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## ABSTRACT

Results of an analysis of Explorer 22 Langmuir probe measurements are presented for the winter periods between November 1, 1964 and February 15, 1967. The atmospheric region characterized by the data is the midlatitude ionization trough at 1000 km. The electron density patterns imply that as solar activity increased, the trough position was unaffected but the density increased threefold. The latitudinal distribution of electron temperature exhibited a nightside maximum at the trough which showed negligible changes in amplitude, width, and location over the period of analysis. The nightside temperature maximum can be related to the plasmapause phenomenon by invoking field-aligned heat conduction from the protonosphere. Within the plasmasphere, heat conduction from hot protonospheric plasma can potentially produce temperatures that increase with latitude at 1000 km, whereas beyond the plasmapause the temperatures can decrease again because the greatly reduced densities retard the heat conduction process.

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# THE MIDLATITUDE IONIZATION TROUGH DURING THE RISING SOLAR CYCLE

## INTRODUCTION

Among aeronomists a consensus has arisen that the magnetosphere contains a region within which the diurnal behavior of the internal thermalized plasma contrasts sharply with that of the external thermalized plasma. This inner magnetosphere, referred to as the plasmasphere, maintains a higher overall level of ionization than the outer magnetosphere (Taylor et al., 1965) and displays approximate diffusive equilibrium along field lines (Mahajan and Brace, 1969).

The impetus to define two distinct subregions for the magnetosphere came from the discovery of a sharp decrease in electron density ($N_e$) beyond $L \sim 4$ in the equatorial plane (Carpenter, 1963). The steep $N_e$ gradient was called "the plasmapause" and is generally considered to mark the transition between the plasmasphere and the outer magnetosphere. Carpenter's results were derived from ground based whistler measurements, but more direct observations of the plasmapause phenomenon have been made using charged particle traps (Gringauz, 1963; Bezrukikh, 1968), ion mass spectrometers (Taylor et al., 1965), and Faraday cups (Binsack, 1967; Vasyliunas, 1968).

In the topside F region, steep decreases in the latitudinal profile of $N_e$ have been measured near 60° geomagnetic latitude by Langmuir probes (Brace and Reddy, 1965). The drop in $N_e$ at midlatitudes is analogous to the ionization gradients associated with the plasmapause except that the former is often accompanied by an enhancement in $N_e$ poleward of the decrease; consequently, a midlatitude $N_e$ gradient appears as a trough of ionization. A midlatitude trough phenomenon at or below the $F_2$ peak has been identified in Alouette I topside sounder data (Muldrew, 1965), in ion trap measurements (Sharp, 1966), and in ground based ionosonde investigations (Bowman, 1969). Above the $F_2$ maximum, the ionization trough is evident in representative $N_e$ and light ion distributions (Thomas and Sader, 1964; Nishida, 1967; Taylor et al., 1968).

This paper analyzes the behavior of the trough region at 1000 km during the rising solar cycle. The analysis employs electron densities measured during the quiet winter periods between November 1, 1964 and February 15, 1967 ($A_p \leq 12$). Through these intervals the mean monthly Zurich sunspot number rose from 7.4 to 111 where 127 is near a maximum for the current solar cycle. The trough location is defined as the latitude of minimum $N_e$ or, if there is no sharp minimum, the latitude of the poleward edge of the rapid decrease in the latitudinal profile of $N_e$. Using this criterion, the experimental results show the year by year variation in trough location. Some electron temperature ($T_e$) information is also included as an aid in interpreting how extensively solar activity affects the trough at 1000 km.

## EXPERIMENTAL METHOD

The data used in this analysis came from the Langmuir probe experiment aboard Explorer 22. The Explorer 22 satellite is at 1000 km in a circular orbit with an 80° inclination. Its Langmuir probe experiment consists of two independent cylindrical electrostatic probes mounted on opposite ends of the satellite. A sawtooth voltage is applied alternately to each probe and the resulting current is measured. Separate sets of $N_e$ and $T_e$ values are deduced from the volt-ampere curves for each probe by using the Langmuir probe equations. The equations, details of the measurement technique and accuracies of the experiment have been discussed in previous papers (Brace and Reddy, 1965; Brace et al., 1967; Brace et al., 1968). The absolute accuracy of the $T_e$ and $N_e$ values is believed to be better than 10% and 20% respectively while relative accuracies are 5% and 10%.

RESULTS

Fig. 1 shows the latitude profile of $N_e$ and $T_e$ near the noon-midnight meridian at 1000 km during the winter of 1964. The straight lines join data points taken on a single satellite pass. The nightside data show clear trends whereas the dayside trends are less well geomagnetically ordered. For this period, the trough is located at 58°, the poleward edge of the latitudinal $N_e$ gradient. There is an apparent $T_e$ maximum associated with the trough. Similar data for subsequent years appears on Figs. 2 and 3. When the data become disordered in geomagnetic coordinates as on the dayside of Fig. 1, no magnetically aligned trough system is apparent even though some individual passes display density minima. Fig. 4 shows the ionization pattern at 1000 km in the dawn-dusk meridian. Here the F region base of the trough is intermediate between being completely illuminated and completely shadowed. Fig. 5 illustrates the effect at 1000 km of nightside solar illumination of the F region base of the trough.

