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Estudo da dinâmica da ionosfera por meio da luminescência OI 6300.

17. Observações

AIRGLOW STUDIES OF THE NIGHTTIME DYNAMICS OF THE IONOSPHERE NEAR ARECIBO

by

J.H.A. Sobral[1]*, H.C. Carlson*[2]*, D.T. Farley*[3]

ABSTRACT

Red line (6300 Å) airglow measurements have been made at Arecibo using a scanning photometer in order to determine the direction and velocity of propagation of major airglow enhancements, which incoherent scatter and ionosonde measurements have shown are in turn associated with pronounced descents of the F region. The most common descent occurs around midnight and is known to be due to an abatement in the equatorward meridional wind. The associated airglow enhancement was observed to travel from South to North with an average phase velocity of about 360m/s at 300 Km of altitude. A second type of enhancement, probably due to traveling ionospheric disturbances, was occasionally observed propagating from North to South with a phase velocity of about 246m/s also at 300 Km altitude. Finally, a third was seen which occurred almost simultaneously at all latitudes observed and was probably caused by electric field disturbances.

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FIGURE CAPTIONS

Figure 1 - Progress of the South to North traveling OI 6300 Å enhancement peak 14-15 January 1972.

Figure 2 - Progress of the South to North traveling OI 6300 Å enhancement peak 5-6 June 1972.

Figure 3 - Progress of the South to North traveling OI 6300 Å enhancement peak 22-23 June 1972.

Figure 4 - Progress of the South to North traveling OI 6300 Å enhancement peak 23-24 June 1972.

Figure 5 - Progress of the South to North traveling OI 6300 Å enhancement peak 17-18 August 1972.

Figure 6 - Progress of the South to North OI 6300 Å enhancement peak versus time and longitude (in zenith angles).

Figure 7 - Progress of the OI 6300 Å enhancement peak versus time and latitude (in zenith angle).

Figure 8 - Enhancement Ratio versus Latitude (in zenith angles).

Figure 9 - Progress of the North to South traveling OI 6300 Å peak.

Figure 10- East-west and North-South simultaneous enhancements.

Figure 11- East-west OI 6300 Å enhancement profiles showing simultaneous enhancements.

INTRODUCTION

The ionosphere near Arecibo exhibits a variety of dynamical effects. One of the most pronounced of these is the so-called "midnight collapse" of the F region which occurs very frequently at Arecibo between about midnight and 3 a.m.. Depressions in the height of the F layer are typically of the order of 50-150 Km. Nelson and Cogger (1971) first investigated the propagation of this collapse phenomenon using ionosonde data from several rather widely spaced stations, and their measurements suggested that the collapse propagated away from the equator. These results were not completely conclusive, however, due to a relative lack of data in their statistics. One object of the present study was to determine accurately the direction and speed of propagation of this disturbance from airglow measurements at relatively closely spaced locations in the ionosphere.

Measurements were made using a 6300 Å filter photometer system (tilting filter type with a band pass of 5.5 Å) which scanned in zenith angle from 68.5^{o}N to 63^{o}S in ten discrete steps, with each full sweep requiring 5.5 minutes. Assuming the airglow to be from a nominal altitude of about 300 Km, N-S scans covered a latitude range of about 1222 Km from 24.8^{o}N to 13.3^{o}N. A total of four similar scans were made in the E-W direction, but most of the interesting results were found in the 13 N-S runs. Concurrent ionosonde and incoherent scatter measurements indicated that the large airglow enhancements were always associated with pronounced descents of the F region.

Our results confirmed those of Nelson and Cogger (1971) in that the most common disturbance, the midnight collapse, was observed always to propagate from South to North. Other disturbances, however, were observed to travel from North to South or to occur nearly simultaneously at all latitudes scanned. These latter two phenomena can probably be attributed to traveling ionospheric disturbances (TID's) originating in polar regions and to electric field effects, respectively. The midnight collapse is now known to be due to a temporary abatement or even reversal in the nighttime equatorward meridional wind (Behnke and Harper 1973), but it is not clear why this alteration in the wind system occurs first near the equator and then propagates to higher latitudes. All the data to be discussed here correspond to relatively quiet magnetic conditions.

Some workers have previously shown the possibility of studying the behavior of the nighttime F region by means of ground measurements of the 6300 Å airglow. VanZandt and Peterson (1968) found that electric fields would cause very large 6300 Å airglow enhancements which helped to determine altitude variations of the ionosphere caused by electric field changes. Nelson and Cogger (1971) studied the dynamical behavior of the ionosphere over Arecibo by means of incoherent scatter experiments and compared the results with 6300 Å airglow measurements.

OBSERVATIONS

SOUTH-TO-NORTH TRAVELING ENHANCEMENTS

The data from five nights of observations are shown in Figures 1-5 and are similar to the data from other nights. Each curve is proportional to the 6300 Å airglow intensity in Rayleighs at a particular zenith angle. The ten zenith angles used in the N-S scans were 68.5^{o}N, 63^{o}N, 53^{o}N, 45^{o}N, 25^{o}N, 0^{o}, 25^{o}S, 45^{o}S, 53^{o}S and 63^{o}S. The south-to-north propagation of the enhancement can be readily seen in Figures 1, 2, 3, 4 and 5. In Figure 3 there are two enhancements which are well separated at the most northern latitudes but are superimposed to the south of Arecibo. One disturbance is propagating from south to north while the other appears more or less simultaneously on all the curves.

The phase velocity of the disturbance in the S-N direction has been evaluated by simply measuring the velocity of the enhancement peaks. Figure 6 shows the progress of the maximum in the meridional plane for five days corresponding to Figures 1 to 5. The distance scale in Figure 6 is calculated for an altitude of 300 Km as indicated. The straight lines in the figure were least square fitted to the data to give the velocity. A set of ten such measurements, including those shown here, gave an average south-to-north phase velocity (at 300 Km of altitude) of 360 m/s, with a maximum value of about 489 m/s and a minimum of 290 m/s.

