Electron, Ion and Neutral Temperatures at the Magnetic Equator

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In this paper we will discuss the thermal structure of the equatorial ionosphere. Electron density and electron and ion temperature profiles measured as explained by Farley et al[1] between June 1965 and November 1966 at the Jicamarca Radar Observatory (dip 2°N) will be discussed. The height range considered will be 200-800 km, with major emphasis on the 200-500 km range.

In the above time and height interval, the nighttime electron temperature (T_e) and ion temperature (T_i) were always equal and constant, to within the experimental errors. It can be concluded, therefore, that there was no measurable input of thermal energy at night up to at least 800 km. Limits of 50 to 75° can be put on both T_e-T_i and the departure of T_e or T_i from constancy at night. The maximum value of Q_e depends on electron density N_e as follows:

$$Q_e/N_e^2 = 5 \times 10^{-7}(T_e-T_i)/T_e^{3/2} \qquad (1)$$
$$< 2.5 \times 10^{-9}$$

Nighttime electron densities varied over a wide range, and it is necessary to consider each example separately. At 400 km the density was sometimes as low as $1-3 \times 10^4$ electrons/cm^3. Thus the nighttime, equatorial upper limit of Q_e was one to two orders of magnitude below the values of 20-40 eV/cm^3/sec at 400 km at night given by Brace, Spencer and Dalgarno[2] and Evans and Lowenthal[3] for temperate latitudes.

In the daytime, except for about 2 hours following sunrise, the T_e and T_i profiles had the general shape shown in Figure 1. The ion temperature increased about 100° between 200 and 300 km, then remained nearly constant from about 300 to 450-550 km. The electron temperature rose to a maximum value of 1500-2000° at 240-260 km, then rapidly decreased, becoming approximately equal to T_i at about 300-350 km and above. The next region, where T_e and T_i were nearly equal and constant, was 100-200 km wide, centered on about 400 km.

The electron density maximum was usually in the lower half of the isothermal region. Figure 2 shows the equatorial isothermal region schematically. Above the isothermal region T_e and T_i were still nearly equal, but increased rapidly with height.

Figure 3 shows the diurnal variation of temperature in the isothermal region at 400 km for six 2 to 6 day periods. Also, the variation of T_i at 200-250 km is shown for two of the periods. The actual data points are shown, except in the last period, 10-16 November 1966. Here, because of the large number of observations, only the limits of the scatter of the data are shown. Figure 4 shows the variation of ion temperature at sunrise, when T_e/T_i was greater than one at all heights to at least 500 km.

Though there are differences in the diurnal amplitude of the curves in Figure 3, their shape is very similar. During sunrise, T_i increased very rapidly. After sunrise, from 08h to 16^h, the temperature in the isothermal region at 400 km increased at a slower, nearly constant rate of about 16°/hour. After reaching a late afternoon maximum, it decreased rapidly (as fast as 100°/hour) around the time of sunset. At night, from 21^h until sunrise, the temperature decreased at a slower, nearly constant rate of about 10°/hour. Evans and Lowenthal[3] show a diurnal curve of T_i at 300 km which varies in nearly the same way.

The observed T_e and T_i variations agree in amplitude but not in shape with T_n variations infered from satellite drag. However, if the incoherent scatter variation were 3 hour time smoothed, the resulting shape would be in better agreement with satellite drag data. The observed minimum and maximum temperatures just before sunrise and sunset are consistent with heating by EUV radiation only[4]. In contrast, satellite drag measurements imply a maximum temperature at 14^h, which requires another heat source in addition to the EUV source to bring the predicted and observed variations into phase[4].

The T_i variations at 200-250 km as shown in Figure 3 are very similar to the T_e and T_i variations at 400 km. Nighttime temperatures at 200-250 km and 400 km are equal. Daytime temperatures at the lower heights are about 100° lower than those at 400 km. This is consistent with reasonable T_n variations.

