Spatiotemporal Variability of the Venusian Ionosphere

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Introduction

Total free electron content (or electron density) varies throughout the Venusian upper atmosphere depending on spatiotemporal factors, providing an insight into the ionization processes that affect the climate and atmosphere. Photochemical processes that lead to the production and loss of free electrons control the Venusian ionosphere. The photochemical processes of the Venusian ionosphere include:

- Photoionization, a production process
- Electron-impact ionization, a production process
- Dissociative recombination, a loss process

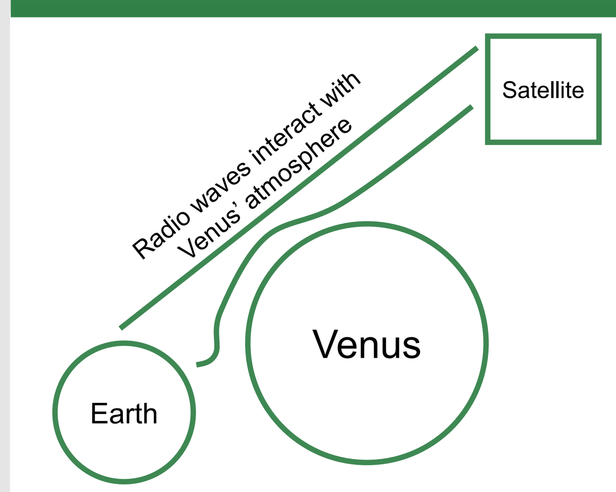
(Hensley et al., 2020[2], Brace & Kliore, 1991[1])

The ionization processes in the Venusian ionosphere depend on atmospheric interactions with photons, which is clear when examining electron density as a function of altitude and the following spatiotemporal variables:

- Solar zenith angle
- Latitude
- Longitude

Despite the differences in the electron density with latitude, longitude, and solar zenith angle, the Venusian ionospheric electron density peaks at approximately 140 km regardless of these factors.

Materials and Methods



The research used electron density profiles from Venera 15/16 (29 profiles) and Pioneer Venus Orbiter (154 profiles) satellites. The satellites performed radio occultation of the Venusian neutral atmosphere and ionosphere to obtain the profiles pictured in the upper left corner.

The electron density profiles from Venera 15/16 and Pioneer Venus Orbiter were then processed based on the following parameters:

- ~ 10° solar zenith angle bins
- ~ 5° latitude bins
- ~ 5° longitude bins
- 5 km altitude bins between 110 and 250 km

The altitude range represents the altitude of the Venusian upper atmosphere and ionospheric peak. The ionospheric peak at ~ 140 km was the point of comparison used to analyze electron density variation with spatiotemporal factors.

Comparison of the ionospheric peak data from Venera 15/16 and Pioneer Venus Orbiter to Akatsuki and Venus Express publications (Hensley et al., 2020[2]; Tripathi et al., 2023[3]) confirmed the findings.

Results

Electron density profiles from Pioneer Venus Orbiter, including spatiotemporal variables, indicated the Venusian ionosphere's dependence on photoionization to produce free electrons.

