RESPONSE OF VENUS IONS TO SOLAR WIND DYNAMIC PRESSURE

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Abstract. Orbiter ion mass spectrometer measurements, as available in the UADS data files are used to study the response of dayside Venus ions at various altitudes to solar wind dynamic pressure, P_{sw}. Ion densities below about 200 km are not affected by changes in P_{sw}. At altitudes above 200 km the ions get abruptly depleted with increase in P_{sw}, and this abrupt depletion occurs at lower altitudes when P_{sw} is high. At lower P_{sw}, the depletion occurs at higher altitudes. The effect is similar for all ions. These results are also compared with the empirical relationship observed by Brace *et al.* (1980) between the ionopause altitude and P_{sw} from electron density measurements on orbiter electron temperature probe.

Key words: Venus, ionopause, ionosphere, solar wind.

1. Introduction

The interaction between Venus and solar wind has been described by many workers (see e.g. Russell and Vaisberg, 1983; Vaisberg and Zeleny, 1984; Luhmann, 1986; Phillips and McComas, 1991). The highly conducting dense ionosphere produced by the solar EUV, acts as an obstacle to the solar wind which is shocked and diverted around the ionosphere. A well known effect of the solar wind interaction is the sudden decrease in the ion density at the upper boundary of the ionosphere, called the ionopause. This boundary has been deduced from the electron concentration (N_e) profiles by Brace et al. (1980) for each orbit during the main phase of the Pioneer Venus mission. Measurements from the Langmuir probe experiment (Krebhiel et al., 1980) were used by Brace et al. (1980) to identify the 100 electron/cm^3 altitude in the steep N_e gradient – the altitude where ions "pause". A major result obtained from the analysis of these data has been the decrease of the ionopause altitudes with P_{sw} and Brace et al. have obtained an empirical relation between P_{sw} and the ionopause altitude.

The ionopause altitude has also been seen to respond to changes in P_{sw} in the O^+ profiles measured by the Orbiter ion mass spectrometer (Taylor et al., 1980). However no statistical analysis, of the kind made from Langmuir probe measurements, exists for the ions data. In this paper we shall examine the response of various Venus ions to P_{sw} at various altitudes. From an analysis of OIMS measurements we find that none of the Venus ions is affected at altitudes below 200 km, a result consistent with the N_e measurements on the Langmuir probe. For altitude above 200 km, each ion shows a sudden fall in density at high P_{sw}. We identify this P_{sw} value for each altitude and it is found that higher the termination

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altitude, lower is the P_{sw} value. These results are compared with those obtained from the Langmuir probe measurements by Brace et al. (1980).

2. Data Base

We have used the in-situ data from the PVO, as available in the low frequency data file (LFDF) of the Unified Abstract Data System (UADS). These data were obtained from the World Data Center, at Goddard Space Flight Center, Maryland, USA. This UADS file allows access to the data from ten instruments aboard the PVO at 12 s time intervals. The data themselves are average values of the high resolution data derived within 12 s of the assigned time. In the present analysis, we have used measurements from two experiments, namely the ion density data from the Orbiter Ion Mass Spectrometer, OIMS (Taylor et al., 1980) and the magnetic field from the Orbiter Magnetometer, OMAG (Russell et al., 1980). The OMAG data has been used primarily to calculate the maximum magnetic pressure $B^2/8\pi$, above the ionopause for each orbit. This parameter provides the P_{sw} component, normal to the ionopause.

We have analysed data for dayside orbits for near subsolar conditions (i.e. $\chi \leq 45°$). These include orbits 155 to 213 and 380 to 437 (corresponding dates being May 8, 1979 to July 5, 1979 and December 20, 1979 to February 15, 1980). These orbits correspond to a period of high solar activity.

3. Analysis and Results

The solar wind pressure consists of three components; the dynamic pressure (ρV^2), the magnetic pressure ($B^2/8\pi$), and the thermal pressure (nkT), here ρ and V are the solar wind density and velocity respectively, B is the embedded magnetic field, n is the density of ions, and T is the total temperature of ions and electrons. At the ionopause the dynamic pressure and the thermal pressure are negligible in comparison to the magnetic pressure, since ρV^2 is converted almost completely into magnetic pressure here (Brace et al., 1980; Elphic et al., 1980). We have therefore used the peak magnetic pressure, $B^2_{max}/8\pi$ just above the ionopause as an index for P_{sw}. For subsolar locations, this is usually a good approximation (Elphic et al., 1980, 1981). Although P_{sw} values measured by the OPA instrument are also available in the UADS file, the data do not exist for all orbits. Further OPA data is a few hours before and after the ionospheric measurements, while the OMAG data is simultaneous.

