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Electron Densities and Temperatures in the F-Region from Backscatter Measurements at Arecibo

by

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UNPUBLISHED PRELIMINARY DATA

ABSTRACT

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The diurnal variation in electron densities and temperatures in the F-region above Arecibo, Puerto Rico is discussed. The morning build-up and nighttime decay of temperatures on several summer and winter days is presented as a function of height, and possible explanations are given for the seasonal differences.

Up to 375 km the ion temperatures appeared to be in good agreement with estimates of the neutral-particle temperatures except for a period of several hours after sunrise when significant departures were observed in the region of 300 km. Electron temperatures were generally observed to be about three times the ion temperatures during the day and to have a rather irregular behavior from day to day.

During the night, ratios of electron-to-ion temperatures, in excess of 1.2 were observed at all times in the region of the F_{max}.

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The site of the Arecibo Ionospheric Observatory in Puerto Rico has important advantages as a location to study F region phenomena. It is to the north of the equatorial anomaly and well to the south of the auroral region. Because its geographic latitude is about 18° and its geomagnetic latitude is 29°, magnetic and solar effects can be separated to some extent. The station is situated close to the termination of the magnetic shell with $L = 1.5$; thus both the length of the field line and the proton content contained in a tube subtending a unit area in the F region are much smaller than for higher latitude stations such as the Millstone Hill Radar Observatory of M.I.T. The conjugate region lies close enough to the South Atlantic anomaly that points throughout the F region have conjugate points below sea level; therefore effects resulting from trapped particles can be neglected.

Figure 1 shows the behavior of the ion and electron temperatures at 75 km intervals throughout an interval of twenty-eight hours on December 17 to 18th, 1964. During the day the electron temperatures in the F region were about three times the ion temperatures, with a marked dip occurring at about 10:00. During the night the temperatures decreased slowly after sunset, and in the 225 km to 400 km altitude range the ratio of electron-to-ion temperatures exceeded 1.5 throughout the night. At about 2:30 the electron temperature at 375 km and 450 km started to increase very rapidly even though local sunrise at these altitudes was not until 5:20

The daytime behavior is illustrated in more detail in figure 2, which shows the behavior of the electron temperatures at 300 km for four winter days. It is apparent that although the days were very similar as far as solar conditions were concerned the behavior of the electron temperature was very different. Of particular interest are the sudden changes in electron temperature that occur during the day. Such changes in the electron temperature are of obvious importance in the study of the F layer, for it is apparent that they will be accompanied by large changes in the equilibrium profile. When the electron temperature is decreasing, the plasma scale height is decreasing, and the electron content above the maximum will consequently decrease, causing ions to diffuse downwards. This will result in an increase in the peak electron density. The increase in electron density will change the rate of heat transport from the electrons, resulting in a further change in temperature. Equilibrium will be established when the recombination causes a sufficient reduction in electron density. A corresponding inverse effect can be produced by an increase in temperature associated with a decrease in density. Figure 3 shows the peak electron density and the electron temperature at 300 km on Dec. 18, 1964 to illustrate these changes.

Figure 4 shows a series of temperature and density profiles throughout this disturbance on December 18, 1964. It is apparent that there is a very large increase in the electron density and electron content between 8:00 and 10:00 hours accompanied by a decrease in electron temperature. From 10:00 to 13:00 hours the density and content are decreasing very rapidly and the electron temperature is increasing. The equations for the densities and temperatures in the layer are thus tightly coupled and, as is apparent from Figure 3, can depart considerably from an equilibrium profile during the period around noon. Serious errors may be made therefore, if under such conditions the layer is considered to be in equilibrium. Although the behavior appears very variable from day to day, it is likely that averaged over a prolonged period, such as a month, a minimum in electron densities at around noon could result in the "noon bite out" observed in some averaged measurements of peak electron density. The behavior during such disturbances is of considerable interest because of the mechanisms involved and because the nonequilibrium distributions allow an independent estimate of recombination and diffusion coefficients. Doupnik and Nisbet (1965) in another paper, to be presented at this meeting, discuss the detailed behavior during such events.

Figure 5 shows the build-up in electron and ion temperatures as a function of time for winter and summer days. During the summer the electron temperatures maintain their nighttime value until local sunrise and then increase rapidly at all altitudes. In winter, however, the electron temperatures start increasing well before local sunrise at altitudes of 300 km and above.

