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16. Summary/Notes

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WAVELIKE SPATIAL STRUCTURES IN RED (λ = 6300 Å) LINE NIGHTGLOW INTENSITY AT 22° 41' SOUTH, 45° 00' WEST, BRAZIL

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ABSTRACT

This work presents and discusses dynamic processes of the nighttime ionosphere over Cachoeira Paulista (geog.22°41'S, 45° 00'W), Brazil, based on recent data of the OI 6300 Å nightglow and ionosonde measurements, both obtained at that site. The 6300 Å photometer scanned the zenith angle range of 75° north to 75° south and along the geomagnetic meridional plane over Cachoeira Paulista (with no azimuthal scanning). Some nights presented remarkable wavelike structures on the meridional profiles of the red line intensity which occurred essentially during the premidnight period. According to the set of results presented here such a set of time and space patterns of the OI 6300 Å intensity present wavelengths of the order of a few hundred kilometers and propagate from north to south at an average speed of 238 m/s $\pm$ 73 m/s, assuming the emitting layer at an altitude of 250 Km. These airglow disturbances seem to be part of a single large-scale wave structure which originates at lower latitudes. An attempt is made to associate such north to south travelling enhancements of the OI 6300 Å emission with gravity waves. Comments are also made on the behaviour of the red line emission during the post midnight period.

1. INTRODUCTION

In an effort to study the dynamics of the ionosphere over Cachoeira Paulista (geographic coordinates $22^{o}41$ 'S, $45^{o}00$'W; geomagnetic coordinates $11^{o}57$'S, $22^{o}32$'W), Brazil, nighttime scanning measurements of the atomic oxygen 6300 Å emission (from now on also referred to as red line) and ionosonde measurements were made at that site. Studies of the ionospheric dynamics by using experimental data of the red line have already been made (Barbier, 1957; Barbier and Glaume, 1962; Peterson et al., 1966; Kulkarni and Rao, 1972; Skinner et al., 1977; Sobral et al., 1978).

The set of airglow measurements presented here is restricted to the geomagnetic meridional plane only and covers the zenith distances ranging from 75^{o} north to 75^{o} south. Cachoeira Paulista is located in the heart of what Gledhill (1976) terms as the Brazilian geomagnetic anomaly. At this site, relatively few measurements concerning ionospheric dynamic effects have so far been made and this fact has served as the principal motivation of our work. The ionospheric measurements performed up to the present at this location mostly concern aeronomic effects of the precipitating electrons stemming from the inner Van Allen radiation belt (Abdu and Batista, 1977; Batista and Abdu, 1977; Abdu et al., 1978).

The set of airglow data introduced here is the first set of extensive scanning measurements, using small time grid, carried out at Cachoeira Paulista. We present, in this work, an analysis based on a total of about 40 hours of photometric and ionosonde observations which were taken on 5 nights and distributed as follows: one night in November 1977, one night in February 1978, two nights in March 1978 and one night in June 1978.

2. THE EXPERIMENTAL SET-UP AND DATA REDUCTION

A filter of the tilting type and 3 Å bandwidth has been used to measure the atomic oxygen red line during nighttime. The sky scanning was made by a mirror placed at an angle of 45^{o} with the horizontal plane, so as to reflect the dim light from the sky into the horizontally disposed photomultiplier tube. The red line measurements were made continuously during a one-way sweep of scan. In the north to south scanning motion, the filter was set at a fixed inclination in order to read the background radiation from the sky (which is here a narrow continuum band placed a few Angstroms away from λ = 6300 Å, according to the transmittance characteristics of the filter). During the south to north motion of the mirror, the filter was set to a second position so as to read the 6300 Å emission itself. The time for the mirror to go back and forth is approximately 4.5 minutes. Figure 1 illustrates the scanning range at the reference altitude of 250 Km, at which altitude the geomagnetic latitude scanning range is approximately 13.3^{o} and the corresponding path length is 1537 Km. At the reference altitude of 300 Km these Figures are 15.4^{o} and 1795 Km. Figures 2 and 3 show typical reproductions of recordings of the red line signal (shown dimensionless) versus latitude, where the continuous lines, whose corresponding time length is around 2.25 minutes, represent integrated intensities of the red line not corrected either for the Van Rhijn effect or the background emission. During the passage of strong travelling nightglow disturbances as described below, the intensity of the red line was always so much stronger than the background emission that the nightglow meridional profiles, even including the spurious background emission, well represent the OI 6300 Å itself but of course not including the Van Rhijn correction.

The error bar in determining one given speed from a set of crests of red line emission is set by the reading resolution of the chart records and is estimated to be of the order of ± 7%. So are the error bars on the speeds shown in Figures 4,5 and 6.

Ionograms were taken at 15 minutes intervals by an ionosonde close to the photometer facility.

3. RESULTS AND DISCUSSION

A remarkable feature of the atomic oxygen nightglow, presented here, is a very high intensity in the early part of the evening (the period of about 1800 - 1930 h), at the south, and a simultaneous low intensity at the north. Later on, still during the premidnight period, the nightglow intensity of the red line tends to increase considerably at north with simultaneous decrease at south (see Figure 2). In other words, the large south to north intensity ratio decreases considerably from the begining of the night until midnight. Such a general feature seems to be consistent with the south to north motion of the intertropical red arc. As presently understood, the intertropical red arc displays itself as a strip of enhanced OI 6300 Å emission extending in the east-west direction and is supposed to have a single crest which moves from low latitudes towards the equator. Kulkarni and Rao's (1972) measurements of the red line at low latitudes, utilizing all-sky scanning, clearly show the ridge and crest of the intertropical red arc in the northern hemisphere. In the southern hemisphere also, the intertropical red arc is expected to occur during nighttime and to appear first around the geomagnetic latitude of 12^{o}S, from where it should travel equatorwards. However, despite the suitable location of Cachoeira Paulista we have not been able to see any slow moving crest of the intertropical red arc. Perhaps the peak of the intertropical red arc had so small a latitudinal variation as not to be easily detected by the photometric measurements. The time variation of the zenith atomic oxygen red line plotted in Figures 7 and 8, together with some ionosonde data, also does not show any clear peak of the intertropical red arc, as such, it is difficult to determine its trace speed.

