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Modeling of the Venusian ionopause variations through the Solar cycle

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Astract

Crossings of the Venusian ionopause by Pioneer Venus Orbiter are analyzed as a function of spacecraft position, solar wind ram pressure and solar EUV flux intensity. Pressure balanced model is deduced for study of ionopause height variation at different zenith angles within solar cycle.

1. Introduction

An upper boundary of the Venusian ionosphere, called ionopause, was first observed by Mariner 5, 10 and Venera 9, 10 radio occultations, while Pioneer Venus Orbiter (PVO) provided large array of this boundary observations by different instruments at different solar zenith angles (*SZA*) and under various upstream solar wind and EUV flux (F_{euv}) conditions. The latest Venus Express (VEX) orbiter enabled possibility of near solar minimum (SA_{min}) in situ studies of magnetic barrier region but not the ionopause, since it was seldom observed due to VEX periapsis of 250 – 350 km during initial stage of mission [1]. Nobody yet modeled changes in the ionopause position and shape with F_{euv} variation within solar cycle. In the present paper we will try to study dependence of the ionopause position and shape on zenith angle, solar wind ram pressure, and EUV flux simultaneously.

2. Observations and modeling

Main part of PVO observations used in the present analysis is the set of the “pressure” ionopause crossings utilized in the detailed study [2]. From this data set, kindly provided by John Phillips, we used ionopause altitude *h*, and ‘flow zenith angle’ *FZA*. Solar wind proton density n_p and velocity *V* were merged from the data sets prepared by [3,4] for studies of the Venusian bow shock. Finally, F_{euv} flux at Venus was inferred from PVO Langmuir Probe measurements [5]. Figure 1a shows the results of F_{euv} measurements during the first 2500 orbits taken from UCLA IGPP Planetary Data System site: www.igpp.ucla.edu/cgi-bin/ditdos?volume=PV07_0001. Large systematic decrease of F_{euv} flux and its variations from SA_{max} to SA_{min} is obvious from this data. Relative variations of ρV^2 are larger than that of F_{euv} at any phase of the solar cycle, but the long term variation of ρV^2 is quite low (Fig. 1b).

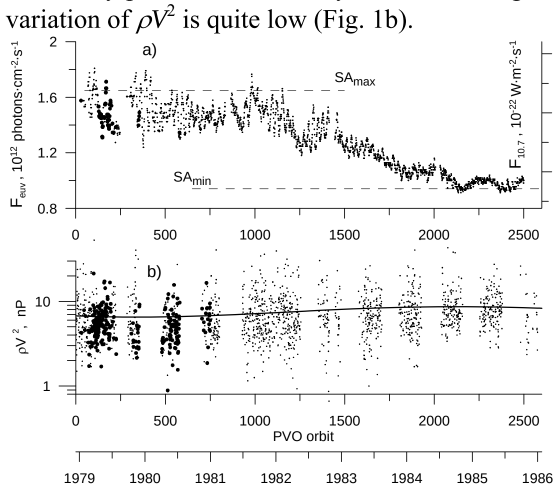

Figure 1: Thick points in Fig. 1b corresponds to ionopause crossings when ρV^2 and F_{euv} are available, while thick points in Fig. 1a corresponds to ionopause crossings with FZA < 90º additionally, and they will be used in our analysis.

As one can see from Fig. 1a the ionopause crossings used in our paper took place when F_{euv} varied in a range about half of the total range of F_{euv} changes within solar cycle.