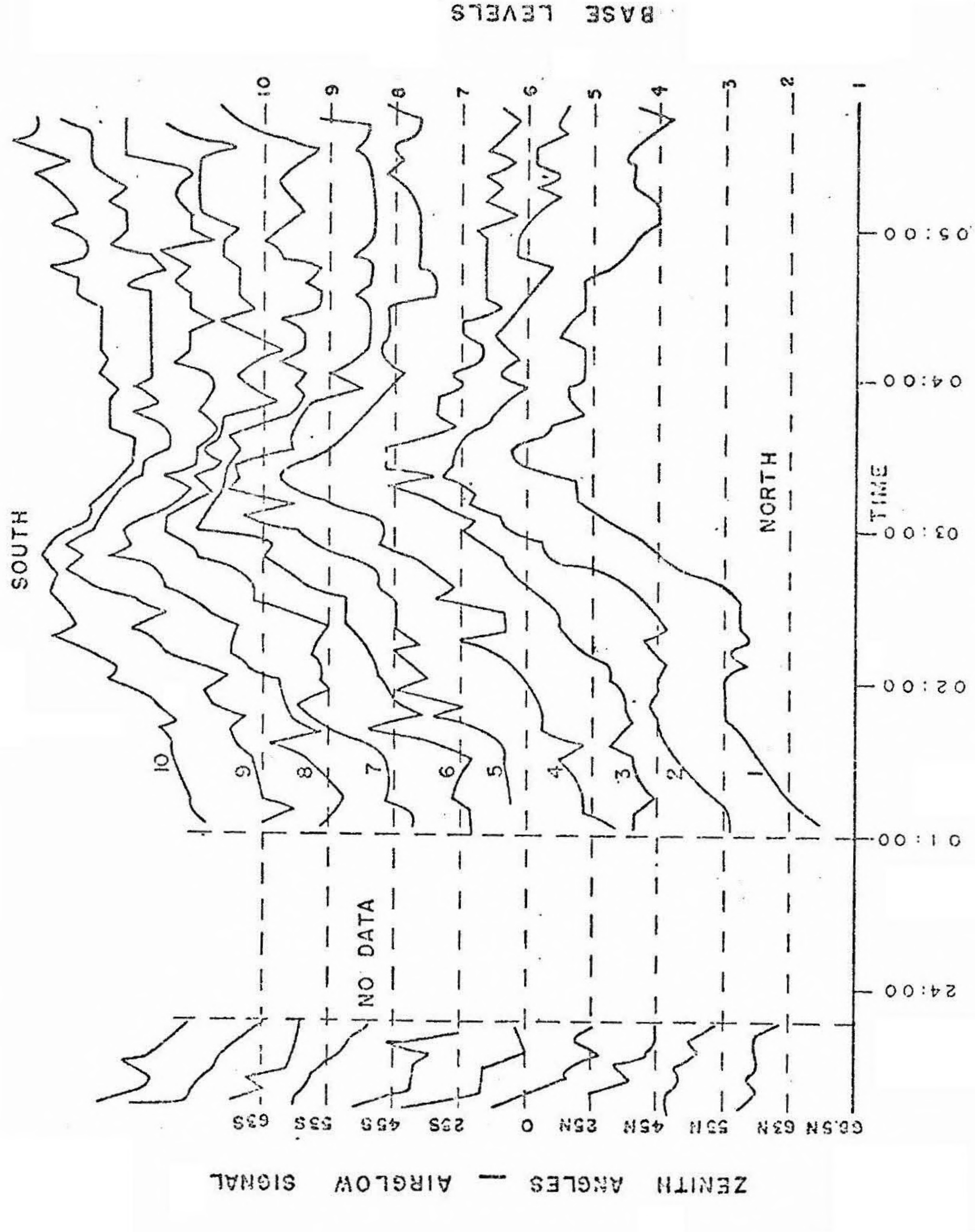

14-15 JAN 1972
ZENITH ANGLES — AIRGLOW SIGNAL
BASE LEVELS
SOUTH
NORTH
NO DATA
TIME
24:00
01:00
02:00
03:00
04:00
05:00
63S
55S
45S
25S
0
25N
45N
55N
63N
69.5N

FIGURE 1

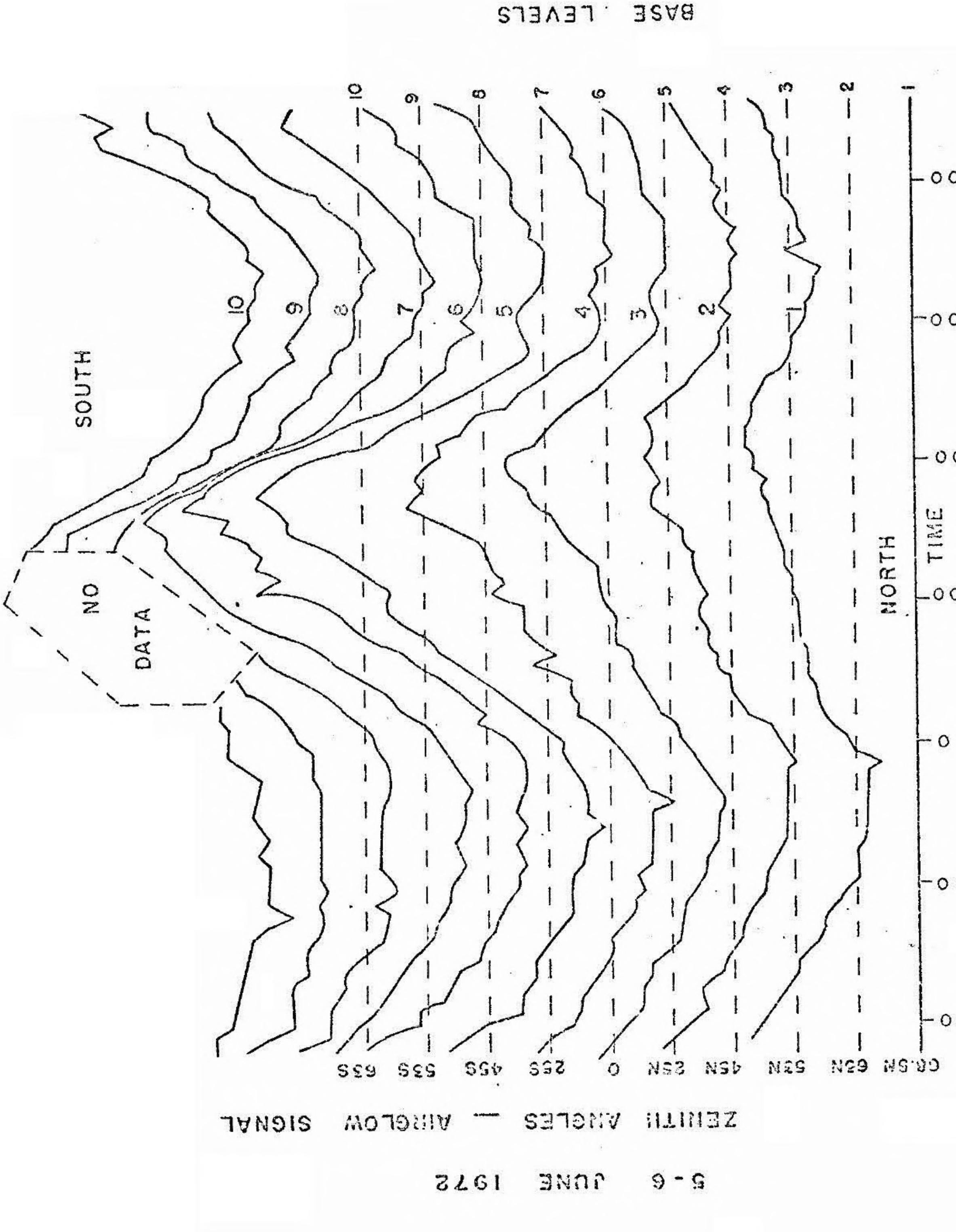

5-6 JUNE 1972
ZENITH ANGLES — AIRGLOW SIGNAL
BASE LEVELS
SOUTH
NORTH
NO DATA
TIME
22:00
23:00
24:00
01:00
02:00
03:00
04:00
63S
53S
45S
25S
0
25N
45N
53N
63N
69.5N