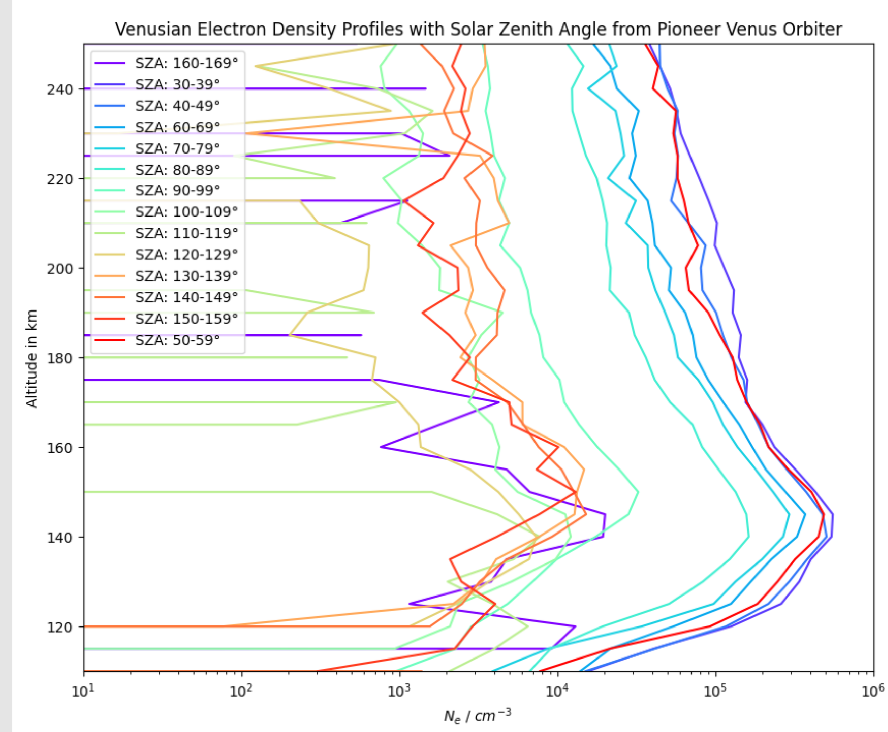


Figure 1: Variation of the number of electrons in cm^{-3} with altitude. Each line represents a range of solar zenith angles (SZA). For SZA values greater than 90°, which correspond to the nighttime ionosphere, there is a decrease in electron density from between 10^5 and 10^6 in the daytime ionosphere to $\sim 10^4$ at nighttime.

The variable that changes between SZA greater than and less than 90° is the ability for photoionization to occur, suggesting it causes the decrease in electron density.