The conjugate point for Arecibo lies at 50°S 67°W and the local sunrise for this point is also included. It is apparent that because it is in the southern hemisphere at a relatively high latitude, sunrise in the conjugate ionosphere takes place much earlier than at Arecibo. The earth's shadow reached a maximum altitude of 300 km at the conjugate point on Dec. 17 to 18th.

This suggests that the rise in electron temperature before dawn is produced by photoelectrons from the conjugate ionosphere. These electrons would traverse the field line in less than one minute, so that the displacement of the minimum of the electron temperature from local midnight can be ascribed mainly to the time constant for electron cooling when the heat source is removed.

Figure 6 shows the behavior at sunset of the electron temperatures for summer and winter days. It is apparent that in summer, when the sun sets at the conjugate point before it sets at Arecibo, the electron temperature drops in about one and one-half hours to a nighttime value. This is in reasonable agreement with the delay in the nighttime minimum of electron temperatures in winter. In winter the electron temperature decreases slowly at 375 km and 450 km while the conjugate point is illuminated. It is apparent that the conjugate ionospheres are coupled by the photoelectrons and that electron temperatures and hence the electron densities are related. In particular when one or the other hemisphere is in darkness, photoelectrons will traverse the magnetic field lines from the sunlit ionosphere to produce heating in the conjugate ionosphere. As already discussed an increase in electron temperature above the F_{max} will produce a decrease in the peak electron density if the electron content is unchanged. It is suggested that the predawn reduction in electron densities often observed is due to heating of the upper ionosphere by photoelectrons from the conjugate locations.

Figure 7 shows the total heat input required to maintain the electron and ion temperatures observed during the night when the entire field line was in darkness, during the predawn period when the ionosphere above the conjugate point had been illuminated for 3 hours, and after local sunrise. Based on an average energy of 13 ev, fluxes of at least 2 x 10^{12} particles per square meter second would be required to maintain the temperatures observed prior to dawn if all the energy of the photoelectrons were assumed to be utilized in heating the ambient electrons. This figure has to be divided by the fraction of the energy utilized in heating the electrons to give the total photoelectron flux from the conjugate point. Carlson (1965) in another paper to be presented at this meeting considers the question of a flux of photoelectrons from the conjugate point and the consequent implications in detail.

The behavior of the ion and electron temperatures and densities as a function of height and time in the dawn and sunset periods is being investigated to provide information on the production and thermalization processes in the F region.

Conclusions

Ion densities and electron temperatures were observed to be very closely related, and large fluctuations in both occurred on separate days. These changes were observed to be very variable from day to day. Observations of the behavior of the layer under such nonequilibrium conditions are expected to provide useful information on the production, combination, and transport processes in the daytime ionosphere.

When the ionosphere above Arecibo was in darkness, and the conjugate ionosphere was illuminated, heating of the upper ionosphere by photoelectrons was observed at Arecibo. The predawn rise in electron temperature and predawn decreases in peak electron densities can be explained by this heating.

As shown by Doupnik and Nisbet (1965) in another paper presented at this meeting, during the daytime a decreasing electron temperature in the upper F region and the associated drop in scale heights leads to a peak electron density which continues to increase until recombination effects become dominant. This increase implies an increase in net electron content. In another paper presented at this meeting Carlson (1965), shows that during the winter nighttime a decreasing electron temperature associated with a conjugate point sunset again tends to increase the peak electron density (recombination effects would have to proceed slowly enough for this process to dominate if an actual increase is to be seen). In the absence of the solar ultraviolet radiation leading to local ion and photoelectron production, however, the effect of the upward heat conduction and the onset of recombination dominance is not present as in the daytime case. Thus the content remains essentially constant and the electron density merely undergoes redistribution in accordance with the changing temperatures and scale heights. Both of these effects are reversible in that the processes proceed in the opposite sense when the electron temperature increases.

In both cases an increase in electron temperature leads to a decrease in critical frequency, but the nighttime processes are very different from the daytime processes. The distinction outlined here must be realized in interpreting ionosonde data.

Comparison of winter and summer electron temperatures just before and after sunrise and sunset should provide interesting information on heat transport processes in the upper F region.

