Global characterization of wave perturbations in the middle atmosphere on Mars

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Small-scale atmospheric waves, such as internal gravity waves, are recognized as an important part of the terrestrial climate system. They ubiquitously exist on the Earth’s upper atmosphere and affect the dynamics, composition, and thermal structure of the terrestrial middle atmosphere and thermosphere. Global characteristics of gravity waves on Earth have been extensively investigated over decades. On Mars, large fluctuations in density and temperature with short vertical wavelengths were first detected in Viking, Opportunity, Spirit, and Mars Pathfinder entry profiles. Wave amplitudes in the Martian atmosphere are larger than those in the terrestrial atmosphere and the important role of gravity waves of tropospheric origin in the middle atmosphere has been appreciated in early modeling studies. Gravity waves strongly affect the large-scale winds, thermal balance, density in the mesosphere and lower thermosphere. Since October 2014, NASA’s Mars Atmosphere and Volatile EvolutioN (MAVEN) mission have been performed comprehensive studies of the Martian atmosphere. In-situ measurements of the upper atmosphere, from 300 km down to 130 km, revealed that wavelike perturbations ubiquitously exist in ions and neutrals in the upper thermosphere. Wavelike perturbations have also been detected by remote sensing with the Imaging Ultraviolet Spectrograph (IUVS) onboard MAVEN at altitudes between 20 and 150 km. These IUVS measurements provide opportunities for investigating possible links between waves in the Martian troposphere and thermosphere.

In order to clarify a global characteristic of waves and its upward propagating processes, we use IUVS stellar occultation measurements to characterize a global distribution of waves in the middle atmosphere between 24 March 2015 and 12 April 2018 for two Martian Years. This study first revealed global characteristics of wave perturbations in the night side temperature profiles derived from MAVEN/IUVS stellar occultations at 20 - 160 km altitudes on Mars. The peak amplitudes of waves on Mars exceed 20 % which is larger than those in Earth’s mesosphere/thermosphere (~5-13 %). Perturbations were found to be notably large in summer hemisphere at L_s = 0-180. These waves can be interpreted as resulting from superposed harmonics of internal gravity waves and thermal tides. The superposition of thermal-tides and small-scale perturbations generate extensive instability layer around 70 - 100 km, which potentially causes wave-breaking and turbulences. Vertical wavenumber spectral density in the Martian middle atmosphere shows a power-law dependence with the logarithmic spectral slope of -3. This is similar to the features seen in the Earth’s atmosphere. The spectral density in southern hemisphere at L_s = 225-315 tends to follow the semi-empirical spectrum of saturated gravity waves on the high-wavenumber side. The spectral power at high-wavenumbers is lower at 80 - 160 km than that at 20 - 80 km. This suggests that the strong radiative damping by CO_2 15-micron could effectively dissipates shorter waves. Instead, the spectral power at low-wavenumbers suggests the amplitude growth with height of unsaturated waves toward upper thermosphere.

Keywords: Mars, mesosphere, thermosphere, waves, tides