The data obtained at Cachoeira Paulista do not show the intertropical red arc appearing first in the neighbourhood of zenith, although its formation is expected to take place at the geomagnetic latitude of $12^{O}S$ (Barbier and Glaume, 1960). The data shows the possibility that such formation may occur south of the zenith distance of 75^{O} as seen for example in Figure 2 where the very high intensity at the southern part doesn't seem to have reached a maximum. The zenith distance of $75^{O}S$ represents, in our case, the geomagnetic latitude of $18.6^{O}S$ or $19.7^{O}S$ (at 250 and 300 Km of altitude, respectively).

During the above mentioned transition period, in which the south to north intensity ratio decreases, quite often occurs a very strong enhancement of the red line travelling north to south, which is a direction opposite to that of the intertropical red arc. As far as we know, such a feature of the OI 6300 Å emission is not cited in the current literature on low latitude nightglow dynamics. As a matter of fact the intertropical red arc may also travel sometimes in the north to south direction. However this is expected to occur mostly during daytime with a time of occurrence depending on atmospheric tidal parameters. Thus, the north to south travelling structure which we observed cannot be mistaken for the intertropical red arc. In addition, we can differentiate these two phenomena by comparing their respective speeds. The speeds of the intertropical red arc have been observed by other authors (Skinner et al., 1977) to be of the order of 65-97 m/s (or 3 - 4^{O} latitude per hour) assuming the emitting layer at the altitude of 300 Km. This value is significantly smaller, than the north to south speeds of 276 m/s estimated by us as discussed later.

Figures 2 and 3 clearly show the previously cited north to south travelling red line enhancements. Notice in these figures the steep gradientes to the left of the main peaks. This suggests a strong nonlinear gravity wave. Figures 4 and 5 show the propagation of these red line crests obtained from a set of observations and also the least square fitted straight lines which give an average speed of 238 m/s with a standard deviation of 73 m/s. If the reference altitude for the emitting layer is taken to be 300 Km then the corresponding speed will be 276 m/s ± 85 m/s. For an illustration of the wavelength of the travelling airglow disturbance, we have presented in Figure 6 data selected during two nights that clearly show the progression of peaks and valleys. The corresponding wavelengths of the disturbance lie in the range of 350 - 550 Km. A close examination of Figure 6 reveals a tendency for the wavelength of the propagating disturbances to increase in the direction of propagation, which is a characteristic of wave dispersion as it travels.

The passage of these emission enhancements and their motion from north to south over Cachoeira Paulista, is often accompanied by spread-F events (Figures 7 and 8) which either cease or become reduced after the passage of the peak of the disturbance at zenith. Röttger (1973) detected spread-F occurences directly associated with TID's at low latitudes and it may be the same sort of event that we are seeing over Cachoeira Paulista. The possibility of TID's (gravity waves) being generated by vertical motions of cumulus clouds in the tropical rain forest regions was considered by Röttger (1977) to explain his observational results obtained by means of ground HF backscatter and HF Doppler techniques. The evidence that he claimed was based on the strong correlation found between the rainfall indices and the frequency of occurrence of TID's (over the Congo territory) and also on the observation of dominance in the TID's, over Huancayo, stemming from the high rainfall index area in the Amazon forest situated geomagnetically north (geographically northeast) of Huancayo. We may note here that the meridional plane, scanned over Cachoeira Paulista, also passes through a region of highest precipitation rates in Brazil (Figure 1) where a high degree of correlation between rainfall and cumulus convection is known to exist (Divino, 1978), as commented later in this section. The mean horizontal trace speed of the disturbances measured by Röttger was 210 m/s, occurring nearly along the geomagnetic meridional plane over Huancayo, which compares reasonably well with our result of 238 m/s which is also along the geomagnetic meridional plane. However, the wavelenghts and periods of the wavelike disturbances in our case are 350-550 Km and 20-60 minutes, respectively, whereas in Röttger's case, at Huancayo, they are 150 Km and 5-30 minutes respectively.

Another unusual pattern of the red line intensity variations is shown in Figures 7 and 8. There we see a positive correlation (marked with a plus sign) between h'F and the zenith intensity of the OI 6300 Å emission during relatively long time intervals. Notice that a positive correlation between these two parameters is also expected to occur ordinarily and independently from the geographical location, during a couple of minutes after h'F has reached its minimum as shown by Sobral (1973), but because of the large discrepancy in the time duration of the positive correlation between that case and the one here, it seems that the present case is a different one. The positive correlation shown in Figures 7 and 8 is probably due to an integrated effect of a gravity wave group in the lower F - region where an organized interference of the gravity waves produces superimposed modes in the electron densities which, in turn, causes a detectable increase of the OI 6300 Å emission. During most of this period, the slow varying h'F and the rapid variations of the red line intensity suggest expansions and contractions as a breathing mode, i.e., the electron density profile expands and contracts without appreaciably changing the height of the base of the ionosphere.

On the other hand we found no evidence that such north to south travelling enhancements are related to TID's originated in the auroral region. An inspection of the geomagnetic indices shows that such nightglow disturbances may occur without any significant variations of the geomagnetic index for many days preceding their occurrences.