From a series of $N_e$ plots similar to Figs. 1 through 4 the location of the trough was determined as a function of local time. The result is displayed as Fig. 6. The curve of trough latitudes is drawn through the data points for 1965 because the measurements were most complete for that year. Including the data points from 1964 and 1966 allows for direct comparison among the years and emphasizes that the most radical year to year change in $N_e$ behavior occurred between the years 1965 and 1966.

DISCUSSION

The results from an analysis of the local time behavior of $N_e$ imply that year by year variations within the midlatitude ionization trough arise from the influence of solar activity on the F region. Trough densities increased as the sunspot numbers increased. This trend is reasonable in view of the intensified ionizing radiation that accompanies rising solar activity.

Besides higher densities, the latitudinal profiles of $N_e$ exhibited less geomagnetic alignment on the nightside as the solar cycle advanced. One measure of alignment is the range of $N_e$ values detected at a given altitude. Fig. 7 compares this parameter for each year using the data from Figs. 1, 2, and 3. A possible cause of the mounting disorder is that as solar activity grows, more solar corpuscules precipitate into the polar ionosphere where they produce irregular $N_e$ enhancements.

All features of the trough region did not respond to solar cycle changes. Two such features will be discussed because of their possible connection with the plasmapause phenomenon.

The Trough Location and the Plasmapause

One trough characteristic that showed scant change with solar activity was its position. The local time behavior of the trough position was similar for each winter period between November, 1964 and February, 1967. Fig. 6 illustrates trough locations that are fartherest north at 0800 hours and fartherest south near midnight. These local time trends are consistent with those reported by Jelly and Petrie (1969).

If the equatorial edge of the trough and the plasmapause share a common formation mechanism, then the small solar cycle effects on trough movements could indicate a similarly small effect on plasmapause movements. Under a common origin postulate, the divergence between the local time behavior, ionization patterns, and L positions of the two phenomena as delineated by Nelms and Chapman (1969) can be attributed to the influence of solar wind compressions (Thomas and Andrews, 1968) and to ionization mechanisms at the lower altitudes. We can compare Figs. 2 and 5 to see one example of the latter effect. In this case, the winter trough pattern which resembles a plasmapause in Fig. 2 has been transformed into a summer pattern with a density minimum in Fig. 5. Nightside solar illumination of the F region has changed the trough configuration. Fig. 8 schematically depicts solar illumination of the summer nightside.

There is already some evidence to indicate that the locations of the trough edge and the plasmapause may have similar responses to variations in magnetic index (Rycroft and Thomas, 1968). It is reasonable to expect that these features should also have similar null responses to solar activity.

**The Trough Temperatures and the Plasmapause**

The other trough characteristic that was negligibly affected by solar activity was the latitudinal profile of $T_e$. The width, location and amplitude of the midnight $T_e$ maximum shown in Figs. 1, 2, and 3 was as unresponsive to changing solar activity as was the trough position.

The $T_e$ maximum can be linked to the plasmapause phenomenon by considering that differing heat conduction mechanisms operate within and beyond the plasmapause. Inside the plasmasphere, high temperature thermal electrons which have been detected in the equatorial plane can serve as a heat source for the 1000 km magnetosphere through heat conduction down the field lines. Measurements with a retarding potential analyzer show that $T_e$ for the hot electrons increases with increasing altitudes near the equator (Serbu and Maier, 1967). The observation requires that field tubes with higher L values should contain warmer plasma since L is proportional to the field tube's equatorial radius. In addition, whistler measurements indicate that while the total electron content within plasmaspheric field tubes increases for higher L values (Angerami and Carpenter, 1966), $N_e$ at 1000 km over similar latitudes decreases i.e., the increase in total tube content is predominately in the protonosphere where the temperatures are higher. The total effect favors an intensified downward heat flux at larger L values (Mahajan and Brace, 1969). This heat flow from the protonosphere creates the latitudinal increase in $T_e$ that is observed at 1000 km.

At the plasmapause, however, there is a rapid drop in total electron content. Theoretical derivations by Mayr and Volland (1968) indicate that plasma heat conduction becomes explicitly proportional to $N_e$ for the conditions that prevail beyond the plasmapause i.e., mean free paths on the order of a field tube length and $T_e$ nonlinearly altitude dependent. The resultant $N_e$ dependent heat conduction is less efficient at decreased $N_e$. Consequently, at 1000 km, $T_e$ within closed field lines in the outer magnetosphere can decrease with increasing L even though the temperature of the protonosphere is high. Under the proposed mechanism, the counter trends in the inner and outer magnetospheric electron temperatures produce the observed $T_e$ peak which should fall at or slightly poleward of the plasmapause field lines.

## CONCLUSION

Cylindrical Langmuir probe measurements made at 1000 km provide data that suggest that the amount of ionization and its distribution within the midlatitude trough are strongly correlated with sunspot number. $N_e$ increases and becomes less well ordered in geomagnetic latitude profiles as the sunspot number increases. However, the trough location and the $T_e$ latitude profiles display negligible solar cycle responses. $T_e$ latitude profiles contained a nightside temperature maximum whose amplitude, width, and location were negligibly modified by sunspot activity. The presence of the temperature maximum is consistent with the model of an abrupt change in the field-aligned heat conduction mechanism across the plasmapause.

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FIGURES

Figure 1. Day-night comparisons at 1000 km in the midlatitude ionization trough region during winter 1964. $R_z$ is the mean sunspot number for the indicated period.

Figure 2. Day-night comparisons at 1000 km in the midlatitude ionization trough region during winter 1965. $R_z$ is the mean sunspot number for the indicated period.