The OIMS has detected several ions and these are H^+, H_2^+/D^+, He^+, O^+, C^+, N^+, O^+, OH^+, H_2O^+, Mg^+, CO^+/N_2^+, NO^+, O_2^+, Ar^+, CO_2^+ and Fe^+. In our analysis we have considered only four of these ions – two heavy and major ions viz O^+, O_2^+ and two lighter and minor ions viz H^+, and He^+. We have chosen altitudes

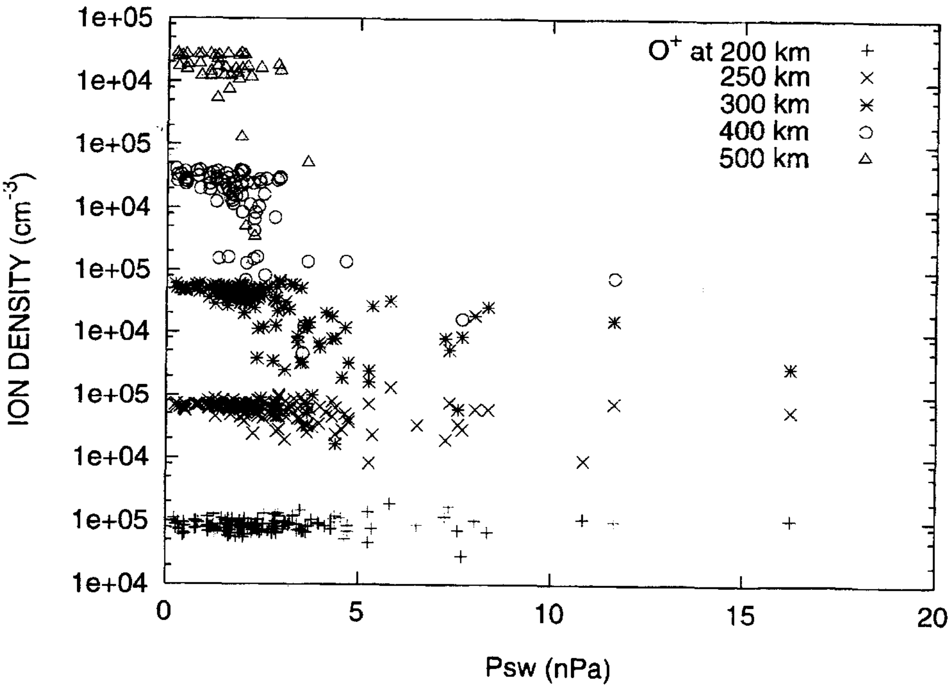

Figure 1. The variation of O^+ ion density to P_{sw} at 200, 250, 300, 400 and 500 km.

of 200, 250, 300, 400, and 500 km for studying the response of these ions to P_{sw} at these altitudes. Data at these altitudes have been obtained by linear interpolation and the interpolation was performed only when measured values were available below and above the desired altitude. Since thermal ion data above the ionopause can be contaminated by the presence of superthermal ions (Taylor et al., 1980), no data were employed in our analysis above the ionopause altitude. Very often, for the same orbit, interpolation was not possible for all the five altitudes. Since the "top" of the ionosphere (the altitude where the steep gradient in the ion density starts) lies generally between 200 to 400 km for the subsolar ionosphere (Brace et al., 1980), the number of data points decreases with increase in altitude. As a result, the number of data points is larger at 200 km than at 500 km.

Figure 1 shows the response of O^+ density to P_{sw} at various altitudes. Within the observed range of P_{sw}, there is no effect on O^+ density at 200 km. At 250 km the ion density shows a little decrease with P_{sw}, which may not be very significant. However at 300 km, the ion density decrease sharply with P_{sw}, although a few orbits could maintain high density even at high P_{sw}. At 400 km, the ion density abruptly falls as soon as P_{sw} increase beyond 2.4 nPa. For 500 km this abrupt fall occurs at about to 2.0 nPa.

