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ROBERT F. BENSON

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SIMULTANEOUS IN SITU ELECTRON TEMPERATURE
COMPARISON USING ALOUETTE 2 PROBE AND PLASMA
RESONANCE DATA

Robert F. Benson

Thermosphere & Exosphere Branch
Laboratory for Planetary Atmospheres
NASA — Goddard Space Flight Center
Greenbelt, Maryland 20771

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GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

ABSTRACT

The electron temperatures deduced from Alouette 2 diffuse resonance observations are compared with the temperatures obtained from the Alouette 2 cylindrical electrostatic probe experiment using data from 5 mid-to-high latitude telemetry stations. The probe temperature is consistently higher than the diffuse resonance temperature. The average difference ranged from approximately 10% to 40% with the lower values occurring at the lowest altitudes sampled (near 500 km) and at high latitudes (dip latitude greater than 55°), and the larger values occurring at higher altitudes and lower latitudes. The discrepancy appears to be of geophysical origin since it is dependent on the location of the data sample. The present observations support the view that the often observed radar backscatter — probe electron temperature discrepancy is also of geophysical origin.

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INTRODUCTION

The ionospheric electron temperature is most frequently determined from either ground-based radar backscatter measurements or from in-situ electrostatic probe measurements. Numerous attempts have been made to correlate these two methods. One of the major problems in such correlative experiments has been to obtain simultaneous observations at the same location. The results have not been consistent in that sometimes the two methods agree and sometimes they do not. The problem is of interest because it is uncertain whether the observed differences are due to errors inherent in the techniques or to geophysical effects which in turn influence the interpretation of the measurements.

The greatest inconsistency has been observed between the various attempts to make a one-to-one comparison between the electrostatic probe electron temperature T_p , as obtained from satellite observations, and the ground-based radar backscatter electron temperature T_b . Hanson et al. (1969) obtained $T_p/T_b \approx 1.7$, (Carlson and Sayers (1970) found the ratio to range from 1.2 to 1.9, Taylor and Wrenn (1970) and Wrenn et al. (1973) found agreement between the two temperatures, and McClure et al. (1973) obtained an average value of 1.15. Part of the reason for the above inconsistency may be the lack of simultaneity in time and space between the satellite probe and radar backscatter observations (typically, the ground track distance between the radar station and the closest sub-satellite point varied between 100 and 1,000 km in these comparisons).

Experiments designed to obtain simultaneity, using rocket borne probes flown through the radar backscatter beam, have obtained more consistent results. Brace et al. (1969) obtained $T_p/T_b \approx 1.0$ during a daytime flight and $T_p/T_b \gtrsim 1.1$ in a nighttime flight. Sagalyn and Wand (1971) found T_p/T_b to vary between 1.1 and 1.2 during two daytime flights. The maximum altitude attained in these comparisons was 300 km. Both high and low altitudes were achieved in the experiment of Brace and McClure (1971) where agreement between T_p and T_b was observed up to about 350 km but large disagreements were observed at higher altitudes ($T_p/T_b \approx 1.8$ at 700 km). These latter observations, although at similar dip latitudes, were not overlapping (the rocket was launched at Natal, Brazil and the radar station was at Jicamarca, Peru).

The contrast between the generally good agreement between T_p and T_b observed using rockets at lower altitudes with the large disagreements sometimes observed in the satellite experiments has led to the suggestion that the electrostatic probes carried on the satellites do not yield results consistent with the rocket-borne probes. The experiments of Brace et al. (1971) indicate that the problem cannot be resolved in this manner. They conducted a series of rocket launches in conjunction with nearby passages of satellites and found the agreement between the satellite and rocket probes to be typically better than 10%. Carlson and Sayers (1970) suggested that the large satellite-backscatter discrepancies may be due to a drift in the work function of the probe surface material during the voltage sweep; a greater drift being expected with the slow sweep

