

NASA TM X-55763

# 3 MAGNETIC DECLINATION AND SOLAR CONTROL OF THE TOPSIDE IONOSPHERE 6

BY

6

R. J. FITZENREITER

R. A. GOLDBERG

B. V. KRISHNAMURTHY 9

N67-23914

FACILITY FORM 802

(ACCESSION NUMBER)	(THRU)
1037RS 22-2111	1
(PAGES)	(CODE)
TMX-55763-2111	13
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

9 FEBRUARY 1967 10



1 NASA

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND 3

Ionospheric Physics Preprint  
Series

MAGNETIC DECLINATION AND SOLAR CONTROL OF THE  
TOPSIDE IONOSPHERE

by

R. J. Fitzenreiter  
R. A. Goldberg  
B. V. Krishnamurthy\*

Laboratory for Space Sciences  
NASA Goddard Space Flight Center  
Greenbelt, Maryland

ABSTRACT

A theoretical model based on the skewness between magnetic control and geographically oriented solar control, initially used to interpret foF2 declination effects, is reviewed and its predictions concerning topside vertical and latitudinal density slope behavior are compared with measured results of the Alouette I Topside Sounder satellite on the 75th meridian from heights of 400 km to 1000 km. The comparison is made for three periods of the day during which pressure is expected to be increasing (morning), nearly constant (afternoon), and decreasing (evening), as indicated by simultaneous studies of foF2 diurnal behavior. The measurements are found to closely match the model, with latitudinal slopes exhibiting large magnitude changes due to declination and vertical slopes exhibiting smaller, but still important, alterations in the predicted manner. The results indicate that the declination effect is a factor which must be considered as an important perturbation when analyzing data in mid dip latitude regions having declinations in excess of  $5^{\circ}$ .

In addition, it has been possible to isolate solar effects in the topside equatorial regions, the general result being that at all altitudes, solar control contributes to a flattening of latitudinal slope at latitudinal positions of up to at least  $\pm 10^{\circ}$  dip-latitude about the solar position. Finally, the data demonstrate the occurrence of the equatorial anomaly on the 75th west meridian at times as early as 1000 local mean time, in disagreement with the results of others studying Alouette data in the same region, but in closer agreement with findings for the Asian zone.

---

\*NAS-NRC Postdoctoral Resident Research Associate

## INTRODUCTION

It is well established that the electron density distributions of the F region ionosphere, particularly in the equatorial regions, are strongly influenced by the presence of the earth's magnetic field. Numerous papers have been written discussing first, the symmetric behavior of foF2 (critical frequency) about the dip equator (often referred to as the geomagnetic anomaly) and later, using Alouette I, the alignment of topside equatorial F region distributions with magnetic field as opposed to geographic coordinates.

Although dip has been an extremely useful coordinate for isolating some properties of the ionosphere previously hidden in a geographic system, it has become increasingly evident that dip alone is insufficient to fully describe magnetic control. One of the major phenomena falling into this category is the longitudinal effect. Work by Maeda (1954), Rao (1963), Lyon and Thomas (1963), Rastogi and Sanatani (1963) and Rao and Malthotra (1964) are representative in demonstrating that the American geographic zone of study exhibits different F region properties when compared to the Asian and African zones. In addition, topside Alouette studies have also indicated such discrepancies (King et al, 1963, Lockwood and Nelms, 1964).

A study of the earth's magnetic field (Figure 1) demonstrates that the Asian and African zones exhibit similar properties, viz. the magnetic field isoclines run nearly parallel to the geographic equator with the magnetic field exhibiting very small declinations over the entire range of the two zones. (Declination can be approximated by the angle between the isocline normal and the geographic meridian in this representation of the magnetic field.) On the other hand, the American zone magnetic field lies extremely skew

in the geographic coordinate system, hence implying large and rapidly changing values of declination. It is reasonable to assume that in regions where such large and variable declination values occur, that the declination must also be considered when discussing magnetic control of the ionosphere.

The first work to directly consider declination as a parameter is that of Eyfrig (1963 a,b). Using foF2 as a measure of ionospheric behavior, he has demonstrated strong correlations between foF2 behavior and magnetic declination and illustrated the importance of this parameter for magnetic control description. In particular, he has resolved such problems as nonconjugate behavior with dip between northern and southern hemispheres and also shown that regions of east declination exhibit different diurnal properties than those of west declination in a given hemisphere. He has also noted that such declination effects are most noticeable during morning and evening hours and at mid to high latitudes, being virtually non-existent during midday, midnight, and in the equatorial regions. At places and times of these effects, combination of data from a group of stations all in one hemisphere and having declinations of opposing sense, would produce scatter in the latitudinal distribution of electron density along the path of study. Because of the paucity of ground based stations to provide data representing monotonically changing or uniform declination effects with latitude, it is difficult to make a systematic study of such scatter. Such effects can be quite noticeable, e.g. some of the differences in the properties of the equatorial geomagnetic anomaly (as studied from foF2 measurements) noted between the American and Asian-African zones can be accounted for by this scatter (Goldberg, 1966).

The effects of magnetic declination on electron density distributions can be studied best from the Alouette topside

sounder data because they provide a nearly continuous latitudinal and declination coverage. In the present paper the results of an investigation of the effects of magnetic declination and solar control on the topside electron density distribution are presented and are examined in the light of a recent theory on the declination effect proposed by Goldberg (1966).

#### FUNDAMENTAL THEORETICAL CONSIDERATIONS

The theoretical model discussed by Goldberg (1966) and to be compared with data herein assumes that conditions are close to steady-state for all times considered. This implies that  $\vec{d}\mathbf{v}/dt \approx 0$  but does not imply  $\partial N/\partial t \approx 0$ , where  $\vec{v}$  is velocity,  $N$  is ion or electron density, and  $t$  is time. Furthermore, the major forces assumed to be governing the plasma are electric, gravitational, and magnetic. Finally, all collisions between neutral and charged particles are neglected. This implies that the fluid form of the plasma is maintained by electron-ion collisions, an assumption normally valid for topside ionospheric study. Such requirements lead to a set of momentum transfer equations which can be used to describe the entire density distribution in the plane of the magnetic meridian when given the vertical distribution at the equator.

The components of the charged particle pressure gradients can be related to those current components normal to the magnetic field. Viewing the equations by means of current components allows determination of the effects of declination, and demonstrates how longitudinal (zonal) pressure gradients, which are most likely to occur in morning and evening hours, can lead to declination effects if the longitudinal pressure gradients are geographically controlled. We note that the magnitudes of the current densities are extremely small by E region standards, the order of magnitude for an electron density of  $10^6/\text{cm}^3$  lying in the  $10^{-9}$  amps/m<sup>2</sup> range.

The only absolute quantity that can be determined by the model are the differences in vertical and latitudinal logarithmic density slopes for various declinations. However, by making some reasonable assumptions, it is also possible to map out the perturbed density distributions due to declination. Figures 2 and 3 show the type of results obtained.

For Figure 2, the theory assumes that all vertical distributions at the same magnetic dip and geographic latitude will be equal below the level where transport is an important phenomenon. The conditions for northern hemisphere, morning and evening, are shown. The theory predicts that the effect of declination should reverse itself in the southern hemisphere. Table 1 summarizes all cases for the slope of the vertical distribution.

In Figure 3, we illustrate the various latitudinal distributions that could occur by assuming that the crests of the latitudinal distributions are always equidistant from the dip equator at dip equinox and that the trough lies at the dip equator. This model is built upon the slope ratios, also printed in the figure. Should the crests or trough not obey the above requirements, the asymmetric forms generated in the figure could be reversed, but in any event the slope requirements remain fixed.

In both the vertical and latitudinal distributions, the theory predicts that strong declination effects will occur only during the morning and evening hours. In addition, declination effects near the equator are theoretically shown to be strongly reduced in magnitude from those of mid and high latitudes.

The above summarizes the results predicted by Goldberg (1966). In the next sections, we present a study of the data with the intent of making comparisons with the theoretical predictions. We will also isolate a direct solar effect, and

determine when and where this can override the declination effect, thus allowing us to correct for the direct solar effect when investigating the data with respect to declination.

#### DATA ANALYSIS

The data used in this study are ionograms from the Alouette Topside Sounder Satellite (Warren, 1962). A semi-automatic ionogram scaling method followed by computer analysis using a parabolic lamination true height reduction technique (Jackson, 1967) have made a large sampling of data possible.

This study exclusively employs passes in the vicinity of the 75th west meridian for two reasons: first, because the rapidly changing declination with longitude in this vicinity is quite conducive to declination study and second, because data of passes running from  $+30^{\circ}$  to  $-30^{\circ}$  dip latitude are available only in this sector of the world. We have considered three periods of the day in our study, viz. morning, afternoon, and evening to coincide with the designated periods in the theoretical study. Finally, whenever possible, we have made comparisons between two consecutive passes such as illustrated in Figure 4, since, as will be described, these provide the best technique for isolating declination effects from those of dip (or dip latitude) and solar control.

It is desirable to study passes over a wide range of dip latitude and make comparisons of results between northern and southern hemispheres at equal dip latitudes. In order to eliminate solar caused asymmetries in such studies, it is necessary to consider those periods close to dip latitude equinox, i.e. when solar control is symmetric about the dip equator.

Dip equinox occurs in the regions near the 75th west meridian on those days when the sun is over approximately  $12^{\circ}$ - $13^{\circ}$

south geographic latitude. This occurrence corresponds approximately to the dates February 15 to 18 and October 25 to 29 for the years 1962 to 1964. The approximate local time for equatorial crossing of satellite passes on these dates for each year are, for February, 0400 and 1600 and for October, 0700 and 1900 LMT. Hence, these are the only times of day during which we can study passes under truly dip symmetric solar behavior. Although the morning passes listed above are too close to sunrise to study the declination effect, the evening passes for October occur during that period during which the declination effect should be very important.

In addition to seeking solar symmetry, we have also attempted to minimize effects of magnetic disturbance by considering those passes occurring on days coinciding with or immediately following international quiet days. The dates for dip equinox are not all suitable for such requirements and we have thereby chosen those passes for which availability of data exists and which occur on quiet days nearest to solar dip equinox.

Although morning and afternoon passes cannot be obtained on dip equinox, it is possible to minimize the departure from this condition by selecting fall and winter month passes. During such periods the sun lies over the southern hemisphere and hence closer to the dip equator (see Figure 1) than in summer months. We have thereby concentrated on winter month passes to obtain morning and mid-afternoon data. In particular, morning passes were selected for winter quiet days corresponding to satellite passes between 0900 and 1200 LMT and afternoon passes, between 1300 and 1700 LMT. It still remains difficult to make declination effect comparisons between northern and southern hemispheres under these non-equinoctial conditions although, as will be seen, such comparisons are possible once the effects of direct solar control are recognized.