Sobral et al. (1978) have reported strong south to north travelling red line enhancements, going at an average speed of 300 m/s at 300 Km of altitude, at Arecibo (geographic coordinates of 18.4°N, 66.8°W) which is roughly symmetric to Cachoeira Paulista with respect to the equatorial plane. The south to north travelling enhancement of the OI 6300 Å observed at Arecibo is, primarily caused by the global pressure system. A pressure bulge, built up near the equator by equatorward transpolar winds, causes a slow down or even a reversal of the Arecibo nighttime equatorward wind system. Comparing the propagating nightglow disturbances, occurring at Arecibo and at Cachoeira Paulista, a time difference of the order of a couple of hours is seen in the appearance of the events at each site. If their source is the same, their starting point should be located between Arecibo and Cachoeira Paulista, since the disturbances travel south-north and north-to-south, respectively, at those sites. It is interesting, then, to bring about an illustrative example showing where the trajectories of two given typical events, occurring at each of the two sites, would encounter each other. The example that follows concern different days for each site since we don't have experiments carried out simultaneously at both sites. In order to make the result more reliable we have chosen two days as much within a seasonal period as possible. On January 15, 1972, Sobral (1973) reported one south to north travelling red line peak at a zenith distance of 75^{o}N, around 2200 h. Accordingly, taking into account the coordinates of the red line peaks, travelling north south at Cachoeira Paulista, on February 3, 1978 and considering a speed of 220 m/s at 300 Km of altitude (which corresponds to the speed of 190 m/s, at 250 Km of altitude shown in Figure 5) and assuming the airglow peaks projected in an hypothetical meridional plane, say, located anywhere between Arecibo and Cachoeira Paulista, the encounter of the two trajectories will be situated at the latitude of 11.9^{o}S (at 300 Km of altitude) which is close to the subsolar point on February 3, 1978. For comparison purposes we should remark that the subsolar points on January 15, 1972 and on February 3, 1978 were at the latitudes of 21^{o} 20'S and 16^{o} 51'S, respectively (A.O.N. (1972); E.A. (1978)). Of course this example is not conclusive as to whether such nightglow disturbances could be originated around the subsolar point or not, but it somehow indicates that such hypothesis is not ruled out. Despite the fact the north to south travelling red line enhancements observed at Cachoeira Paulista consistently occur during the transition period, any association of it with the intertropical red arc, which travels in the opposite direction, is not obvious. Therefore a combined effort of carrying out such measurements both at Arecibo and Cachoeira Paulista would certainly contribute to elucidate many aspects of the atmospheric dynamics implied by the red line structures.

The fact that the origin of the travelling airglow disturbances is close to the subsolar point, suggests that tidal motion is a possible initial cause of the disturbances. On the other hand, large scale vertical convection of cumulus clouds as well as rain precipitation are known to occur between sunset and midnight, at a distance of about 1500 Km geomagnetically north of Cachoeira Paulista in a zone of very high annual rainfall index located in the Amazon region (Figure 1). Such a zone is right in the neighbourhood of the meridional plane over Cachoeira Paulista. However the high rain precipitation between sunset and midnight above mentioned, does not seem directly related to tidal motions. Therefore, further studies are needed in order to pinpoint the physics underlying the three following events: the vertical cumulus convection north of Cachoeira Paulista, tidal motions in the upper atmosphere and the north to south travelling wave structures of the atomic oxygen 6300 Å emission.

The general behaviour of the meridional profiles of the red line, during the rest of the night, is quite smooth and practically does not present any propagating disturbances, at least within the meridional plane. In other words, the nightglow during the premidnight period present very complex structures as compared with those of the post midnight period. However, during this less active part of the night, larger but random red line enhancements were observed, roughly simultaneously, all over the meridional plane, but the general tendency of the line emission during this period of the night is to decrease monotonically with time until sunrise.

4. CONCLUSIONS

The combined set of meridional scanning measurements of the OI 6300 Å emission and ionosonde data, here presented and discussed, allow the following conclusions about the dynamics of the ionosphere over Cachoeira Paulista:

1- The north-south atomic oxygen red line profiles present a variety of wavelike structures during the premidnight period. On the other hand, the post midnight enhancements of this line, whenever they exist, often occur simultaneously along the meridional plane.

2- There is a definite north-to-south propagation of the red line crests at an average speed of 238 m/s ± 73 m/s, in a wave pattern of a few hundred (350-550) kilometers of wavelength (at the altitude of 250 Km), and occuring concurrently with the south to north moving intertropical red arc.

3- Simultaneous data of h'F and OI 6300 Å intensity acquired during the passage of the north to south travelling disturbance at zenith suggest, by means of a positive correlation between themselves, a constructive interference of the different modes of a gravity wave group on the electron density distribution in the F-region.

4- Although the gravity wave triggered by tidal motions could be the causal mechanism of the interaction between neutral and ionized constituents, which might result in the north to south travelling enhancements, other possibilities for the gravity wave energy source cannot be ruled out, such as large scale vertical cumulus convection (Röttger, 1977) over the tropical rain forest of the Amazon region.

5- The formation of the intertropical red arc was not obviously seen at zenith, as expected at this geomagnetic latitude by some authors. On some days, such formation seems to have taken place south of the geomagnetic latitudes of 18.6°S or 19.7°S (considering, respectively, the references altitudes of 250 Km and 300 Km. respectively).

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1 - Geometry of the geomagnetic meridional scanning range of the photometer measurements. The scanning range shown refers to an altitude of 250 Km and the path length at this altitude is limited by the zenith distances of $\pm 75^{o}$. The curved lines represent the loci of equal rain precipitation, whose magnitude, indicated in millimeters,represents the total precipitation during one year. The rainfall data is given by the Atlas Climatológico do Brazil, edited by the Brazilian Ministery of Agriculture, 1969.

Figure 2 - Sequences of geomagnetic meridional profiles of the OI 6300 Å nightglow intensity with the typical wavelike structure discussed in the text. Date: February 3, 1978.

