火星下部熱圏における大気重力波の季節変動

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Seasonal variations of small-scale waves in the martian lower thermosphere

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Small-scale gravity waves (GWs) are recognized as an important part of the terrestrial climate system. They affect the dynamics, composition, and thermal structure of the terrestrial middle atmosphere and thermosphere. On Mars, similar important role of GWs of tropospheric origin in the middle and upper atmosphere is being increasingly appreciated.

Since October 2014, comprehensive studies of the Martian atmosphere have been performed with NASA's Mars Atmosphere and Volatile EvolutionN (MAVEN) mission. In-situ measurements of the upper atmosphere, down to 130 km, revealed that the wave structures ubiquitously exist in ions and neutrals in the upper thermosphere. Numerical simulations were able to reproduce these structures qualitatively and explain them by GWs propagating from below, but also found a certain degree of discrepancy between numerical modeling and measurements. Wave structures, which are presumably associated with GWs, have also been detected by remote sensing with Imaging Ultraviolet Spectrograph (IUVS) at altitudes between 30 and 150 km. IUVS measurements provide opportunities for investigating possible links between GWs in the Martian troposphere and thermosphere. In this paper, a global distribution of small-scale temperature perturbations in the Martian lower thermosphere (100-130 km) associated with GWs has been obtained from stellar occultation measurements by MAVEN/IUVS obtained between March 2015 and January 2017. It includes the campaigns which were performed in the season of Ls 315, 22, 64, 124, 159, 186, 227, 262, and 298. The dataset covers all longitudes, and latitudes between 60S and 40N.

Over all campaigns, more than 100 profiles that have altitude sampling better than 5 km and whose altitude coverage is larger enough to detect waves between 100 and 130 km. The observed perturbations demonstrate wave signatures with vertical wavelengths of 10-20 km and amplitudes of up to 10% of the mean temperature and 15-20% of the mean density. Large amplitude waves are broadly found in low and middle latitudes. It is not correlated with those at the lower atmosphere (lower than 30 km), where potential energy of GWs peaks in the tropics.

Two comprehensive Martian general circulation models (MGCMS), a GW resolving MGCM and the Max Planck Institute MGCM incorporating a state-of-the-art whole atmosphere GW parameterization have been used to interpret the observations. MGCS simulations demonstrate that the background winds play an important role in the vertical propagation of GWs generated in the lower atmosphere, which can explain the vertical decay of the orographically-generated GW harmonics in the tropics. This is a known phenomenon which occurs due to a preferential filtering by alternating mean winds in low latitudes. On the other hand, westerly zonal jets in high latitudes favor vertical propagation of harmonics with intrinsic phase speed (lower than zero). These waves penetrate to the upper atmosphere with minor attenuation, grow in amplitudes and create the regions of enhanced GW activity in high latitudes. Unfortunately, the IUVS did not cover high latitudes in this period, it is important to further validate GW processes in high latitudes with further observations in the future. Seasonal variations of GW activity were addressed in detail.

GWs are expected to induce vertical mixing in the martian upper atmosphere by driving global meridional circulation via momentum deposition and by generating turbulence. The vertical mixing induced by such high-altitude waves should play a crucial role in the control of the homopause, which separates the homosphere and the heterosphere. The location of the homopause influences the thermospheric composition and thereby the species escaping to space. Here, we will also discuss the relationship between GW activity and observed homopause height by MAVEN.