Vertical wavenumber spectra of gravity waves in the Martian atmosphere obtained from the Mars Global Surveyor radio occultation data H. Ando[1], T. Imamura[2], T. Tsuda[3] [1]University of Tokyo (hando@ac.jaxa.jp), [2]ISAS/JAXA, [3]RISH/Kyoto University.

Introduction: Gravity waves generated in the Earth's lower atmosphere grow in amplitude with height, become convectively and/or dynamically unstable, and break in the stratosphere and mesosphere. Under such conditions the amplitude growth stops and the waves are considered 'saturated' [2, 4]. Theory predicts that the superposition of saturated gravity waves over a broad spectrum results in the vertical wavenumber spectrum of gravity wave energy following a power law with an exponent of -3 [6, 7]. Radiosonde and Global Positioning System (GPS) radio occultation measurements confirmed that the spectra of the stratospheric and mesospheric gravity waves are roughly consistent with theoretical predictions [7, 8], although there are reports that the spectra in the troposphere show smaller (negative) logarithmic spectral slopes and amplitudes greater than the saturation model [5].

The theoretical vertical wavenumber spectrum for saturated waves is based on several semi-empirical considerations. The logarithmic spectral slope of -3 relies on the assumption that the spectrum is composed of wave packets with widths inversely proportional to the central wavenumber and that these packets are saturated due to convective instability [2]. The apparent universality of the spectrum in the Earth's atmosphere does not guarantee the applicability of the theory to the atmospheres of other planets, where the wave generation process and the propagation condition can be much different from those of the Earth. Studies of the vertical wavenumber spectra of planetary atmospheres would shed light on the universality of wave saturation.

The present study investigates Martian gravity waves with vertical wavelengths of 2.5-15 km using temperature profiles obtained by the MGS radio occultation experiment, which has a high vertical resolution of ~1.25 km. Creasey et al. [1] obtained the global distribution of the potential energy of the gravity waves using MGS radio occultation data, and found that the wave energy is maximized in the tropics and that the activity there is enhanced in northern summer. In this study, vertical wavenumber spectra are obtained for the first time to examine whether Martian gravity waves are saturated via convective instability.

Analysis Procedure: Each temperature profile is interpolated (oversampled) at evenly spaced bins with 0.017 km intervals and a cubic function is fitted to the profile (Figure 1). This fitted function is regarded as the background temperature T_0 and subtracted from the original temperature profile similarly to Creasey et al. [1]. The residual is regarded as the temperature perturbation T' associated with gravity waves (Figure 2). The minimum vertical wavelength resolved in this study is 2.5 km because the vertical resolution is ~1.25 km. To study the dependence of the spectrum on the altitude, temperature distributions in the two altitude regions 3–20 km and 15–32 km are analyzed separately. Obtained spectra are classified into four seasons in terms of the solar longitude *Ls* (315°-45°, 45°-135°, 135°-225°, and 225°-315°) and five latitude regions (75°S-45°S, 45°S-15°S, 15°S-15°N, 15°N-45°N, and 45°N-75°N). The spectra are then averaged in each season and latitude bin.

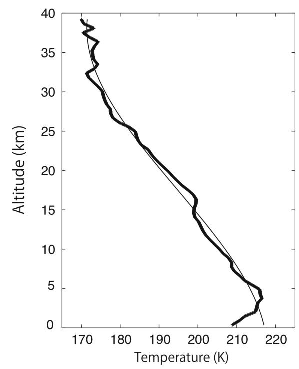

Figure 1 Examples of the vertical temperature profile (thick solid curve) and the fitted cubic function (thin solid curve).

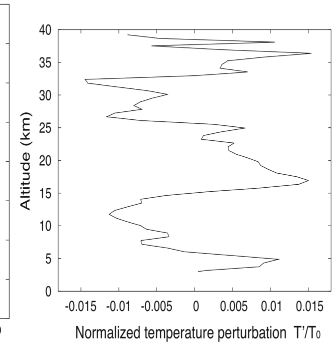

Figure 2 Normalized temperature perturbation profile obtained from the difference between two curves in Figure 1.

The vertical wavenumber spectrum of the normalized temperature perturbation for saturated gravity waves is predicted by theory as [7, 8]

$$F_{T'/T_0} = \frac{N^4}{10g^2k_z^3}$$

where g is the gravitational acceleration in unit of m s^{-2}, N is the Brunt-Väisälä frequency in unit of radians s^{-1}. The unit of k_z requires attention: one k_z in the cube of k_z has a unit of cycles m^{-1}, and other two k_z have a unit of radians m^{-1}. Thus a scaling factor $1/4\pi^2$ is required to convert to corresponding power spectral densities in terms of k_z all in unit of cycles m-1. In the next section, we compare observed wavenumber spectra divided by N^4 with the theoretical one above divided by N^4.