The values of T_e and T_i presented here are upper limits for the value of T_n. At night T_n is probably very nearly equal to T_e and T_i due to the low value of nighttime heat input discussed above. However, in the daytime, T_e and T_i may be substantially above T_n. The correction factor depends on the value assumed for the daytime heat input. An examination of the data in Figures 1 and 3 reveals that, if the nighttime correction factor T_e-T_n is small, then the daytime correction factor cannot be larger than about 50-150° (except for the December 1965 data) without reducing the diurnal amplitude of T_n excessively.

Our measurements of N_e, T_e and T_i give information on the heat source. Figure 5 shows Q_e computed from the data of Figure 1. The N_e^2 and $(T_e-T_i)/T_e^{3/2}$ terms are shown separately. T_e-T_i is not a well determined quantity above about 300 km. However, Q_e can be extrapolated upwards from the region where it is well determined. Using a 55 km scale height, Q_e is 300 eV/cm^3/sec at 400 km. Formula 1 then predicts a T_e-T_i of 60°. This is not inconsistent with the measurements of T_e and T_i. T_e, the more accurately determined quantity, was $980^\circ \pm 50^\circ$ at this height (see Figure 1), but T_e/T_i could have been as great as 1.1. T_i-T_n can be computed from

$$Q_e = 9 \times 10^{-14}\, n(O)\, N_e (T_i - T_n) \qquad (2)$$

since atomic oxygen is the dominant ion and neutral particle. The coefficient 9×10^{-14} is taken from Banks[5] for $T_i = T_n = 900^\circ$. Using 7×10^7 for n(O), $T_i - T_n = 85^\circ$. The total T_e-T_n is 145°, which is a large correction of the diurnal amplitude shown in Figures 1 and 3, but still within acceptable limits considering the accuracy of the data.

Other investigators[2,3] have measured the daytime Q_e at 400 km in temperate latitudes for similar solar activity and obtained values of 50-70 eV/cm^3/sec. These Q_e values were directly measured, as T_e-T_i is an observable quantity at 400 km in temperate latitudes. The lower Q_e values imply a T_e-T_n correction factor of only 25-35° for this example. Further investigation of the heat input and temperature corrections discussed here is desirable.

In closing, one additional point deserves brief mention. From June 1965 to January 1967 the maximum value of Q_e observed at Jicamarca increased from approximately 1000 to 4000 eV/cm^3/sec. This parameter may prove to be a more sensitive index of the solar EUV heat flux than presently used parameters such as the 10.7 cm flux.

References

(1) Farley, D. T., J. P. McClure, D.L. Sterling and J.L. Green, in press, 1967.

(2) Brace, L. H., N. W. Spencer, and A. Dalgarno, Planet, Space Sci., 13, 647, 1965.

(3) Evans, J. V., and M. Lowenthal, Planet. Space Sci., 12 . 915, 1964.

(4) Harris, I., and W. Priester, J. Geophys. Res., 67, 4584, 1962.

(5) Banks, Peter., Planet, Space Sci., 14, 1105, 1966.