Figure 3 - Same as Figure 2, for the date of June 29, 1978.

Figure 4 - Least square fitted straight lines ajusted to the points representing red line crests. The vertical scale represents distances at the altitude of 250 Km. Date: November 9, 1977.

Figure 5 - Same as Figure 4, for the dates of March 11, 13, February 3 and June 29, all in 1978.

Figure 6 - Straight lines least square fitted to subsequent crests and valleys of the north to south travelling red line wave structure for two days from the set of observations discussed in the text. The vertical scale is as in Figure 4 and 5.

Figure 7 - Profiles of the zenith OI 6300 Å intensity (shown dimensionless) and h'F versus time. Notice the presence of spread-F during the more intense airglow variations, which is the red line signature when the north to south travelling disturbance passes over zenith. The positive sign shown indicates the period of time during which a positive correlation between h'F and the intensity of the red line emission exists. Notice the long duration of such periods. Date of the observation: February 4, 1978.

Figure 8 - Same as Figure 7, for the observation carried out on the following days: March 11-12, and March 13-14, 1978.

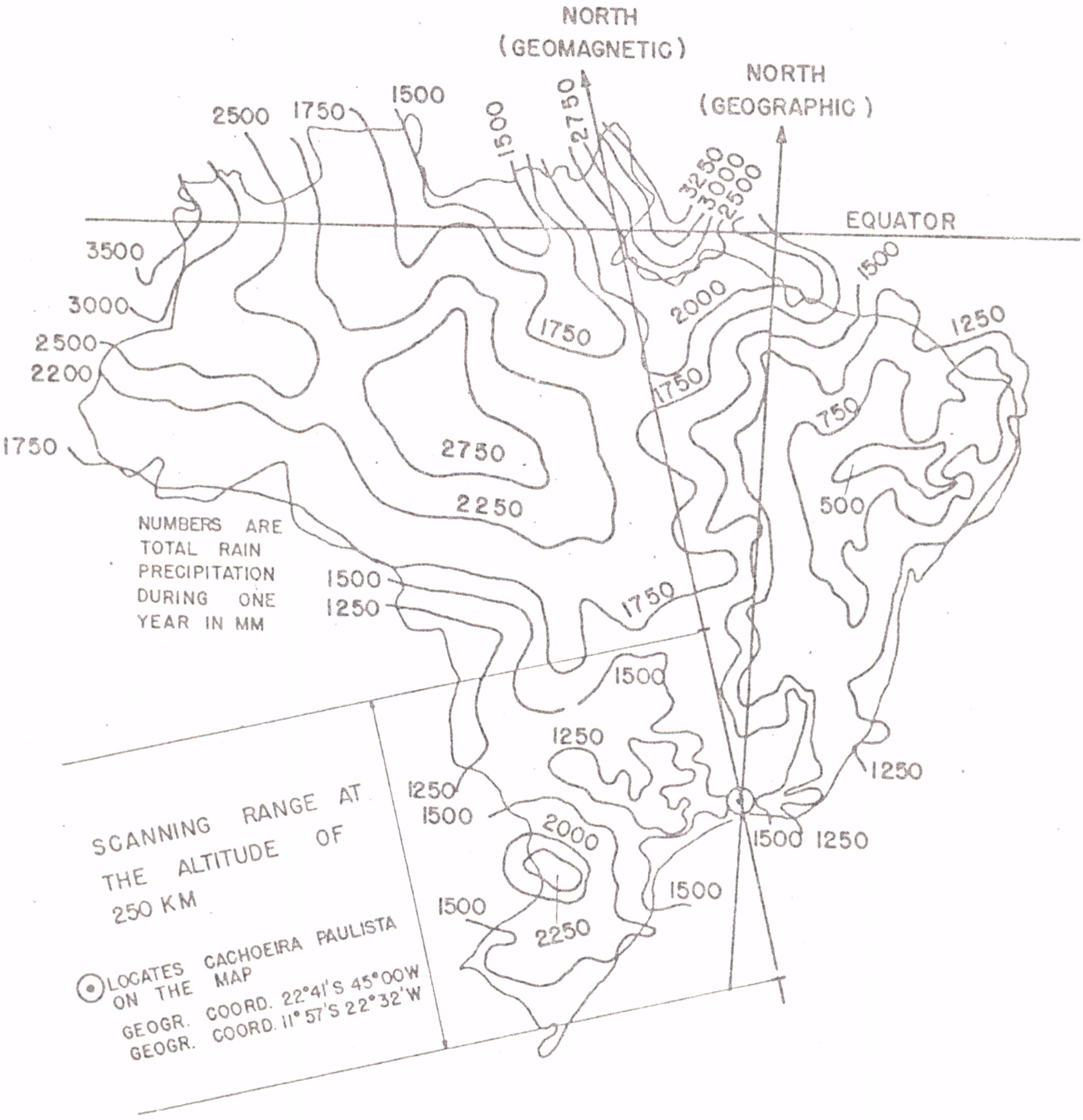

Fig. 1 - Geometry of the geomagnetic meridional scanning range of the photometer measurements. The scanning range shown refers to the altitude of 250 Km and the path length at this altitude is limited by the zenith distances of ± 75°. The curved lines represent the loci of equal rain precipitation, whose magnitude indicated in millimeters, represents the total precipitation during one year. The rainfall data is given by the Atlas Climatológico do Brazil, edited by the Brazilian Ministery of Agricultura, 1969.

