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ELECTRON DENSITIES AND TEMPERATURES IN THE VENUS IONOSPHERE: EFFECTS OF SOLAR EUV, SOLAR WIND PRESSURE AND MAGNETIC FIELD

R. C. Elphic,* L. H. Brace** and C. T. Russell*

*Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024, U.S.A.
**Laboratory for Planetary Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.

ABSTRACT

The Venus ionosphere is influenced by variations in both solar EUV flux and solar wind conditions. On the dayside the location of the topside of the ionosphere, the ionopause, is controlled by solar wind dynamic pressure. Within the dayside ionosphere, however, electron density is affected mainly by solar EUV variations, and is relatively unaffected by solar wind variations and associated magnetic fields induced within the ionosphere. The existence of a substantial nightside ionosphere of Venus is thought to be due to the rapid nightward transport of dayside ionospheric plasma across the terminator. Typical solar wind conditions do not strongly affect this transport and consequently have little direct influence on nightside ionospheric conditions, except on occasions of extremely high solar wind dynamic pressure. However, both nightside electron density and temperature are affected by the presence of magnetic field, as in the case of ionospheric holes.

INTRODUCTION

Data from the Pioneer Venus orbiter (PVO) spacecraft in orbit around Venus clearly indicate that the Venus ionosphere responds to variations in solar extreme ultraviolet (EUV) radiation and to variations in solar wind conditions as well. Bauer and Taylor /1/ discussed EUV-induced variations of ion densities at low altitudes in the dayside Venus ionosphere (see also /2/, and /3/). The ionospheric response to solar wind variations is most evident in the day to day changes in the altitude of the ionopause, the boundary between the shocked solar wind plasma and the ionosphere /2,4,5,6/. The location of the ionopause is governed by the balance between total ionospheric pressure and the incident solar wind ram pressure; high dynamic pressures result in low ionopause altitudes, low dynamic pressures result in high ionopause altitudes. The nightside ionosphere is much more structured and variable than the dayside. In part this is due to the presence of ionospheric 'holes', regions of depleted plasma and strong radial magnetic field (cf. /2/). Cravens et al. /7/ have shown, moreover, that the nightside ionosphere can all but disappear during times of high solar wind dynamic pressure. This behavior plus the observed nightward flow of dayside plasma has led to the suggestion that high solar wind pressures may 'choke off' the flow to the nightside by forcing the upper boundary of the transterminator flow channel, the ionopause, to low altitudes.

We investigate here the dependence of day and nightside Venus ionospheric conditions on solar EUV, solar wind conditions and the associated magnetic fields in the ionosphere. We use electron density and temperature normalized by empirical models of Theis et al. /8/ to investigate variations about mean conditions.

DAYSIDE IONOSPHERIC CONDITIONS

We begin by investigating the response of the dayside electron density and temperature to solar EUV variations. Since there is no solar EUV spectrometer aboard PVO we must either resort to earth-based measurements mapped around to the location of Venus or use the photocurrent response of the Langmuir probe to EUV variations. Elphic et al. /9/ have shown that the latter technique yields quite reasonable results when compared to solar spectrometer data taken at the same time and solar longitude when Venus is at inferior conjunction. We use this solar EUV index to search for associated variations in the dayside ionosphere.

Electron density, and to a lesser extent temperature, vary over orders of magnitude as a function of altitude and solar zenith angle within the Venus ionosphere. One must remove this systematic spatial variation before looking for externally driven variations. To do this we normalize electron density and temperature to empirical models for the global Venus ionosphere /8/.

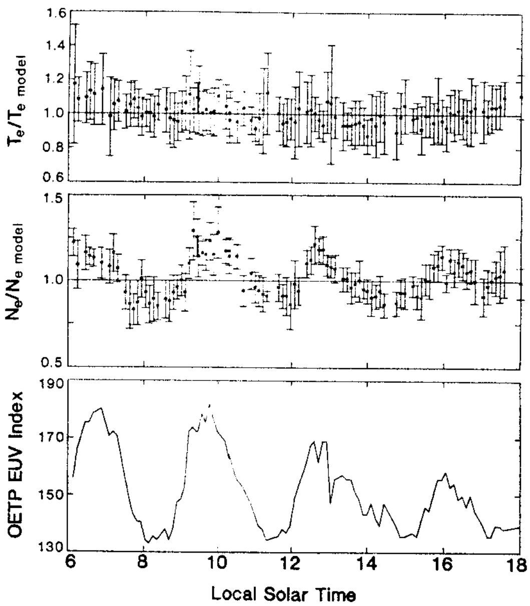

Fig. 1. Ionospheric electron number density and temperature below 200 km altitude, normalized for altitude and solar zenith angle by empirical models /8/ and averaged over each orbit versus the local solar time of periapsis for the orbit. Also plotted is the EUV index. Error bars denote standard deviations about the mean.