Acknowledgments

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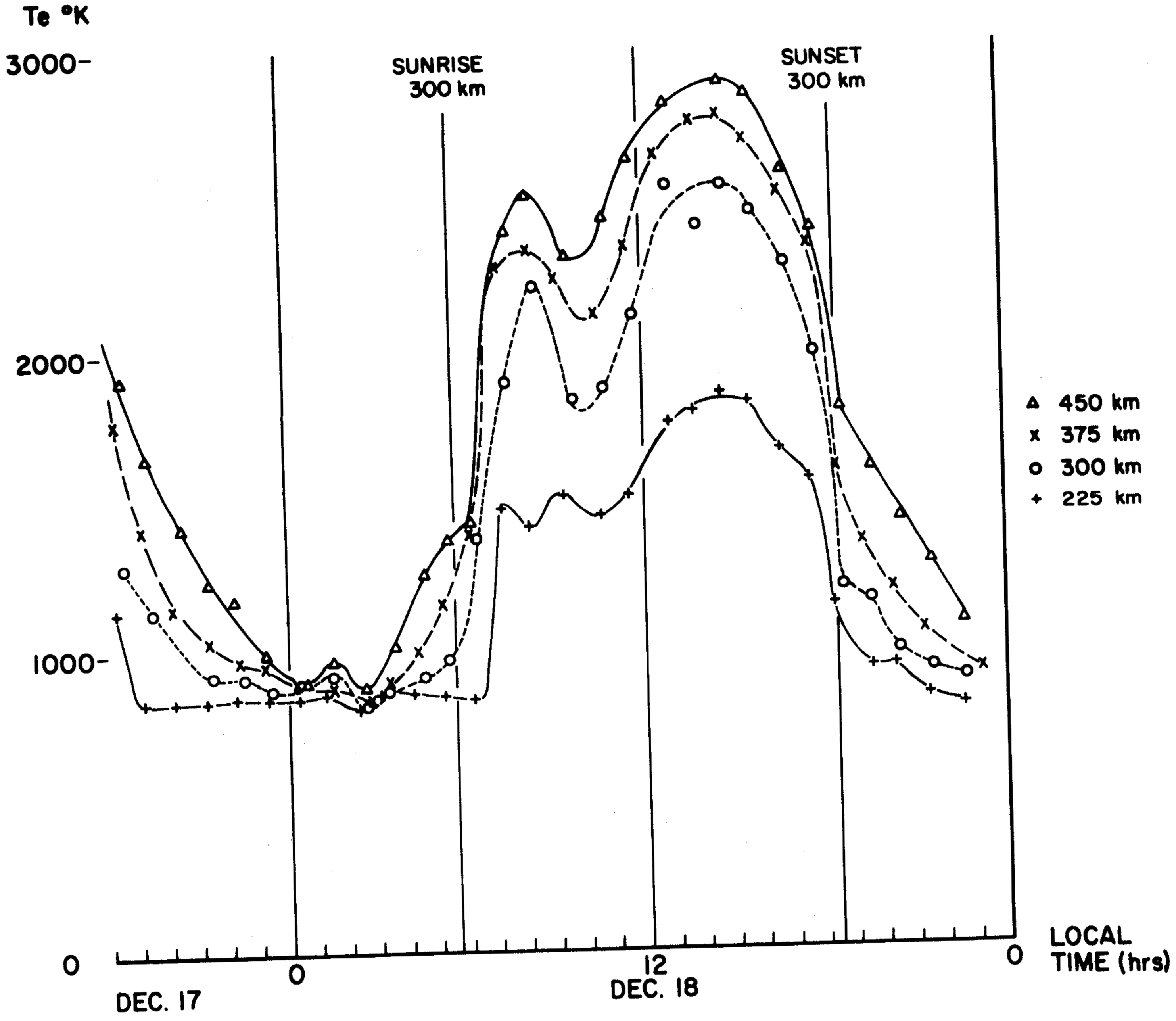
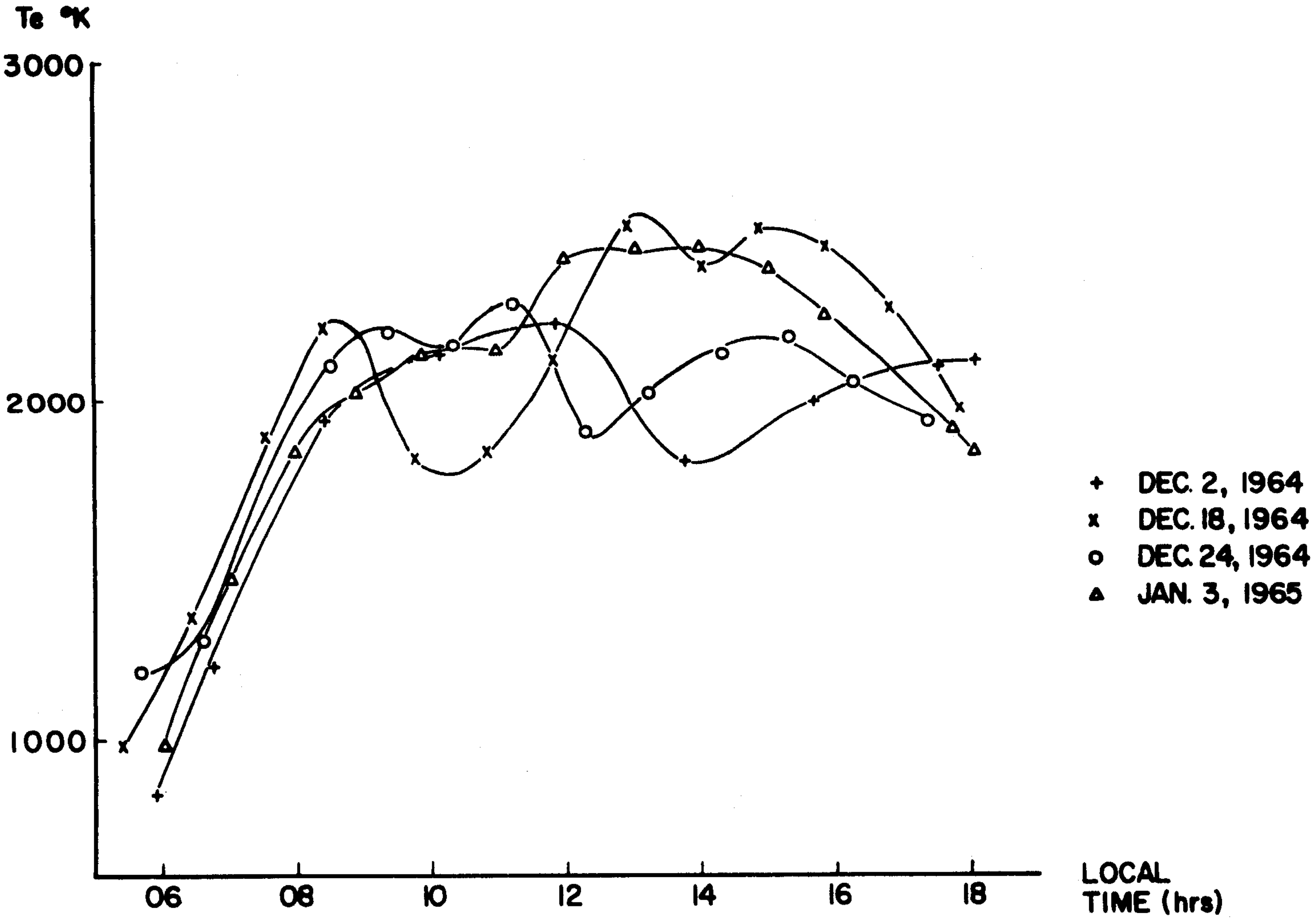


