Response of Ionospheric Electron Temperature to Solar Wind Dynamic Pressure from Pioneer Venus

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The variation of dayside ionospheric electron temperature ($T_e$) with solar wind dynamic pressure (SWDP) is examined by using measurements from the electron temperature probe and magnetometer experiments aboard the Pioneer Venus Orbiter. A number of dayside periapsis orbits with SWDP varying from $2 \times 10^{-8}$ to about $1.7 \times 10^{-7}$ dynes cm$^{-2}$ are selected to study changes in $T_e$. It is seen that there is a statistically linear relationship between the SWDP and $T_e$, which is seen to vary from 3000K to more than 10,000K at an altitude of 250km during the above mentioned SWDP range. The topside heat flux at the ionopause is seen to increase by more than one order of magnitude during conditions of very high SWDP. These results imply that electron temperature variability in the Venusian ionosphere is essentially controlled by solar wind heating.

1 Introduction

Electron temperatures ($T_e$) in the dayside ionosphere of Venus have been measured with the electron temperature probe (OETP) and with the retarding potential analyser (ORPA) on the Pioneer Venus Orbiter (PVO). These measurements have indicated a value of about 3000K at an altitude of 200km increasing to around 5000K at 1000km with practically no change with solar zenith angle (SZA). Some variability from orbit to orbit and occasional wavelike irregular structures during very high solar wind conditions were also observed. A statistical analysis of the OETP measurements from the second dayside periapsis passes by Elphic et al. showed that the ionospheric magnetic fields associated with solar wind had no effect on the electron density and electron temperature. Unfortunately this conclusion was based upon an analysis of OETP measurements below an altitude of 200km only and perhaps was not applicable to all the ionosphere heights as pointed out by Luhmann et al.

While presenting a detailed study of the characteristics of Mars like limit of the Venus-solar wind interaction, Luhmann et al. examined a large number of OETP measurements with periapsis in the subsolar range, covering the full range of SWDP. They concluded that localised heating occurred within the upper electron density gradient and this heating extended to at least 200km, when the ionopause had been forced to its minimum (200km) altitude. While Luhmann et al. were more concerned with the enhanced thermal pressure during high solar wind dynamic conditions, their representative plots for low, typical and high dynamic pressure did indicate the influence of dynamic pressure on electron temperature.

Theoretical calculations of electron temperature in the Venusian ionosphere have shown that even under normal conditions, energy fluxes at the topside are required to explain the observed electron temperatures, and EUV heating is inadequate to explain the observations. Elphic et al. showed that $T_e$ is not affected significantly by variations in EUV and thus emphasized the importance of solar wind heating from the topside as compared to photochemical heating. Since this energy flux can be supplied by solar wind protons, we thought it desirable to study the response of electron temperature to SWDP.

In this paper we examine the variations in electron temperature at an altitude of 250km for various values of SWDP varying from $2 \times 10^{-8}$ to about $1.7 \times 10^{-7}$ dynes cm$^{-2}$ by using OETP and magnetometer (OMAG) measurements from PVO. We show that there is a definitive relationship between the two parameters, with $T_e$ varying from 3000K to more than 10,000K in this dynamic pressure range, thereby concluding that $T_e$ in the Venusian ionosphere is largely controlled by solar wind conditions.

2 Data Base

The analysis was done by using the in situ measurements on PVO taken from the low frequency data file (LFDF) of the unified abstract data system (UADS) obtained from the World Data Centre at Goddard Space Flight Centre, Greenbelt, Maryland, USA. These data are average values of the high resolution measurements derived with 12s
of the assigned time and we have used measurements from the OETP and OMAG experiments. We have selected a large number of orbits from the first three sets of dayside perihelion passes namely 5 Dec. 1978 to 22 Dec. 1978 (orbits 1 to 18), 14 Apr. 1979 to 31 July 1979 (orbits 131 to 239) and 24 Nov. 1979 to 24 Mar. 1980 (orbits 355 to 467). We have restricted the analysis to outbound legs as these are closer to true altitude profiles than the inbound legs.3

3 Results
To study the response to $T_e$, we have selected from the above data about 30 orbits with SWDP varying from $2 \times 10^{-8}$ to $1.7 \times 10^{-7}$ dynes cm$^{-2}$. Since the SWDP is transformed almost completely into magnetic pressure just outside the ionopause, we have inferred the dynamic pressure from the expression

$$B_m^2 \times \frac{1}{8 \pi} \frac{1}{0.88 \times \cos^2 \psi}$$

where $B_m$ is the maximum external field observed just outside the ionopause and $\psi$ is the angle between the upstream solar wind flow direction and the normal to the ionopause. The angle $\psi$ can be approximated well by SZA except near the terminator. We have restricted our analysis to SZA $\leq 60$. As pointed out in our earlier work the magnetic field fluctuated considerably, just outside the ionopause but the value of peak magnetic field, $B_m$, did not change very much.