A shape of the ionopause can be determined from generally accepted pressure balance equation:

$$k\rho V^2 \cos^2 \alpha_{vn} = p(r)\,, \qquad (1)$$

where α_{vn} is an angle between the solar wind velocity vector $\boldsymbol{V}$ and normal to the ionopause $\boldsymbol{n}$, $p(r)$ is a radial profile of the inner pressure and k ~ 0.88. Considering *x*, *y* coordinates with *x* axis pointing to the Sun and y being the distance to the *x*-axis, equation (1) can be rewritten as:

$$\frac{dx}{dy} = -\sqrt{\frac{p(r_0)}{p(r)} - 1}\,, \qquad (2)$$

where r_0 – is a 'subsolar' distance to the ionopause from the center of the planet $p(r_0) = k\rho V^2$. A reasonable analytical approximation of the obstacle shape might be produced using ionopause nose curvature radius R_0 and bluntness b_0 from the exact solution of equation (2) in the vicinity of $x = r_0$ [6], and numerical approximation of ionotail diameter D at infinity ($x \to -\infty$). For exponential internal pressure $p(r) = p(r_0)\cdot\exp((r_0 - r)/H)$ with scale height H:

$$D(H, r_0) = r_0 \cdot \left(2 + \frac{17}{3}\left(\frac{H}{r_0}\right)^{5/7} - \frac{4}{3}\left(\frac{H}{r_0}\right)^{4/7} + \frac{4}{5}\left(\frac{H}{r_0}\right)^{3/2} \right). \qquad (3)$$

The following empiric expression reasonably approximates the solution of equation (2):

$$x(y) = r_0 - \frac{y^2}{2R_0} - b_0 \frac{y^2 D^2}{32 R_0^3} \ln\left(1 - \frac{4y^2}{D^2}\right), \qquad (4)$$

In the present study we use more complicated biexponential internal pressure profile

$$p(r) = \frac{p_{eq}}{2} \cdot \left(\exp\left(\frac{r_{eq} - r}{H_1}\right) + \exp\left(\frac{r_{eq} - r}{H_2}\right) \right), \qquad (5)$$

defined by four parameters: p_{eq}, r_{eq}, H_1, H_2., and thus more sophisticated approximate solution instead of (4). We assume p_{eq}, r_{eq}, H_1, H_2 to be linear functions of F_{euv} with some coefficients k_p, k_r, k_{H1}, k_{H2} , and search for a 8D vector (p^*_{eq}, r^*_{eq}, H^*_1, H^*_2, k^*_p, k^*_r, k^*_{H1}, k^*_{H2}) that provides minimal value for mean squared deviation of real ionopause crossings from the modelled ionopause surfaces.

Figure 2a presents modeled dependence of the ionopause nose height on ρV^2. Upper and lower thick curves in this figure correspond to solar EUV fluxes specific for high SA_{max} and low SA_{min} solar activity periods (Fig. 1a). Dot and dashed line in Fig. 2a marks altitude of ~ 250 km – specific for Venusian dayside ionopause observations during SA_{min} according to PVO radio occultations data [1].

More details on the analytical model developed and on the correspondence of our ionopause model to observed ionopause crossings at different ρV^2 and EUV fluxes will be presented in the talk, as well as comparison of our model with the results of other PVO observations.

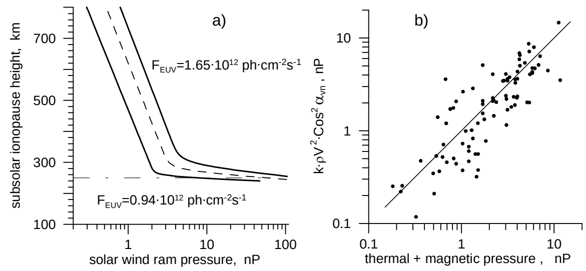

Figure 2: Subsolar ionopause height profiles (a). Correspondence between the external and internal pressures at the ionopause provides some evidence of rationality of model ionopause shape (b).

3. Conclusions

Venusian analytical ionopause model is developed considering variations of its position and shape both on solar wind ram pressure and solar EUV flux. This model provides possibility to trace ionopause within solar cycle. Our ionopause model can also be applied for the Venusian bow shock studies, thus ensuring reasonably correct mapping, normalization, and multifactor analysis of its crossings, and for clarification of relative role of different factors of unusually large variation of the bow shock terminator position within solar cycle.

Acknowledgements

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