rates sometimes employed on the satellite experiments. Rocket experiments, however, which employ different sweep rates on the same probe do not support this view (Brace et al. 1971). In addition, the rocket experiment of Sagalyn and Wand (1971), where T_p and T_b differed by only 10% to 20%, used a sweep rate of only 6V/sec – slower than that used on any of the above referenced satellite or rocket experiments. Also, the good agreement obtained between T_p and T_b in the statistical comparison of Evans (1965), where 3 months of overlapping Explorer 17 probe and Millstone radar backscatter measurements were compared, argues against the work function drift hypothesis since a low sweep rate (7.5 v/sec) was used on the satellite borne probe. Additional satellite evidence against the drift hypothesis has been provided by Wrenn et al. (1973) where essential agreement was obtained between a "slow sweep" temperature estimate and an estimate based on their normal temperature reduction process (which approximates a "fast sweep" condition) using the same probe. Thus it appears that the conflicting results obtained in the comparisons of T_p and T_b cannot be attributed to changes in the probe surface characteristics during the probe voltage sweep.

The observations of Oya and Benson (1972) are related to the probe-backscatter temperature problem, and suggest that the often observed discrepancy is of geophysical origin. These observations are based on the plasma waves stimulated by the Alouette 2 sounder and on the cylindrical electrostatic probe on board the same satellite. Significant differences were found between the plasma wave temperatures and the probe temperatures, with the probe temperatures being

higher. It is the purpose of this paper to present additional observations and to relate them to the probe-backscatter discrepancy.

OBSERVATIONS

The method of obtaining the electron temperature by Oya and Benson (1972) is based on the Doppler splitting of the diffuse resonance which occurs at the frequency f_{D1} . The notation f_{D1} is used to indicate that it is the diffuse resonance between the electron cyclotron frequency f_H and $2f_H$ that is of interest (Oya, 1970). The Doppler splitting, which is illustrated in Figure 1, occurs only in mid-to-high geomagnetic latitudes. In addition to this restriction, long duration f_{D1} resonances (which are desirable for electron temperature measurements) are only observed when f_N/f_H is between 2.3 and 3.3, where f_N is the electron plasma frequency.

The above conditions were satisfied during the April-May period of 1966 when the Alouette 2 perigee occurred during the afternoon hours in middle northern geomagnetic latitudes. All the available data from this time period, where the diffuse resonance electron temperature $T_{f_{D1}}$ and the electrostatic probe temperature T_p could be determined, were used in the present study. The results are presented in Figures 2a-2f in the form of the ratio $T_p/T_{f_{D1}}$ versus dip latitude λ in the left column and altitude z in the right column. All of the data points are presented in the top row of figures and subsets are presented in the lower figures. The main features to note are the following:

(1) T_p is consistently higher than $T_{f_{D1}}$. When all the data points are included, i.e., Figure 2a or Figure 2b, the average value for the ratio $T_p/T_{f_{D1}}$ is 1.22.