The need for consecutive passes is desirable since two such passes occur at the same local time (differing in 105 minutes universal time) for a given geographic latitude and approximately the same magnetic dip. For example, Figure 4 shows that pass 283 is predominantly in a west declination region in the northern hemisphere whereas 284 is in a predominantly east declination region. As a result, side by side comparison of the two passes should illustrate the declination effect quite clearly with no spurious behavior from asymmetric solar control. This approach, as will be seen, is extremely effective but unfortunately is limited by the very small amount of data available for consecutive passes ranging from hemisphere to hemisphere. Because of this problem we have also studied comparisons between two passes occurring on consecutive days between which no important changes in solar activity have occurred, hence assuming that all major differences observed are exclusively those due to declination. As will be seen, the results of such studies are also valuable for analyzing declination effects.

Our analysis then partially involves examining data suitably fitting the appropriate conditions listed above. The results to be presented and discussed in the next section are representative of the fifty (approximately) Alouette I passes near the 75th west meridian for the years 1962, 1963 and 1964 satisfying the above conditions and for which suitable data are available.

In addition to Alouette data, we have also studied simultaneous foF2 data from a series of stations lying in the vicinity of the 75° west meridian. By studying the time behavior of foF2 during the period immediately surrounding a satellite pass and treating longitude and time interchangeably we have been able to determine whether longitudinal (zonal) pressure gradients are more likely to be increasing, decreasing, or

nearly zero at that time and hence, which period of the day is more representative for the observed satellite data. Since foF2 is a measure of density and not temperature and since it does not represent density at a uniform height, the comparisons to be made using this data are to be considered suggestive but not conclusive as evidence for the longitudinal pressure gradients occurring at the time of the pass under question.

Finally, we note that all latitudinal studies in the next section are related to dip latitude ( $\alpha$ ) instead of dip (I). This is necessary to maintain linearity in slope comparison at all latitudes.

## RESULTS AND DISCUSSION

### 1. Evening Conditions

We first consider evening passes since these provide us with the best symmetrical solar conditions about the dip (or dip latitude) equator. Figure 5 illustrates constant height electron density profiles for two consecutive passes, 446 and 447, occurring on October 31, 1962. We have also presented the declination and local mean time for the passes at various dip latitudes and finally, indicated the solar position. In this figure and all following, the values for dip latitude and declination are those at 600 km, as calculated from the 1960 magnetic field coefficients (Jensen and Cain, 1962).

We note that within  $\pm 20^\circ$  dip latitude, the two passes exhibit virtually identical profiles at all altitudes with very little, if any, declination effect, as expected for low declination values occurring in the equatorial region. It appears that the northern crests at 400 km and 450 km for 447 are slightly lower than those of 446, and Figure 3 indicates this to be the expected behavior for their relative declinations. However, the data in 447 are too scanty to ascertain whether or not this effect is real. We also find from 446, that the

distributions are extremely symmetric, as would be expected for the centered position of the sun over the dip equator.

A comparison between passes 446 and 447 in the northern hemisphere illustrates a strong declination effect beyond  $20^{\circ}$ N dip latitude. Here, differences of 50 to 100 percent occur between latitudinal logarithmic slopes in regions of  $7^{\circ}$ E declination when compared to  $5^{\circ}$ W declination at all heights studied. Unfortunately, no comparison is possible in the southern hemisphere since 447 data do not reach sufficiently far into the hemisphere for comparison to be made. Pass 446 also shows a very shallow trough in the equatorial region, an effect more pronounced than we would expect for this time of day. We expect this is a solar effect and will discuss it in more detail when considering morning passes.

Continuing with northern hemisphere comparison, we present, in Figure 6, a sequence of vertical topside density profiles at various dip latitudes. As expected, no important disparities between the two passes take place below  $20^{\circ}$ N dip latitude. However, at  $26^{\circ}$  and  $30^{\circ}$ , separation between the two profiles occurs as predicted in Figure 2 and Table 1. This separation remains up to 1000 km with the slopes becoming equal at the higher levels.

Measurement of the relative vertical logarithmic slopes of the curves in Figure 6 at about 500 to 600 km indicates differences in the order of 15 percent. Hence, the declination effect clearly alters latitudinal slope more than vertical slope. A review of the fundamental equations illustrates why this is so. In Goldberg (1966) it is shown that the latitudinal logarithmic slope is directly proportional to  $j_{\phi}$ , a quantity representative of the longitudinal current in the magnetic coordinate system. On the other hand, the vertical logarithmic slope is proportional to the sum of two terms  $(1/2H) + \beta j_{\phi}$ ,

where  $H$  is the normal scale height for electron density distributions as measured along a field line and  $\beta$  is a variable independent of declination. Furthermore, the contribution of each term to the vertical slope is not equal, that of the scale height normally being the larger. Declination affects the slopes by perturbing the value of  $j_\phi$ ; hence, it is a direct effect on latitudinal slope change but only a second order effect with regard to vertical slope change. Throughout our study, we have observed this type of proportionate behavior between vertical and latitudinal slopes, and hence, will present latitudinal studies exclusively to represent the remaining passes in this paper.

Before leaving passes 446 and 447, it is of interest to view the foF2 diurnal (longitudinal) behavior occurring during their transit. We note from Figure 7 that the critical frequency is decreasing at all stations during this period indicating an evening type situation.

We now turn to passes 283 and 284, illustrated in Figure 8, occurring on October 19, 1962, at approximately  $1\frac{1}{2}$  hours LMT later than 446 and 447. We note from Figure 7 that foF2 indicates these passes to be representative of evening behavior. A view of 283 indicates that the anomaly is better formed than in 446 and 447, perhaps because of the weaker solar effect at this later hour, with the slopes in the equatorial region ( $+15^\circ$ ) behaving in a west declination manner for evening (cf. Figure 3). Once again, it is impossible to make comparison at higher latitudes because of insufficient data. Turning to 284, we have a pass lying in an east declination zone with magnitudes of declination much larger than those studied previously. The slopes for this pass compare very well with Figure 3, passing from a relatively weak east declination region in the northern magnetic hemisphere to a strong east

declination region in the southern magnetic hemisphere; i.e., curve B in region "a" to curve C in region "d". This pass, because only 105 minutes apart in UT from 283 and equivalent in LMT, is a clearcut example of the strength this effect can attain at low latitudes for reasonably large declinations. Finally we note a reduction of latitudinal slope near the equator in the northern hemisphere at 400 and 450 km heights and feel that this may also be, in part, due to the solar control. This effect will be established and discussed in the following sections.

## 2. Morning Conditions

Because of non-availability of data for morning-time consecutive passes we have, for representation of our study of the morning declination effect, selected the two passes illustrated in Figures 9 and 10, viz. 5013 on October 1, 1963, and 1247 on December 29, 1962. Figure 11 illustrates the foF2 behavior for these two passes and demonstrates that both are most likely measuring data under morning type conditions.

Before interpreting these passes with regard to declination, we must first establish the effect of asymmetric solar control, since the sun is over the northern crest in 5013 and over the southern crest in 1247. In both cases, we note (Figures 9 and 10) that the crest below the sun appears to be broader and somewhat flattened or hollowed out than its counterpart in the opposite hemisphere. Hence, the sun appears to reduce the slope of the latitudinal distribution for at least  $\pm 10^\circ$  dip latitude about its overhead position. This solar effect is also possibly present in the symmetrical situation as previously noted for evening passes such as 446 and 447 in Figure 5, where we note a very flat ledge within the crests of the latitudinal distribution exhibiting little, if any, trough at the dip equator. Furthermore, this reduced slope effect

occurs in 5013 and 1247 up through the 1000 km contour, although at 600 km and above the effect is less well defined and also causes a lifting in the solar hemisphere. This indicates that direct solar control may not be a negligible effect in the topside F region up to heights of at least 1000 km.

Returning to 5013 and the declination effect, we observe that the latitudinal slopes of this pass beyond the probable range of the direct solar effect exhibit the distributional behavior predicted in Figure 3, i.e. curve B in the northern magnetic hemisphere (weak declination) to curve C in the southern magnetic hemisphere.

Pass 1247 occurs in an equivalent range of east declination, but the magnitudes are less. The pass also occurs much closer to noontime conditions. With these considerations in mind it is not surprising that the slopes beyond expected solar influence are nearly equal at all altitudes. Furthermore, the solar effect could also reduce the slopes between  $-20^{\circ}$  and  $-30^{\circ}$  more than between  $+10$  and  $+20^{\circ}$ , and a correction weighted in this manner would then admit a declination effect similar to that of 5013.

Finally, it is of interest to note that 5013 shows strong latitudinal crests at 1000 LMT and 1247 at 1045 LMT in contrast to reports by Lockwood and Nelms (1964) that 75th west meridian passes do not exhibit properties known as the geomagnetic anomaly before 1100 LMT. This result in our work, which is the rule rather than the exception, appears to demonstrate closer accord between density behavior in the American and Asian zones than comparison between the results of Lockwood and Nelms (1964) and King et al (1963) would indicate. The absence of data between 1000 and 1100 LMT and the paucity of data between 9:30 and 10:00 LMT in Lockwood and Nelms (1964) as shown in their Figure 11, would appear to account for their conclusion that the American zone anomaly forms later than 1100 LMT.

### 3. Afternoon Conditions

We have reserved our study of afternoon passes for last since these are the most difficult to interpret. One can never expect to obtain the ideal situation depicted by curve B in Figure 3 since foF2 studies indicate that most stations do not reach a condition where longitudinal (zonal) gradients in density are zero for more than one or two hours in the afternoon, this happening at different times for different latitudes. In addition, the longitudinal pressure gradient may still occur during such a period due to unknown temperature variations. To add to the confusion, Alouette passes are not available in early afternoon during dip equinox and we are forced to interpret our results including the direct solar effect. Nevertheless, we feel that such problems are not insurmountable and will now present four passes which illustrate typical afternoon behavior.

We first compare pass 4646 on September 5, 1963, to pass 4660 on September 5, 1963, as shown in Figure 12. Although these passes are not consecutive they are separated by only one day during which time solar conditions were quiet. Also, both passes occur at approximately the same LMT. The sun for each pass is over the northern hemisphere crest and hence, we observe the solar effect previously discussed. This once again leads to a flattening of slope on the solar side of the dip equator as can be seen on 4660. At first glance, it appears that there may also be a morning east declination effect superimposed on 4660 (curve B-north to curve A-south in Figure 3), but a look at foF2 behavior in Figure 13 indicates that longitudinal density slopes are mixed with all but the most northerly stations showing negligible longitudinal (diurnal) gradients at this time. Furthermore, if we compare the northern latitudinal slopes of 4660 to those of 4646, we find negligible differences

although the declination difference in this region averages about  $8^{\circ}$ . We observe that 4646 foF2 behavior is also mixed, with the northern stations exhibiting weakly increasing values for foF2 during the pass transit, but these could easily be counteracted by opposing temperature gradients leaving a nearly zero longitudinal pressure gradient. We therefore conclude that there is little if any declination effect occurring during the passes 4646 and 4660 and that the major asymmetry in density observed at this time is solar controlled directly.