Figure 3. Day-night comparisons at 1000 km in the midlatitude ionization trough region during winter 1966. $R_z$ is the mean sunspot number for the indicated period.

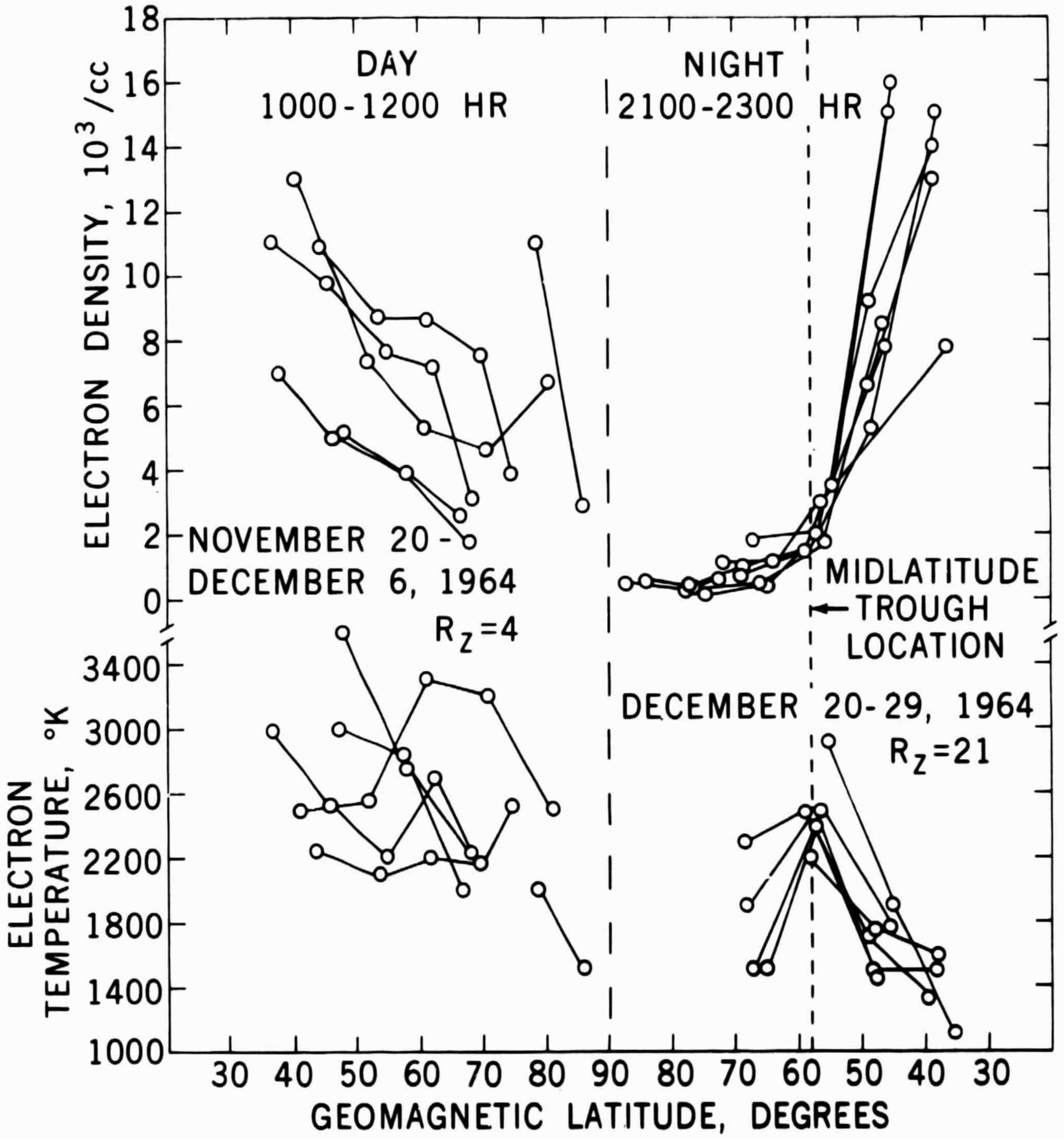
Figure 4. $N_e$ at 1000 km in the dawn-dusk meridian during winter 1965. $R_z$ is the mean sunspot number for the indicated period.

Figure 5. Nightside photoionization effects at 1000 km in the midlatitude ionization trough region during summer, 1965. $R_z$ is the mean sunspot number for the indicated period.

Figure 6. Local time behavior of the midlatitude trough position and its associated electron density at 1000 km. The 1965 data points are joined by a line so that the curve can be a basis for comparison with data from other years.

Figure 7. Summary of the increasing disorder shown in the nightside ionization patterns of Figures 1, 2, and 3. The range of density values at a given latitude is plotted. The 1964 data points are joined by a line so that the curve can be a basis for comparison with data from other years.

Figure 8. Schematic diagram of the midnight hemisphere depicting $N_e$ of the nightside ionosphere and the change induced in the ionization pattern at 1000 km. The shaded earth section is in darkness.