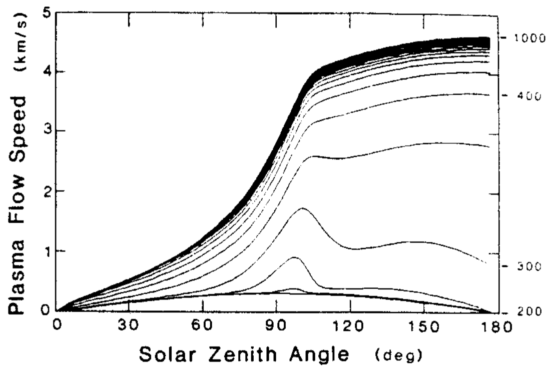

Fig. 2. Horizontal flow speed of ionospheric plasma as a function of solar zenith angle. Traces correspond to altitudes between 150 and 1000 km in 50 km steps.

Figure 1 shows average normalized values of electron number density and temperature (Ne and Te) and the EUV index versus the local solar time of periapsis for orbits in the second complete dayside periapsis season. Each point is an average of the normalized Ne and Te values taken between 150 and 200 km altitude for that particular orbit. The error bars are standard deviations about the mean. One can see that there is considerable correlation between the EUV index and the average normalized density, but no discernable correlation with temperature. For a full dayside dataset the correlation between normalized density and the EUV index is 0.78. The correlation between temperature and the EUV index is 0.29.

In order to search for the effect of solar wind-induced magnetic fields on Venus ionospheric conditions, we must remove the above EUV dependence. The re-normalized data can be compared directly with the observed magnetic fields in the ionosphere. Past studies have indicated that the Venus dayside ionosphere has two basic states: (1) a low field state threaded with magnetic filaments or 'flux ropes' and (2) a large scale, steady horizontal field /5,10/. The latter state represents the condition that most inhibits vertical diffusive transport and may be expected to affect the vertical profiles of density. This state is also associated with high solar wind dynamic pressures. We characterize the magnetic state of the orbit by using the average field strength between the altitudes of 150 and 200 km.

The resulting correlation between the re-normalized density data and the average field strength is small, -0.18. For the temperature data it is -0.14. Thus the variability of the EUV-detrended low altitude data is not clearly due to solar wind-induced magnetic fields nor to associated changes in vertical diffusive plasma transport. This is because collisions dominate the ion dynamics at altitudes below 200 km; the ions are unmagnetized and diffuse vertically the same way whether low or high fields are present. Consequently, the establishment of an equilibrium density distribution at low altitudes in the dayside ionosphere does not depend strongly on the magnetic state; however, $\underline{J}\times\underline{B}$ forces may cause some variation in equilibrium profiles.

NIGHTSIDE IONOSPHERIC CONDITIONS

As was mentioned earlier, the nightside Venus ionosphere is more spatially and temporally variable than the dayside. We investigate the dependence of nightside ionospheric density and temperature on solar wind dynamic pressure and magnetic field because (1) the solar wind may 'choke' the nightward flow during times of high ram pressure and (2) radial fields are associated with ionospheric holes. Again we use density and temperature data normalized to empirical models /8/. We consider only data from solar zenith angles beyond 110 degrees in order to avoid complicated structure near the terminator.

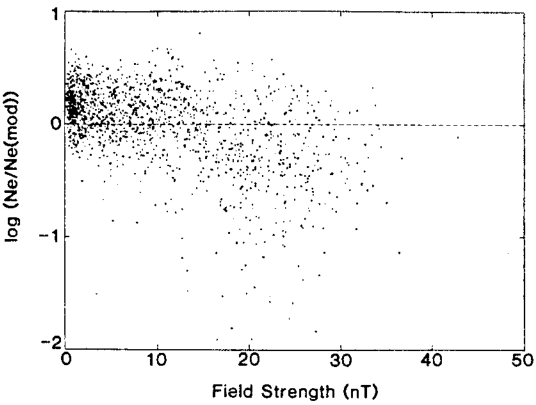

Fig. 3. Nightside electron densities normalized to an empirical model /8/ versus the local magnetic field strength.