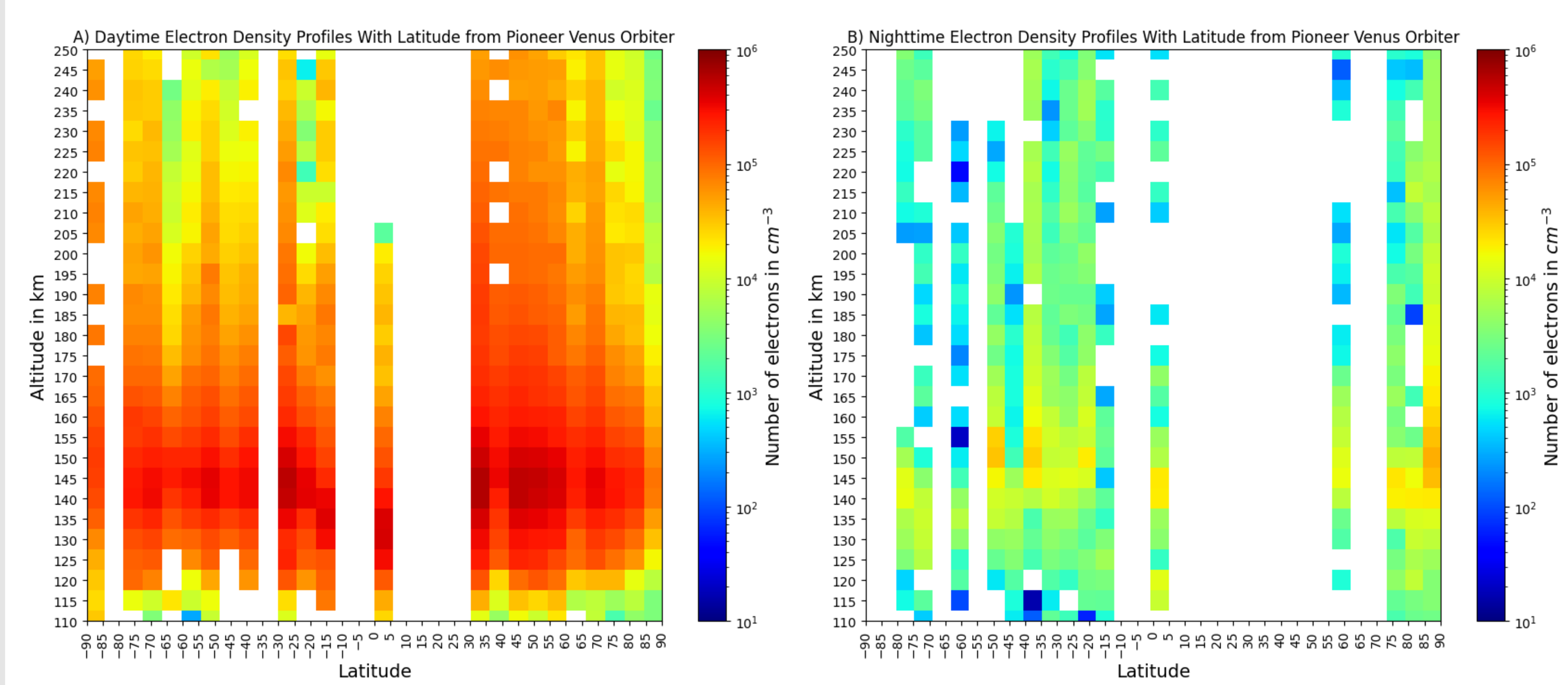


Figure 2: Whitespaces represent data gaps. A) Variation of the number of electrons in cm^{-3} with latitude and altitude in the daytime ionosphere including all longitudes. There is an increase in electron density from ~ 10^5 at high latitudes to ~ 10^6 at mid to low latitudes. B) The same as A but in the nighttime ionosphere. There is no correlation between electron density and latitude in the nighttime profile.

The increase in electron density from high latitudes to low latitudes in the daytime profile suggests that increased solar intensity at low latitudes near the equator increases photoionization and, therefore, total free electron content.

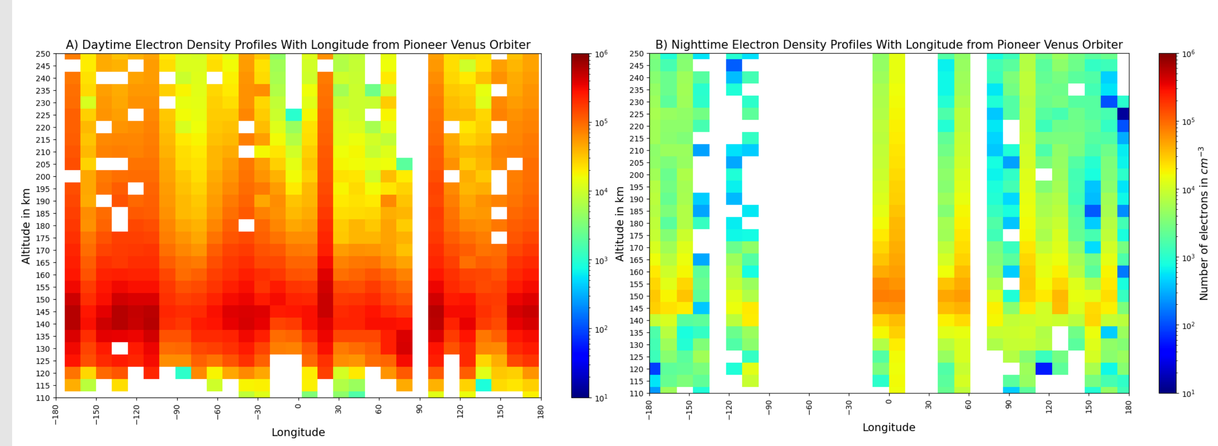


Figure 3: White spaces represent data gaps. A) Variation of number of electrons in cm^{-3} with longitude and altitude in the daytime ionosphere. B) Same as A but in the nighttime ionosphere. There is no clear longitudinal pattern.

Conclusions & Future Work

Main findings are as follows:

1. Photoionization is a major source of Venusian ionospheric production.
2. The Venusian ionosphere exhibits a significant degree of spatiotemporal variability

The implications of these conclusions to further studies of planetary atmosphere and ionosphere are as follows:

- Greater understanding of ionization processes
- A comparison point to investigate the effects of photoionization on other planets with orbits, axial tilts, and rotation speeds that are different from Venus'

Potential future work with the Venusian ionosphere:

- It would be ideal to utilize data from the more recent Venus Express and Akatsuki missions due to the greater number of profiles
- Investigate seasonal and solar irradiance variation and their effect on spatiotemporal variation

Major Citations

1. Brace, L., & Kliore, A. (1991). The Structure of the Venus Ionosphere. *ßr, 55(1-4), 81-163.* https://doi.org/10.1007/BF00177136
2. Hensley, K., Withers, P., Girazian, Z., Pätzold, M., Tellmann, S., & Häusler, B. (2020). Dependence of dayside electron densities at Venus on solar irradiance. *Journal of Geophysical Research: Space Physics*, 125, e2019JA027167. https://doi.org/10.1029/2019JA027167
3. Tripathi, K. R., Choudhary, R. K., Jose, J. S., Ambili, K. M., & Imamura, T. (2023). Gravity wave modulations at the lower altitudes of Venus ionosphere. *Geophysical Research Letters*, 50, e2022GL101793. https://doi.org/10.1029/2022GL101793

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