Fig. 2 Fig. 3

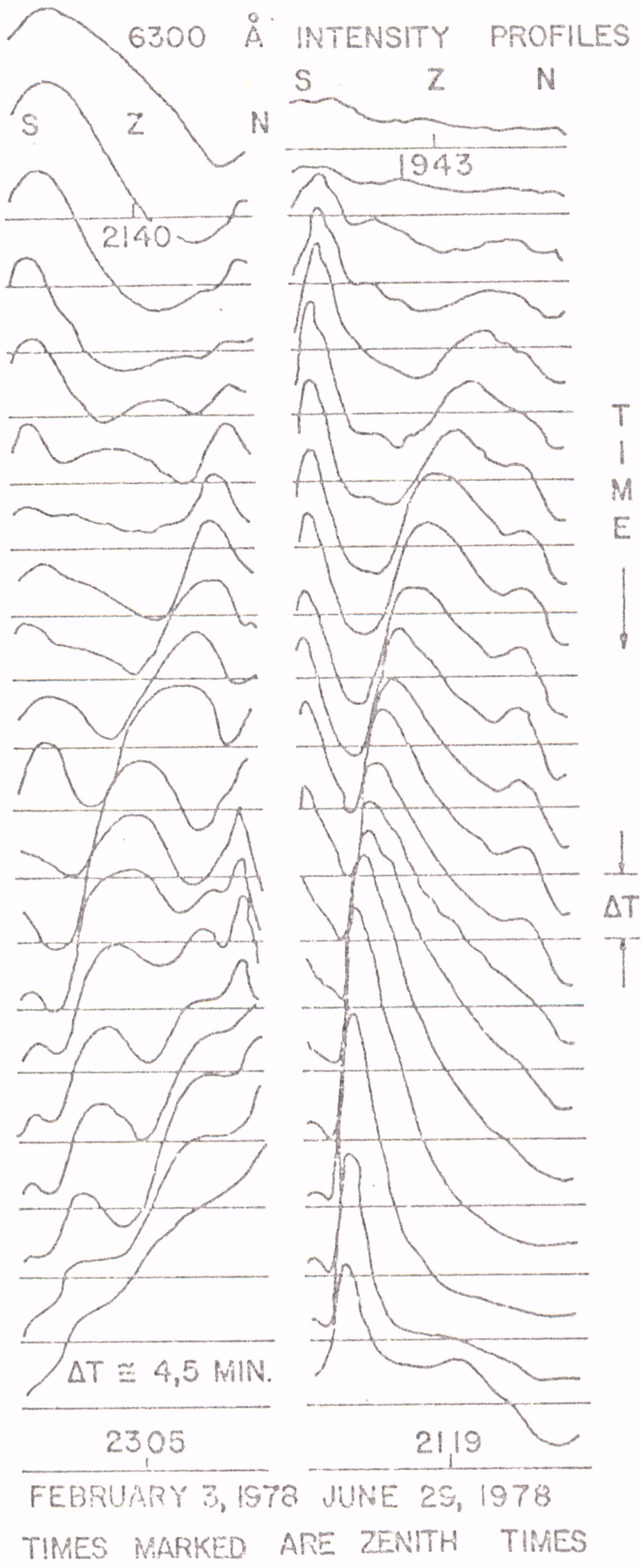

Fig. 2 - Sequences of geomagnetic meridional profiles of the OI 6300 Å nightglow intensity with the typical wavelike structure discussed in the text. Date: February 3, 1978.

Fig. 3 - Same as Figure 2, for the date of June 29, 1978.