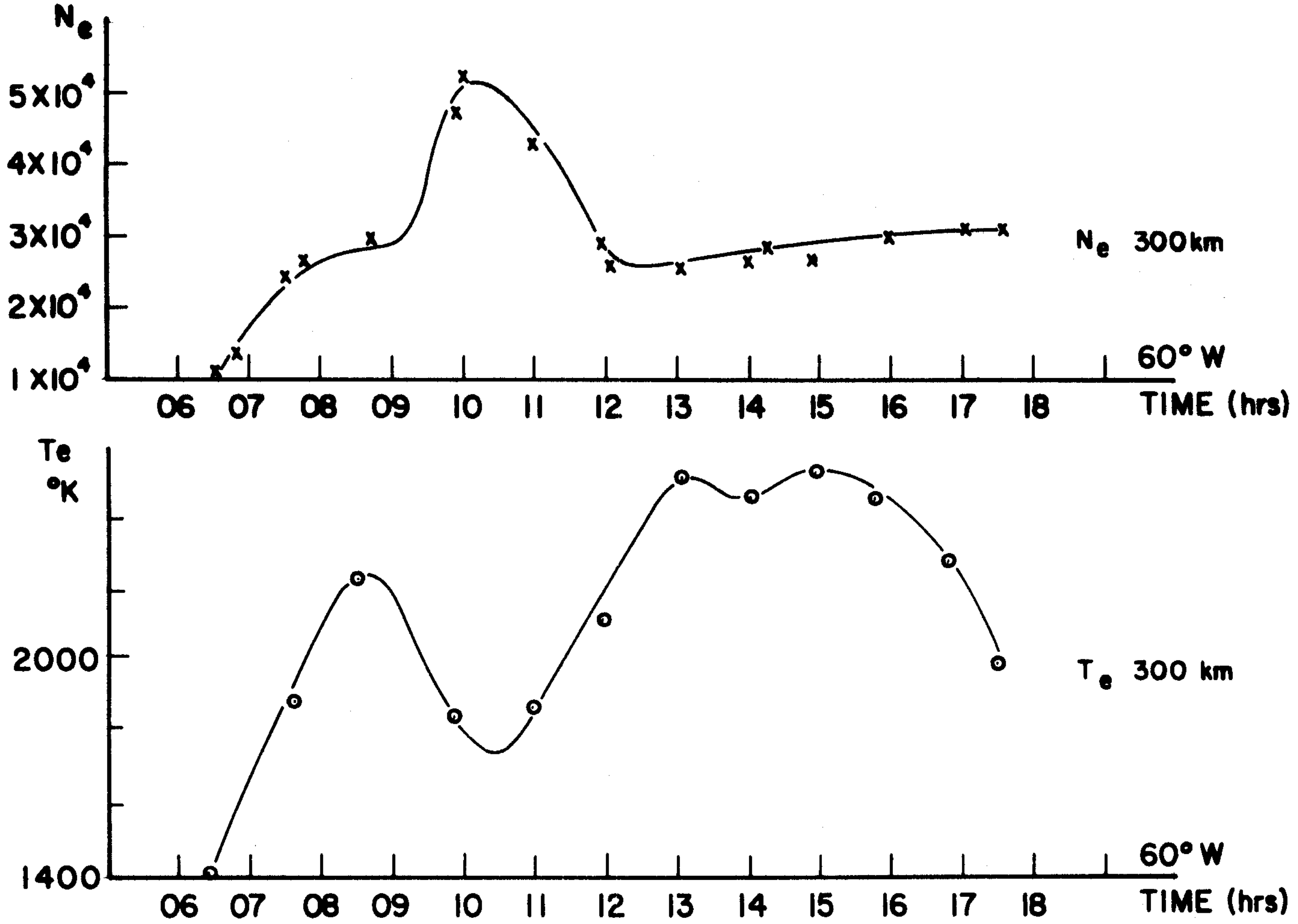
ELECTRON TEMPERATURES DEC. 17 – 18 , 1964