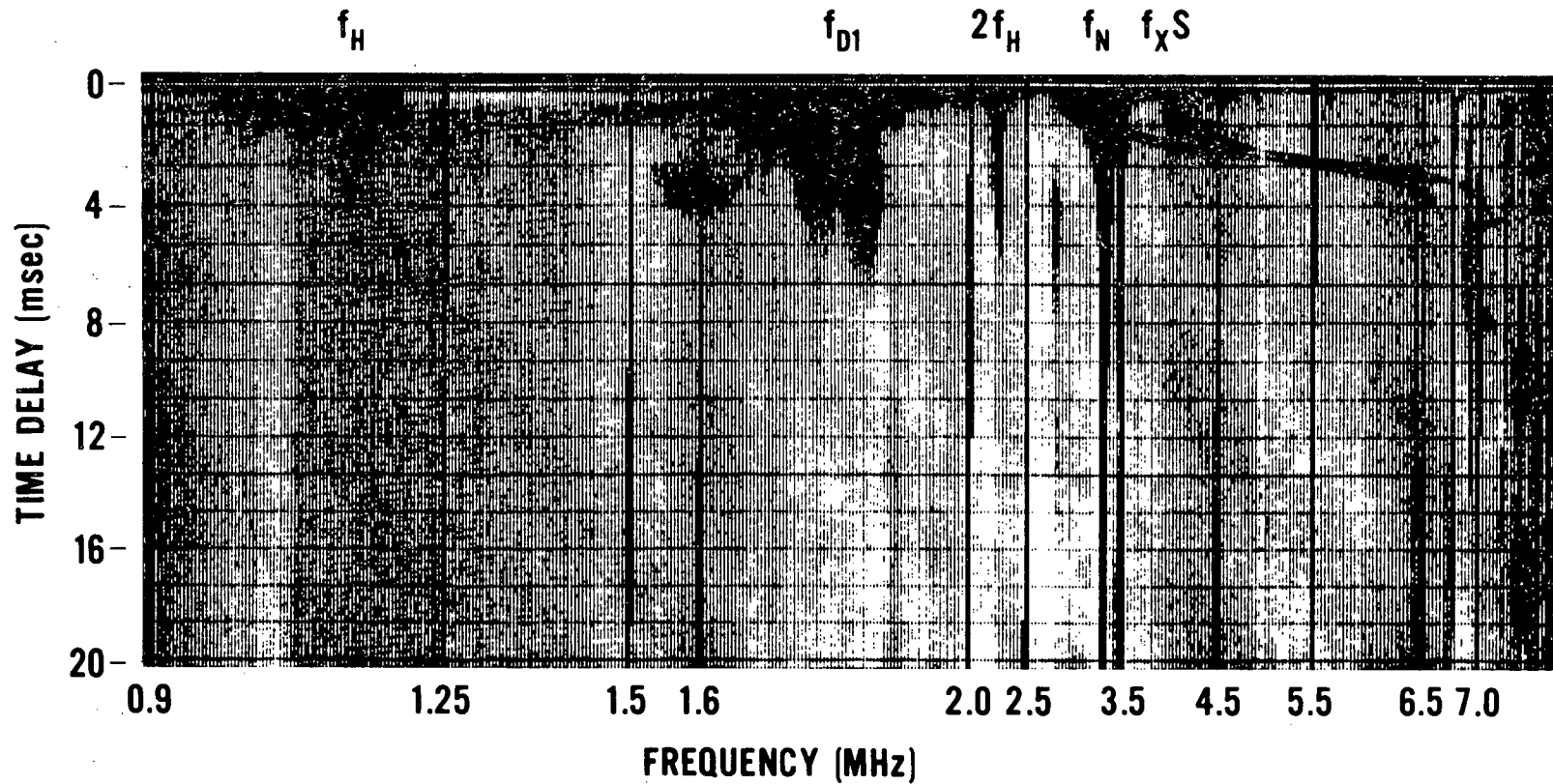


Figure 1. Alouette 2 ionogram illustrating the Doppler splitting of the f_{D1} resonance. (FTM pass 1834, 2 May 1966, 2108:26 UT (1524 LT); 29.4° north geographic latitude (42° dip latitude), 86.9° west longitude, 516 km.)