FIGURE 2

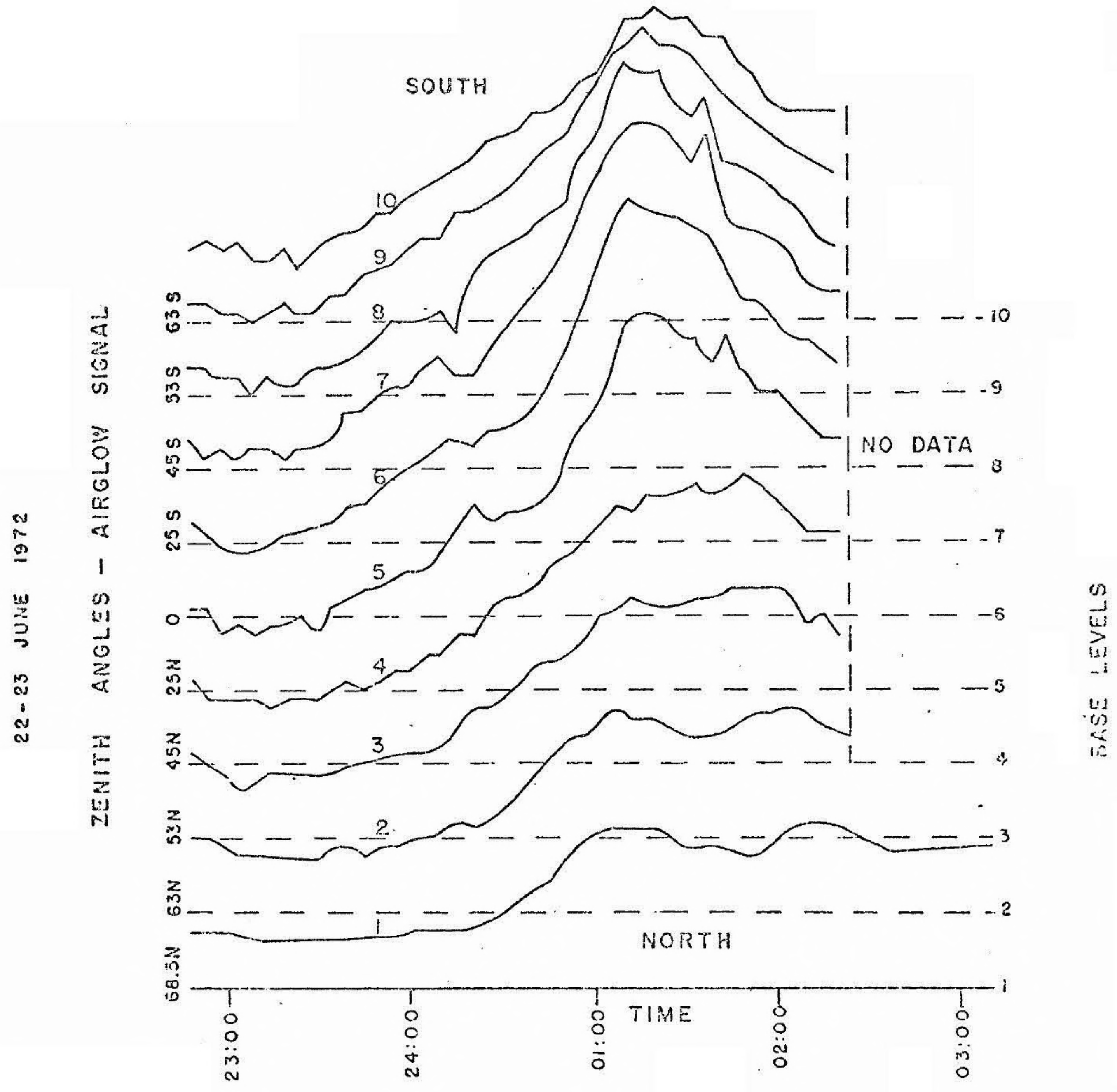

22-23 JUNE 1972
ZENITH ANGLES - AIRGLOW SIGNAL
SOUTH
NORTH
NO DATA
BASE LEVELS
TIME
63 S
53 S
45 S
25 S
0
25N
45N
53N
63N
68.3N
23:00
24:00
01:00
02:00
03:00

FIGURE 3

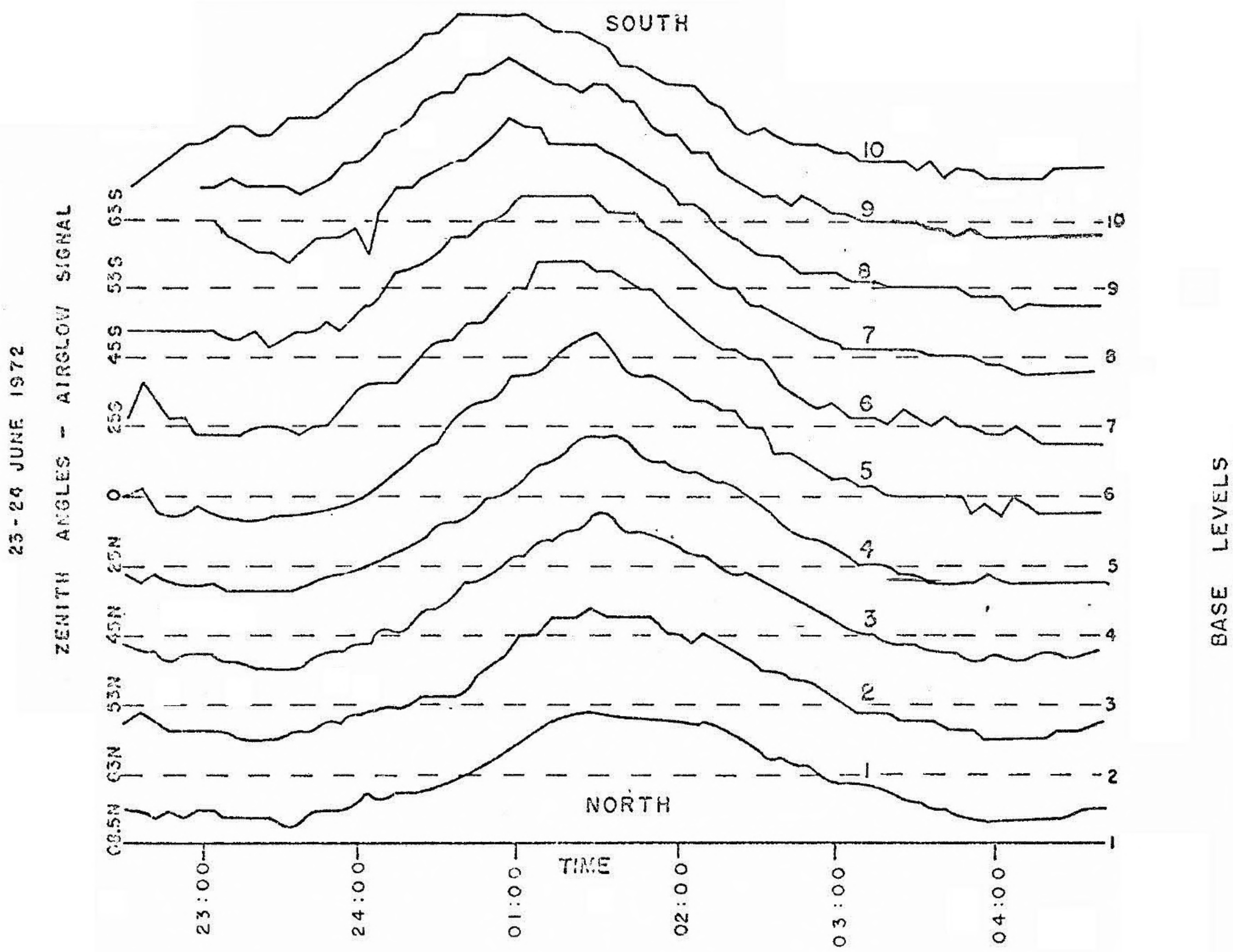

23 - 24 JUNE 1972
ZENITH ANGLES - AIRGLOW SIGNAL
SOUTH
NORTH
BASE LEVELS
TIME
23:00
24:00
01:00
02:00
03:00
04:00
63S
53S
45S
25S
0
25N
45N
53N
63N
68.5N
1
2
3
4
5
6
7
8
9
10