Finally we consider two late afternoon passes, 6939 and 6940 on February 19, 1964, shown in Figure 14. These examples are interesting because they represent nearly symmetric solar control. We first note that the limited amount of data available for 6939 is virtually coincident with that of its counterpart (except for a small solar effect within its crest), indicating no measurable declination effect within the realm of  $\pm 13^{\circ}$  about the dip latitude equator. This is further borne out by the symmetric conditions in this region for 6940. We conclude that any declination effect present at such low latitudes is entirely masked by solar control. Next we observe that at higher latitudes, 6940 exhibits stronger latitudinal slopes in the southern than in the northern hemisphere indicating a declination effect representative of morning conditions according to Figure 3. Unfortunately, a study of foF2 is inconclusive for this case since data are available from four stations only (Figure 13) and these do not agree as to whether conditions are more morning or evening like with regard to pressure gradient. Finally we note that the trough in 6940 is relatively shallow when compared to 4660, thereby once again illustrating the effect of a symmetric sun.



## SUMMARY AND CONCLUSIONS

The results of this work isolate two effects of external origin observable in the topside F region of the earth's ionosphere. The first of these is an effect correlated with magnetic declination and on the basis of Goldberg (1966), is an effect caused by the skewness of the earth's magnetic field with geographically oriented solar control. Hence, it appears to account for many of the differences in geomagnetic control commonly attributed to longitude.

In addition to explaining the declination effects observed through studies of foF2 (Eyfrig 1963 a,b), Goldberg (1966) has also made predictions for the behavior of the topside density distribution to be expected because of differences in magnetic declination. These differences have been described in terms of latitudinal and vertical density slopes. By an analysis of Alouette I topside sounder satellite passes in the vicinity of the 75th west meridian, we have been able to obtain successful verification of the predicted effects and further, roughly estimate their magnitudes. We find for example, that declinations of approximately  $8-9^{\circ}$  can alter latitudinal logarithmic slopes as much as 25 to 50 percent and vertical slopes as much as 5 to 10 percent from zero declination values for heights between 400 km and 1000 km in the vicinity of  $+25^{\circ}$  dip latitude. The effects become considerably diminished as we approach the dip latitude equator, but this is expected on the basis of the theory.

We have analyzed the data for three different periods of the day: evening, morning and afternoon; taken in order of increasing difficulty for analysis. We have also compared our results with simultaneous foF2 data from a series of six stations ranging in dip latitude from  $-30$  to  $+30^{\circ}$ , to determine

the usefulness of foF2 time behavior as a measure of longitudinal pressure gradients. These results are consistently in agreement except, as expected, during the mixed transition periods of mid-afternoon.

The characteristics of the satellite orbit only allow evening and late afternoon passes to be studied with solar control symmetric about the dip latitude equator. The declination effect results obtained in evening are in full accord with those predicted in Figures 2 and 3, the effects being larger for larger declinations. Next, a study of morning passes indicates similar good agreement with theory, once the effects of asymmetric direct solar control are understood and corrected for. Finally, afternoon passes show mixed effects which are difficult to correlate with foF2 data, but nevertheless can be interpreted. Unlike morning and evening, afternoon longitudinal temperature gradients may not be additive with those of electron density and hence, the declination effect, which depends on longitudinal (zonal) pressure gradients, may not be well represented by foF2 gradients.

The second major effect observed in our study is that of direct solar control. We find that the sun, when at a position over either the northern or southern crest of the equatorial geomagnetic anomaly, tends to flatten the slope of and increase the width of the crest, in some cases producing a secondary trough within the crest itself. Even above heights where the anomaly is observed, the flattening of the latitudinal slope occurs. This effect is also noticed when the sun lies directly over the dip latitude equator. In this case, the tendency is to fill in the equatorial trough lying between the two crests.

Next, we offer two of several 75th west meridian morning passes, all showing the presence of a well defined equatorial

geomagnetic anomaly as early as 1000 LMT. This appears to disagree with the results of Lockwood and Nelms (1964), who maintain that the anomaly never appears before 1100 LMT near this meridian, and hence our result is in better accord with the results of King et al (1963) for the Asian sector.

Finally, we observe that in our analysis, we have limited ourselves to medium and low dip latitudes mainly because of accessibility of data. One can argue on the basis of the theory that declination effects should increase and be larger at high latitudes and in fact, Eyfrig's foF2 studies appear to indicate this tendency. We feel however, that such additional analysis is not necessary within the scope of this work since our purpose with regard to magnetic control was to determine the degree to which the data can be interpreted on the basis of declination effects as predicted and this has been demonstrated. Naturally, uniqueness is not claimed, and it remains for further investigation to determine whether this is the major effect responsible for most longitudinal differences in electron density (known or unknown) occurring in the topside ionospheric F region.

## REFERENCES

- Eyfrig, R. W., J. Geophys. Res. 68, 2529-2530, 1963a.
- Eyfrig, R. W., Ann. Geophys. 19, 102-117, 1963b.
- Goldberg, R. A., Ann. Geophys., 22, 588-598, 1966.
- Jackson, J. E., 1967, (IN PREPARATION).
- Jensen, D. C. and J. C. Cain, J. Geophys. Res. 67, 3568, 1962.
- King, J. W., P. A. Smith, D. Eccles, H. Helm, D.S.I.R. Radio Res. Sta. Rept. RRS/I.M. 94, July, 1963.
- Lockwood, G. E. K. and G. L. Nelms, J. Atmospheric Terrest. Phys. 26, 569-580, 1964.
- Lyon, A. J. and L. Thomas, J. Atmospheric Terrest. Phys. 25, 373-386, 1963.
- Maeda, K., "Physics of the Ionosphere", Physical Soc., London 245-253, 1954.
- Rao, B. C. N., J. Geophys. Res. 68, 2541-2549, 1963.
- Rao, C. S. R. and P. L. Malthotra, J. Atmospheric Terrest. Phys. 26, 1075-1085, 1964.
- Rastogi, R. G. and S. Sanatani, J. Atmospheric Terrest. Phys. 25, 739-742, 1963.
- Warren, E. S., Can. J. Phys. 40, 1692, 1962.

TABLE I

Declination	Time	Magnetic Hemisphere	Effect on Slope Magnitude
East	Morning	Northern	Reduction
East	Evening	Northern	Increase
West	Morning	Northern	Increase
West	Evening	Northern	Reduction
East	Morning	Southern	Increase
East	Evening	Southern	Reduction
West	Morning	Southern	Reduction
West	Evening	Southern	Increase

Vertical slope changes of the topside F region density distribution due to declination as a function of time and hemisphere. Results given are relative to the zero declination case. (After Goldberg, 1966)

## FIGURE CAPTIONS

1. Worldwide representation of the earth's magnetic field isoclines. Declination can be approximated by the angle between the geographic meridian and the isocline normal.
2. Possible variations in the vertical topside F region electron density distribution because of differences in magnetic declination (After Goldberg, 1966). Comparisons are made between northern hemisphere stations of east and west magnetic declination during both morning and evening conditions. (Opposite results occur in the southern hemisphere, Refer to Table I). The inequalities shown for slopes refer to topside magnitude only.
3. Possible configurations of a latitudinal constant height electron density profile due to differences in magnetic declination (After Goldberg, 1966). It is understood that the latitudinal slopes designated by a, b, c and d refer to magnitude only.
4. Two consecutive Alouette I passes relative to both geographic and magnetic dip coordinates. Declination can be approximated by the angle between the geographic meridian and the isocline normal.
5. Comparison of constant height latitudinal electron density profiles at five altitudes from 400 km to 1000 km for two consecutive Alouette passes (446 and 447 on 10/31/62) occurring under evening conditions in regions of low to moderate magnetic declination. Overhead position of the sun, magnetic declination, and LMT are also provided. QUI and AGA refer to data taken at Quito and Antofagasta respectively. (In the following illustrations, AGA is often replaced by SNT, Santiago.)
6. Comparison of vertical topside electron density profiles at several dip latitudes for passes 446 and 447.

7. Time (or zonal) behavior of foF2 at several dip latitudes on dates corresponding to passes studied under evening conditions.
8. Comparison of two consecutive Alouette passes (283 and 284 on 10/19/62) under similar conditions to those studied in Figure 5 but in regions of moderate to high magnetic declination. Description of the curves can be found in the caption of Figure 5.
9. Constant height electron density profiles with dip latitude for a morning Alouette pass (1247 on 12/29/62) with the overhead sun lying in the southern magnetic hemisphere.
10. Constant height electron density profiles with dip latitude for a morning Alouette pass (5013 on 10/1/63) with the overhead sun lying in the northern magnetic hemisphere.
11. Time (or zonal) behavior of foF2 at several dip latitudes on dates corresponding to passes studied under morning conditions.
12. Comparison of two afternoon Alouette passes (4646 on 9/4/63 and 4660 on 9/5/63) separated by one day (quiet conditions) under solar asymmetric conditions. Description of the curves can be found in the caption of Figure 5.
13. Time (or zonal) behavior of foF2 at several dip latitudes on dates corresponding to passes studied under afternoon conditions.
14. Comparison of two afternoon consecutive Alouette passes (6939 and 6940 on 2/19/62) under solar symmetric conditions. Description of the curves can be found in the caption of Figure 5.

