

The effect of atmospheric gravity waves on the water transport and its escape on Mars

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It is believed that Mars underwent drastic climate change from warm and wet to cold and dry. Atmospheric evolution is an important key to understanding the history of Martian habitability. However, precise estimates of past atmospheric inventories including water, and their loss mechanisms, are difficult to be obtained. Recent studies revealed the highly variable nature of exospheric hydrogen escape in a time-scale of a season or shorter [Chaffin et al., 2014; Clarke et al., 2017]. Because the production timescale of H₂ (major source of exospheric hydrogen to escape) from H₂O in the lower atmosphere is predicted to be 10,000 years by the model (Hunter and McElroy, 1970), the hydrogen escape rate should not vary from month-to-month or from year-to-year. This may represent H₂O was carried from the surface to the upper atmosphere, which dramatically increases hydrogen production. These results show that hydrogen escape is more variable than previously suspected, potentially resulting in much larger integrated water loss over Martian history. In addition, it is interesting to note that high-altitude (40-80km) H₂O was first identified by SPICAM occultations (Maltagliati et al., 2011; 2013) especially in the southern summer, which happens to be a dusty season at a solar longitude of 240 or later. Chaffin et al. (2017) demonstrated that the high-altitude H₂O can considerably increase hydrogen escape on the weekly timescale, which can potentially explain the observations mentioned above. The new pathway of water loss proposed by these studies implies much higher loss to space, in addition to the diffuse-limited escape of H₂ (Catling and Kasting, 2017). However, the mechanisms for upward transport of water to high altitudes to provide a source of hydrogen escape are not known. One of the possible scenarios is upward transport of water vapor due to enhanced diffusion caused by gravity waves (GWs) of lower atmospheric origin.

Large-scale winds and eddy diffusion are responsible for the main transport effect in the Martian middle-upper atmosphere. GWs are important in defining large-scale winds and eddy diffusion [Medvedev et al., 2011]. The IUVS onboard MAVEN provides a new set of data to address the regional couplings on Martian atmosphere. Here we investigate the effects of GWs on the upward transport of water and resultant water escape based on an integrated data analysis of neutral atmospheric observations by MAVEN/IUVS.

We used IUVS data to observe the small-scale waves, the convective instability layers, and the homopause height simultaneously in order to investigate how the instability affects on the atmospheric composition. The observed perturbations in IUVS temperature profile demonstrate wave signatures with vertical wavelengths of 10-20 km and amplitudes in excess of 20% of the mean background in the range of 30-150 km altitudes. Convective instabilities inferred from the temperature profile, which implies GWs drag, widely found in mesosphere and lower thermosphere. This suggests the turbulent layer in the mesosphere-lower thermosphere caused by the breaking of GWs, as seen in the terrestrial mesosphere [Tsuda et al., 2014]. The noticeable activities were found in the southern summer. The averaged amplitude is about three-times the values in the northern winter. Consequently, much more layers of low stability were found in this season. Martian General Circulation Model (MGCM) [Medvedev and Hartogh, 2007] underestimated the observed wave amplitudes in the southern summer, which might suggest

improvements of the GW-sources and background winds in the model. Meanwhile, the homopause height appears to increase in synchrony with the wave activity. It is also noted that the mesospheric aerosols in 40-80 km altitude also exhibit an enhancement with the waves. To summarize, the GWs produce a low stability layer and lead to turbulence generation in the mesosphere-lower thermosphere. The wave-induced turbulence increases vertical mixing of the atmosphere then it affects the homopause height. Since the homopause height has a large influence on the atmospheric composition that has to be escaped to space, it is noteworthy that the GWs in the lower atmospheric origin may have on the atmospheric evolution. Our result tells us that Mars is a mutually coupled system comprising the planet's surface, lower and upper atmospheres.

Keywords: Mars, Water, Gravity waves