Non-migrating atmospheric tides as a driver of variability in the nightside Martian ionosphere

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Understanding the dynamics of the nightside ionosphere of Mars has presented more of a challenge than those on the dayside due to the nightside being more difficult to characterize as a result of the plasma density being lower and more variable there [e.g., Girazian et al., 2017; Nemnec et al., 2010]. Causes of this enhanced electron density variability are not yet fully understood, but have been studied in the context of ionizing electron precipitation [e.g., Fowler et al., 2015; Lillis et al., 2018], combination of ionizing electron precipitation and horizontal transport from the dayside [e.g., Adams et al., 2018], composition and chemistry [Girazian et al., 2017], and solar flare events [Harada, et al., 2018]. One possible source of nightside variability is nonmigrating tides in the neutral atmosphere. It had been shown that nonmigrating tides do play a role in the dayside ionospheric variability [e.g., Bougher et. al 2001; Mendillo et al., 2017; Fang et al 2021; Thaller et al., 2020; 2021]. Altitude profiles of the amplitude of the normalized longitudinal electron density variations on the night side have been presented by Thaller et al. [2020; 2021], but they did not investigate the cause of those variations. The study presented herein is motivated by the nightside observations of significant (~40% relative to the background) longitudinal variations in electron density presented in Thaller et al [2021], and the goal of understanding whether and to what extent those electron density variations result from the tidal variations observed in the neutral atmosphere, also reported in Thaller et al. [2021]. In doing so, this investigation contributes to the broader goal of understanding the nightside dynamics of the Mars ionosphere.

In this study, we investigate whether, on the nightside of Mars, the variation in ionospheric electron density (with respect to the zonal mean electron density) as function of longitude, constructed from 20-day intervals of data, is the result of nonmigrating atmospheric tides and ionosphere-thermosphere (IT) coupling. Here, nightside is defined as solar zenith angles > 110^o, comprising three more specific regions, namely, pre-midnight, deep-midnight, and post-midnight. This investigation uses a combination of in situ neutral and electron density measurements by the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft and a simple model. The in situ neutral abundance and electron density measurements are made by MAVEN's Neutral Gas and Ion Mass Spectrometer (NGIMS) and the Langmuir Probe and Waves (LPW) instruments, respectively. From these in situ datasets, longitudinal profiles at discrete altitudes of the density variations (percent variation with respect to the zonal mean) are produced and studied both individually and statistically. Instances in which the neutral and electron zonal density perturbations either correlate or anti-correlate with one another are found, suggesting the possibility of a causal relation. The simple model consists of an approximate expression for electron density as function of the neutral density, derived from the plasma fluid equations for the conditions that ion-neutral collisions are important, vertical transport is allowed, and the chemical and diffusion timescales are shorter than the tidal wave period allowing for the system to maintain approximate equilibrium. The inputs for the model are sets of three neutral density values, one +20% and another -20% about some baseline (zonal mean) neutral density which is the third value in the set. The range of baseline values for the neutral densities used corresponds to that observed by MAVEN in the region studied. The amplitude of 20% for the neutral variations was chosen based on the observed amplitudes of the tidal density variations in the neutral atmosphere. The model outputs are the percent variation of the electron density from a baseline electron density. The amplitudes of the variation in the electron density are plotted against the baseline neutral densities, and compared to those found from the MAVEN data. The comparison between the electron density variations predicted by the simple model and those determined from the MAVEN data shows that, to first order, the simple model does a reasonable job predicting the amplitude of the electron density variations as function of the neutral density undergoing tidally driven perturbations. Another result of the study is that the region where the IT coupling transitions between being dominated by ionospheric chemistry, at lower altitudes (higher neutral densities), to where diffusion becomes increasingly important, at higher altitudes (lower neutral density), is the region where tidal variations in the neutral atmosphere result in quicky increasing amplitudes in the electron density variations with increasing altitude (decreasing neutral density). These results lead to the conclusion that nonmigrating tides in the neutral atmosphere do contribute to driving variations in the nightside ionosphere. Models with the aim of reproducing the structure and variability of the nightside ionosphere should thus include the tidal motions of the neutral atmosphere.

Bibliography:

Adams, D., Xu, S., Mitchell, D. L., Lillis, R. J., Fillingim, M., Andersson, L., et al. (2018). Using magnetic topology to probe the sources of Mars' nightside ionosphere. Geophysical Research Letters, 45, 12,190–12,197. https://doi.org/10.1029/2018GL080629

Bougher, S. W., Engel, S., Hinson, D. P., & Forbes, J. M. (2001). Mars Global Surveyor radio science electron density profiles: Neutral atmosphere implications. Geophysical Research Letters, 28, 3091–3094. https://doi.org/10.1029/2001GL012884

Fang, X., Forbes, J. M., Gan, Q., Liu, G., Thaller, S., Bougher, S., et al. (2021). Tidal effects on the longitudinal structures of the Martian thermosphere and topside ionosphere observed by MAVEN. Journal of Geophysical Research: Space Physics, 126, e2020JA028562. https://doi.org/10.1029/2020JA028562

Fowler, C. M., et al. (2015), The first in situ electron temperature and density measurements of the Martian nightside ionosphere, Geophys. Res. Lett., 42, 8854–8861, doi:10.1002/2015GL065267.

Girazian, Z., P. R. Mahaffy, R. J. Lillis, M. Benna, M. Elrod, and B. M. Jakosky (2017), Nightside ionosphere of Mars: Composition, vertical structure, and variability,J. Geophys. Res. Space Physics,122, 4712–4725,doi:10.1002/2016JA023508.

Harada, Y., Gurnett, D. A., Kopf, A. J., Halekas, J. S., Ruhunusiri, S.,DiBraccio, G. A., et al. (2018). MARSIS observations of the Martian nightside ionosphere during the September 2017 solar event. Geophysical Research Letters, 45, 7960–7967. https://doi.org/10.1002/2018GL077622

Lillis, R. J., Mitchell, D. L., Steckiewicz, M.,Brain, D., Xu, S., Weber, T., et al. (2018). Ionizing electrons on the Martian nightside: Structure and variability. Journal of Geophysical Research: Space Physics, 123. https://doi.org/10.1029/ 2017JA025151

Mendillo, M., Narvaez, C., Vogt, M. F., Mayyasi, M., Forbes, J., Galand, M., …Andersson, L. (2017). Sources of ionospheric variability at Mars. Journal of Geophysical Research: Space Physics, 122. https://doi.org/10.1002/2017JA024366

Nemec, F., Morgan, D. D., Gurnett, D. A., & Duru, F. (2010). Nightside ionosphere of Mars: Radar soundings by the Mars Express spacecraft. Journal of Geophysical Research, 115, E12009. https://doi.org/10.1029/2010JE003663

Thaller, S.A., Andersson, L., Pilinski, M.D., Thiemann, E., Withers, P., Elrod, M., Fang, X., Gonz´alez-Galindo, F., Bougher, S., Jenkins, G., 2020. Tidal wave-driven variability in the Mars ionosphere-thermosphere system. Atmosphere 11. https://doi.org/ 10.3390/atmos11050521, 521. 21

Scott A. Thaller, Laila Andersson, Edward Thiemann, Marcin D. Pilinski, Xiaohua Fang, Meredith Elrod, Paul Withers, Stephen Bougher, Geoffrey Jenkins, Martian nonmigrating atmospheric tides in the thermosphere and ionosphere at solar minimum, Icarus, 2021, 114767, ISSN 0019-1035, https://doi.org/10.1016/j.icarus.2021.114767.