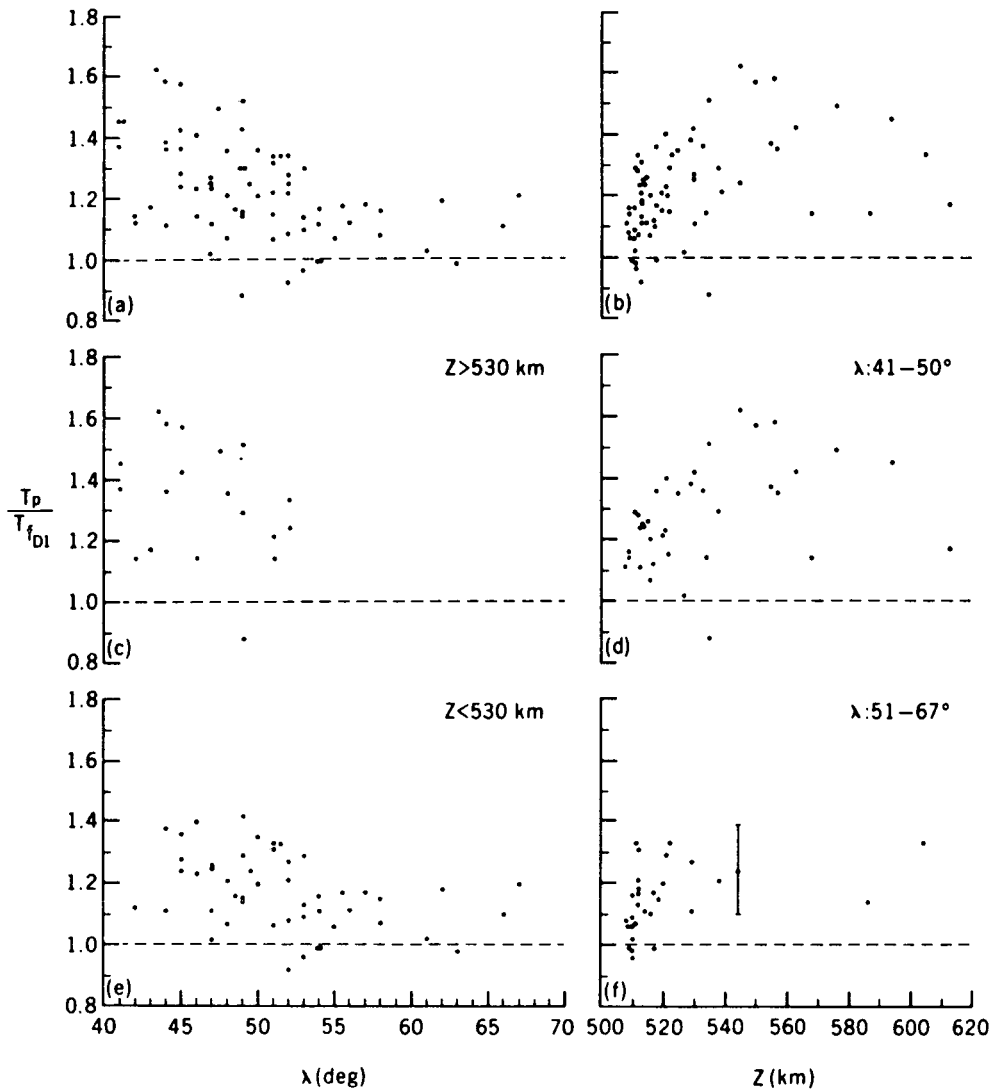


Figure 2. The ratio of the probe electron temperature to the diffuse resonance electron temperature versus dip latitude λ (left figures) and altitude z (right figures). All of the available temperature comparisons are presented in a and b (68 simultaneous temperature comparisons using Alouette 2 data recorded at the FTM, WNK, OTT, BLR, and NFL telemetry stations); subsets of these data are presented in c, d, e, and f. Most of the observations corresponded to local times between 1500 and 1700; in all cases $K_p \leq 3$. The estimated scaling uncertainty is indicated in f. One third of the data points are from the earlier work of Oya and Benson (1972). [Note: during the present study, the accuracy associated with the original T_p values was increased which changed the previously reported values for the ratio T_p/T_{fDI} from 1.09 to 1.17 in the WNK data and from 1.40 to 1.26 in the OTT data as presented in Figure 4 of Oya and Benson (1972).]

(2) The discrepancy between the two temperatures appears to be reduced in higher latitudes (Figure 2a) and at lower altitudes (Figure 2b).

(3) The above dependence on λ and z cannot be completely separated using the present data since most of the high altitude data were obtained at the lower latitudes sampled, e.g., see Figure 2c. The data subsets of Figures 2c-f are presented in an attempt to make this separation, and the results support statement (2) above, e.g., see Figures 2d and 2e.

The latitude and altitude dependence referred to in (2) and (3) above can be illustrated further by comparing the high altitude portion of Figure 2d with the high latitude portion of Figure 2e. For example, the average value for $T_p/T_{f_{D1}}$ in the data of Figure 2d with $z > 530$ km is 1.36 with a standard deviation from the mean $\sigma/\sqrt{n} = 0.05$, whereas in the data of Figure 2e with $\lambda > 51^\circ$ it is 1.13 with $\sigma/\sqrt{n} = 0.02$.