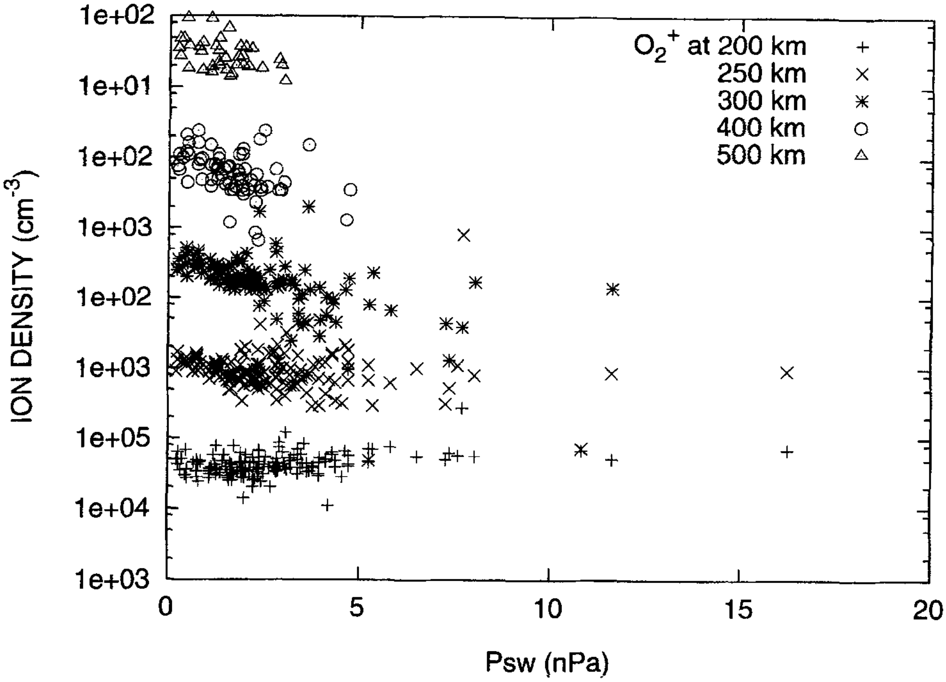

Figure 2. The variation of O_2^+ ion density to P_{sw} at 200, 250, 300, 400 and 500 km.

The response of O_2^+ ions to P_{sw}, is similar to that of O^+ ions as can be seen in Figure 2. Again the ion density at 200 km remains unaffected. At higher altitudes there is an abrupt cut off in ion density for different values of P_{sw}. For cut off at 300, 400, and 500 km, the P_{sw} values are 7.5, 3.5, and 2.0 nPa, respectively.

In Figure 3 we have presented the response of H^+ ions to P_{sw}. Like other ions, the variation of H^+ density at 200 km remains unaffected. As we approach higher altitudes, the response is quite clear. For the cut off at 300, 400, and 500 km, the P_{sw} values are 6.0, 3.5 and 2.2 nPa respectively. In Figure 4 the response of He^+ density to P_{sw} is examined. This is very similar to H^+ density.

In Figure 5 we have plotted the ionopause altitude variation with magnetic field pressure using the OETP data of season one and two. These data are an update of Brace et al. (1980), which contained measurements of season one only. These points were fitted by an expression of the form;

$$h_i = A + B \exp C P_b \, Km$$

where h_i is the ionopause height, P_b is the magnetic pressure, and A, B, and C are constants determined by the fit to have the following values and standard deviations;

$$A = 312 \pm 25, \quad B = 699 \pm 39, \quad \text{and} \quad C = -6.56 \times 10^7 \pm 0.85 \times 10^7$$

