} according to equation (1), and of the observed ratio $(J_{7774})^{1/2}/J_{6300}$ for different zenith distances taken from the simultaneous north-south OI 7774 Å and 6300 Å scanning observations obtained on October 2-3, 1980. The observed intensities used in figure 2 were corrected for Van Rhijn effect. Under no spread-F conditions, the observed J_{7774} can be directly related to $n_m(e)$ (or $f_0\,F_2$) (Tinsley and Bittencourt, 1975; Sahai *et al.*, 1981*b*). However, during spread-F conditions, the depletions seen in the $f_0\,F_2$ values, reflects only a decrease in the column integrated electron density, rather than a decrease in $n_m(e)$ (or $f_0\,F_2$), because of the presence of irregularities in the electron density profile (see e.g. Szuszczewicz *et al.*, 1980; Narcisi and Szuszczewicz, 1981).

Before the onset of the spread-F, the observed ratio $(J_{7774})^{1/2}/J_{6300}$ is a good indicator of the peak height ($h_m\,F_2$) variations of the F-layer, and the data of figure 2 between 19 : 00 and 20 : 00 L.T. show much faster rise in the northern than in the southern side. Also, the large-scale depletions appear first in the north, possibly associated with the initial formation phase of plasma depletions. Large depletions were observed around 21 : 30 and 23 : 30 L.T. over entire north-south scanning range, possibly formed west of us earlier during the night. The large drop-out seen at 45° N between 23 : 30 and 24 : 00 L.T. seems to bifurcate as we scan from north to south.

The scanning data presented in figures 3 and 4 were selected at the particular local time periods when the zenith observations showed large intensity depletions. Simultaneous north-south meridional scans for both the 7774 Å and the 6300 Å emissions are presented in figure 3 for the local time ranges 21 : 09-21 : 37 and 23 : 20-23 : 55. The intensity scales in Rayleighs are shown in each figure. The intensity variations shown are

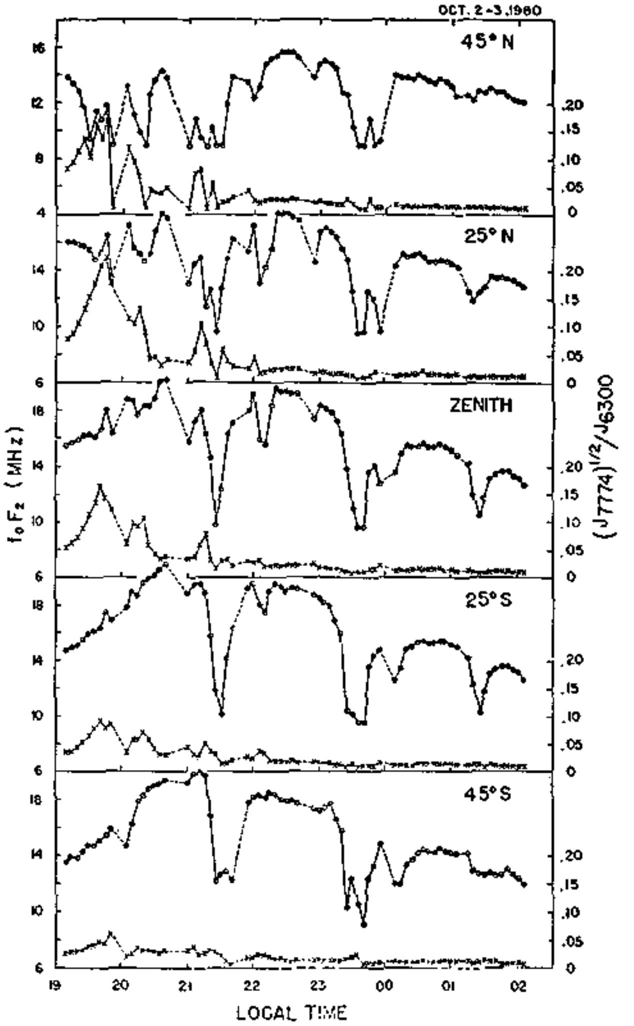

Figure 2

Local time variations of $f_0\,F_2$ (circles), determined from J_{7774}, and the ratio $(J_{7774})^{1/2}/J_{6300}$ (crosses) for different zenith distances for the night of October 2-3, 1980. at Cachoeira Paulista (see text for details).

not corrected for the Van Rhijn effect. In the early part of the night, figure 3*a*, both emissions show, in general, larger intensities on the southern than on the northern side, which indicates a well-developed equatorial anomaly, with the anomaly crest to the south of the observation site. This behavior is associated with the rapid upward lifting of the F-layer just after sunset, thus enhancing the equatorial fountain effect, since larger upward drift velocities result in correspondingly higher latitudes of the anomaly crests (Hanson and Moffett, 1966; Bittencourt and Tinsley, 1976). Also, intensity drop-outs are observed in the north-south meridional scans of both emissions, which appear to move from north to south (figs. 3*a* and 3*b*) as well as from south to north (fig. 3*b*).