FIGURE 4

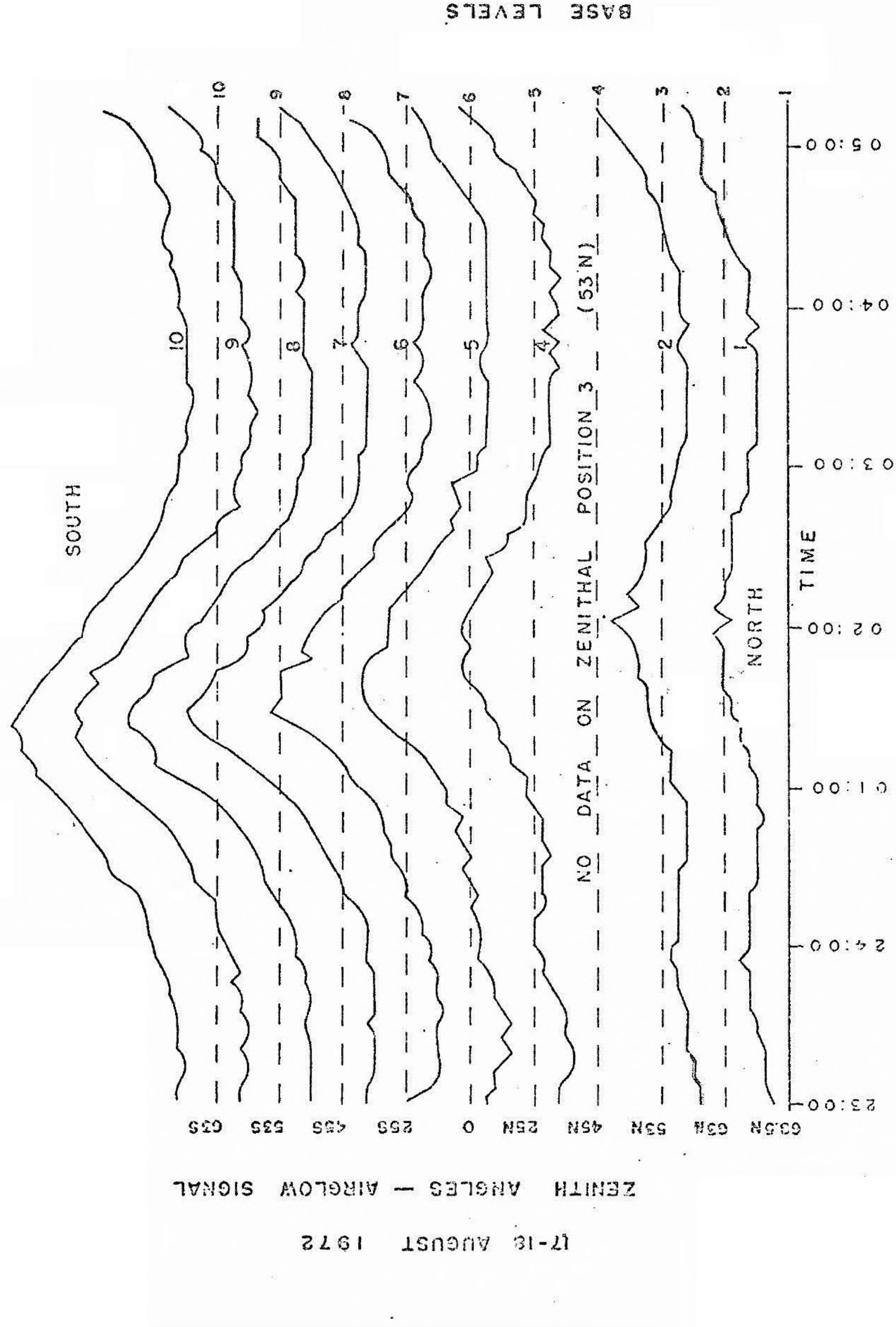
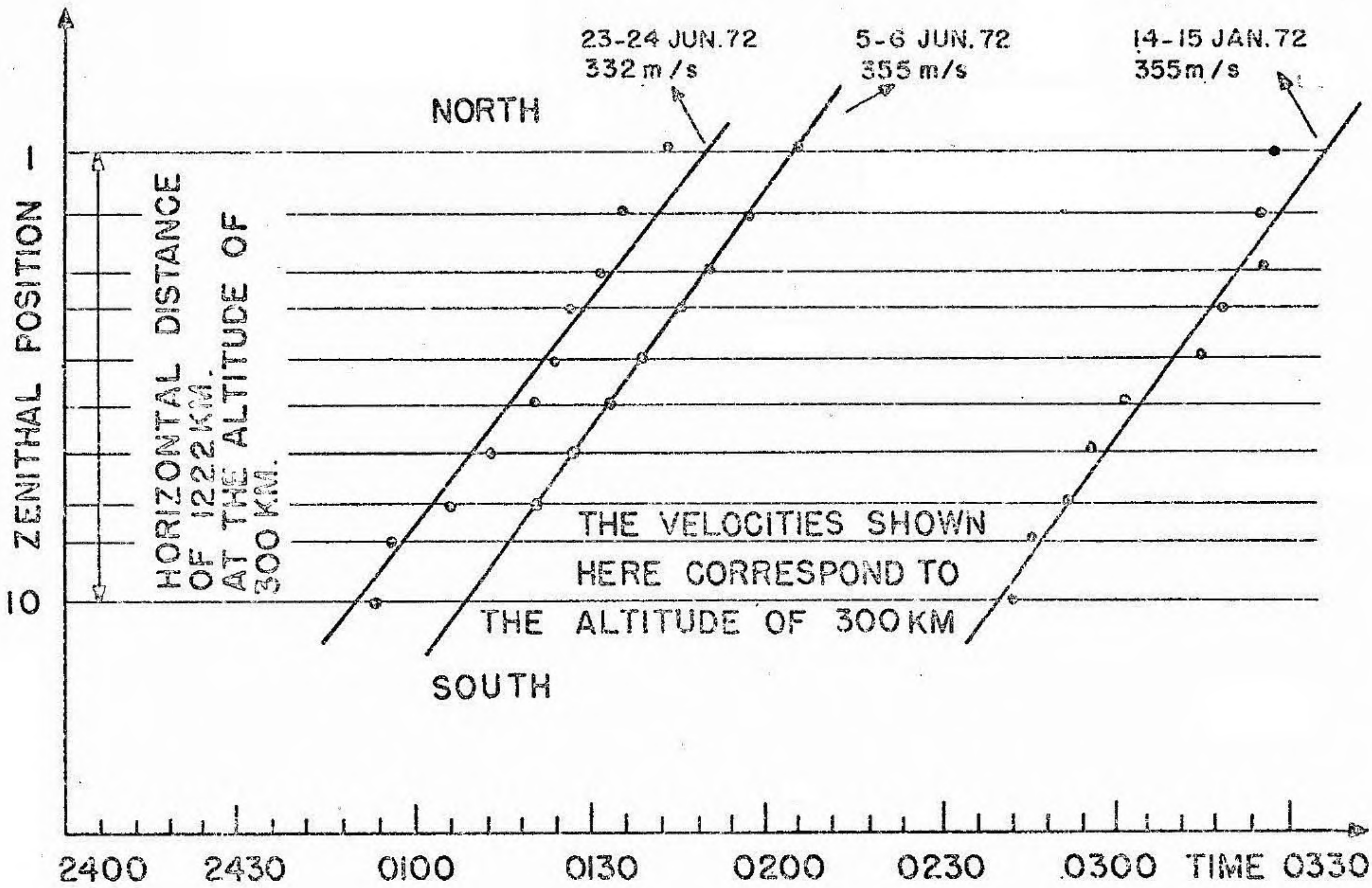

BASE LEVELS
SOUTH
NORTH
NO DATA ON ZENITHAL POSITION 3 (53°N)
TIME
05:00
04:00
03:00
02:00
01:00
24:00
23:00
63S
53S
45S
25S
0
25N
45N
53N
63N
63.5N
ZENITH ANGLES — AIRGLOW SIGNAL
17-18 AUGUST 1972

FIGURE 5


23-24 JUN.72
332 m/s
5-6 JUN.72
355 m/s
14-15 JAN.72
355m/s
NORTH
SOUTH
ZENITHAL POSITION
1
10
HORIZONTAL DISTANCE OF 1222KM. AT THE ALTITUDE OF 300 KM.
THE VELOCITIES SHOWN HERE CORRESPOND TO THE ALTITUDE OF 300KM
2400
2430
0100
0130
0200
0230
0300
TIME 0330