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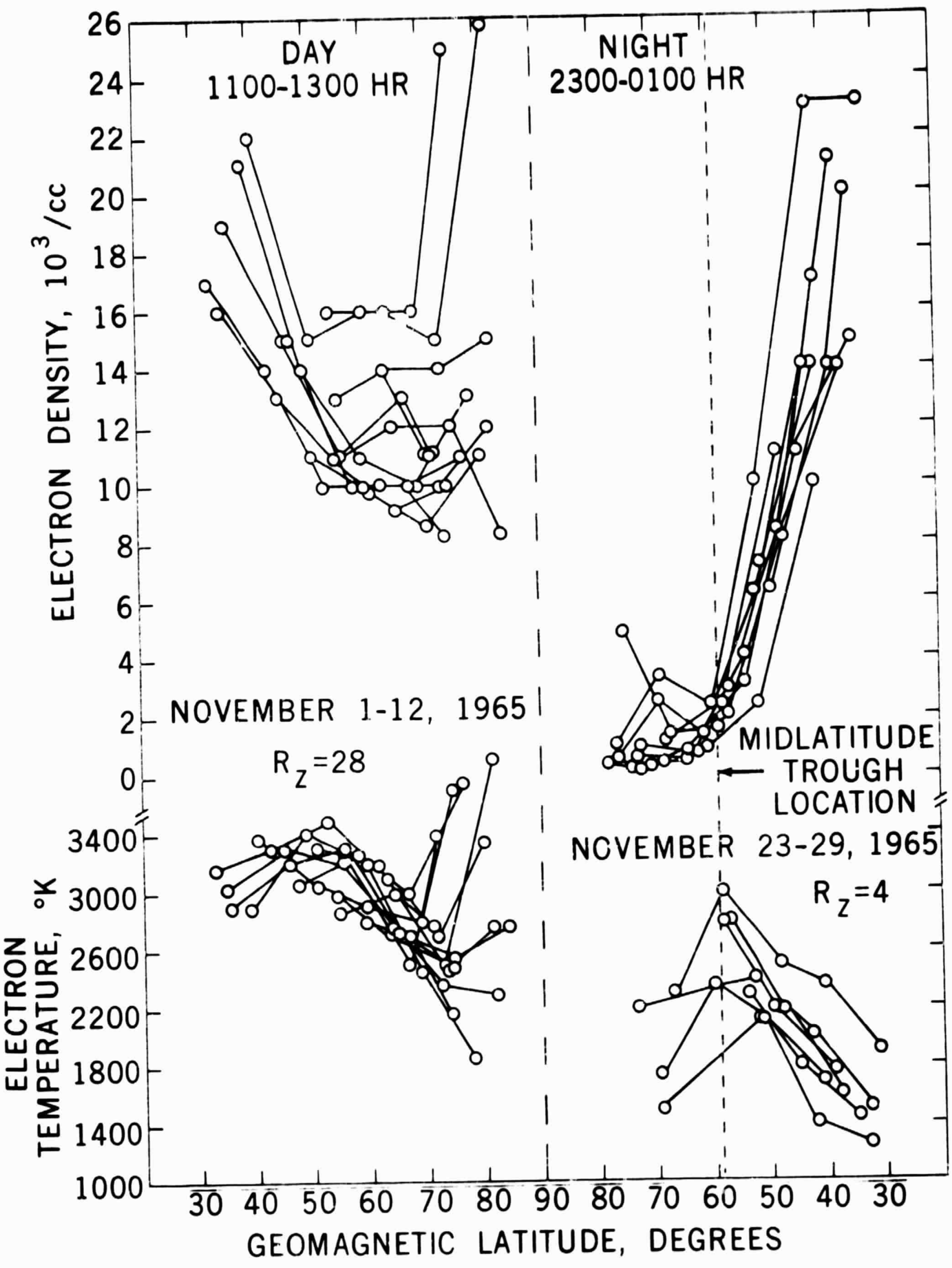