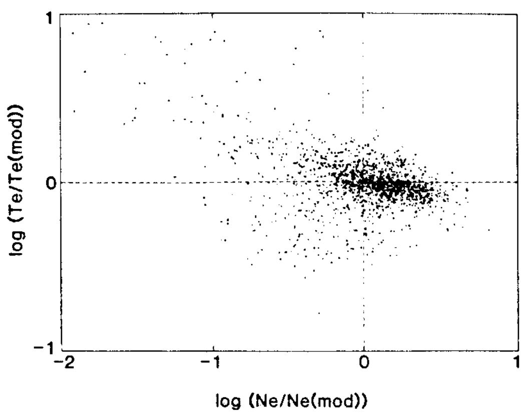

Fig. 4. Normalized nightside temperatures and densities from all altitudes.

It is now generally agreed that the nightside ionosphere is maintained by the transport of dayside ionospheric plasma across the terminator. This supersonic plasma flow has been measured by the orbiter retarding potential analyzer /11/, and various flow calculations /8,12,9/ all indicate that the nightward flow is a result of the large pressure difference between the day and nightside plasmas. This flow field is shown in Figure 2. The net flux of plasma, and hence the rate of supply to the nightside, depends upon the location of the upper boundary of the flow channel, namely the ionopause. When the solar wind drives the ionopause to low altitudes, the nightside ionosphere is supplied with much less plasma, leading to depleted or 'disappearing' ionospheres /7/. Therefore, some of the nightside variability may be controlled by this solar wind ram pressure choke effect.

However, normalized electron number density shows no obvious correlation with solar wind dynamic pressure for the interval studied here. There may be a slight trend toward lower densities for higher pressures, but there is also more than two decades of scatter in normalized density even at low dynamic pressures. Electron temperature likewise shows no trend. This lack of trend lies partly in the fact that the terminator ionopause is found at low altitudes only rarely; for the interval considered here the ionopause is never below 500 km. The typical terminator ionopause altitude is 1000 km. Thus, the flow channel varies in scale by perhaps a factor of 2, and the net nightside supply varies accordingly. Consequently for typical solar wind (and terminator ionopause) variations, the resultant changes in nightside density and temperature are smaller than the variations in normalized density. Some other factor, such as the presence of magnetic field, must be controlling the density.

The most remarkable magnetic structure in the nightside Venus ionosphere is the radial field associated with ionospheric holes, regions of depleted plasma density. In Figure 3 we plot the normalized density versus the local magnetic field strength, the higher values of which are usually associated with holes. Clearly the lower densities, and the greater variability, is found at higher field strengths; lower fields are associated with much less scatter in density. Electron temperature too shows greater scatter for the larger fields. One should recall that the depleted plasma found in holes is actually made up of two populations, one a cold ionospheric component, the other a hot tenuous solar wind component. The former shows up as the lower values of temperature in high fields, while the latter contributes to the high values of temperature.

Figure 4 shows this effect in a different way. Here we have plotted the normalized temperature versus the normalized density. The higher values of density tend to be associated with the more well-behaved temperature values, and both correspond to non-hole, low field regions. Conversely, the lower densities are associated with greater temperature scatter. More importantly, the values of intermediate low density ($-1 < \log(Ne) < 0$) tend to correspond to low temperatures, while very low densities ($\log(Ne) < -1$) are associated with high temperatures. This reflects the two plasma populations in the holes: At intermediate density depletions, only the cold ionospheric population contributes significantly to temperature, while at very low hole densities the hotter solar wind population contributes to the temperature.

SUMMARY

Venus' dayside ionosphere is influenced both by solar wind and solar EUV effects. The solar wind controls the location of the ionopause, while solar EUV is the most significant modulator of ionospheric density. The relative insensitivity of dayside density and temperature profiles to solar wind-induced ionospheric magnetic fields is due to the fact that at the low altitudes studied, the ions are unmagnetized and diffuse vertically without regard for the magnetic field state. However, large magnetic fields may cause some density and temperature variation on a case by case basis.

The nightside ionosphere is thought to derive from the pressure gradient driven transport of plasma across the terminator. As a result, the nightside density should be at the mercy of solar wind variations as they force the ionopause up and down, alternately opening up and closing down the flow channel. Certainly extreme cases of this are seen in the 'disappearing' nightside ionospheres observed during very high solar wind ram pressures. For the most part, however, the terminator ionopause only varies in altitude by a factor of two from the average, so that nightside density variations due to this effect are small. Large temperature and density variations are associated with ionospheric 'holes', regions of plasma depletion and strong radial magnetic field.

ACKNOWLEDGMENTS

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