A sporadic layer in the Venus lower ionosphere of meteoric origin

M. Pätzold,1 S. Tellmann,1 B. Häusler,2 M. K. Bird,3 G. L. Tyler,4 A. A. Christou,5 and P. Withers6

Received 1 September 2008; revised 22 October 2008; accepted 29 October 2008; published 12 March 2009.

[1] The Venus Express Radio Science (VeRa) experiment aboard Venus Express has detected, by means of radio occultation, distinct, low-lying layers of electron density below the base (115 km altitude) of the ionosphere of Venus. A plausible origin of these lowest layers is ionization by the influx of meteoroids into the atmosphere. The layers appeared only occasionally during the 2006 and 2007 Venus Express occultation seasons, could be identified only on the dayside and seem to be geographically localized as they usually occur in either the northern or southern hemisphere of the same orbit; they are detected at all latitudes, but only at solar zenith angles between 55° and 90°. Typical peak plasma densities of \(10^{10} \text{ m}^{-3}\) are reached between 110 and 120 km altitude. Peak meteor layer electron densities increase with decreasing solar zenith angle. Layer shapes are symmetric with respect to peak altitude. The present observational statistics and lack of dedicated models prevents definite statements to be made on the origin of the source meteoroids. Citation: Pätzold, M., S. Tellmann, B. Häusler, M. K. Bird, G. L. Tyler, A. A. Christou, and P. Withers (2009), A sporadic layer in the Venus lower ionosphere of meteoric origin, Geophys. Res. Lett., 36, L05203, doi:10.1029/2008GL035875.

1. Introduction

[2] The ionosphere of Venus was first detected by the radio science experiment on Mariner 5 in 1967 [Kliore et al., 1967]. Several instruments on the Pioneer Venus Orbiter (PVO) returned in situ information on ionospheric composition [Taylor et al., 1980]; height profiles of the electron density distribution were measured by the PVO Radio Occultation experiment (see, e.g., the review by Brace and Kliore [1991]).

[3] The Venus Express Radio Science Experiment, VeRa (see Häusler et al. [2006] for details) onboard the ESA Venus Express (VEX) spacecraft sounds the Venus atmosphere and ionosphere using coherent, highly-stable, radio carrier downlink signals at frequencies of 2.3 and 8.4 GHz, driven by an Ultra-Stable Oscillator (USO). Radio occultations, as seen from a terrestrial tracking station, occur as the spacecraft disappears behind the planetary disk and later emerges from behind the opposite limb. These events occur once per VEX orbit of 24 hours over a period of some months or weeks, referred to as a “season”, which depends on the geometry of the spacecraft orbital plane relative to the positions of Earth and Venus. At ingress, the radio ray path moves downward from the top of the ionosphere and atmosphere to a minimum altitude approaching the physical limit near 32 km, the level at which the atmosphere is critically refractive [Fjeldbo et al., 1971]. Refraction by the neutral atmosphere and ionosphere alters the path of the radio signal, leading to a frequency shift as received by the ground station. A vertical profile of the refractive index in the Venusian atmosphere/ionosphere is derived from the measured frequency. Vertical ionospheric electron density profiles are derived from the respective refractive index profiles between 50 and 1500 km altitude. Derived ionospheric electron densities typically exceed their uncertainties of \(2,000 \times 10^{6} \text{ m}^{-3}\) from 100 to 400 km.

2. Observations

[4] During the first three VEX occultation seasons of 2006–2007 the VeRa experiment retrieved 118 profiles, equally divided between occultation ingress and egress, of pressure, temperature, and neutral number density from the lower atmosphere (<90 km) together with profiles of electron density from the overlying ionosphere [Pätzold et al., 2007]. Within the southern hemisphere the height profiles are well-distributed in latitude, whereas the northern hemisphere observations are restricted to latitudes above 65°. About half of all profiles are nighttime profiles with solar zenith angles ranging from 90° to 113°.

[5] Figure 1 shows daytime electron density profiles from the first occultation season. These profiles were observed on DOY 204, 2006, for occultation ingress (Figure 1, left) and egress (Figure 1, right). In addition to the main layer at \(\approx 140 \text{ km altitude}, V2\), a secondary layer, \(V1\), at the lower altitude of \(\approx 125 \text{ km}\) is readily identified.

[6] We report here the presence of a sporadic layer below \(\approx 115 \text{ km altitude}\), i.e., below the base of the \(V1\) layer. An example of the additional layer is presented in Figure 1 (left), well below and distinctly separate from \(V1\); no such layer is present in the corresponding egress profile (Figure 1, right) obtained at high northern latitude. This new layer has a peak electron density of \(10,000 \times 10^{6} \text{ m}^{-3}\) at \(\approx 110 \text{ km}\) altitude, well above the noise level \((2,000 \times 10^{6} \text{ m}^{-3})\). Witasse and Nagy [2006] pointed out that such a layer may be visible in two profiles from the PVO Radio Occultation Experiment. Similar features are present in the dayside ionosphere profile from Mariner 10 [Fjeldbo et al., 1975] and in some ionospheric electron density profiles at Mars [Pätzold et al., 2005].

Copyright 2009 by the American Geophysical Union.

0094-8276/09/2008GL035875S05.00
[7] Figure 2 shows three further examples of layers below V1 from 2007 DOY 016, 164 and 173. None of the corresponding profiles from the opposite hemisphere display a lower layer. Figure 2a (top) and Figure 2a (bottom) show a layer well detached from V1, in contrast to the additional layer in Figure 2b, which is clearly merged with the V1 base. Finally, double peaks below V1, illustrated in Figure 2c, are observed in several profiles; these double layers are well resolved and distinct from each other, although the upper layer partially merges with V1.