Electron temperatures were taken directly from the OETP experiment and Fig. 1 shows a series of $T_e$ profiles under various solar wind conditions. A point to be noted is the near smooth behaviour of $T_e$ with altitude, with $T_e$ gradient (and thus topside heat flux) increasing with solar wind dynamic pressure. At an altitude of 250km, $T_e$ has increased from the lowest value of 3000K to a value close to 10,000K. Another point to be noted is that as solar wind dynamic pressure increases, the highest altitude of $T_e$ measurement decreases. This is expected to be so since the ionopause altitude decreases as SWDP increases. The OETP cannot measure $T_e$ above the ionopause region as the electron concentration goes below the sensitivity limit for the $N_e$ and $T_e$ measurements. Our choice of 250km as the altitude for studying the effect of SWDP on $T_e$ was commensurate with this fact.

The relationship between $T_e$ and the inferred SWDP is examined in Fig. 2 which shows a plot of $T_e$ at 250km against SWDP. A very definite relationship can be readily noted, thereby suggesting that the topside heat flux, which controls the ionospheric electron temperature, is directly proportional to solar wind dynamic pressure. In Fig. 3 we have plotted the electron temperature at 250km as a function of the peak magnetic pressure ($B_m^2/8 \pi$). It can be clearly seen that the electron temperatures are much better correlated with the peak magnetic pressure than with the inferred upstream solar wind magnetic pressure. Further, in both Figs 2 and 3, $T_e$ reaches the limiting value of about 3000K for very low SWDP, which will result from the solar EUV heating alone. This is quite consistent with the model $T_e$ profile calculated by Cravens et al.8

Fig. 1—Electron temperature profiles during various solar wind conditions [Orbit number is given on each profile. Numbers in parentheses denote the value of solar wind dynamic pressure (in dynes cm$^{-2}$) inferred from the maximum magnetic pressure observed just outside the ionopause.]

Fig. 2—A plot of electron temperature at an altitude of 250km against solar wind dynamic pressure (SWDP) for selected orbits. [The selection was made so as to cover orbits with SWDP varying from $2 \times 10^{-8}$ to $1.7 \times 10^{-7}$ dynes cm$^{-2}$.]
The data used in Figs 1, 2, and 3 do not contain \( T_e \) profiles which exhibited irregular structures of the type observed by Brace et al. An examination of the various \( T_e \) profiles shows that wave-like structures appear very rarely except perhaps for this SZA conditions accompanied by high SWDP. This aspect is being studied further.

4 Discussion

A significant fraction of the incident solar wind is expected to be absorbed by Venusian atmosphere. Gombosi et al. stated that charge exchange of solar wind protons with neutral particles in the Venusian atmosphere would completely replace any solar wind protons reaching 215km altitude with heavy planetary ions. The soft protons deposit their energy by charge exchange collisions and ionizing Coulomb collisions thereby heating the atmosphere and ionosphere. As the energy to be deposited in the ionosphere is expected to be related to solar wind dynamic pressure, one would expect a strong relationship between SWDP and \( T_e \). Such a relationship does indeed exist, as shown in this paper from in situ measurements aboard the PVO. However, the relationship is stronger if we consider the peak magnetic pressure rather than the upstream SWDP. The latter is perhaps explained by the fact that the peak magnetic pressure is the effective pressure that is transmitted on to the ionopause.

The \( T_e \) profiles provide an estimate of topside heat flux which is given as

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\phi_e = 7.7 \times 10^5 \times T_e^{2/3} \frac{dT_e}{dh} \text{ eV cm}^{-1} \text{s}^{-1} \text{deg}^{-1}
\]  

At an altitude of 250km, \( \phi_e \) is found to vary from \( 1.4 \times 10^{10} \text{ eV cm}^{-2} \text{s}^{-1} \) to \( 8.5 \times 10^{12} \text{ eV cm}^{-2} \text{s}^{-1} \) for a low SWDP of \( 2 \times 10^{-8} \text{ dyne cm}^{-1} \) to a high SWDP of \( 1.7 \times 10^{-7} \text{ dyne cm}^{-1} \). However, these fluxes are much higher when calculated at the highest altitude of observation (i.e. near the ionopause). For example for orbit No. 148 (a case of low SWDP), \( \phi_e \) is about \( 1.3 \times 10^{12} \text{ eV cm}^{-2} \text{s}^{-1} \) while it is \( 1.5 \times 10^{13} \text{ eV cm}^{-2} \text{s}^{-1} \) for orbit No. 210 (a case of high SWDP).

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References