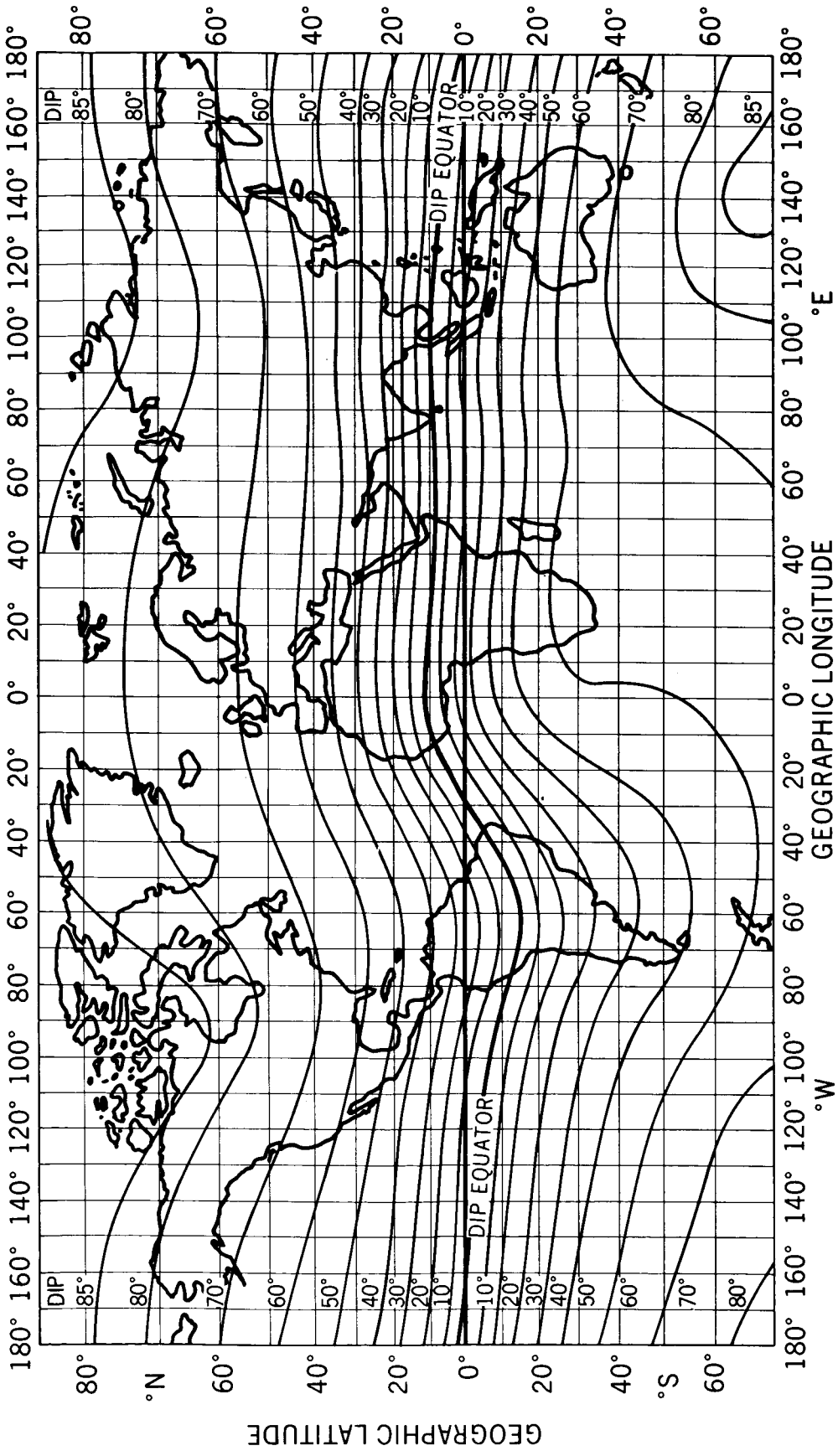
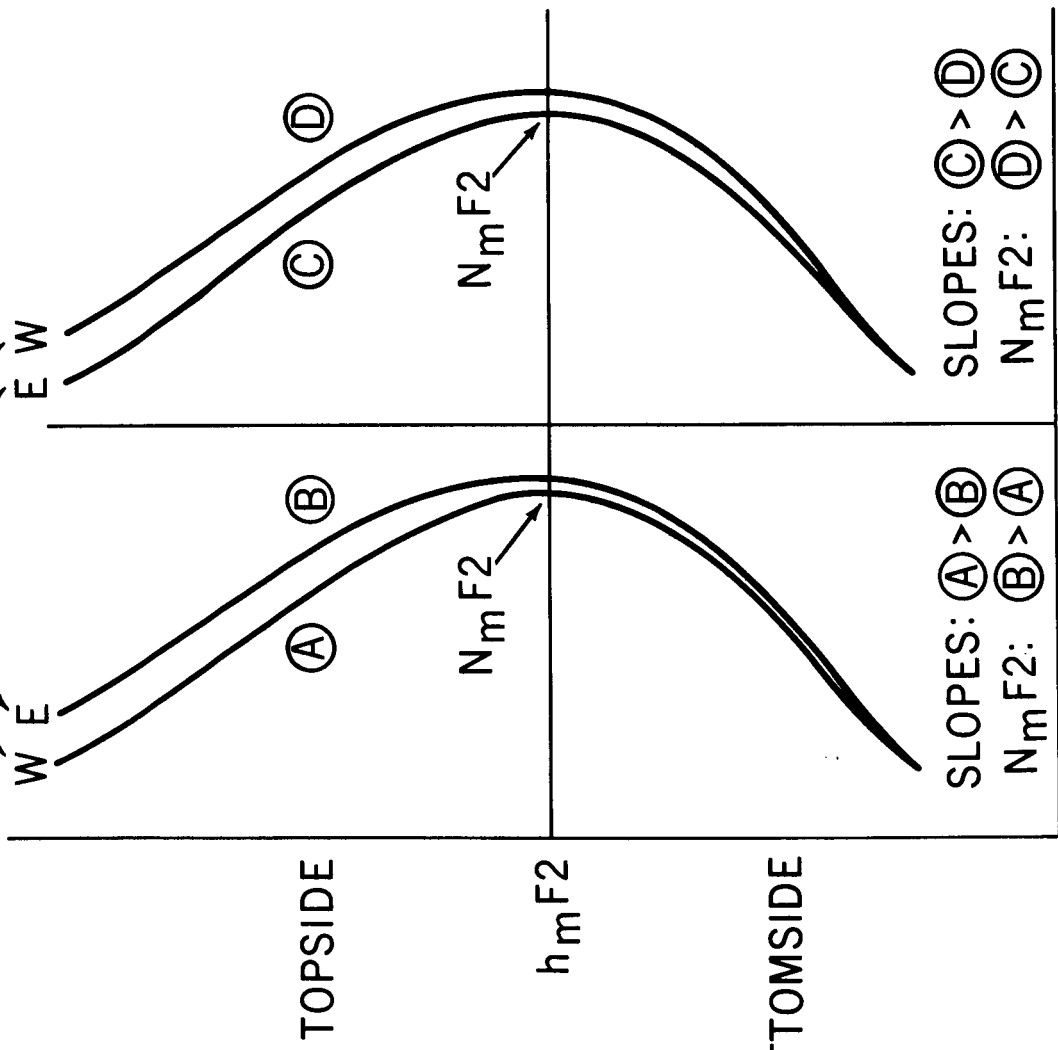


Figure 1



DECLINATION (NORTHERN HEMISPHERE)



ALTITUDE (ARBITRARY UNITS)

TOPSIDE

$h_m F2$

BOTTOMSIDE

MORNING EVENING  
LOG DENSITY (ARBITRARY UNITS)