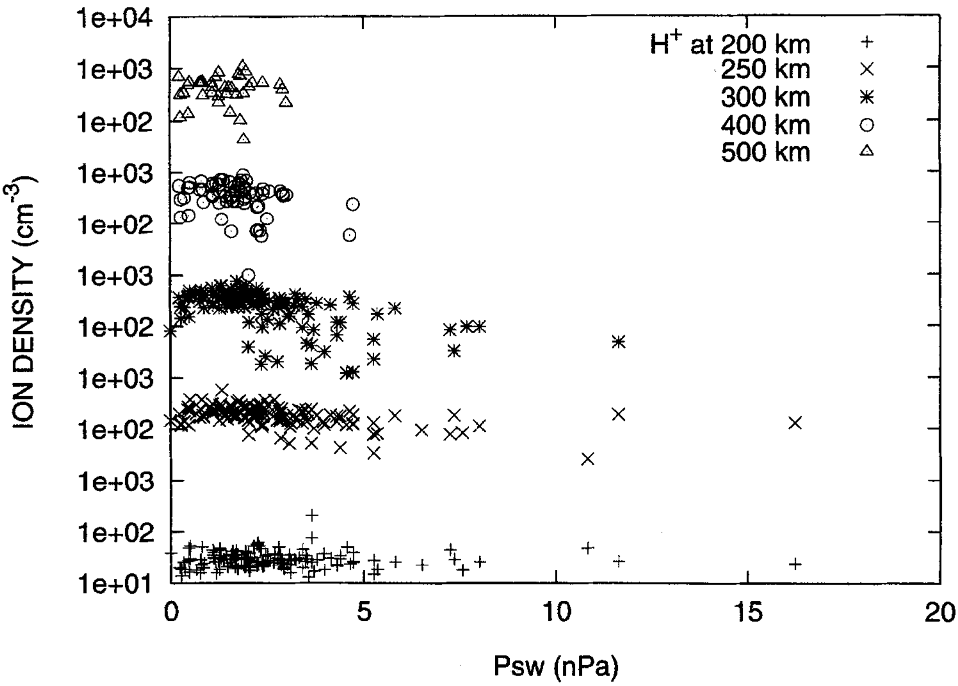

Figure 3. The variation of H^+ ion density to P_{sw} at 200, 250, 300, 400 and 500 km.

We have also included in this Figure the cut of P_{sw} of these four ions which matching very well with our best fit data.

4. Discussion

The ionopause or the boundary between the thermal ionosphere and the ionosheath region has been defined somewhat differently by investigators using different instruments onboard the PVO. A comparison of ionopause altitudes based on these various definitions was carried out by Phillips et al. (1988). Generally in these definitions, altitude where the thermal pressure and magnetic pressure are equal, a specific plasma number density (100 cm^{-3} for the ionopause from the OETP and ORPA data, 10^4 cm^{-3} for the "top" of the ionosphere in absence of a sharp drop of scale height from ORPA data etc.) was used to identify the ionopause. The pressure balance ionopause typically occurs a few kilometers below the density ionopause and increases with increase in SZA (Phillips et al., 1988).

However, as regards the measurements from the OIMS, the original definition was based on the boundary between the thermal ionosphere and the incidence of the superthermal ions. This boundary can often be somewhat ambiguous and difficult to define. We have therefore studied the behaviour of various ion densities from

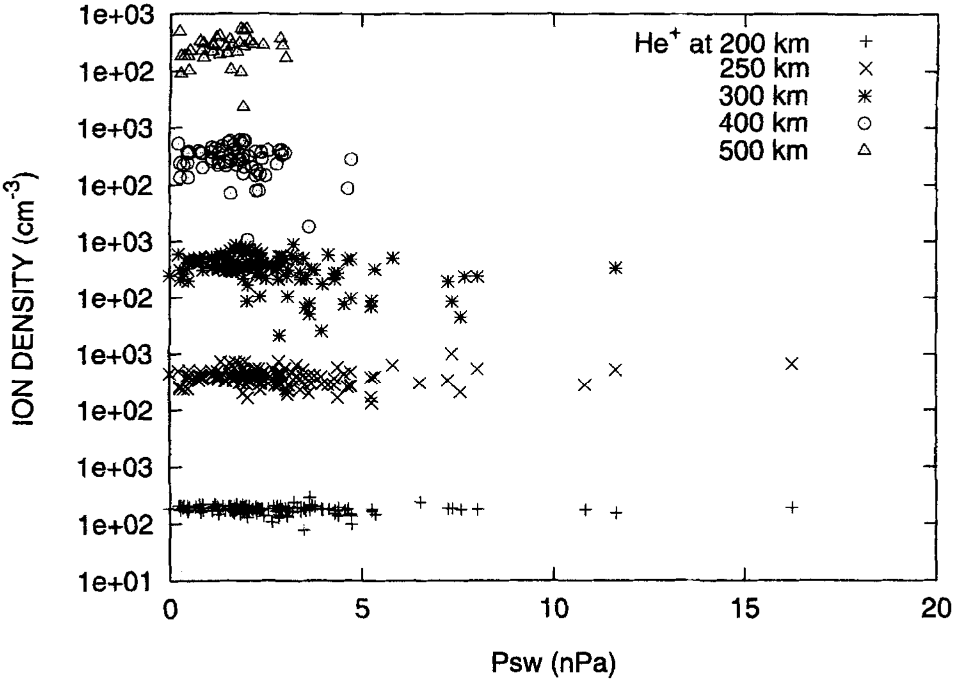

Figure 4. The variation of He^+ ion density to Psw at 200, 250, 300, 400 and 500 km.

