Annual variability in the thermospheric wave perturbations at Mars

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Although there have been very limited observations in the Martian thermosphere, especially on the night side, our understanding of the region has been rapidly enhanced in recent years by the MAVEN spacecraft (Bougher et al. (2015) ; Yigit et al. (2015) ; England et al; Siddle et al. (2019) ; Nakagawa et al. (2020) Recent observations have reported that wave-like perturbations are ubiquitously observed in the thermosphere, especially on the night side, with large amplitude density perturbations exceeding 50%. The anti-correlated amplitudes with the background temperature suggest the saturated atmospheric gravity wave (Terada et al., 2017). There are two possible excitation sources: (1) atmospheric gravity waves propagating upward from the lower atmosphere, and (2) energy injected from the upper atmosphere by external factors such as solar wind or energetic solar particles.

The widespread diffuse aurora on Mars (Schneider et al., 2015, 2020), recently discovered by the MAVEN spacecraft, is a luminous phenomenon that covers the entire Martian night side with the arrival of solar energetic particles (SEPs) and has an emission altitude of 60 km. This suggests that energetic particles can have a significant impact on the deep Martian atmosphere by globally injecting energy. In particular, ionization, dissociation, heating, and disturbance effects in the upper atmosphere can potentially have an impact on the escaping atmosphere, and are important for understanding the response of Mars, a non-magnetic planet, to space environment changes.

In this study, we use the MAVEN onboard mass spectrometer NGIMS to reveal the long-term interannual variation of density perturbation components in the Martian thermosphere. In particular, NGIMS has realized the multi-molecular observation since Viking, and here we focus on the difference in behavior between CO_2 and N_2 density perturbations in order to constrain the excitation source. In this study, we used the MAVEN/NGIMS data Level-2 and version-8 registered in NASA PDS.

In the evolution of the CO_2 density disturbance components over the five-year period from 2015 to 2020, we find that the amplitude of the density perturbations is significantly larger in the nighttime than in the daytime throughout the five-year period. This is consistent with the results of recent previous studies (Terada et al., 2017; Nakagawa et al., 2020). On the other hand, it should be noted that the amplitude of the density disturbance differs from year to year. In this paper, we will discuss in detail the relative importance of the lower and external factors on the interannual variation. Another important feature is the relationship between the perturbation amplitude components of CO_2 and N_2. The statistical results show that the two are basically well correlated, with CO_2 of a larger perturbation amplitude than N_2. This is consistent with the arguments of Cui et al. (2014) and England et al. (2016, 2017), because the disturbance amplitude normalized by the background density is anti-correlated to the scale height, and the amplitude ratio corresponds to the mass ratio of the molecular species. In fact, a scatter plot of the disturbance amplitudes of CO_2 and N_2 shows a distribution that follows with a mass ratio of 28/44 ~ 0.64, the mass ratio of CO_2 and N_2. Analysis of the perturbation components for each orbit shows that CO_2 and N_2 are well in phase with each other in many cases. On the other hand, we also find the N_2 perturbation

amplitude sometimes exceeds that of CO_2, meanwhile the perturbations seen in N_2 appear to be out of phase with those in CO_2. Interestingly, according to the predictions of the full-particle Direct Simulation Monte-Carlo (DSMC) modeling of the Martian upper atmosphere (Terada et al., 2016), the atmospheric waves excited at thermospheric altitudes during the injection of energetic particles from space have different wavelengths and amplitudes at each species. It is suggested that the amplitude of N_2 perturbations exceeds that of CO_2 at the distance from the source region (Terada et al., in prep.). In this paper, we compare and discuss the predictions with this numerical model and the implications of the observations.

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