Figure 2

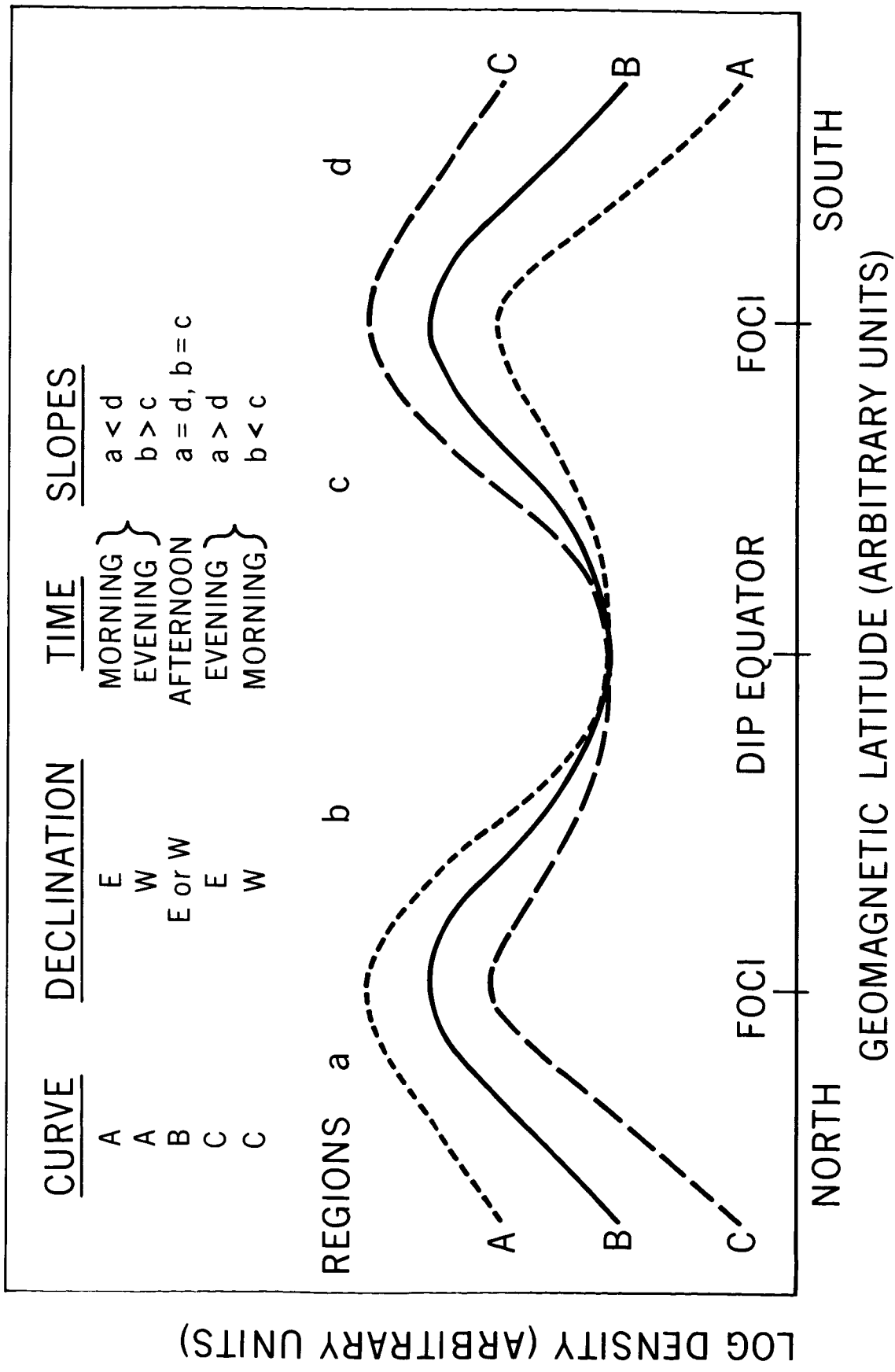


Figure 3

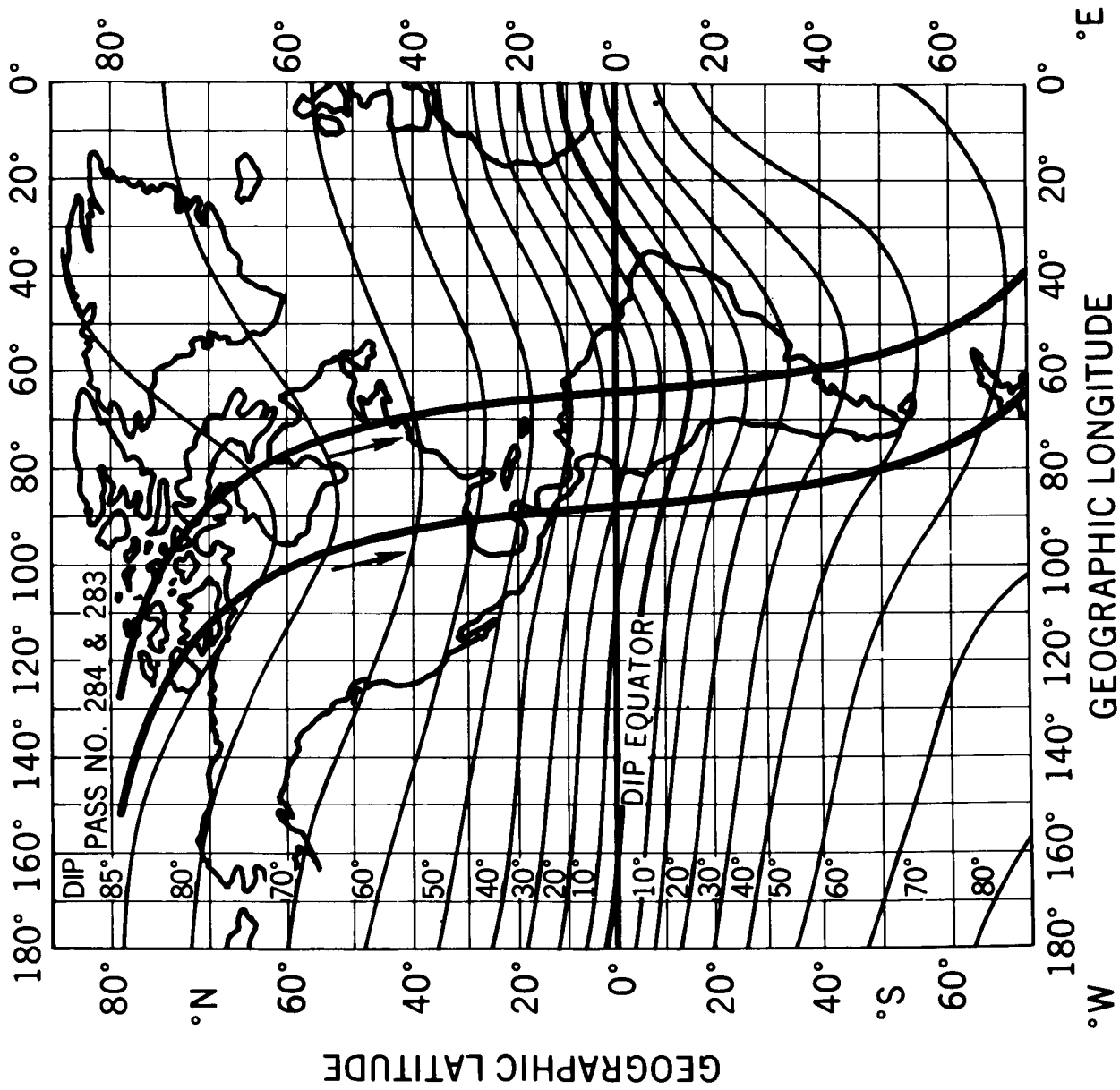


Figure 4