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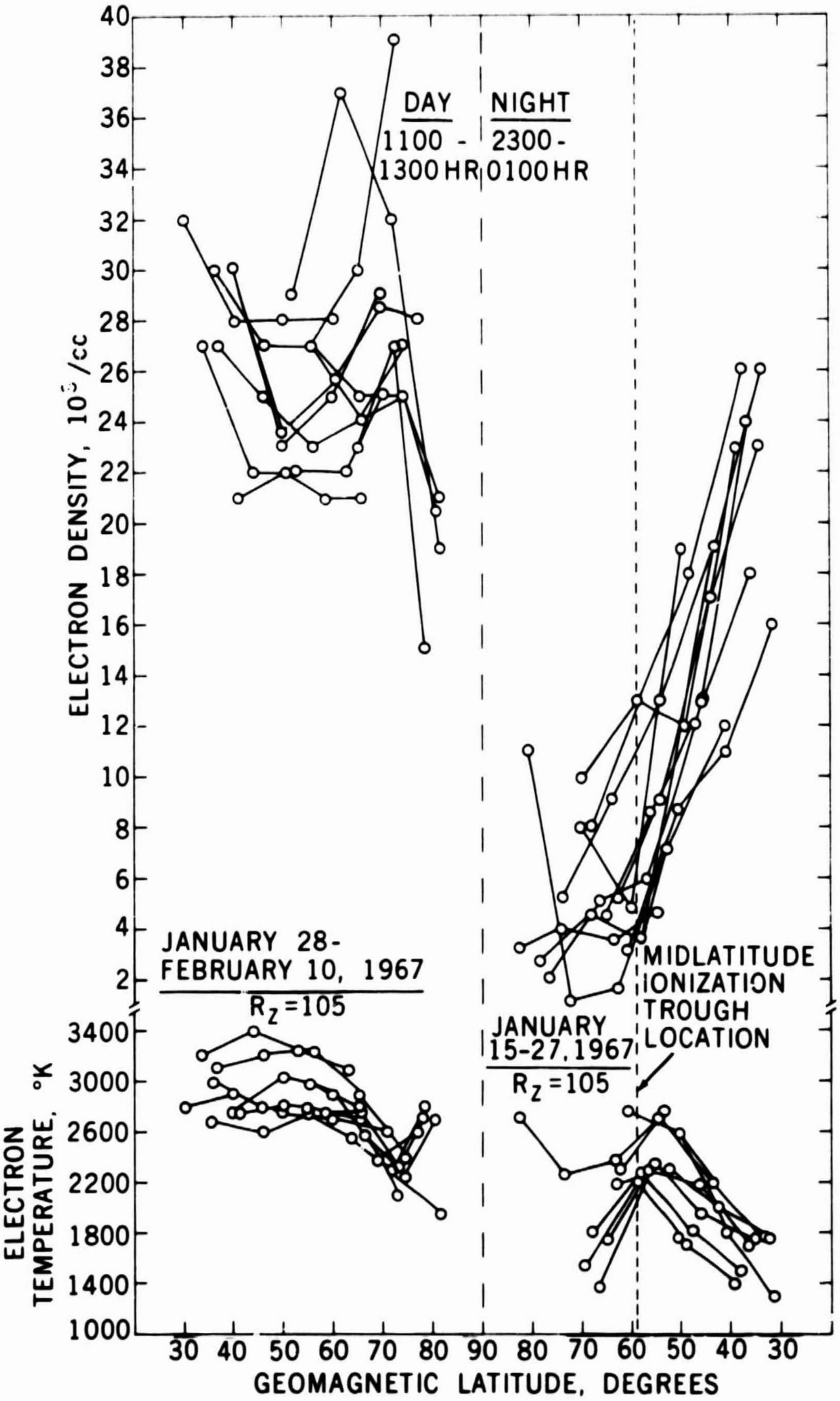
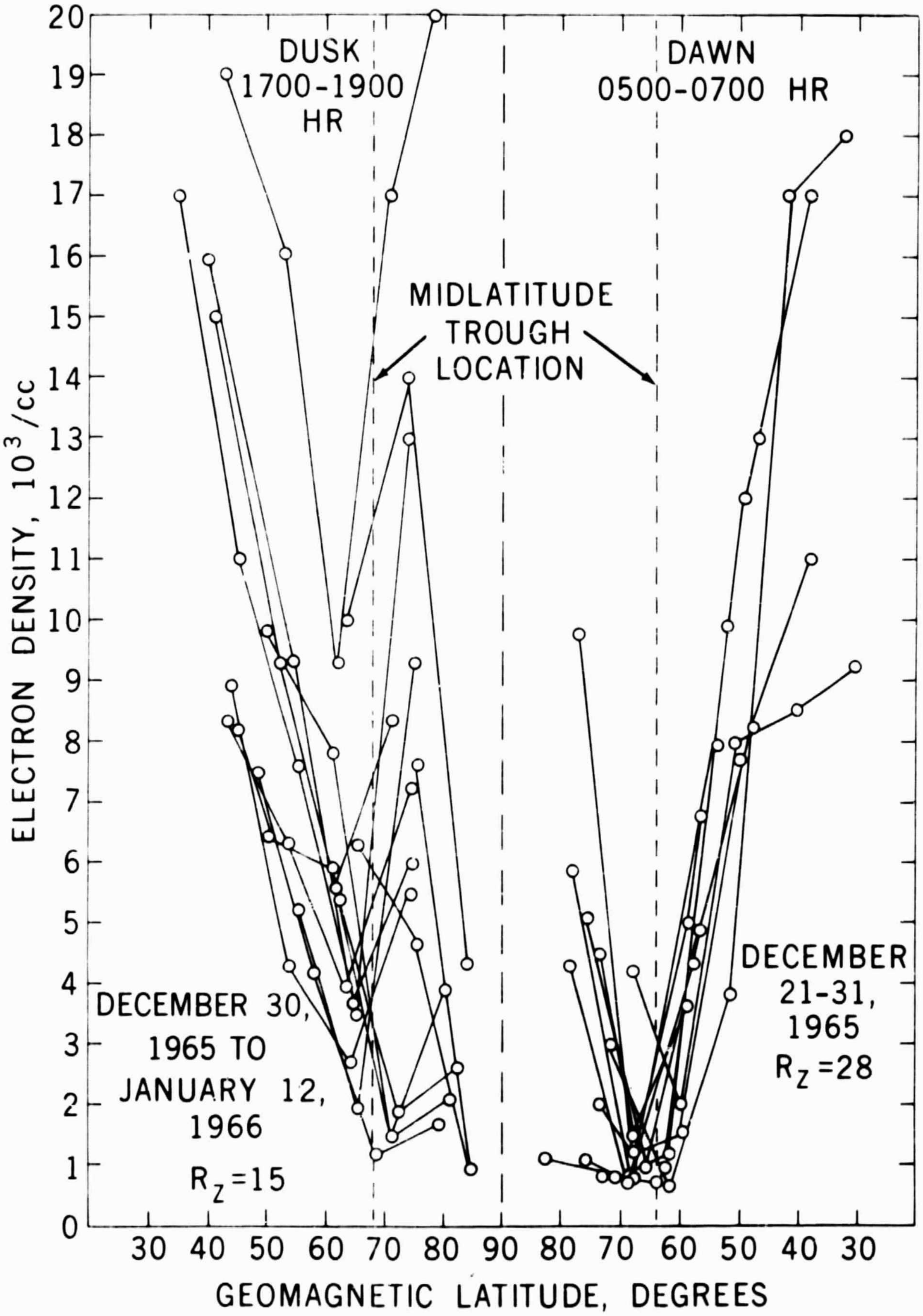



Figure 3. Day-night comparisons at 1000 km in the midlatitude ionization trough region during winter 1966. $R_z$ is the mean sunspot number for the indicated period.