FIGURE 1



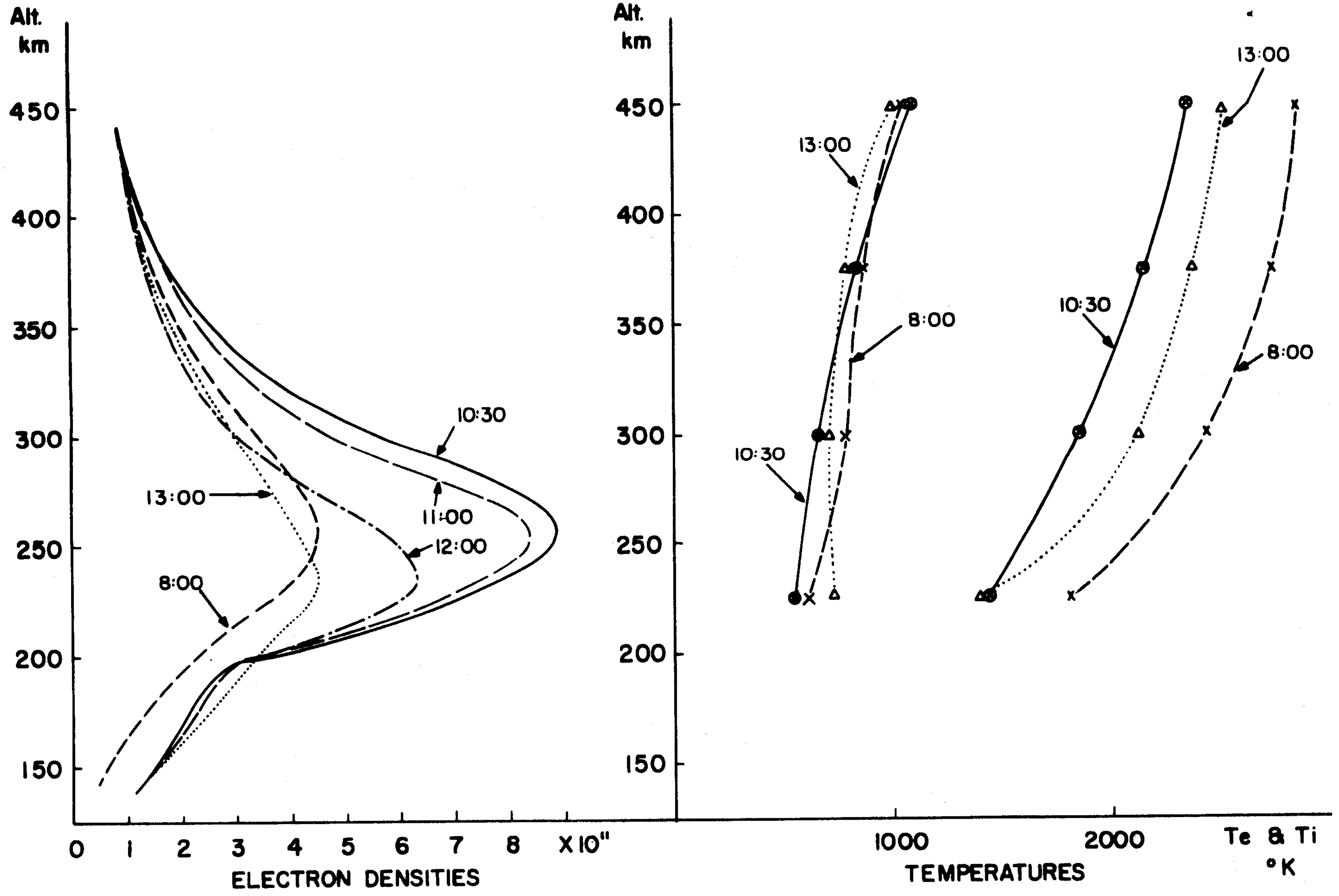
ELECTRON TEMPERATURE AT 300 km

FIGURE 2



DECEMBER 18, 1964

FIGURE 3



18 DEC. 1964
FIGURE 4