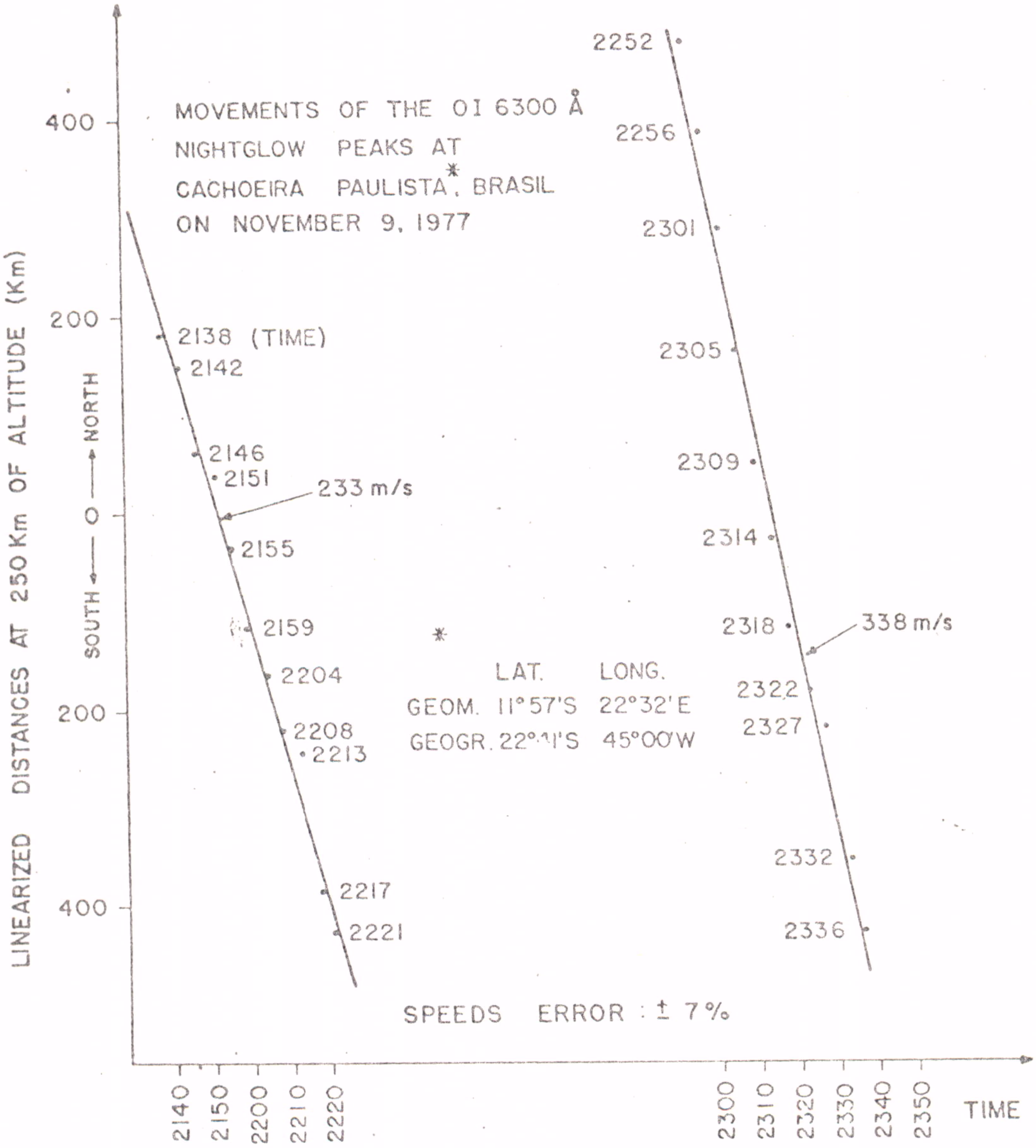

Fig. 4 - Least square fitted straight lines ajusted to the points representing red line crests. The vertical scale represents distances at the altitude of 250 Km. Date: November 9, 1977.

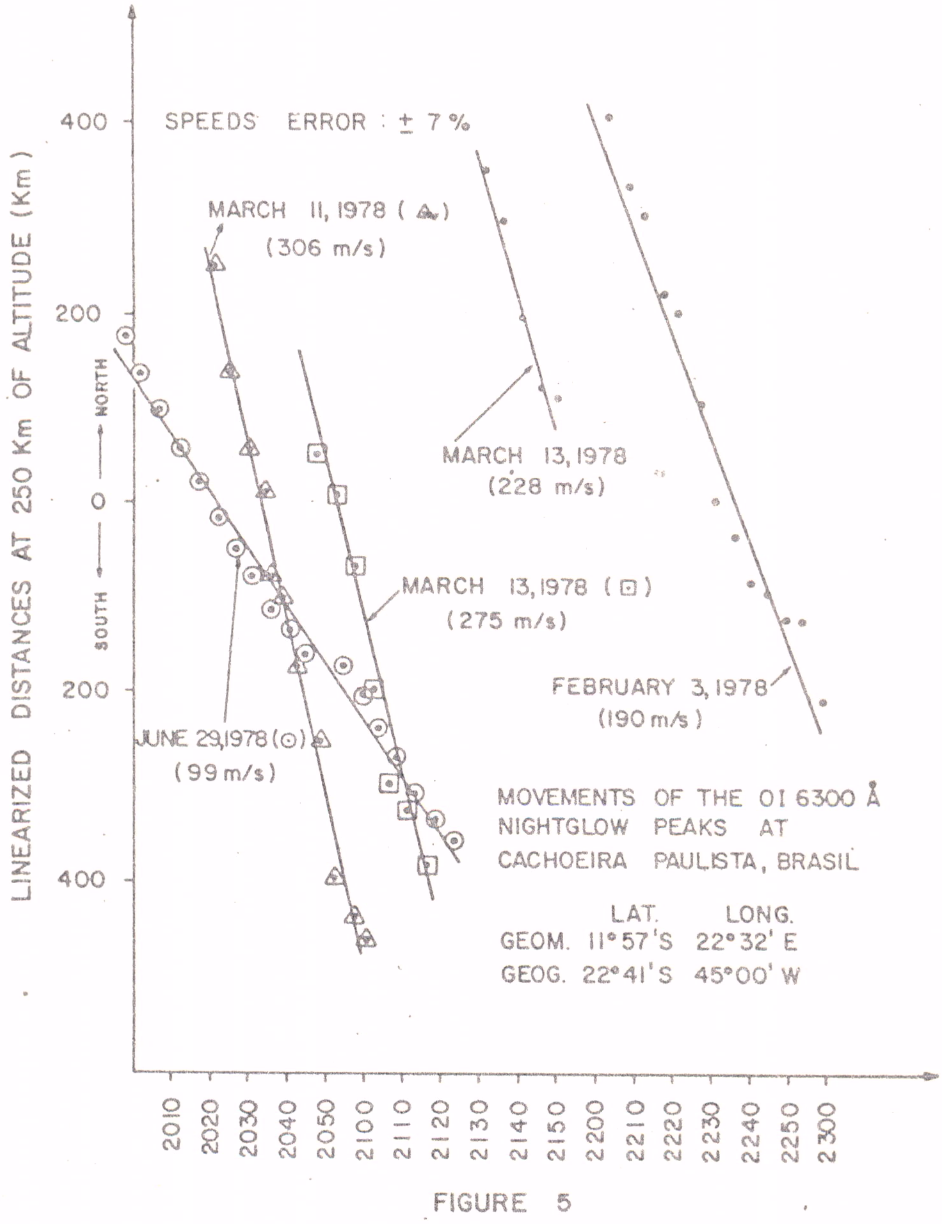

Fig. 5 - Same as Figure 4, for the dates of March 11,13, February 3 and June 29, all in 1978.