The propagating disturbances seen in figure 3, in both the emissions, is detected at a smaller zenithal angle for the 7774 Å emission, since the 7774 Å volume emission rate maximizes at the $F2$-peak, while the 6300 Å volume emission rate has its maximum at a lower height in the bottomside of the F-region. Also, the depletions in the 7774 Å emission primarily reflect only the corresponding depletions in the electron density, whereas those of the

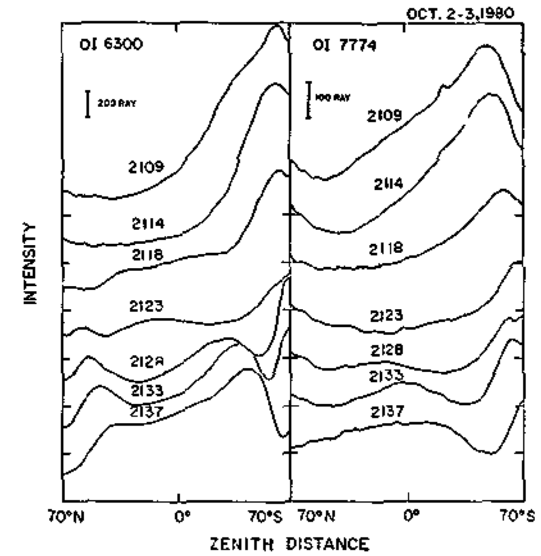

Figure 3a
Simultaneous north-south scanning measurements of the 6300 Å *and* 7774 Å *intensities for the night of October* 2-3, 1980, *in the local time range* 21:09-21:37, *at Cachoeira Paulista. The intensity scales in Rayleighs are shown for each emission.*

6300 Å emission are due to both electron density depletions are vertical motions of the bottomside *F*-region, because of the strong dependence of this emission on the height of the layer.

The 6300 Å east-west scans presented in figure 4, for the local time range 23 : 03-00 : 20 show the presence of large intensity depletions or valleys propagating from west to east. The eastward propagation of the valleys seen in the airglow data is expected, since it is well-known that, during the night-time, the ionospheric plasma as a whole drifts to the east due to the vertical dynamo electric field (Fejer *et al.*, 1981). Eastward propagating 6300 Å intensity depletions have also been previously observed at Cachoeira Paulista (Sobral *et al.*, 1980). The average velocity of the perturbations propagating from west to east, shown in figure 4, is of the order of 200 m/s considering an emission height of 250 km for the 6300 Å emission. The velocity inferred here is somewhat larger than the *F*-region east-west drifts measured at Jicamarca (Fejer *et al.*, 1981).

The intensity depletions or valleys can be interpreted as the optical signature of transequatorial ionospheric bubbles generated just after sunset in the bottomside of the *F*-region. These bubbles, elongated along the magnetic meridian, move upward and, generally, westward with respect to the background plasma, while the whole ionospheric plasma moves eastward (McClure *et al.*, 1977). The intensity depletions produced in the airglow emissions, in the height range where they are originated, are generally expected to be aligned west of north in the northern hemisphere, and west of south in the southern hemisphere. As shown by all sky imaging measurements (Weber *et al.*, 1978, 1980; Moore and Weber, 1981), equatorial plasma depletions in the OI 6300 Å and 7774 Å emissions extend across the equator up to about $\pm$ 15° MLAT, and often display a tilt or curvature toward the west of the magnetic meridian. The westward tilt is most apparent near the poleward ends where the depletions intersect the anomaly region. Due to the geometry, north-south scans are sensitive to both real and apparent north-south motions at observation sites close to the crests of the anomaly region.