Figure Captions

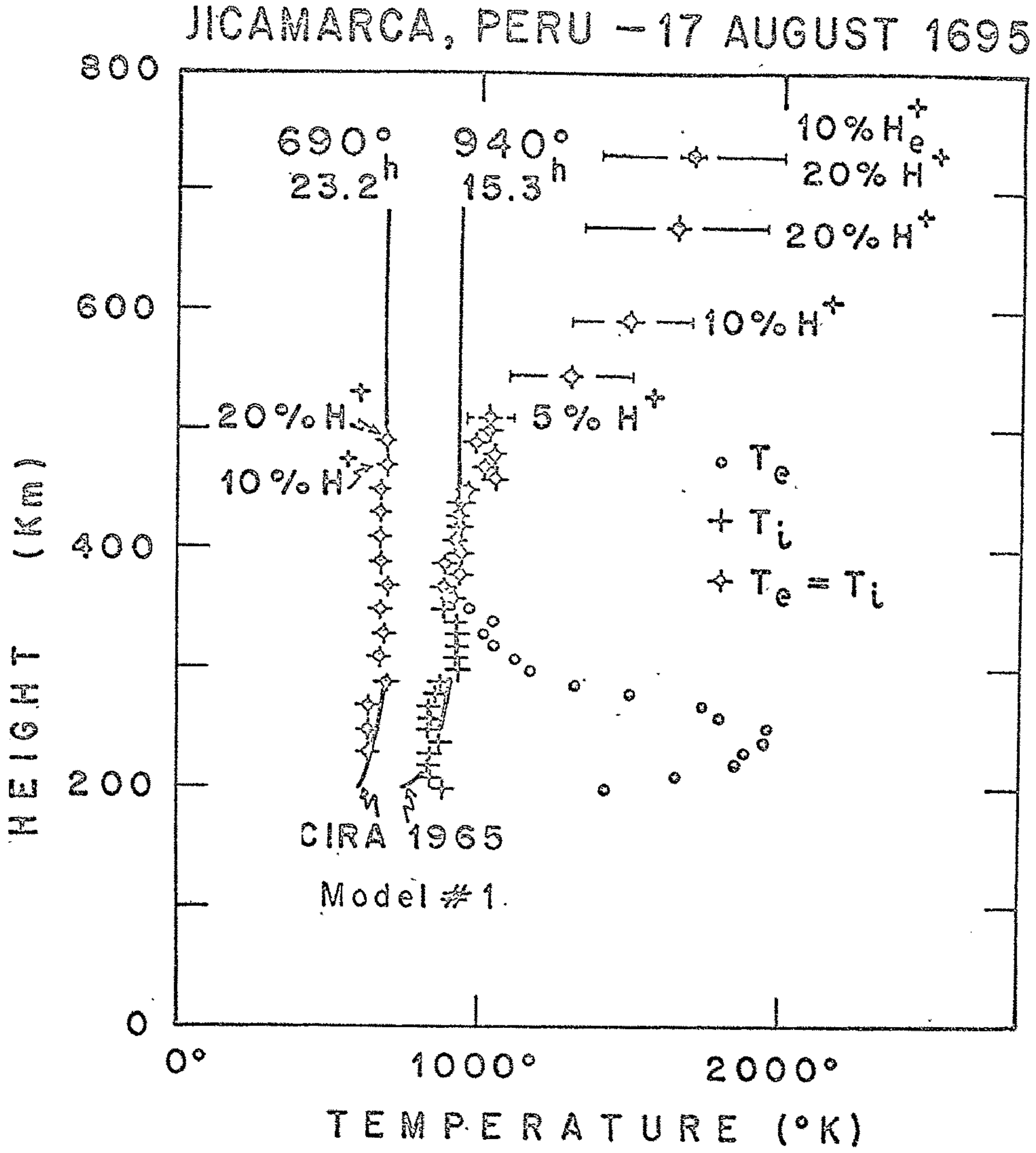
Fig.1. Electron and ion temperature profiles.

Fig.2. The equatorial belt of nearly equal and constant T_e and T_i. At night the belt extends from 200 to 800 km.