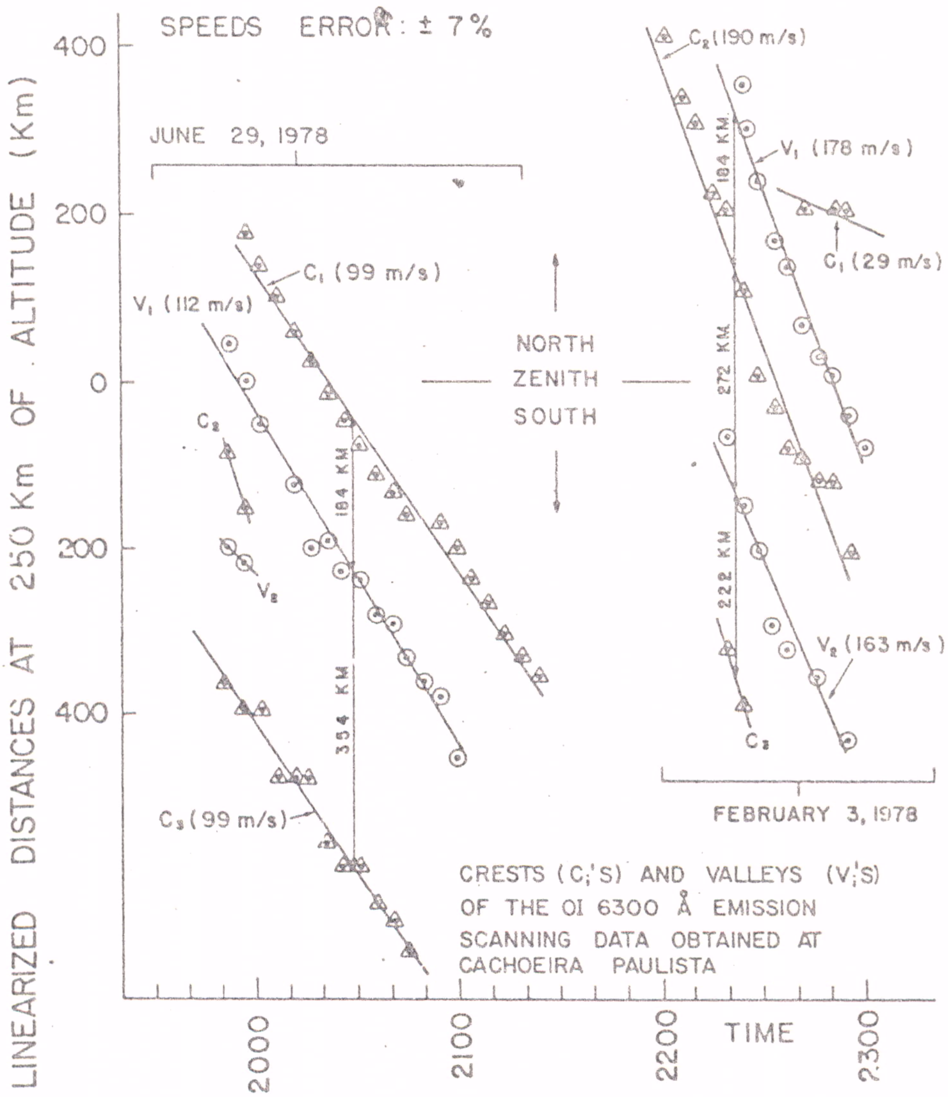

FIGURE 6

Fig. 6 - Straight lines least square fitted to subsequent crests and valleys of the north to south travelling red line wave structure for two days from the set of observations discussed in the text. The vertical scale is as in Figures 4 and 5.