During the formation phase of plasma depletions, actual poleward motion of the end of a depletion has been observed (Weber *et al.*, 1980), which is associated with

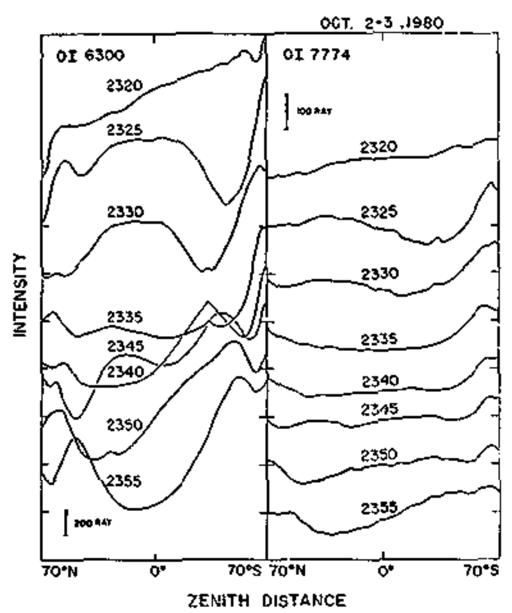

Figure 3b
Same as in figure 3a but for the local time range 23:20-23:55.

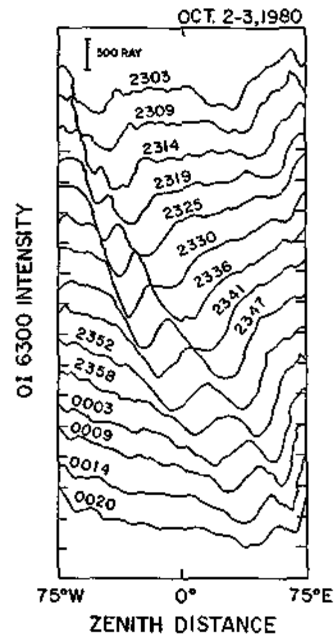

Figure 4
Observed east-west scanning measurements of the 6300 Å *intensities for the night of October* 2-3, 1980, *in the local time range* 23:03-00:20, *at Cachoeira Paulista, showing the presence of intensity depletions moving eastward.*

the horizontal north-south motion of the bubble foot in the height range of emission, as the bubble moves upward. However, after the formation phase of the plasma depletions, an apparent north-south motion may result from the eastward plasma drift and the angle between the depletion axis and the magnetic meridian. This effect is apparent in the east-west and north-south scans presented in figures 4 and 3*b* respectively for the period 23 : 41 and 24 : 00 L.T. The east-west scans show a depletion to the west of zenith at ~ 23 : 42-23 : 47 L.T., moving into the zenith at 23 : 58 L.T. The north-south scans show a depletion north of zenith at 23 : 45 L.T. and moving into the zenith at ~ 23 : 55 L.T. (last 6300 Å scan presented). The simultaneous appearance of this feature in the zenith for both east-west and north-south scans suggests a geometrical effect due to the eastward plasma drift. This picture is consistent also with the 6300 Å airborne observations of Weber *et al.* (1980), using an all sky imaging photometer, and with the generally westward tilt of plume structures observed with the incoherent scatter radar at Jicamarca (Woodman and La Hoz, 1976), and with the Altair radar (Tsunoda, 1980).

CONCLUSIONS

The results presented here have shown that north-south and east-west scanning measurements of the atomic oxygen emissions at 7774 Å and 6300 Å are very useful to study the dynamics of large scale irregularities in the intertropical ionospheric *F*-region. Raster scans of these two emissions across the magnetic meridian can provide maps in latitude and longitude of $n_m(e)$ and $h_m F_2$ and will be useful to study the *F*-region morphology before the onset of irregularities and developments later on. This will be important for studies of the generation processes of the transequatorial bubbles. Considering that the plasma irregularities or ionospheric bubbles are aligned along the magnetic field lines and often extend more than several thousands of kilometers north and south of the magnetic equator, it would be useful to make simultaneous observations of these emissions at magnetically conjugate points and at the magnetic equator to investigate the structure and dynamics of ionospheric transequatorial bubbles. Further, as suggested by Tinsley (1982), observations of atomic oxygen radiative recombination emissions, using a photometer with a sufficiently small angle of view, from a given magnetic latitude where the photometer line-of-sight would be almost tangent to the magnetic field lines at the heights where the volume emission rate is maximum, could provide enough spatial resolution for observing the sharp electron density variations across the walls of ionospheric plasma bubbles.

Acknowledgements

We thank J. P. McClure for suggesting this experiment; B. A. Tinsley and B. R. Clemesha for useful discussions; J. H. A. Sobral for providing the 6300 Å east-west scanning data of October 2-3, 1980; and M. A. Abdu for providing the ionosonde data. This work was partially supported by the Brazilian Fund for Science and Technology (FNDCT), under contract 537-CT.

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