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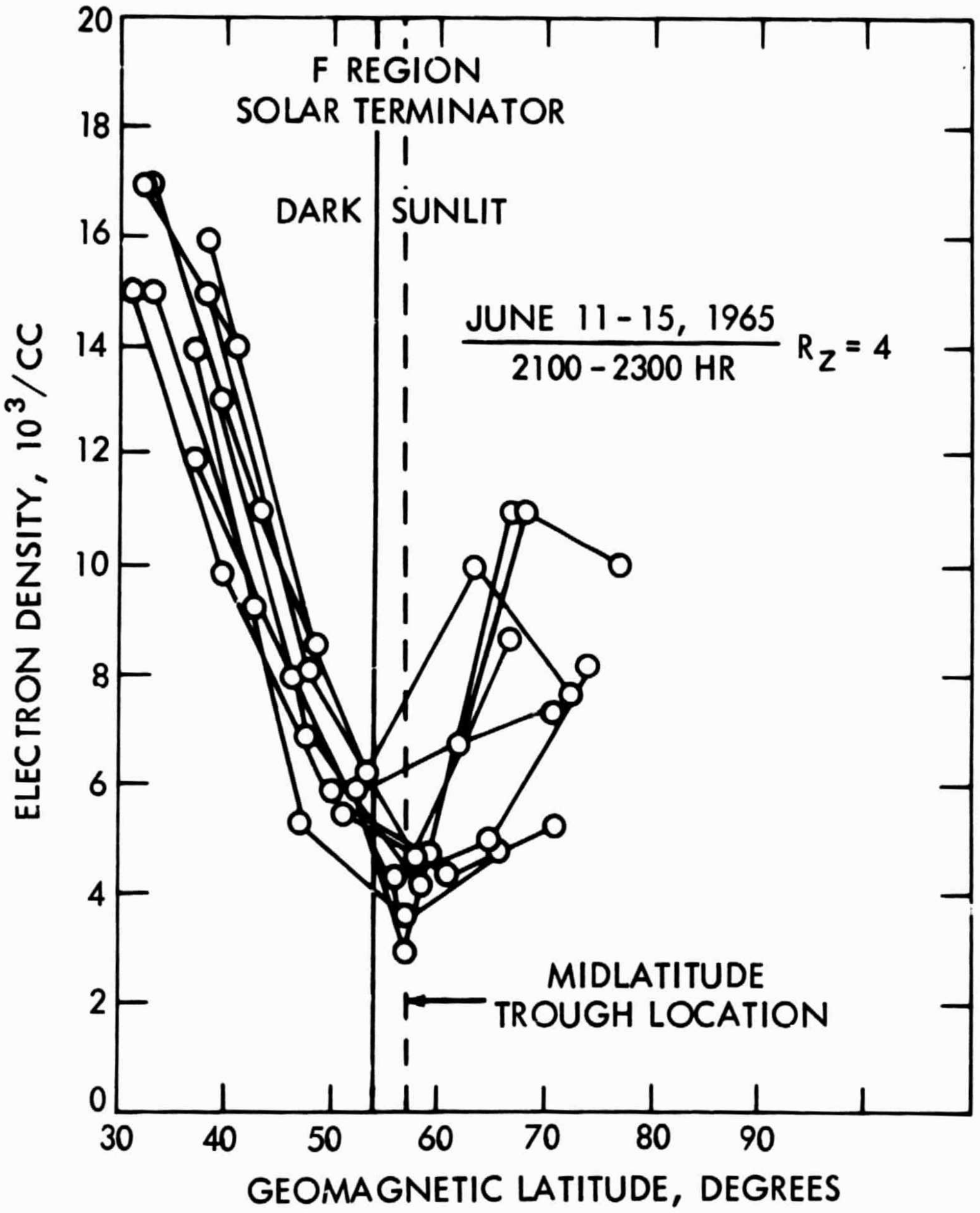