There are certain similarities between the present diffuse resonance-probe comparisons and the previously mentioned radar backscatter-probe comparisons. In both cases the discrepancies are small, i.e., less than 10 to 20%, at low altitudes (e.g., compare the average value near 510 km in Figure 2b with the results of Evans (1965), Brace et al. (1971), and Sagalyn and Wand (1971)). Also, large disagreements have not been observed in either type of comparison in high latitudes (e.g., compare the values above 55° dip latitude in Figure 2a with the results of Taylor and Wrenn (1970)).

DISCUSSION

The main conclusion from the present observations is that $T_p > T_{f_{D1}}$ and that the discrepancy appears to be dependent on the position of the satellite. The average minimum discrepancy in the present data sample is approximately 10%; the average maximum discrepancy approaches 40%. The minimum value is observed when Alouette 2 is near the perigee condition of approximately 500 km in high latitudes ($\lambda > 51^\circ$); the maximum value is observed at higher altitudes and lower latitudes.

One may ask the following question: what bearing does the diffuse resonance-probe electron temperature discrepancy have on the problem of the radar backscatter-probe electron temperature discrepancy? In order to answer this question, it is appropriate to ask a more basic question, namely, what is meant by the term electron temperature? The electron temperature is a physical quantity dependent on the shape of the electron velocity distribution function. Benson and Hoegy (1972) found that when a distortion is present in the isotropic plasma in the low energy portion of the electron velocity distribution, the effect on T_b and $T_{f_{D1}}$ is similar. Thus an interpretation of the discrepancy between T_p and $T_{f_{D1}}$ may also apply to the discrepancy between T_p and T_b .

In order to explain the observed differences between the plasma wave and probe temperatures solely by the above isotropic thermal distortion, however, the

required non-equilibrium state is too extreme to appear reasonable (Benson and Hoegy, 1972). Thus it was suggested that electron temperature anisotropies, such as those observed by Clark et al. (1973), should be considered. Recent observations by Wrenn et al. (1973) indicates that the temperature anisotropy contributes to the probe-backscatter electron temperature discrepancy. The observed anisotropy appropriate to the present observations (near 45° dip latitude, between 1500 and 1600 LT, $K_p \leq 3$, and $500 < z < 600$ km) is $(T_{\parallel} - T_{\perp})/T \approx 0.2$ where T_{\parallel} and T_{\perp} are the electron temperatures corresponding to electron motion parallel and perpendicular to the earth's magnetic field and $T = 1/3 T_{\parallel} + 2/3 T_{\perp}$. The temperature obtained from a cylindrical electrostatic probe (as used on Alouette 2) is not considered to be very sensitive to direction, but the diffuse resonance temperature corresponds to T_{\perp} (Oya and Benson, 1972). If we approximate T by T_p and T_{\perp} by T_{fD1} , then

$$\frac{T_{\parallel} - T_{\perp}}{T} = 3 \frac{T_p - T_{fD1}}{T_p}.$$

Using the 20% anisotropy observed by Clark et al. (1973) as a rough estimate for the anisotropy existing during the present observation period, gives a probe-diffuse resonance temperature discrepancy of approximately 7% which is a factor of 5 less than the observed value. Similar comments should hold for the probe-radar backscatter discrepancy since in low latitudes (where the large differences have been observed) the backscatter temperature is more sensitive to T_{\perp} than is the probe (Hoegy, personal communication, 1973).

While the effect of the temperature anisotropy observed by Clark et al. (1973) is very significant, it is not sufficient to fully explain the discrepancy often observed between the temperatures measured by probes and those obtained by radio techniques. The cause of the anisotropy is unknown, but its existence suggest that the topside ionosphere can experience significant departures from the equilibrium state. Under such conditions thermal distortions to the electron velocity distribution function may occur which would also contribute to the discrepancy (Benson and Hoegy, 1972).

It appears that an experiment combining in-situ observations of T_{\perp} and T_{\parallel} using probes and T_{\perp} based on the diffuse resonance would be highly desirable for monitoring non-equilibrium conditions in the ionosphere. The space shuttle may provide an ideal platform for such an experiment since the man in space could tune-in the maximum f_{D1} signal by making real-time experimental adjustments.

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