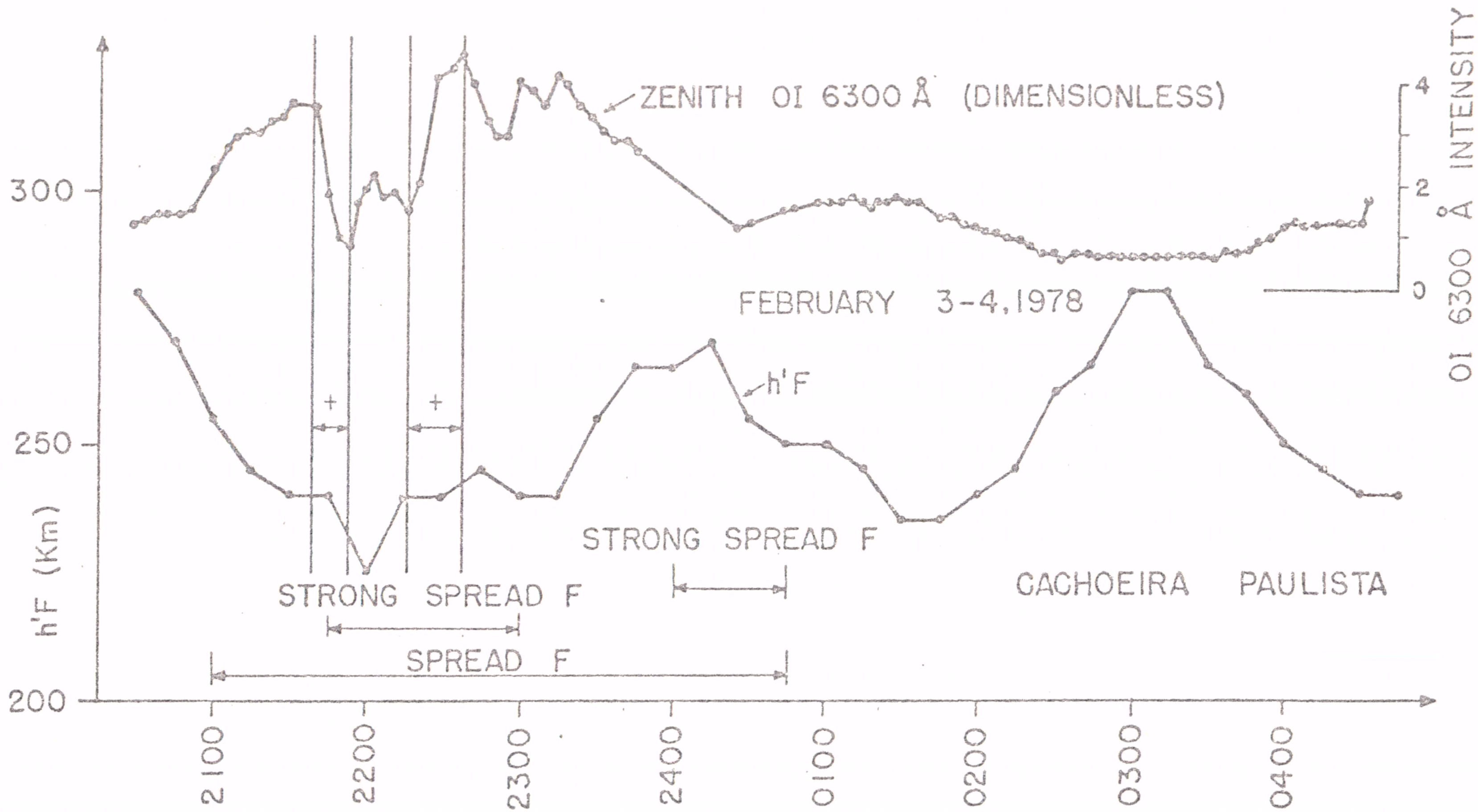

Fig. 7 - Profiles of the zenith OI 6300 Å intensity (shown dimensionless) and h'F versus time. Notice the presence of spread-F during the more intense airglow variations which is the red line signature when the north to south travelling disturbance passes over zenith. The positive sign shown indicates the period of time during which a positive correlation between h'F and the intensity of the red line emission exists. Notice the long duration of such periods. Date of the observation: February 4, 1978.

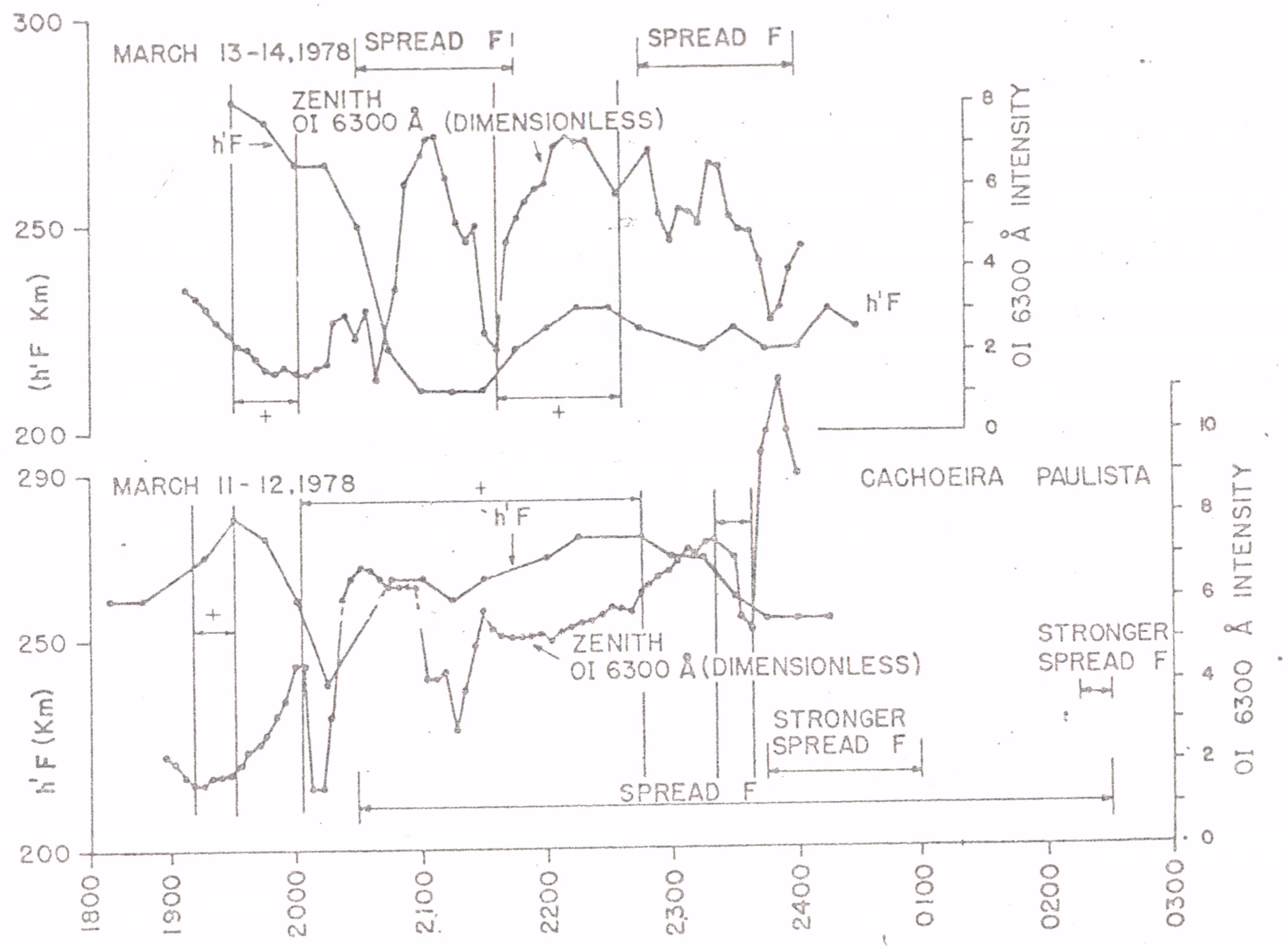

Fig. 8 - Same as Figure 7, for the observations carried out on the following days: March 11-12, 1978 and March 13-14.

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Divino, A.D.	1978	Private communication. Meteorological Department of INPE.