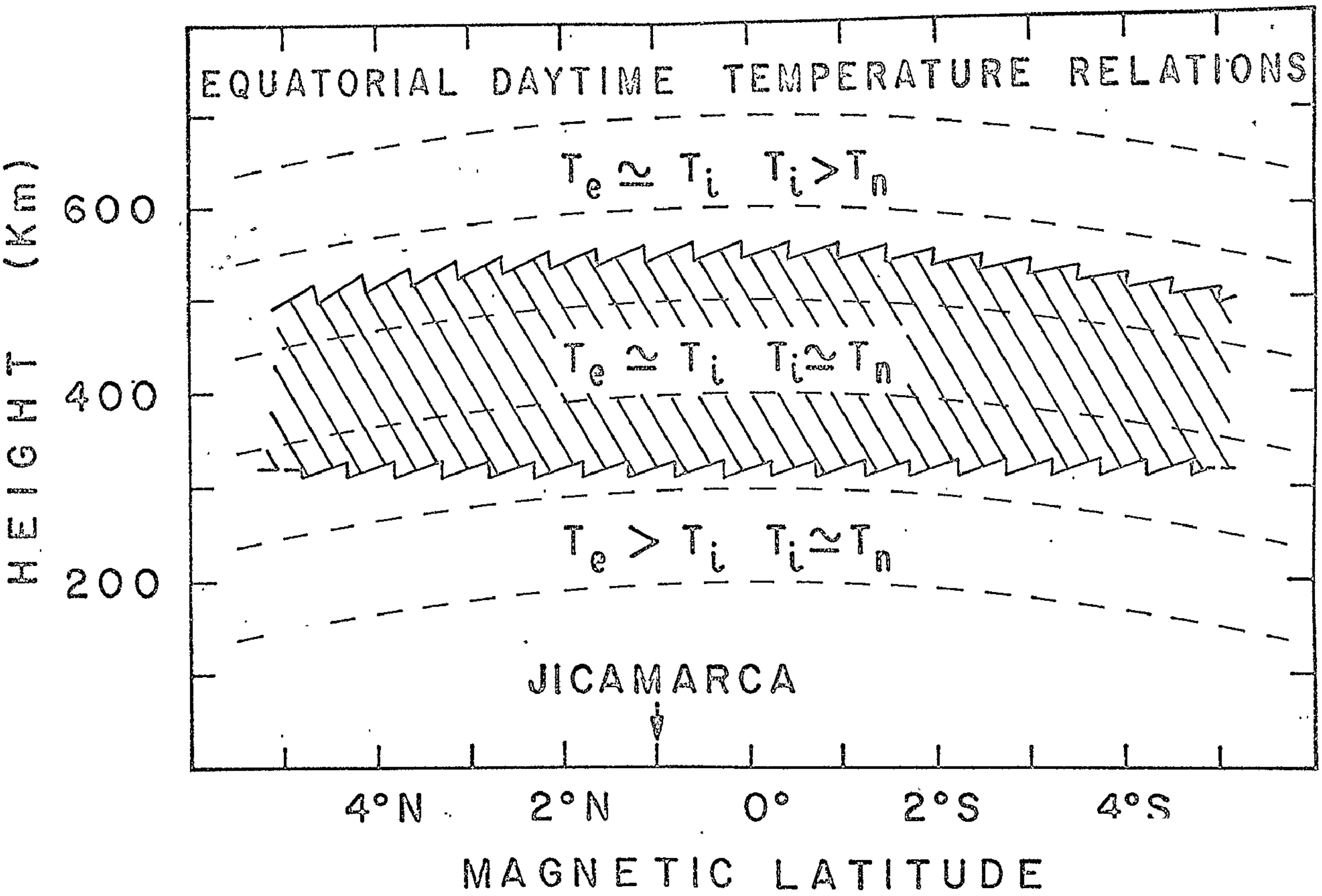
Fig.3. Diurnal curves of T_e and T_i at 400 km. T_i at 200-250 km is also shown on two occasions.

Fig.4. Sunrise ion temperatures.