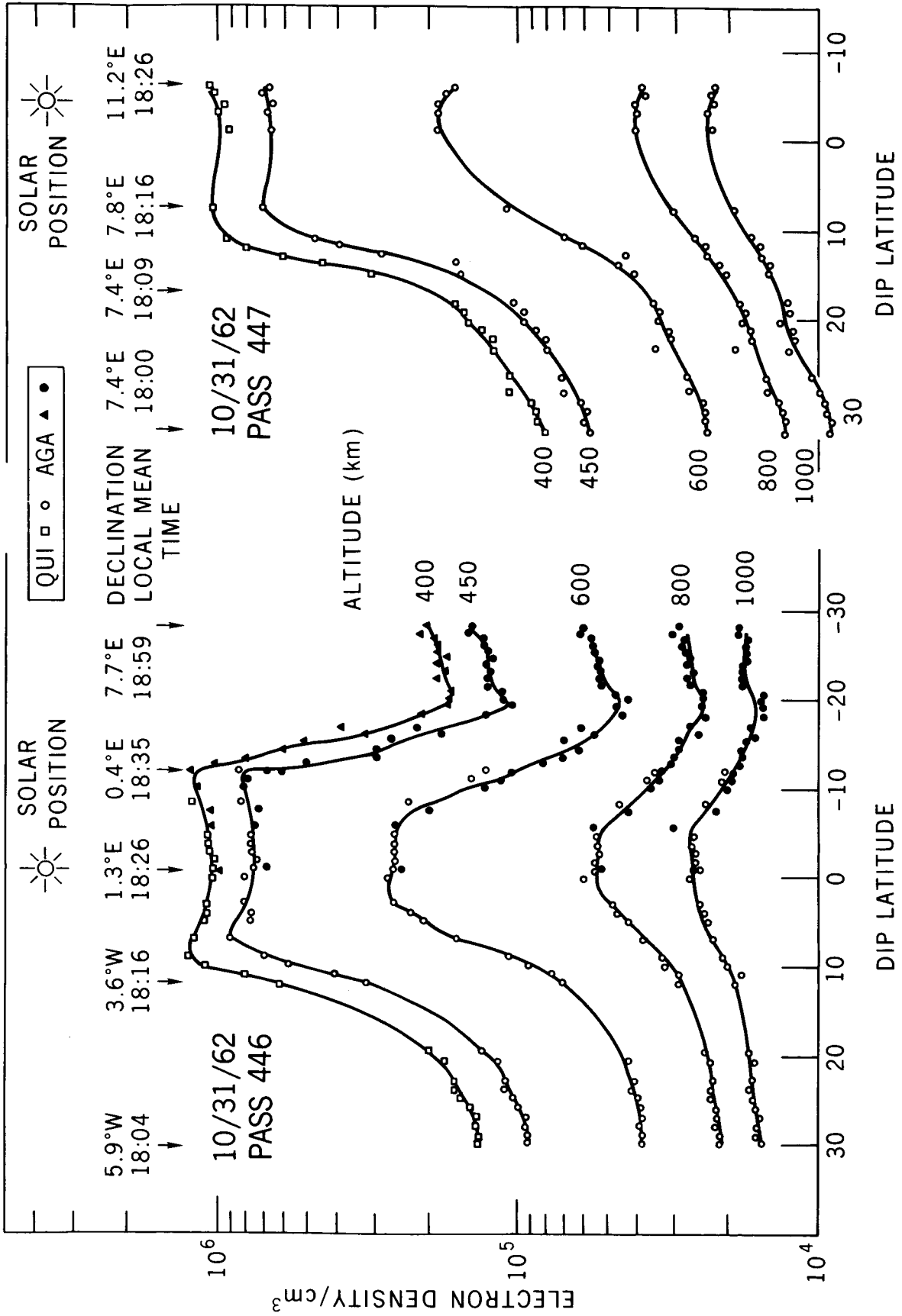


Figure 5

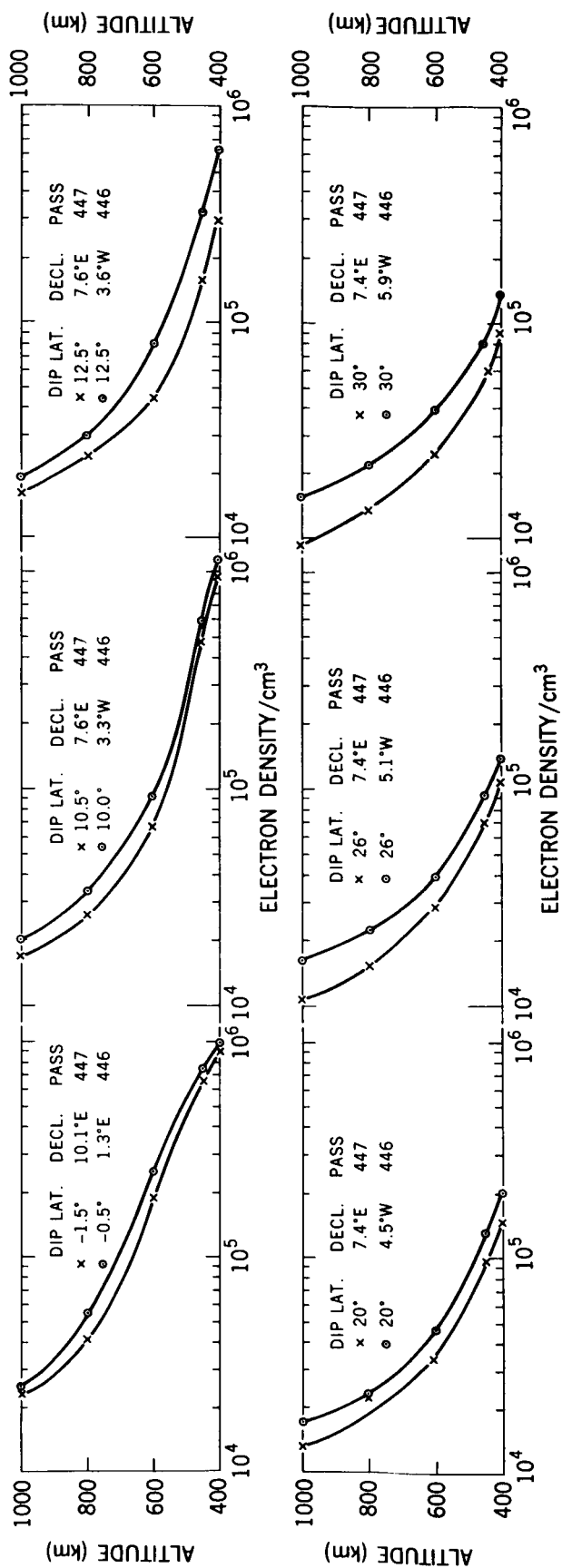
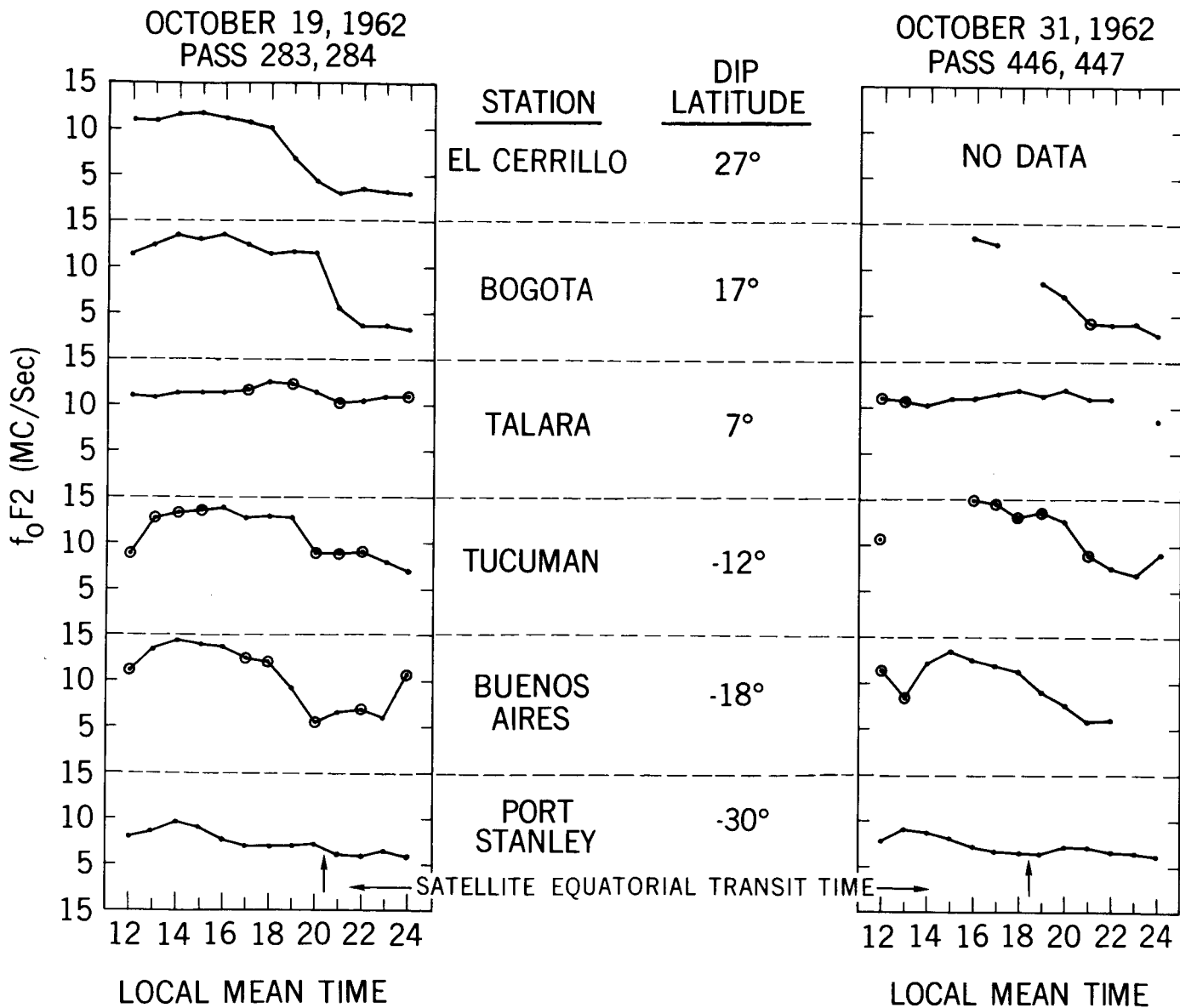