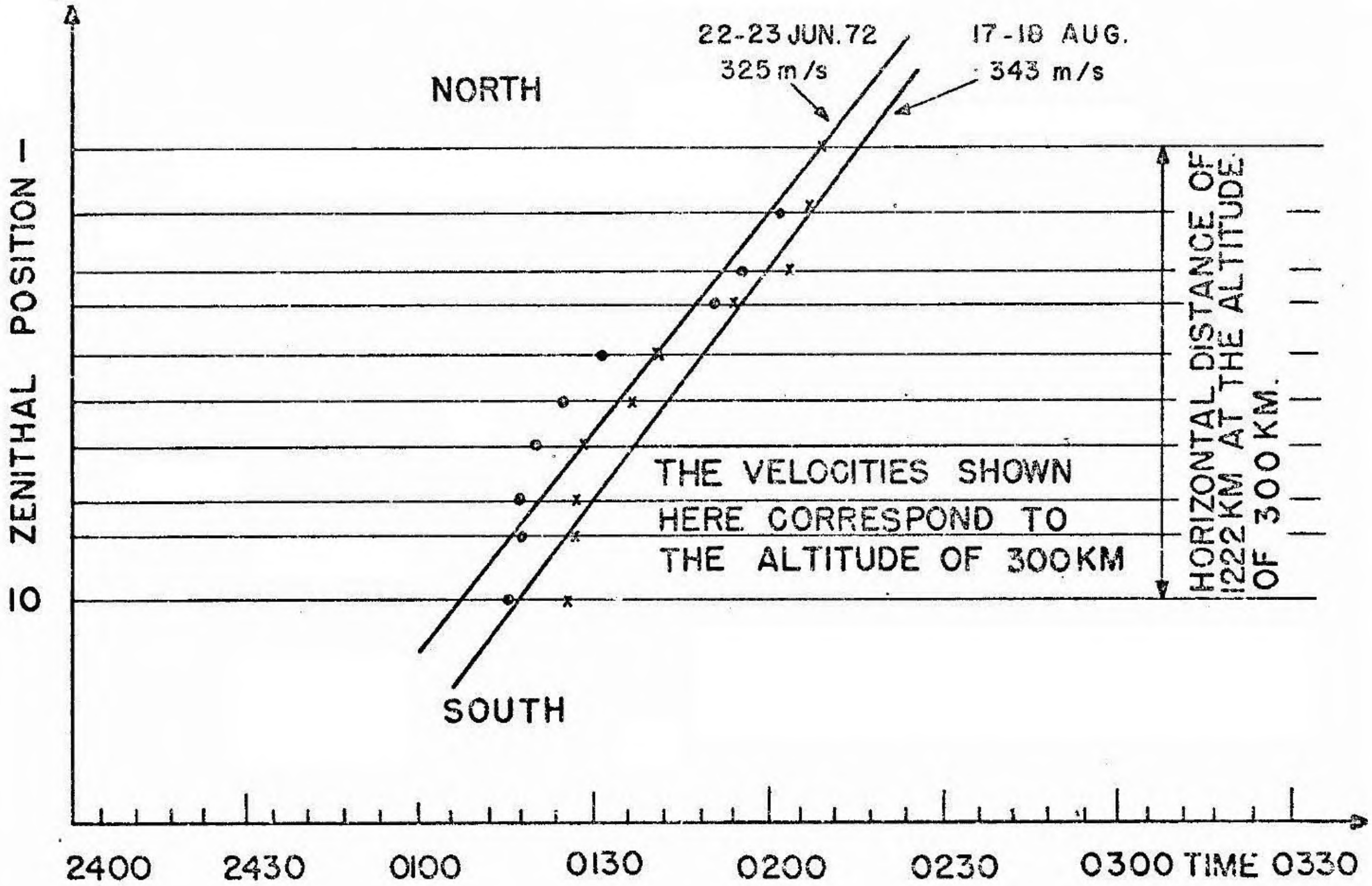

22-23 JUN.72
325 m/s
17-18 AUG.
343 m/s
NORTH
SOUTH
ZENITHAL POSITION
1
10
THE VELOCITIES SHOWN HERE CORRESPOND TO THE ALTITUDE OF 300KM
HORIZONTAL DISTANCE OF 1222KM AT THE ALTITUDE OF 300KM.
2400
2430
0100
0130
0200
0230
0300
TIME 0330

FIGURE 6

If we consider the altitude of 250 Km these values reduce to 337 m/s, 457 and 243 m/s respectively. In general the phase velocity tended to be faster at the south as clearly seen in the bottom of Figure 6. The enhancement appeared to occur earlier during summer than during winter by about two hours (see Figure 6).

Figure 7 shows the time of occurrence of maximum enhancement for nights during which the scanning was in the east-west direction from 68.5^{o}W to 63^{o}E using the same angles as in the N-S scans. For these four nights at least, there appears to be no significant variation in the E-W direction; (as will be remarked later the east-west scan of Figure 7 seems to correspond to the south to north traveling enhancements) the occurrence is essentially simultaneous to within the accuracy of the measurement.

Since the midnight collapse propagates away from equatorial latitudes we might expect the effects, including the airglow enhancements, to be stronger to the south of Arecibo than to the north. Nelson and Cogger's (1971) results using ionograms in fact show that the frequency of occurrence of the midnight collapse decreases with increasing geomagnetic latitude. Such behavior was often but not always observed in our data. Figure 8 shows a plot of the enhancement ratio during the midnight collapse as a function of position for five different nights. The enhancement ratio is defined as the maximum airglow intensity during the collapse divided by the intensity before the collapse. Such a ratio helps to remove uncertainties due to geometrical factors, i.e., the Van Rhijn correction (Smith et al.,

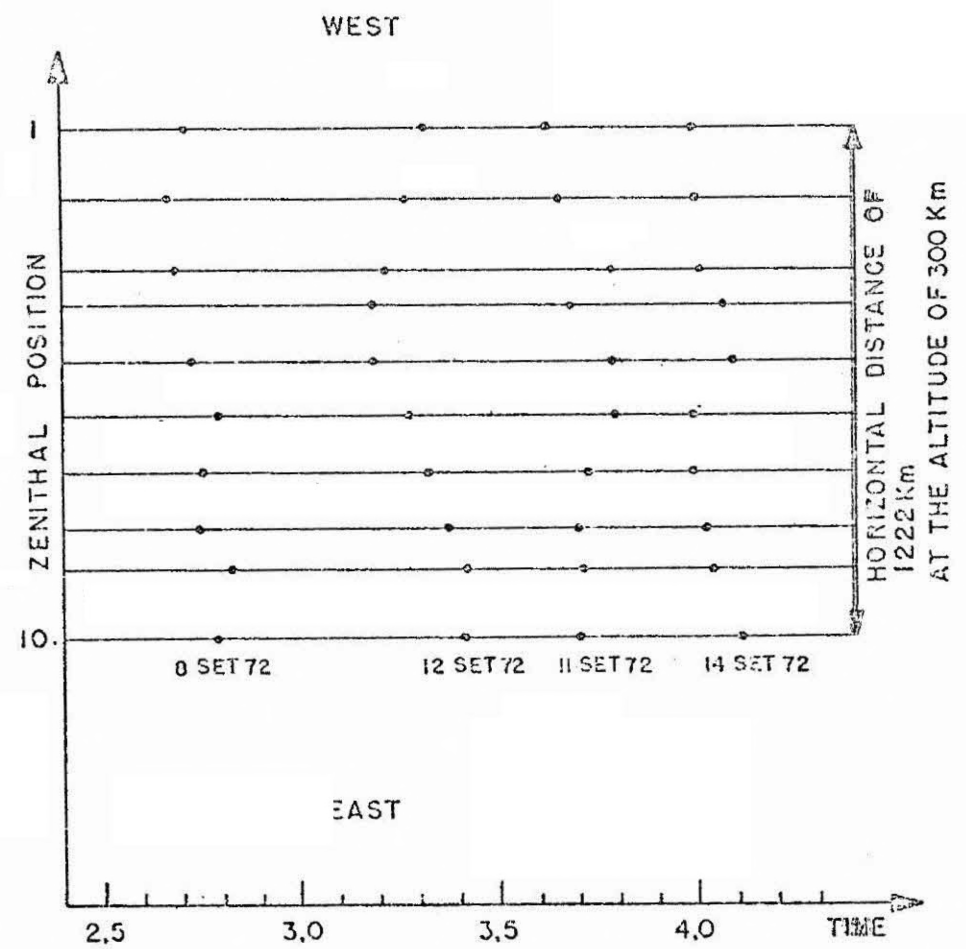

WEST
1
ZENITHAL POSITION
HORIZONTAL DISTANCE OF
1222 Km
AT THE ALTITUDE OF 300 Km
10.
8 SET 72
12 SET 72
11 SET 72
14 SET 72
EAST
2,5
3,0
3,5
4,0
TIME