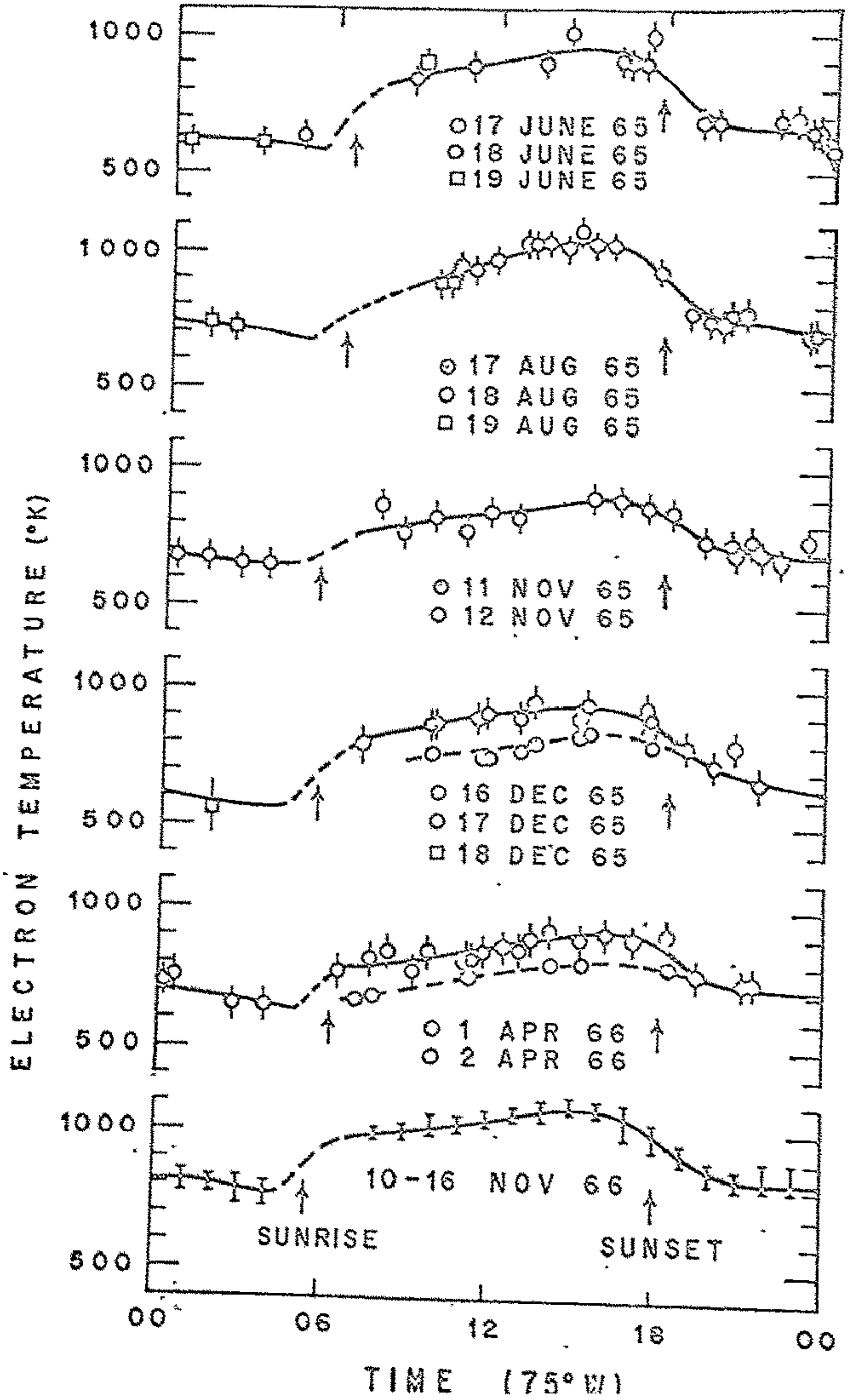
Fig.5. Profiles of $N_e^2, (T_e-T_i)/T_e^{3/2}$ and Q_e for the daytime temperature profile of Fig.1.