3. Analysis and Interpretation

[8] Sporadic plasma layers below the expected lower boundary of the ionosphere were predicted prior to these observations [e.g., Pesnell and Grebowsky, 2001; Pesnell et al., 2004; Grebowsky et al., 2002]. They are believed to be caused by the surface ablation of metallic atoms from impacting meteoroids and subsequent ionization. This well-known phenomenon in the Earth’s ionosphere occurs at altitudes of 95 to 100 km [e.g., McNeil et al., 2001]. A “meteor layer” containing metallic ions, predicted at Mars at altitudes between 80 and 100 km, was recently detected [Pätzold et al., 2005]. The Martian meteor layer typically has a peak electron density of $8 \times 10^6$ m$^{-3}$ at altitudes between 70 and 100 km. While the observed number density of metallic ions in the Martian meteor layer agrees well with previous models [Pesnell and Grebowsky, 2000; Molina-Cuberos et al., 2003], the observed density peak in the Venus layers reported here is many times larger [Grebowsky et al., 2002] and at different altitudes [Molina-Cuberos et al., 2008] than predicted.

[9] Three processes have been proposed to form ions from the ablated atoms [Pesnell and Grebowsky, 2000; Molina-Cuberos et al., 2003]: (i) photoionization and photoelectron impact ionization, (ii) charge exchange, and (iii) direct ionization by hyperthermal collisions. Since the VeRa observations clearly show an increase in the electron density, photoionization is the likely dominant daytime process for creating the extra layer. On the other hand, charge exchange between short-lived ($\text{O}_2^+$) and long-lived metal species ($\text{Mg}^+; \text{Fe}^+$) may decrease the recombination loss rate. Electrons can thus accumulate in “bottleneck” fashion, increasing their density even if their production rate (by CO$_2$ photoionization) is unchanged.

[10] Figure 2 (bottom) shows the result of separating the low layers from V1. The contribution of V1 has been removed by fitting and subtracting a Chapman function from the observed profiles. The density distributions of the additional layers are symmetric in altitude about their peak, the residuals—observed electron density minus the fits—scattering randomly about zero.

[11] The density and deposition altitude of the ablated metal atoms depend on the relative impact speed into the atmosphere. Fast meteors ablate considerably more metal atoms, and at higher altitudes, than do slower meteors of the same mass. Hence, the double peaks below V1 (Figure 2c) may represent two different meteoric populations.

[12] Molina-Cuberos et al. [2008] predict a peak metal atom deposition altitude at Venus of 110–120 km and a metal ion peak altitude of 120–130 km. The ionized meteor layer would be very difficult to detect in this altitude range because it would merge directly with V1. The VeRa observations, however, show the peak of the meteor layer at an average altitude of 113 ± 4 km (see Table S1 in the auxiliary material), well below the predicted lower limit of 120 km. Table S1 lists the observational characteristics of all detected low lying layers.

[13] Plotting the meteor layer peak density versus solar zenith angle shows that the peak density tends to increase with decreasing SZA (Figure 3). No low-lying layers have been observed outside the range $59^\circ < \text{SZA} < 91^\circ$, which may indicate that impacts preferentially occur near the terminator. Compared with the total number of observed electron density profiles per $10^6$ solar zenith angle range (Figure 3), about 30% of all observed profiles in the range

---

 Auxiliary materials are available in the HTML. doi:10.1029/2008GL035875.
contain a meteor layer. A similar correlation of the peak altitude with solar zenith angle, however, could not be verified but, as already mentioned, the deposition altitude is controlled by the relative impact speed of the meteors [Molina-Cuberos et al., 2008].

It is very difficult to identify a meteor layer in the nighttime profiles with unstructured ionization. Although there is significant ionization below 120 km in many of the nightside profiles [Pätzold et al., 2007], it is not a distinct layer as on the dayside (Figures 1 and 2). It is premature to conclude that the lower peak of this structure [Kliore et al., 1979; Pätzold et al., 2007] is formed by meteors because the altitude does not agree with the VeRa dayside meteor layer observations, the shape of the layer is not symmetric as on the dayside and the peak amplitude is comparable to the fluctuation of the electron density within the entire profile.

The VeRa data show the observed meteor layers to be a sporadic phenomenon with regard to the sensitivity of the radio science method, rather than a permanent dayside feature. We note two instances, 2007 DOY 014 and DOY 016, where the meteor layer was observed on both the ingress and egress occultations of an individual orbit.

4. Meteoroid Source Regions: Discussion

Annual meteor activity at the Earth consists of the sporadic background and showers. The sporadic background flux is continuous but is neither constant nor isotropic. It mainly originates from discrete sources near the ecliptic plane [Campbell-Brown and Jones, 2006]. The principal seasonal and latitudinal trends in sporadic meteor activity as observed by radars over several years have been attributed to the geometric effects of the Earth’s obliquity.


M. K. Bird, Argelander Institut für Astronomie, Universität Bonn, D-53121 Bonn, Germany.

A. A. Christou, Armagh Observatory, College Hill, Armagh BT61 9DG, UK.

B. Häusler, Institut für Raumfahrttechnik, Universität der Bundeswehr München, D-85577 Neubiberg, Germany.

M. Pätzold and S. Tellmann, Rheinisches Institut für Umweltforschung, Abteilung Planetenforschung, Universität zu Köln, D-50931 Cologne, Germany. (martin.patzold@uni-koeln.de)

G. L. Tyler, Department for Electrical Engineering, Stanford University, Stanford, CA 94305-9515, USA.

P. Withers, Center for Space Physics, Boston University, Boston, MA 02215, USA.