FIGURE 7

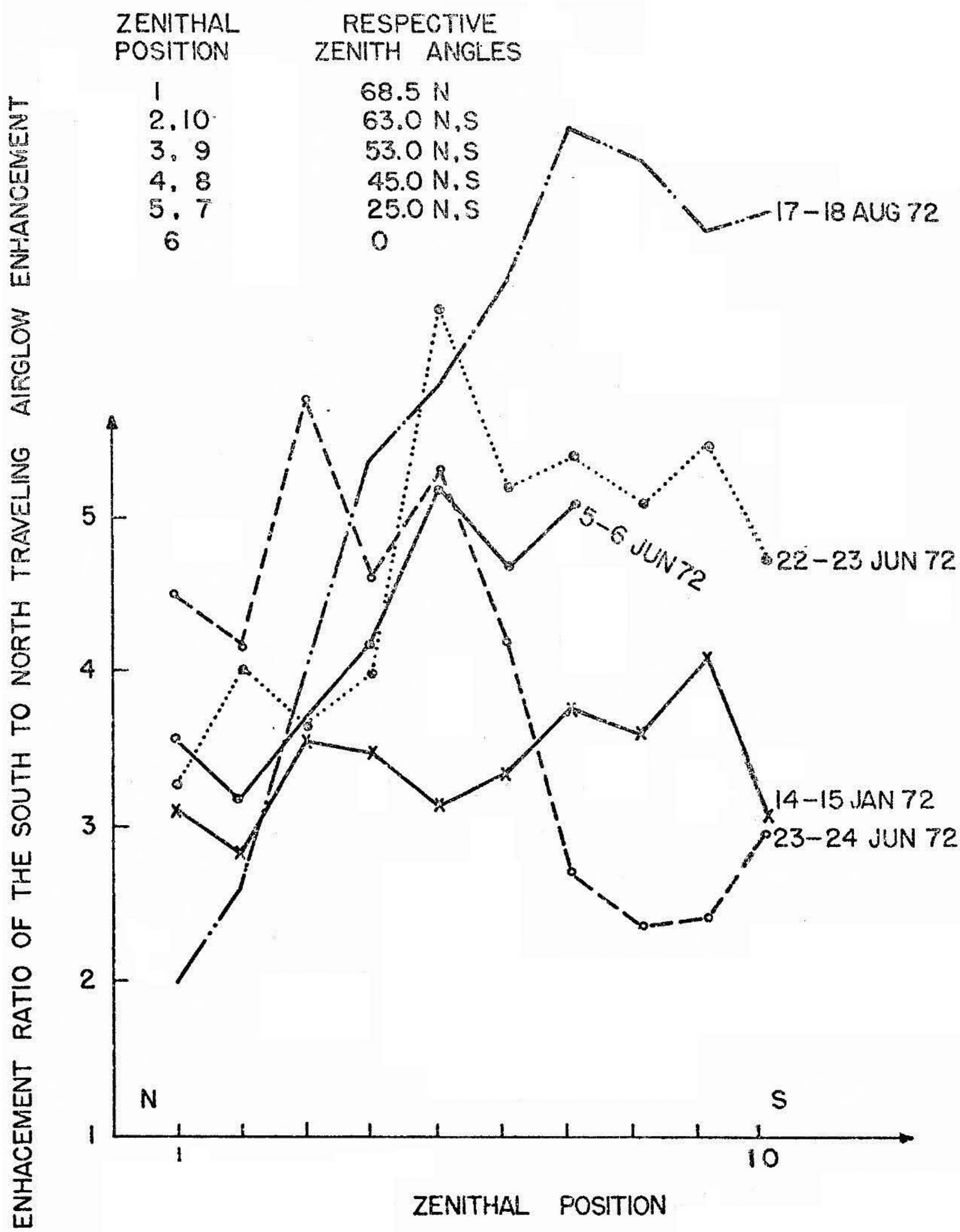

ZENITHAL POSITION
RESPECTIVE ZENITH ANGLES
1 68.5 N
2, 10 63.0 N, S
3, 9 53.0 N, S
4, 8 45.0 N, S
5, 7 25.0 N, S
6 0
ENHACEMENT RATIO OF THE SOUTH TO NORTH TRAVELING AIRGLOW ENHANCEMENT
17-18 AUG 72
5-6 JUN 72
22-23 JUN 72
14-15 JAN 72
23-24 JUN 72
N
S
1
2
3
4
5
1
10
ZENITHAL POSITION

FIGURE 8

1965). Three of the nights plotted show the expected strong monotonic decrease from south to north in the intensity of the airglow. The other two nights, however, do not, and thus the data are not conclusive. The intensity of the airglow enhancement obviously will depend upon factors other than the strength of the disturbance in the neutral wind pattern, however, and so perhaps these results should not be too disturbing.

NORTH-TO-SOUTH TRAVELING ENHANCEMENTS

Only two examples of disturbances traveling towards the south were seen, and these are shown in Figure 9. In both cases the enhancements were observed before midnight. There were no observations after midnight on March 3, 1972, because of bad weather conditions. In fact, because of the generally bad weather conditions at Arecibo in the premidnight period, we were able to observe only six times in this interval. Figure 9 also shows the behavior of related ionospheric parameters at Arecibo (zenith angle number 6) during the period of observation. Note that in the data of 12-13 July the traces at positions 8, 9 and 10 do not show the expected decrease after midnight. The regular enhancement due to the midnight collapse began in the southernmost positions before the enhancement due to the north to south traveling disturbances had declined appreciably. This effect can be clearly seen in the original data, which is only partially reproduced in Figure 9.

The velocities of these two north-to-south disturbances were obtained by following the motion of the maximum enhancement, as

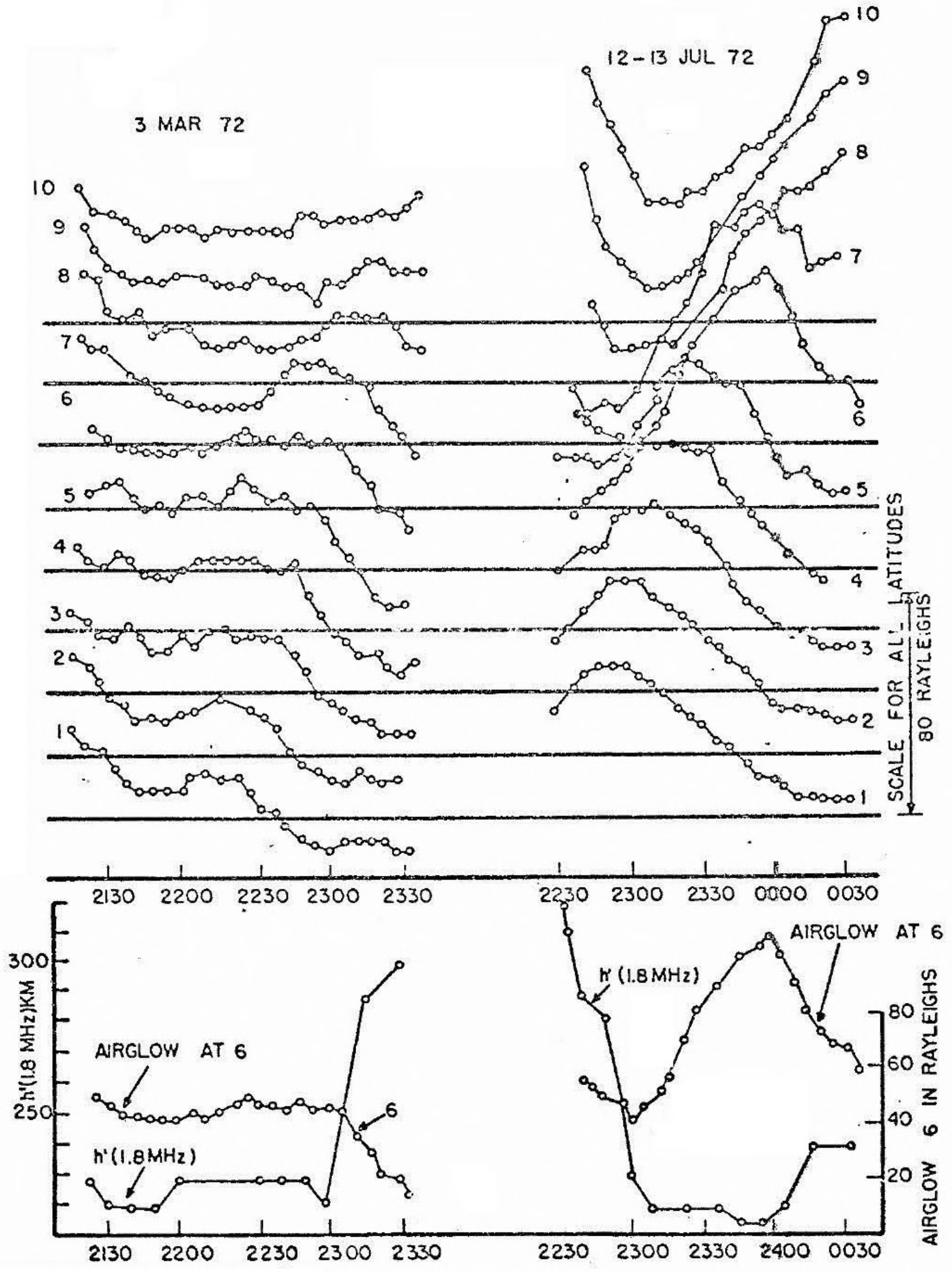

3 MAR 72
12-13 JUL 72
SCALE FOR ALL LATITUDES
80 RAYLEIGHS
2130 2200 2230 2300 2330
2230 2300 2330 0000 0030
h'(1.8 MHz)KM
300
250
AIRGLOW AT 6
h'(1.8MHz)
AIRGLOW 6 IN RAYLEIGHS
80
60
40
20
2130 2200 2230 2300 2330
2230 2300 2330 2400 0030

FIGURE 9

described previously. The results were 199 m/s for July 12 and 226 m/s for March 3, both results regarding the altitude of 300 kilometers.

SIMULTANEOUS ENHANCEMENTS

About two enhancements were observed occurring nearly simultaneously at most latitudes during the premidnight in the N-S scanning equipments (Figure 10a and b). The data of February 3 are not as clear as those of the preceding night, but there is a definite effect in the northern positions. Another example, which occurred after midnight, has already been mentioned in connection with Figure 3. Again the effect is most obvious in the northern positions: in the south it is mixed with the midnight collapse enhancement.

All the enhancements observed in which the scanning was made in the E-W direction occurred more or less simultaneously at all longitudes. Examples are shown in Figures 10 (c and d) and 11 (a and b). Unfortunately it was not possible to scan in both the N-S and E-W directions on the same night. The system was easily capable of detecting motions with velocities as large as the F region acoustic velocity ($\sim 10^3$ m/s), which would require over 20 minutes for an enhancement to travel through the scanning range. Thus the "simultaneous" disturbances had considerably larger phase velocities.