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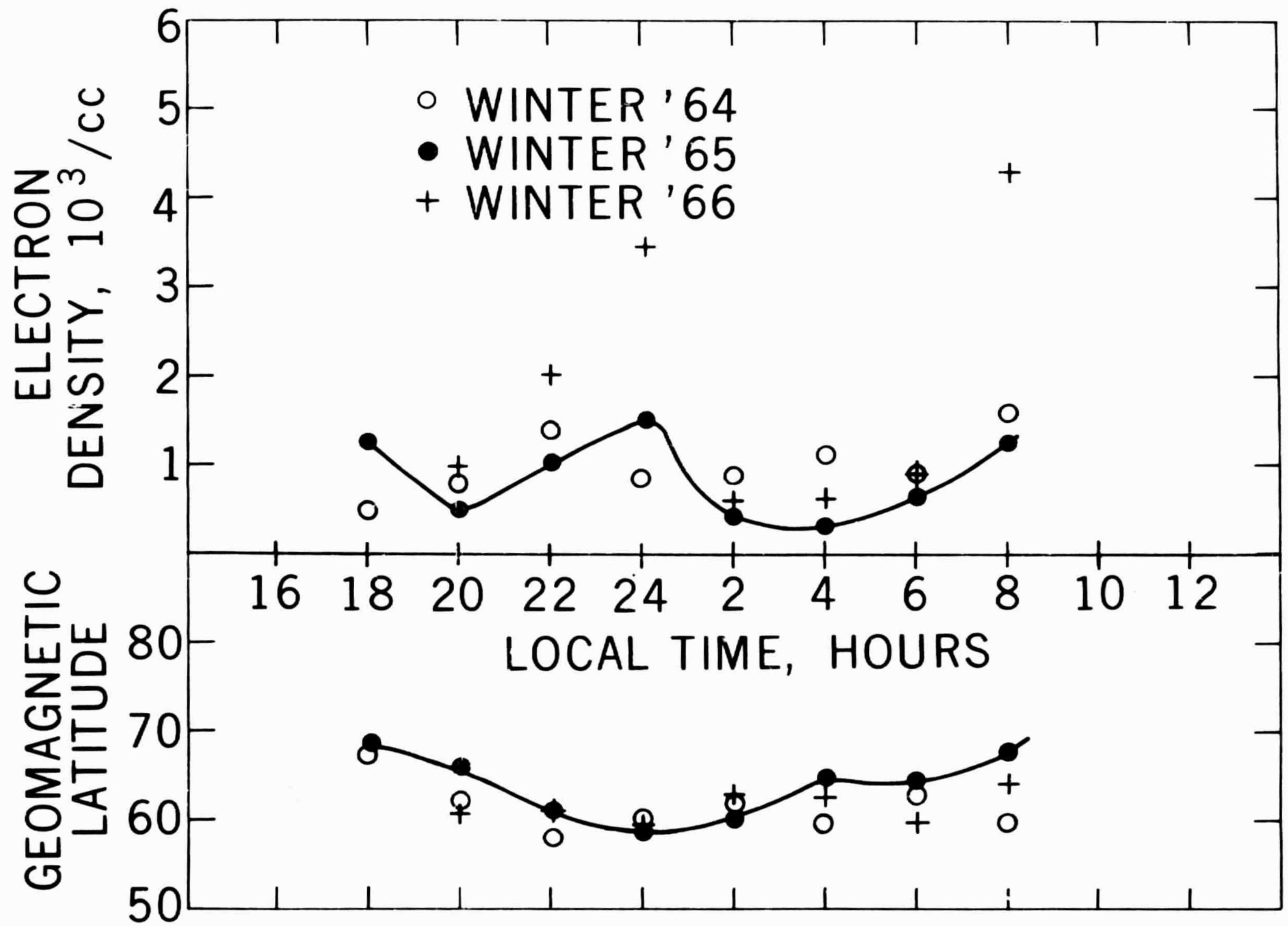


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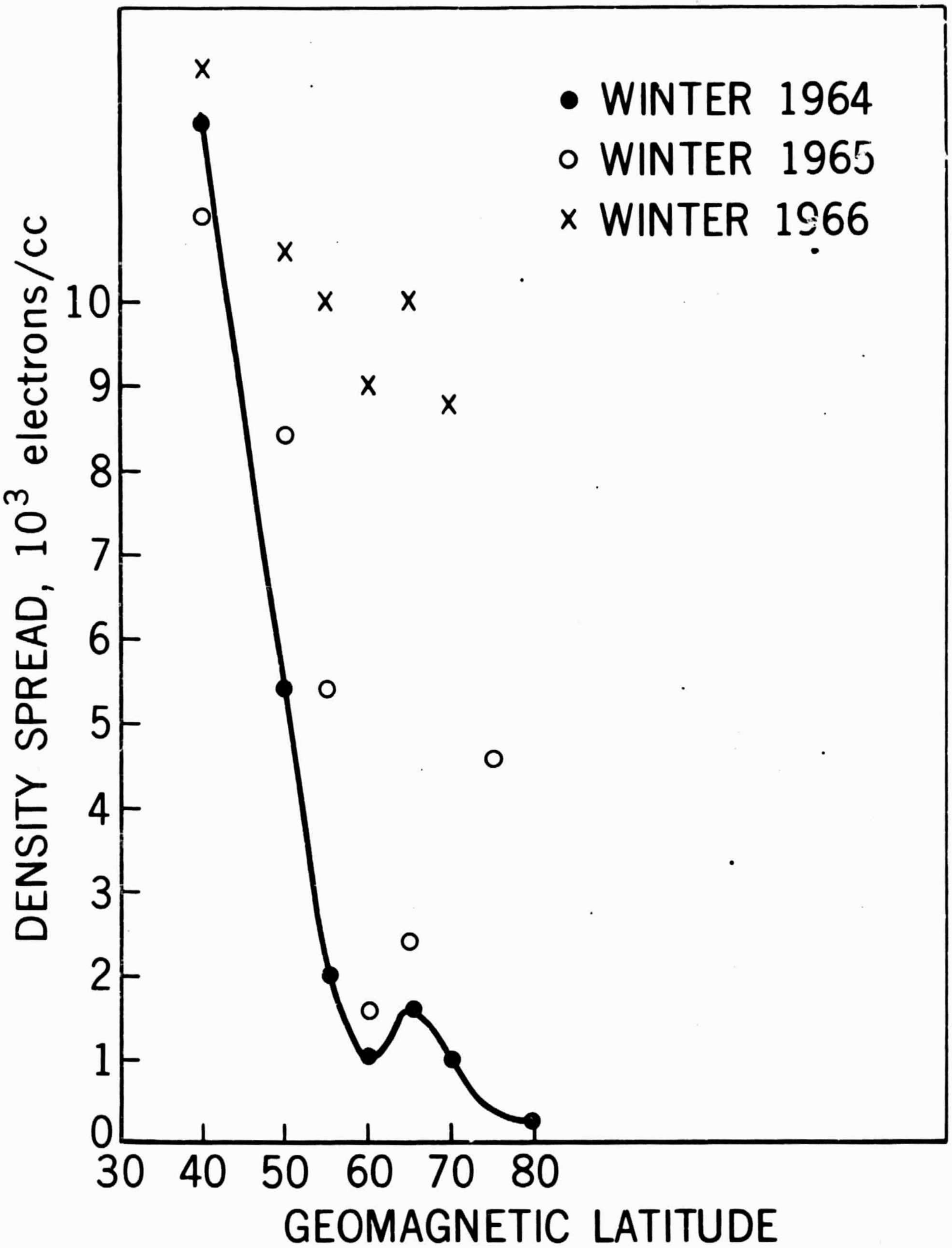