Figure 6

• ACCURACY  $\pm 2\%$     ⊙ ACCURACY  $\pm 10\%$



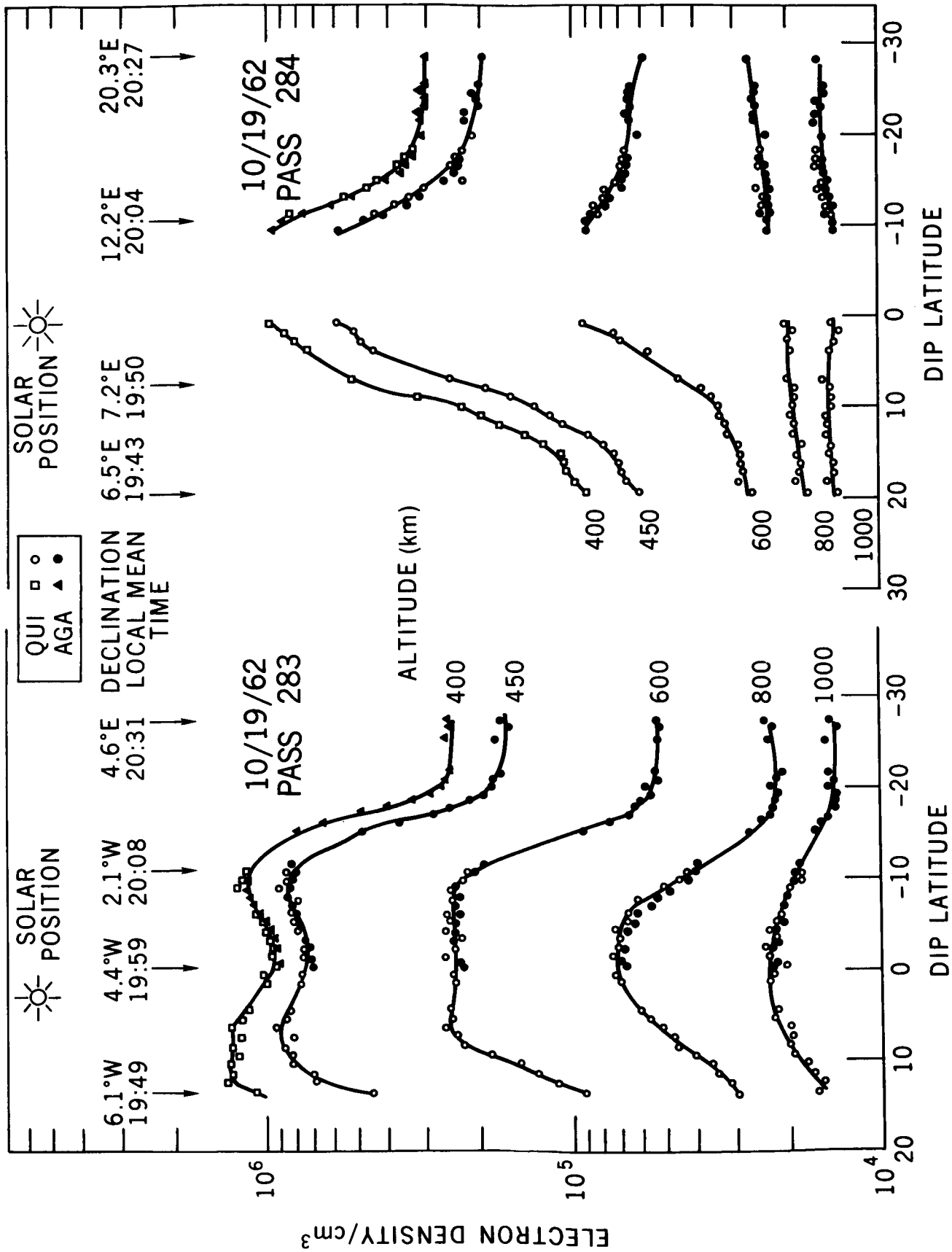


Figure 8

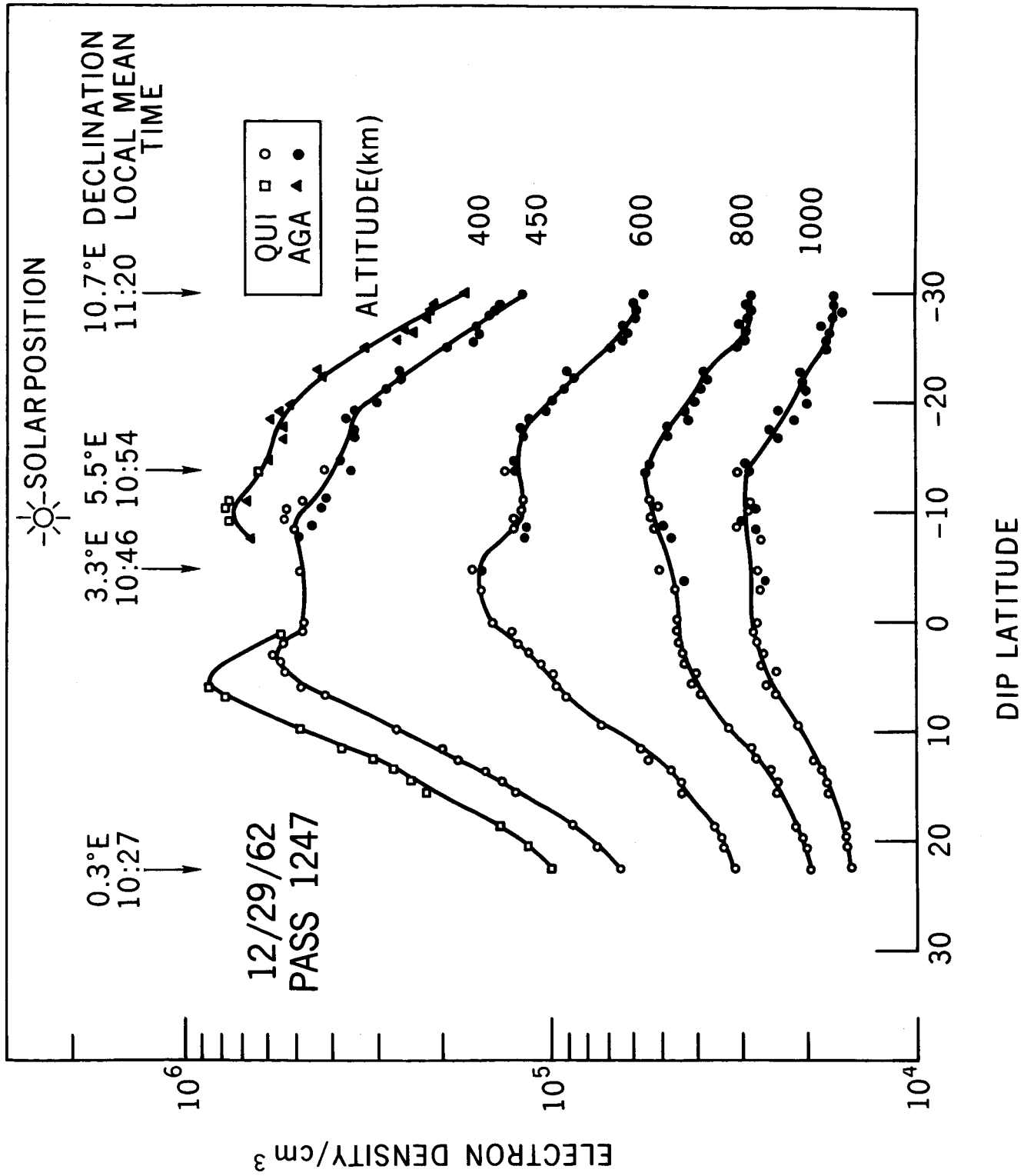


Figure 9



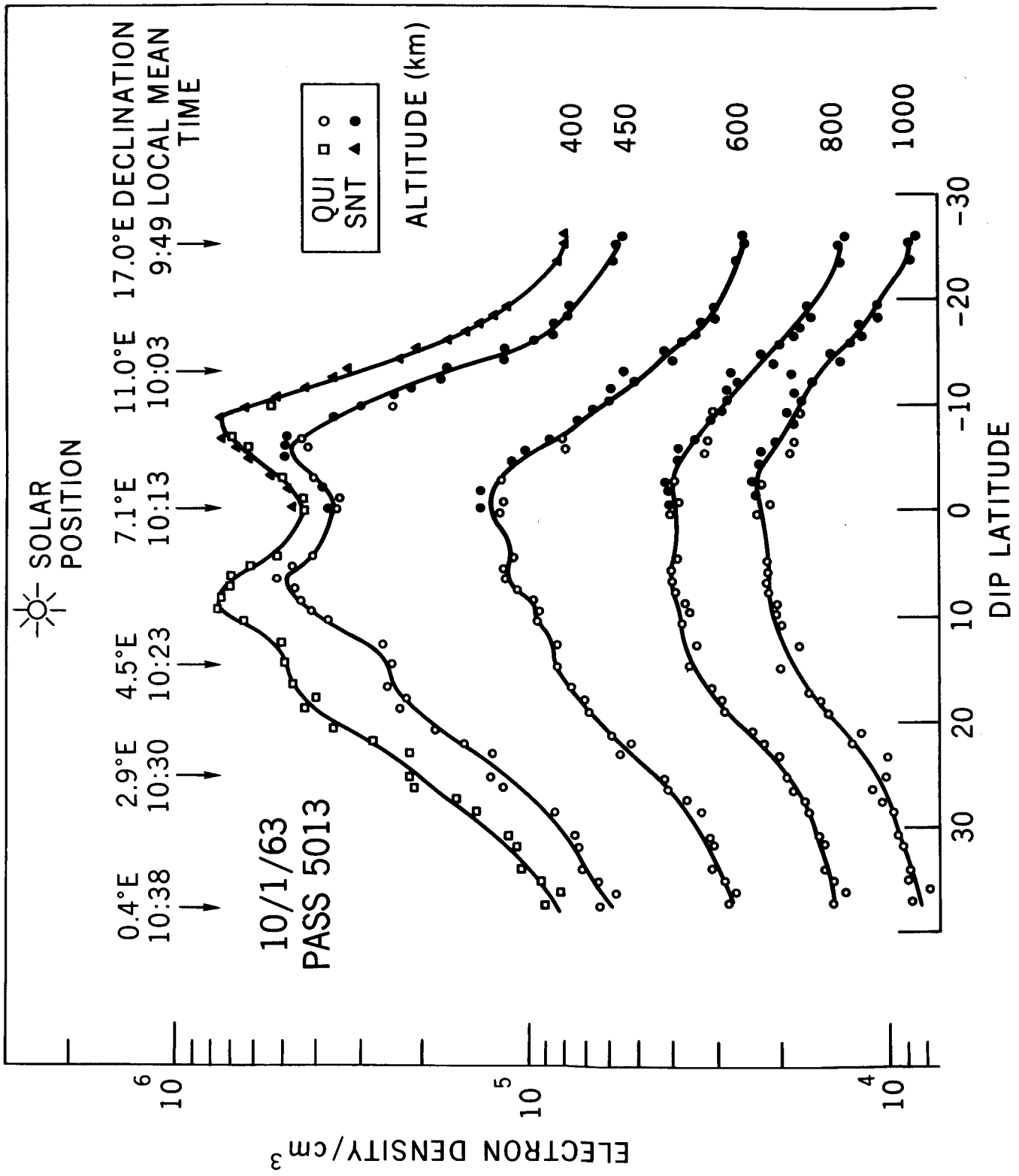


Figure 10

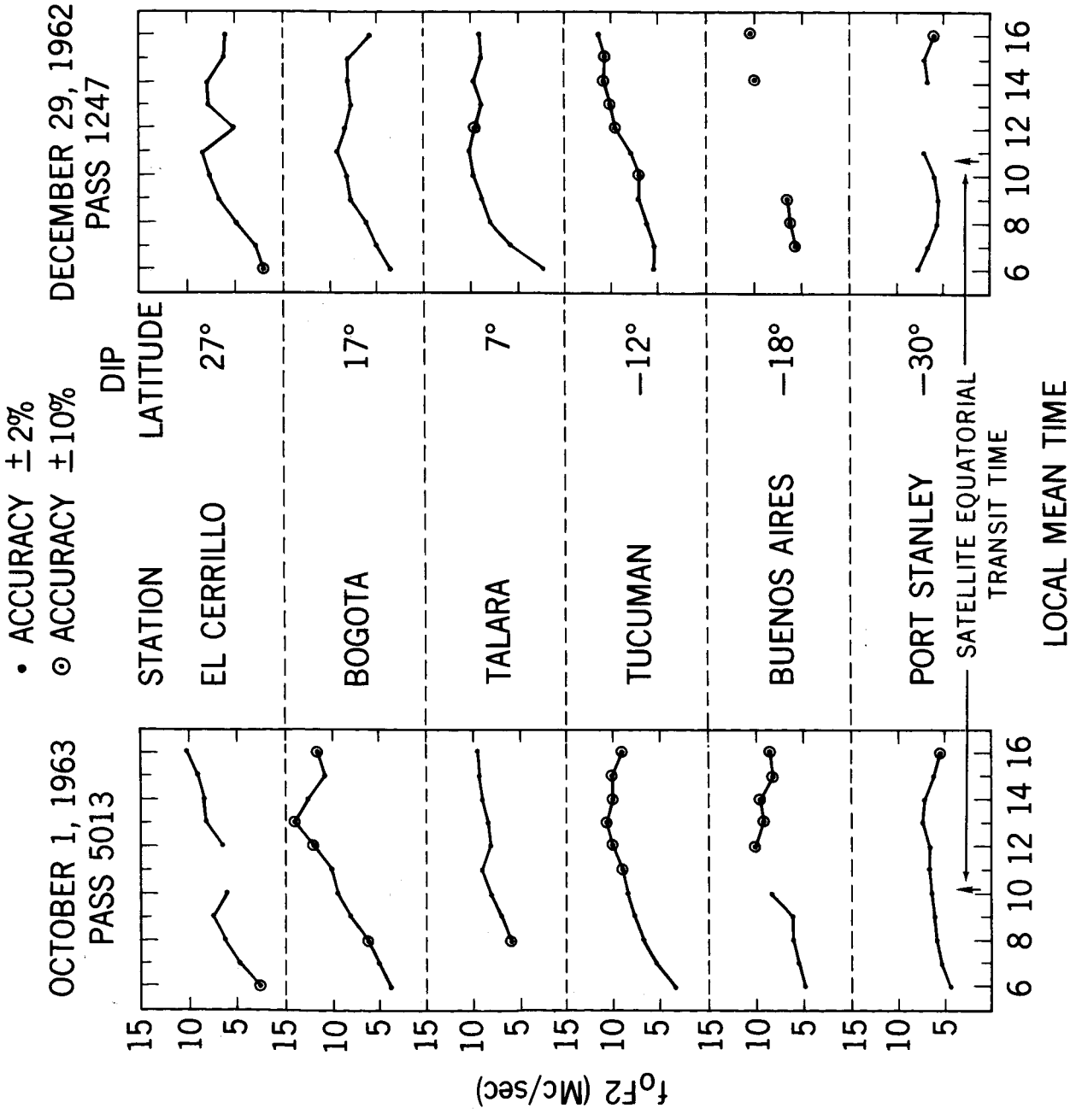


Figure 11

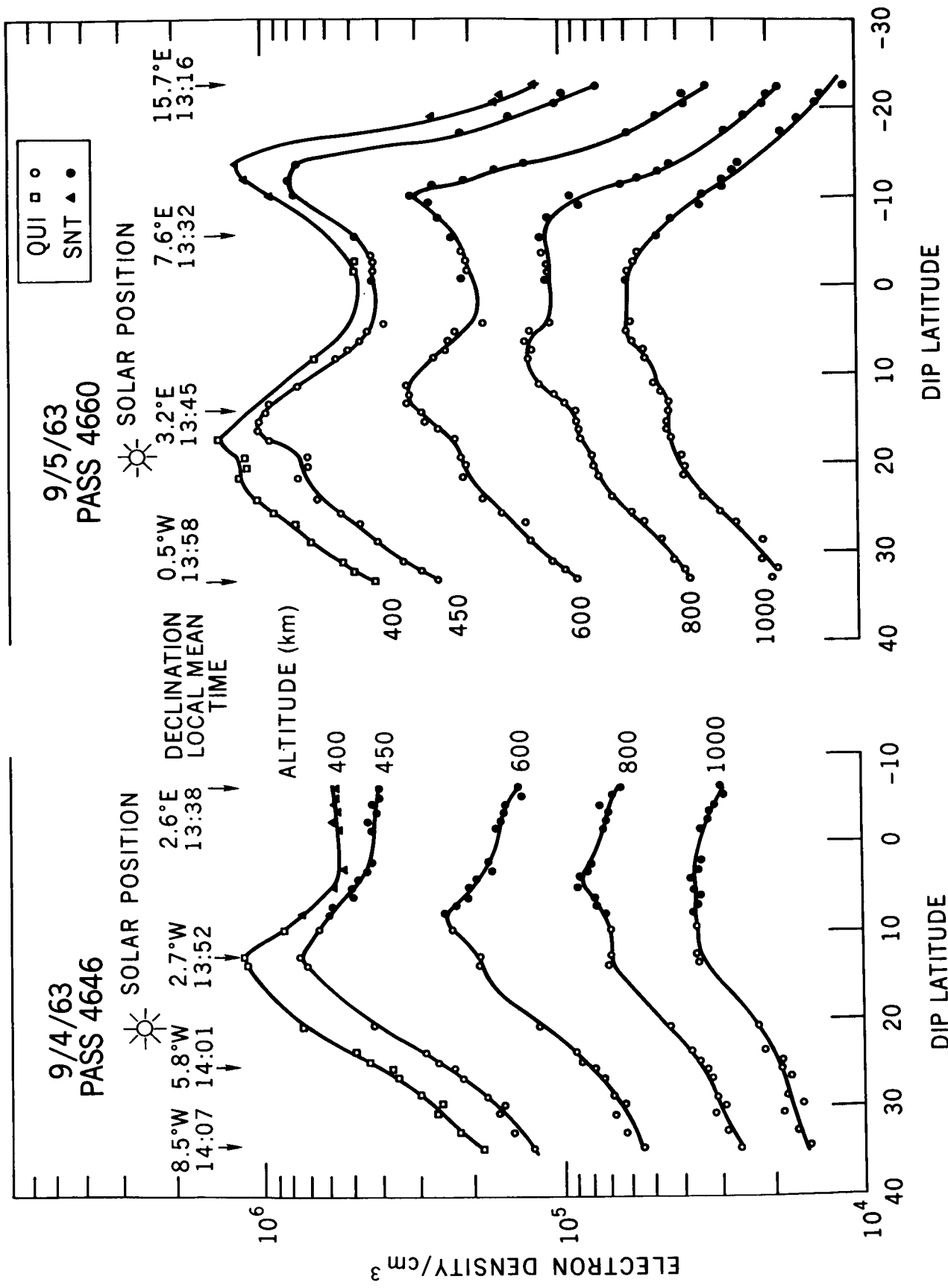


Figure 12

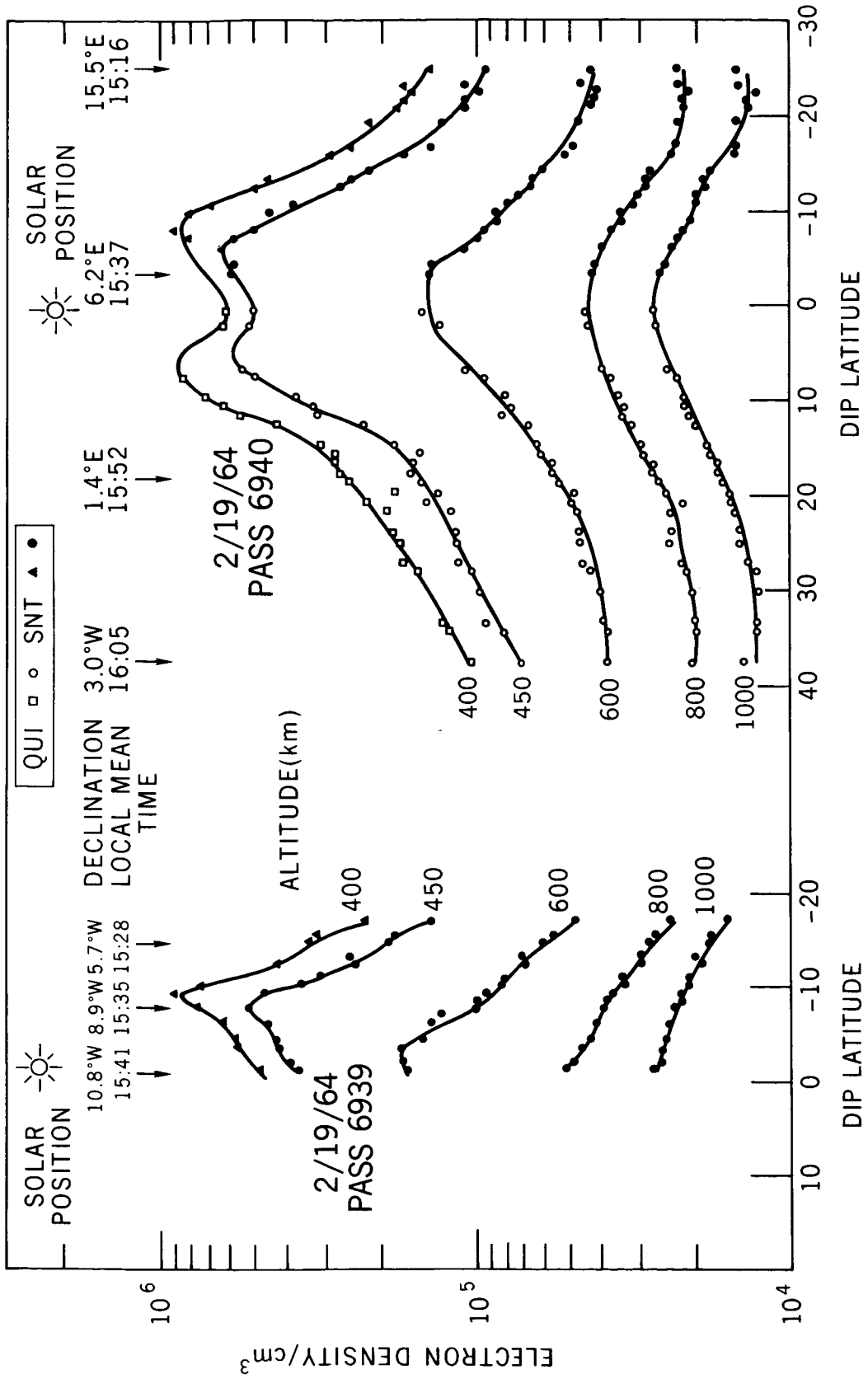


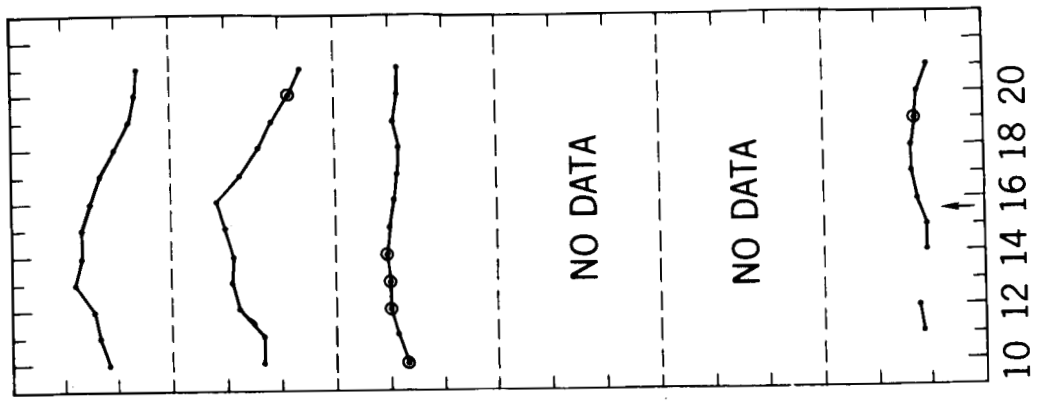
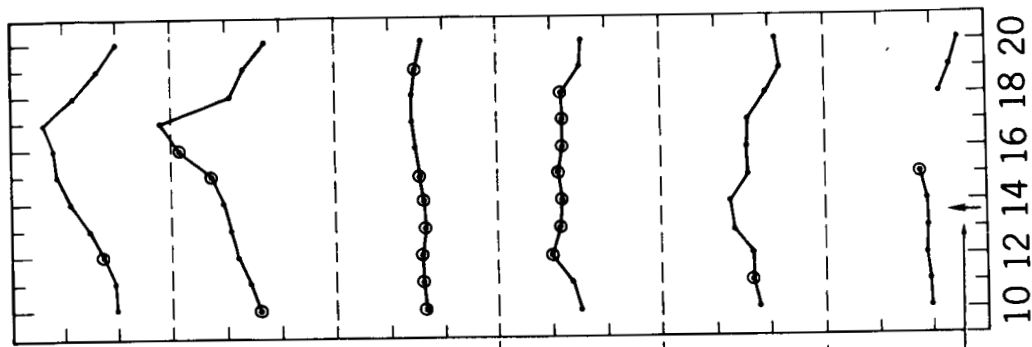