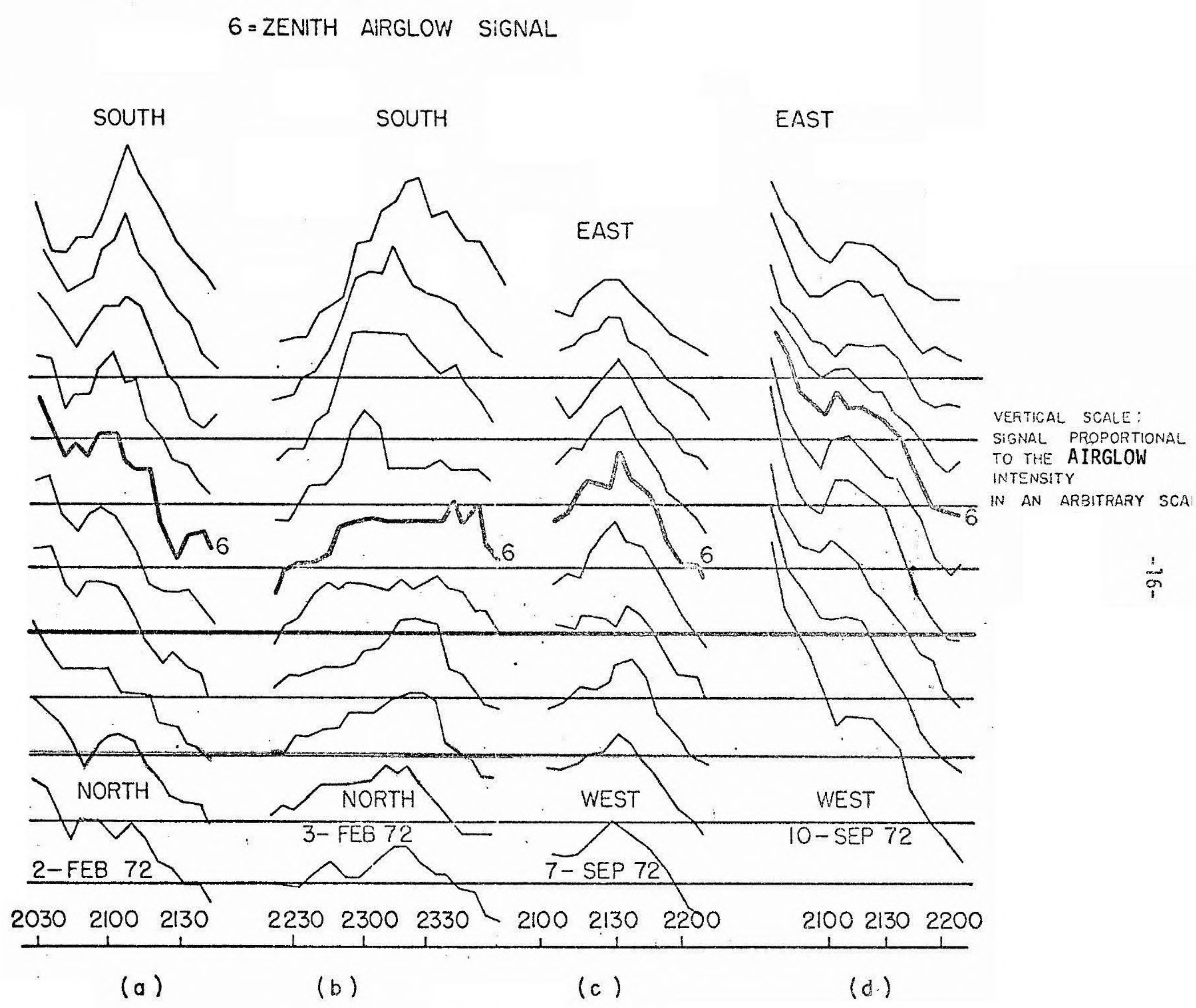

6 = ZENITH AIRGLOW SIGNAL
SOUTH
SOUTH
EAST
EAST
VERTICAL SCALE: SIGNAL PROPORTIONAL TO THE AIRGLOW INTENSITY IN AN ARBITRARY SCA
6
6
6
6
NORTH
NORTH
WEST
WEST
2-FEB 72
3- FEB 72
7- SEP 72
10-SEP 72
2030 2100 2130
2230 2300 2330
2100 2130 2200
2100 2130 2200
(a)
(b)
(c)
(d)

FIGURE 10

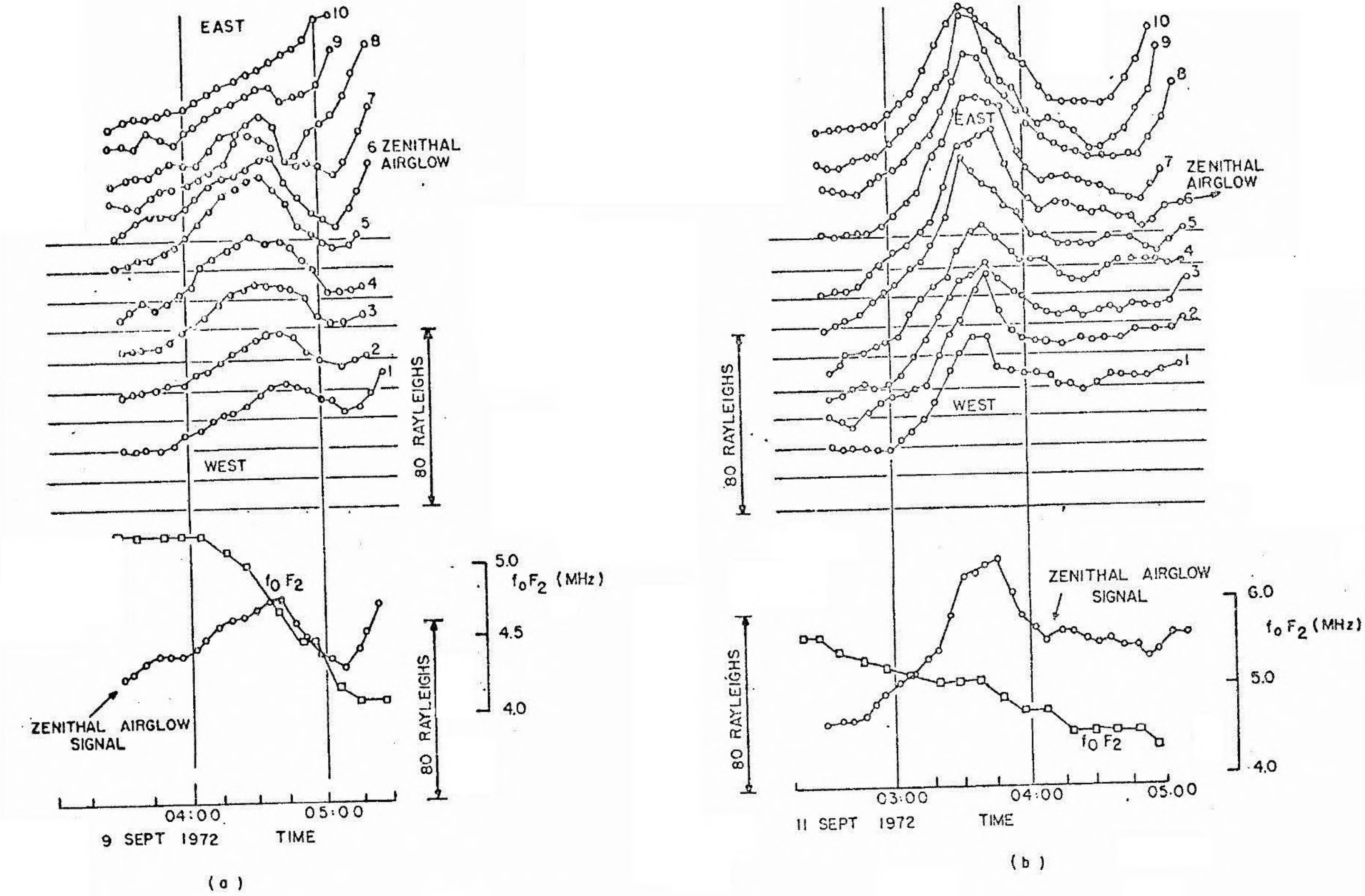

EAST
10
9
8
7
6 ZENITHAL AIRGLOW
5
4
3
2
1
WEST
80 RAYLEIGHS
$f_0 F_2$
5.0
$f_o F_2$ (MHz)
4.5
4.0
ZENITHAL AIRGLOW SIGNAL
04:00
05:00
9 SEPT 1972
TIME
(a)
EAST
WEST
ZENITHAL AIRGLOW
ZENITHAL AIRGLOW SIGNAL
6.0
$f_o F_2$ (MHz)
5.0
4.0
03:00
04:00
05:00
11 SEPT 1972
TIME
(b)

FIGURE 11

DISCUSSION

The south-to-north traveling disturbances were in all cases related to the midnight collapse discussed by Nelson and Cogger (1971). Roughly scaling the data from their Figure 15 gives an average velocity of the disturbance from magnetic equator to ± 30^{0} geomagnetic latitude of the order of 300 m/s, based on the average time of occurrence of the collapse at a few locations. Considering the very crude nature of this estimate, it compares reasonably well with our result of 360 m/s (regarding the altitude of 300 Km) for the average phase velocity.