OIMS at specific altitudes as a function of the prevailing P_{sw}. At each altitude there is generally a sharp drop in the ion density at a certain P_{sw} for each ion species. This corresponds to the limiting P_{sw} for this altitude above which a thermal ionosphere can not be sustained. For the major ion O^+, this sharp drop-off in ion density is very clearly observable at higher altitudes. For minor ions H^+ and He^+ this is somewhat less obvious. However, at any specific altitude this drop-off occurs for the same P_{sw} for all the ions. This shows that all the ions take part in the solar wind interaction process in a similar manner. Further the observation of the limiting P_{sw} at each altitude for all the ions essentially implies that the ions "pause" at this altitude for this P_{sw}. This was clearly shown by the close correspondence of these altitudes as a function of the limiting P_{sw} with the average ionopause altitudes as obtained from the OETP. In particular, the observation of a kind of limiting ionopause altitude from OETP data around 200 km is also borne out by the OIMS measurements for all the ions studied/examined. This study is thus an attempt to define the ionopause from the OIMS data in a more quantitative manner than in terms of the boundary between thermal and superthermal ions. The data used in this analysis corresponds to entirely thermal ionosphere and thus avoids ambiguities.

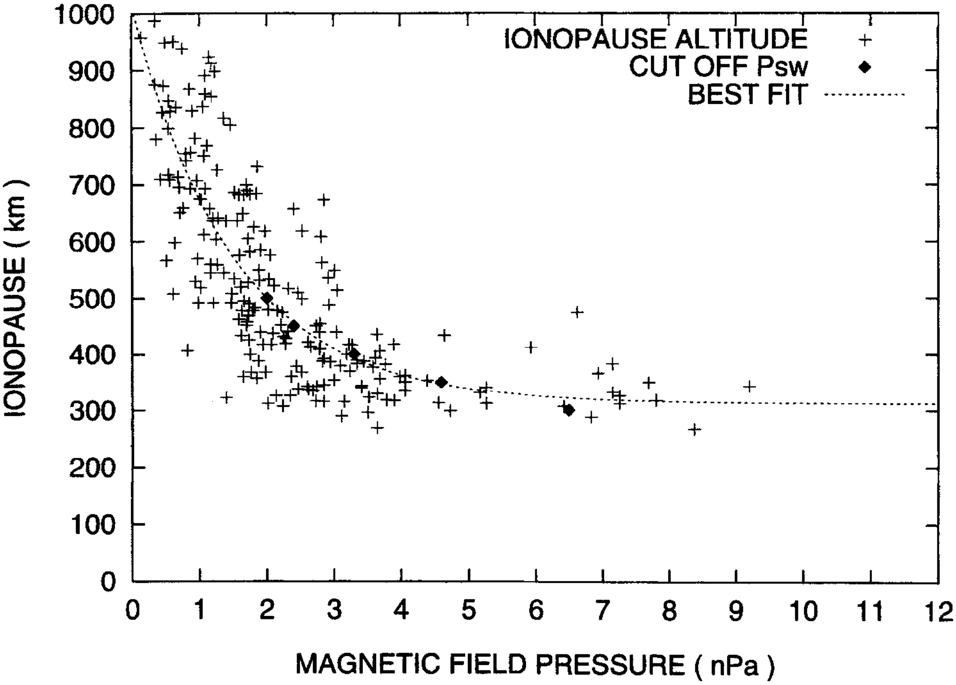

Figure 5. The cut off P_{sw} with altitude for four ions O^+, O_2^+, H^+, He^+. The line is the best fit of ionopause altitude vs Magnetic field pressure, with Brace et al. OETP ionopause data.

5. Conclusions

Brace et al. (1980) defined the ionopause using OETP data. For season one, they have shown the variation of P_{sw} vs ionopause altitude and given the best fit for ionopause altitude. Here in the present analysis we used the OIMS data for seasons one and two using four ion species and calculated the cut off P_{sw} for these species at various altitude and compared with the best fit of ionopause data for seasons one and two. We found that these match very well. For the major ion O^+, this sharp drop-off in ion density is very clearly observable at higher altitudes. For minor ions H^+ and He^+ this is somewhat less obvious. However, at any specific altitude this drop-off occurs for the same P_{sw} for all the ions. This shows that all the ions take part in the solar wind interaction process in a similar manner.

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