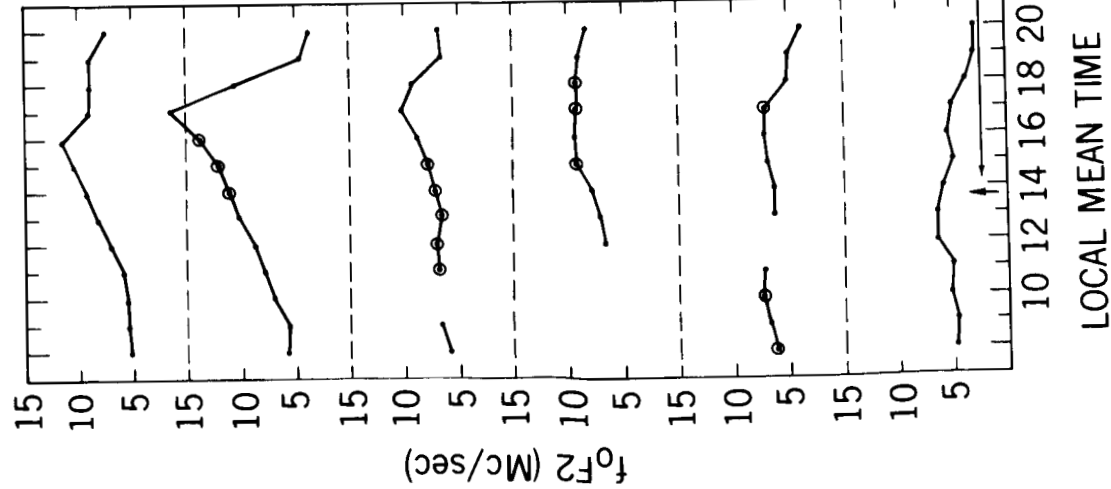
Figure 14

- ACCURACY  $\pm 2\%$
- ACCURACY  $\pm 10\%$

SEPTEMBER 4, 1963  
PASS 4646

SEPTEMBER 5, 1963  
PASS 4660

FEBRUARY 19, 1964  
PASS 6939, 6940



STATION      DIP      LATITUDE

EL CERRILLO      27°

BOGOTA      17°

TALARA      7°

TUCUMAN      -12°

BUENOS AIRES      -18°

PORT STANLEY      -30°

← SATELLITE EQUATORIAL TRANSIT TIME

LOCAL MEAN TIME

LOCAL MEAN TIME

Figure 13