Two possible explanations for the midnight collapse were suggested by Nelson and Cogger: 1) the descent is due to a reversal in the electric field, or 2) is due to neutral air motions associated with gravity waves generated at the magnetic equator by the rapid descent of the F region due to the electric field reversal (Chimonas, 1970). Since measurements by Behnke and Harper (1973) have shown that the collapse is due mainly to motions of the neutral atmosphere, the second explanation seems more promising than the first.

Because of the south-to-north traveling direction of the velocity of our 6300 Å enhancements it would be interesting to compare the behavior of the 6300 Å airglow at Arecibo with that at some lower latitude. Let us take the measurements of Casaverde and Giesecke (1963) at Huancayo (geographic coordinates of $12^{o}03'S$ and $75^{o}20'W$ and geomagnetic latitude of $-.6^{o}$). Huancayo is very close to the Arecibo (geographic coordinates of $18^{o}30'N$ and $76^{o}08'W$) meridian and almost at the geomagnetic equator which makes Huancayo location unique with respect to Arecibo to study the meridional propagation of neutral atmosphere waves generated at the magnetic equator. Casaverde and Giesecke's (1963) extensive measurements of the OI 6300Å line during five years resulted in two hundred and seventy-eight useful experiments which have clearly shown the occurrence of a maximum between 2200 and 0200. From the point of view of time of occurrence their observations are fairly consistent with ours if we consider our average phase velocity of 360 m/s and the distance between Arecibo and Huancayo of approximately 3500 Km at the altitude of 300 Km. Considering these data the disturbance would take two hours and fourty minutes to travel from Huancayo to Arecibo. This implies that we would observe our maximum in the interval of 0040 to 0440. In fact we have observed our maximum to occur within approximately the next three hours after midnight (but never as late as 0440). As an example of the variability of the time of occurrence of our maximum, Figure 1 shows a maximum around 0300 at zenith while Figure 3 shows it around 0100. Although the 6300Å enhancements at the equator and at Arecibo are not directly caused by identical mechanisms, both of them might result from a same source phenomenon located at the magnetic equator.

According to earlier 6300 Å airglow experiments performed at Huancayo (Silverman and Casaverde, 1961) the strong enhancement occurring between 2200 and 0200 were observed in 38 out of 44 experiments which is a frequency of occurrence (86%) very close to ours (88%). Unfortunately such frequency of occurrence is not mentioned in Casaverde and Giesecke's (1963) paper since they considered the results of a much larger number of experiments (278). There is another agreement between Silverman and Casaverde (1961) results and ours: the time distribution of the enhancements. Of their 38 called middle-of-the-night enhancements, 20 showed a maximum at midnight, 13 before midnight and 5 in the post-midnight period. If we consider these enhancements traveling northwards at the speed of 360 m/s their time of observations distribution at Arecibo would be: 20 at 02:40, 13 before 02:40 and 5 after 0240. In fact, we often observed the enhancement maximum to occur above Arecibo between midnight and 03:00 as in the case of Figures 1 to 5. However, there is a disagreement between Silverman and Casaverde (1961) results and ours: the latitudinal distribution of the enhancement ratio. According to their Figure 3 an enhancement ratio of about 1 at the geomagnetic latitude of 50^{o}N (Arecibo) is expected. According to our observations (Figure 8) the enhancement ratio is of the order of a few units.

Huancayo Ionograms of the night January 14-15, 1972 were kindly sent to us by the Huancayo Observatory. The ionograms were recorded every 15 minutes. From them we read the minimum of h' (2 MHz) occurring exactly at midnight. In this same night the maximum zenith airglow intensity observed at Arecibo occurred at approximately 0300 hrs (Figure 1).

This would imply an average phase velocity of propagation (in the 3500 Km Huancayo - Arecibo path) of 1167 Km/h, which is close the value we found of 1296 Km/h (or 360m/s). The difference between these two values will decrease if we consider the time of occurrence of the minimum of h' (2 MHz) above Arecibo instead of the time of occurrence of the maximum airglow intensity. If we consider that the minimum of h' (2 MHz) occurred 15 minutes earlier than the maximum airglow intensity (which is a good estimate for Arecibo) then the phase velocity would shift from 1167 Km/h to 1273 Km/h which is very close the above mentioned speed we found with the scanning photometer.

We have observed the south-to-north traveling disturbances to occur in fifteen out of seventeen experiments (which is a frequency of occurrence of 88%). Although four of the seventeen experiments scanned EW we suggest south-to-north traveling enhancements in these runs because of not only its characteristic duration compared to the other two types of enhancement (the north-to-south and simultaneous enhancements) but also because these four runs were made together with an NS scanning (clearly showing the south-to-north traveling enhancement) in five consecutive nights and this NS scanning helped the identification of the south-to-north traveling enhancements in the EW runs.

Chimonas (1970) has studied in detail the generation of waves in the auroral and equatorial zones and calculated the pressure waves generated in the equatorial electrojet by the Lorentz force

$\underline{F} = (\underline{J} \times \underline{B})/\rho$ (were $\underline{J}$, $\underline{B}$ and ρ are the local current density, magnetic field and neutral density, respectively) which seems to be the most important mechanism to generate gravity waves in the equatorial electrojet.

A hint about the equatorial generated pressure waves intensity is given in Chimonas' (1970) Table 1 where it is shown that the theoretical ratio of the second pressure maximum of the wave launched from the region with vertical magnetic field (the well known gravity waves launched from the polar region) to the corresponding value when the magnetic field is horizontal (at a distance of 3000 Km from the source and altitude of 300 Km) is about 1:.15. Still according to Chimonas (1970) calculations the pressure waves had periods of approximately 120, 80 and 40 minutes at the altitudes of 100, 200 and 300 Km respectively. For comparison, our south-to-north traveling enhancements lasted about 180 minutes from onset to disappearance (which is equivalent to one period of the Chimonas waves commented above). Therefore our results are more consistent with the Chimonas 100 Km level values than with the 300 Km level.

The north-to-south traveling airglow enhancements were presumably due to TID's generated in polar regions. The velocities and durations of the two such enhancements seen were consistent with velocities and periods of TID's (Thome 1968, Rishbeth 1969). One might have expected to see evidence of more than one cycle of the TID, but in one case (3 March 1972) the experiment was terminated, due to a sudden bad weather condition, right after the first cycle and in the other

12 July 1972, the north-to-south enhancement was followed by a strong midnight collapse enhancement.

The enhancements which were essentially simultaneous over the latitude range scanned were presumably due to electric field changes. According to Matsushita and Tarpley (1970) the electric field should not vary appreciably within the latitude range observed. In some cases the simultaneous enhancements observed during the premidnight period seem consistent with the prediction (Matsushita and Tarpley 1970) of a rapidly increasing westward electric field around 22:00 hrs. The simultaneous enhancement observed during the midnight collapse of June 22-23, 1972 (Figure 3) seems to be related to the reversal of the electric field from eastward to westward predicted by Matsushita and Tarpley whenever the sun-earth-moon angle is about 145^{o}. This angle was about 149^{o} at the time of enhancement (Hartung, 1972). Unfortunately, there were no incoherent scatter ion velocities measurements made during these airglow observations, and so the hypothesis that these enhancements were due to the electric field could not be verified.

In summary, our results show that airglow measurements can provide a relatively simple and inexpensive means for studying some nighttime F region dynamical effects over a latitude and longitude range of 1000 Km or more which is much more extense than the range covered by the Arecibo radar.

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