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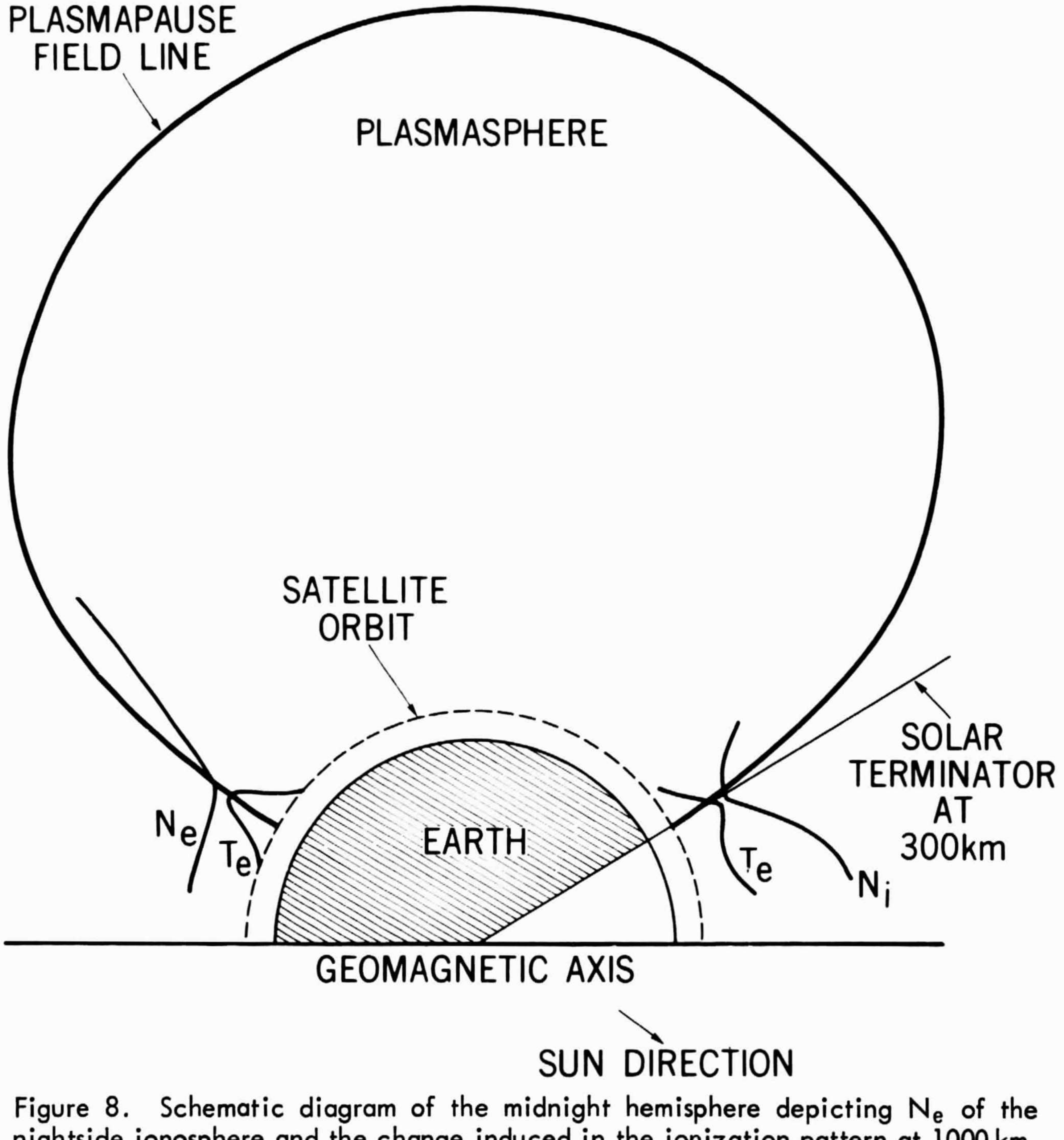


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