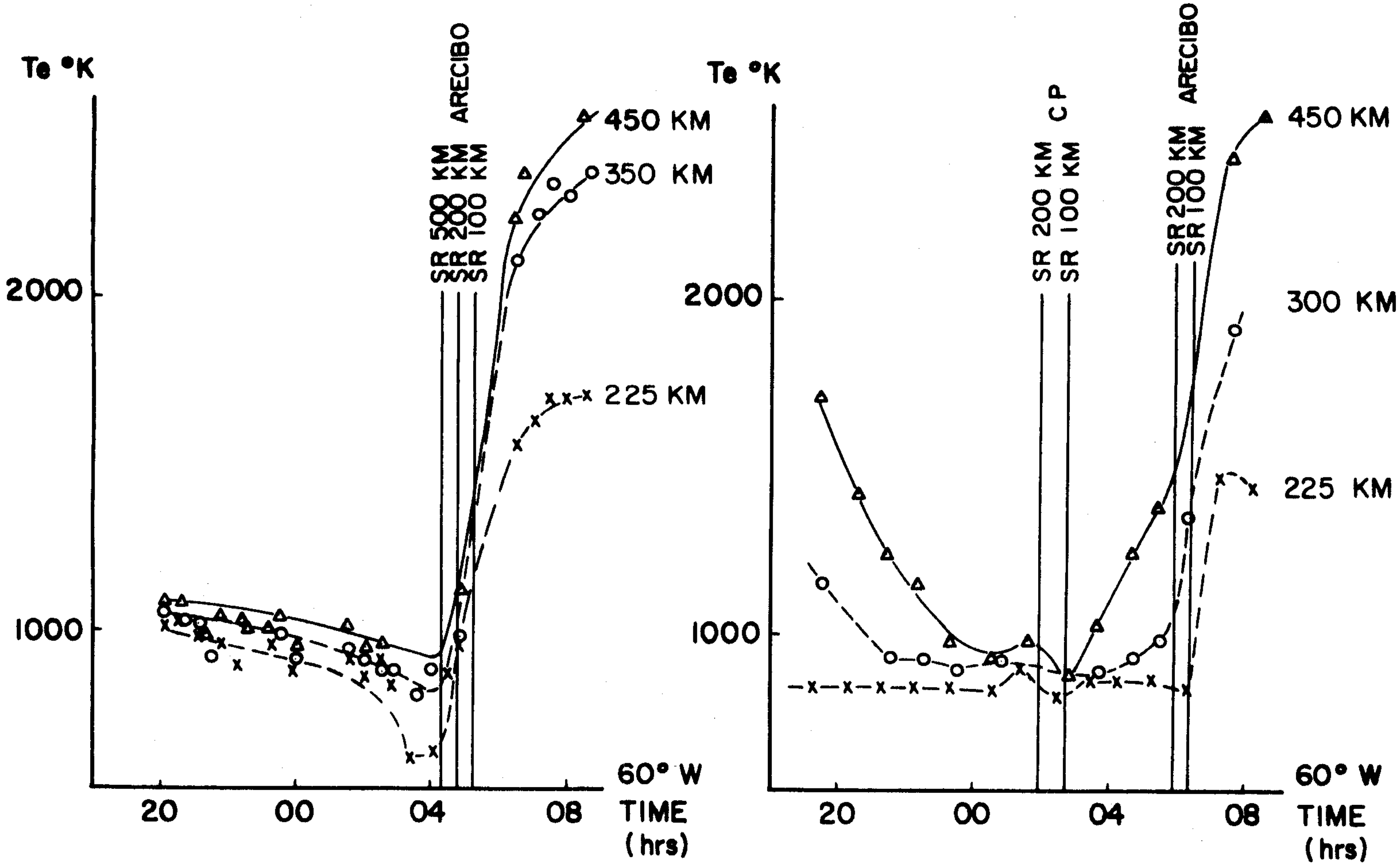


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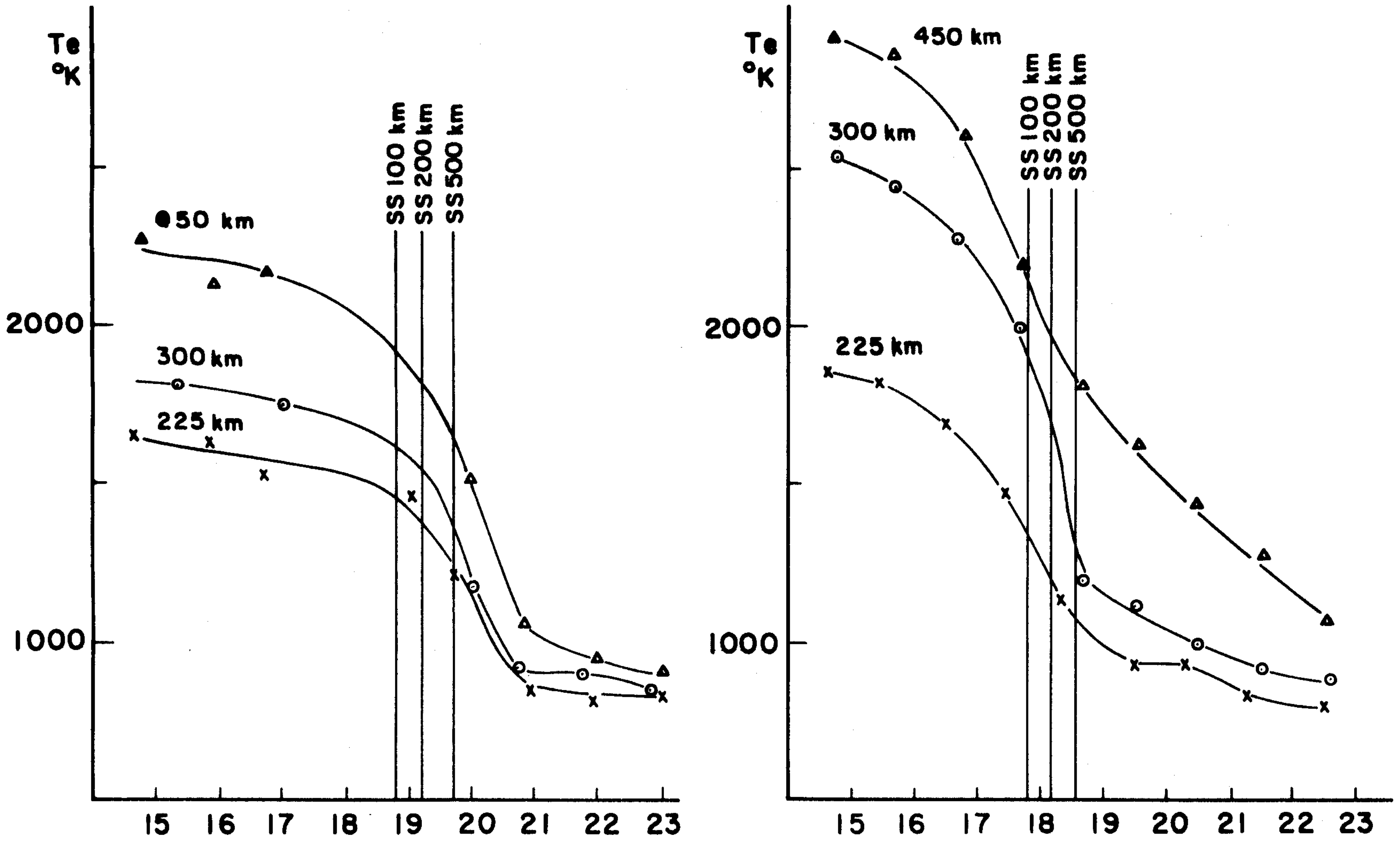
FIGURE 5