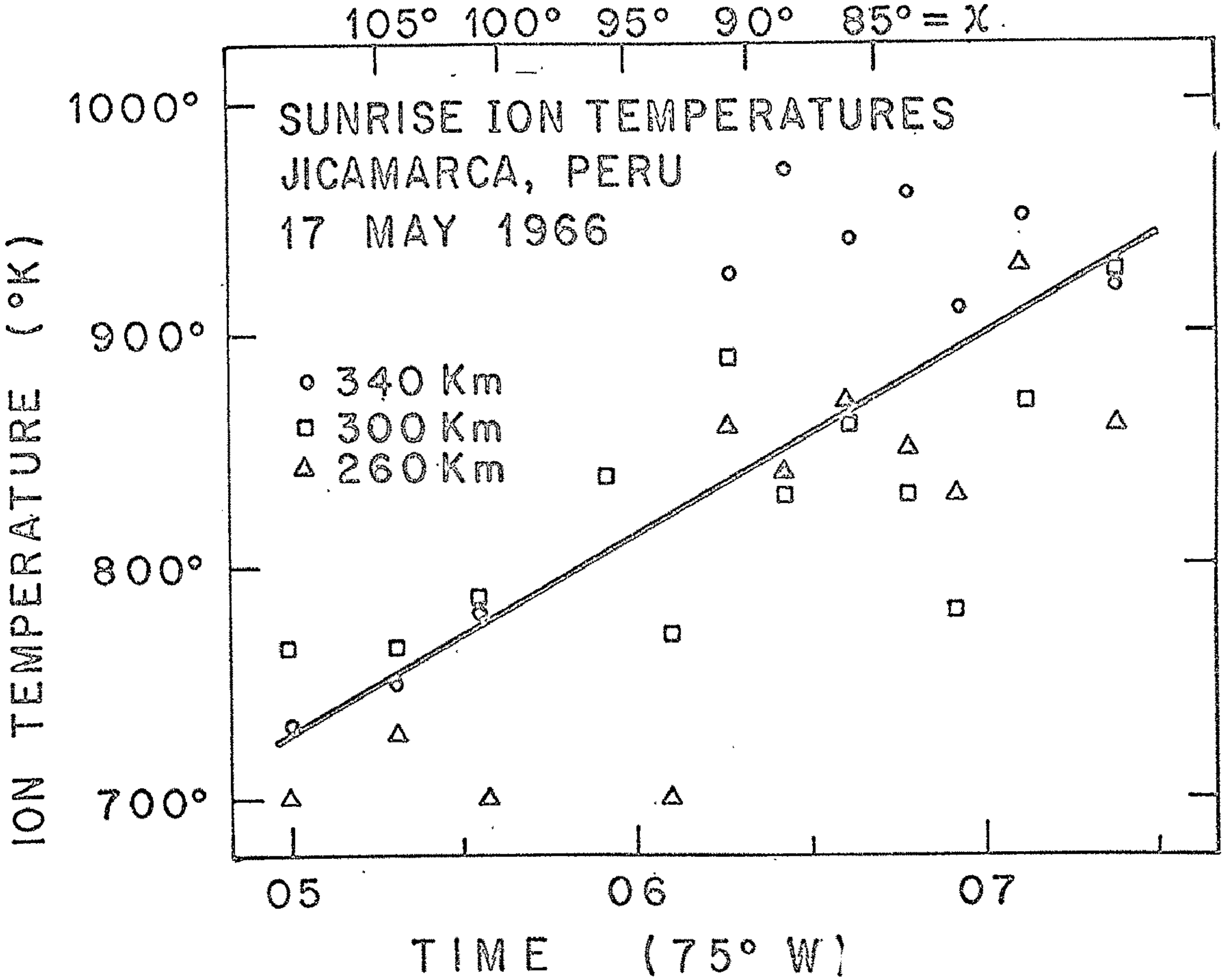


JICAMARCA, PERU — 17 AUGUST 1695


EQUATORIAL DAYTIME TEMPERATURE RELATIONS
$T_e \simeq T_i$ $T_i > T_n$
$T_e \simeq T_i$ $T_i \simeq T_n$
$T_e > T_i$ $T_i \simeq T_n$
HEIGHT (Km)
600
400
200
JICAMARCA
4°N
2°N
0°
2°S
4°S
MAGNETIC LATITUDE

②


ELECTRON TEMPERATURE (°K)
1000
500
17 JUNE 65
18 JUNE 65
19 JUNE 65
17 AUG 65
18 AUG 65
19 AUG 65
11 NOV 65
12 NOV 65
16 DEC 65
17 DEC 65
18 DEC 65
1 APR 66
2 APR 66
10-16 NOV 66
SUNRISE
SUNSET
00
06
12
18
00
TIME (75° W)


105° 100° 95° 90° 85° = χ
SUNRISE ION TEMPERATURES
JICAMARCA, PERU
17 MAY 1966
○ 340 Km
□ 300 Km
△ 260 Km
1000°
900°
800°
700°
ION TEMPERATURE (°K)
05
06
07
TIME (75° W)

(4)

JICAMARCA, PERU. 17 AUGUST 1965 $15^h 25^m$