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DECEMBER 18, 1964

FIGURE 6

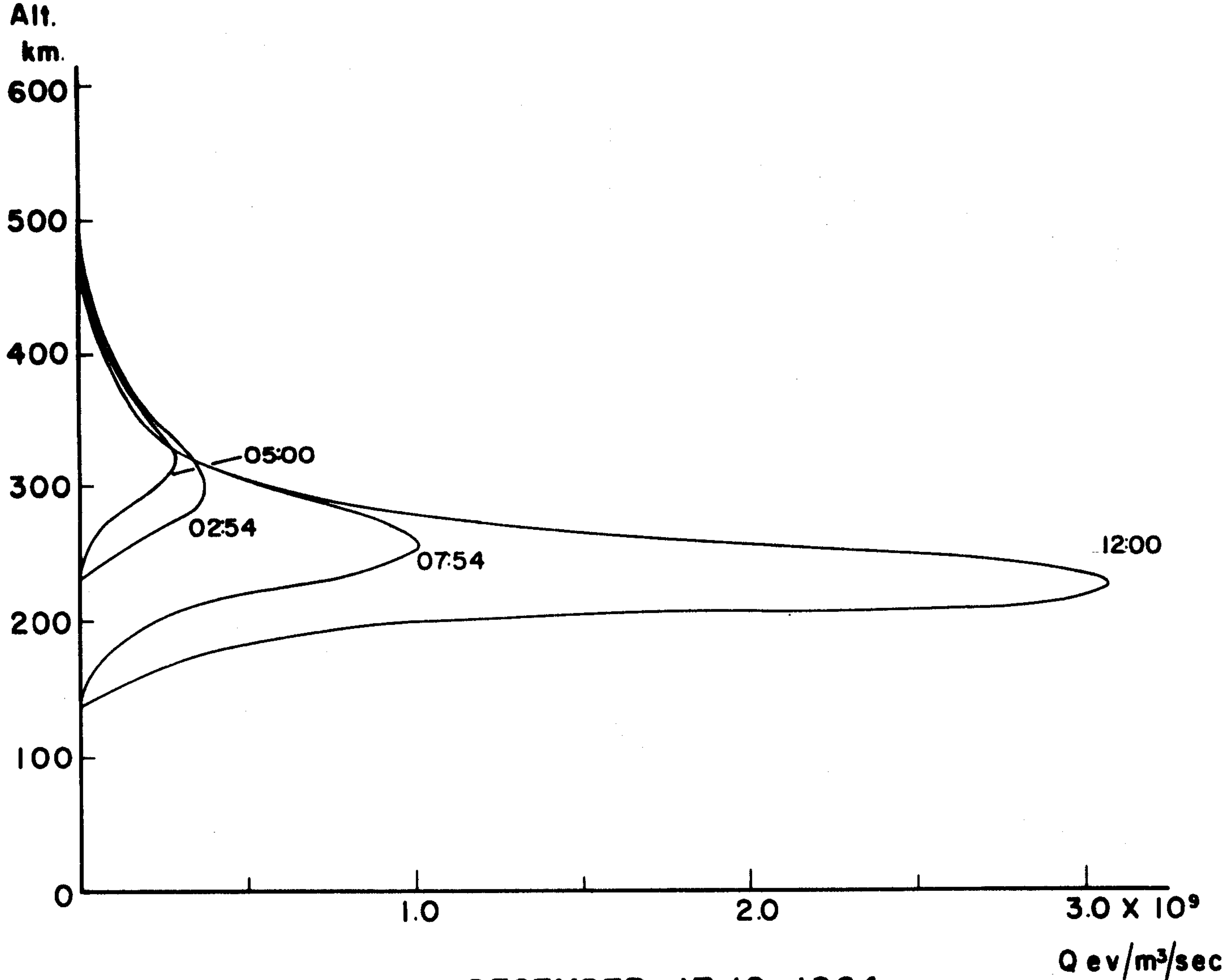

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FIGURE 7