Result: Figures 3 and 4 show the vertical wavenumber spectra obtained for the altitude ranges of 3–20 km and 15–32 km, respectively. We see a general tendency that the spectral density decreases with the wavenumber similarly to those in the terrestrial stratosphere and mesosphere. The logarithmic spectral slope is close to -3 at $k_z > 0.12$ km^{-1} (wavelength < 8 km) and becomes flatter at larger scales. The equatorial region tends to have the highest power and the high latitudes tend to have the lowest power in all seasons; a notable exception is Ls = 135˚-225˚ in the 15-32 km range, where the springtime southern middle and high latitudes show relatively high powers. The difference between the two altitude regions is small.

Also plotted in the figures is the theoretical spectrum of saturated gravity waves. In the equatorial region (15˚S-15˚N) the observed spectra are close to the saturation curve at k_z = 0.12–0.4 km^{-1} (wavelengths of 3–8 km) in all seasons. Exceptions are Ls = 45˚-135˚ and Ls = 135˚-225˚ in the altitude range of 3-20 km, where the equatorial region shows spectral densities three or four times larger than the saturation value. This apparent 'excess' energy might be attributed to the influence of thermal tides.

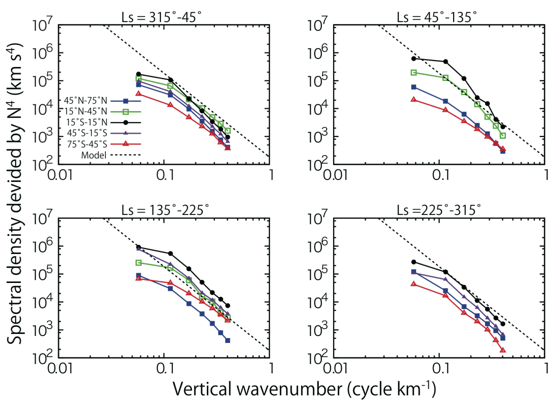

Figure 3 Vertical wavenumber spectra of the normalized tempareture fluctuation divided by N^4 in the altitude range of 3-20 km.

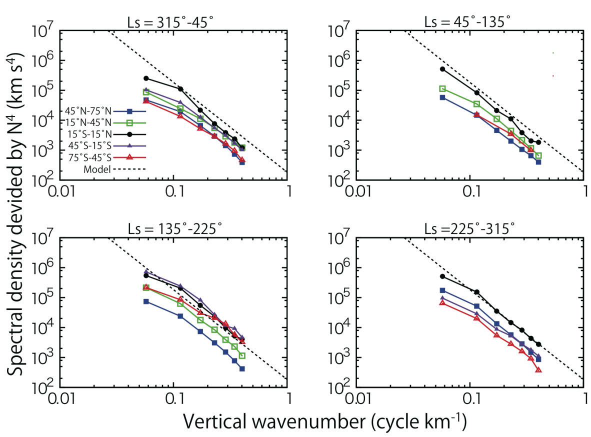

Figure 4 Same as Figure 3 but in the altitude range of 15-32 km.

Discussion: The result suggests that the upper limit of the spectral density is determined by the theoretical spectrum of saturated gravity waves. This implies that small-vertical scale waves are frequently saturated also in the Martian atmosphere and that the saturation spectrum, which has been constructed quasi-empirically and tested in the Earth's atmosphere, is applicable also to Martian gravity waves. Saturated gravity waves will contribute to the acceleration of the mean flow and the generation of turbulence to induce diffusive transport of energy, momentum, dust and other atmospheric constituents.

Power-law spectral indices near -3 are seen also in the spectra that have up to one order of magnitude less power than the saturation value. This can be explained by the influence of the radiative damping or the mean wind variation with altitude, depending on its direction, which reduces spectral densities or leaves the spectrum saturated.

It should be noted that Doppler spread theory [3] might also explain the observed spectra. Hines [3] suggested that nonlinear interaction between the waves of the full spectrum causes the Doppler shifting of the local intrinsic frequency of any given wave in the wind field imposed by all waves, and spread the waves in vertical wavenumber, particularly into large-k tail, to create the k_z^{-3} spectral form. In this sense, the observed k_z^{-3} spectra do not necessarily mean saturation through convective instability.

References: [1] Creasey, J. E. et al. (2006) *GRL, 55,* 1803–1806. [2] Fritts, D. C. and M. J. Alexander (2003) *Rev of Geophysics., 41,* 1–64. [3] Hines, C. O. (1991) *JAS, 48,* 1360-1379. [4] Lindzen, R. S. (1981) *JGR, 86,* 9707-9714. [5] Nastrom, G. D. et al. (1997) *JGR, 102,* 6685-6701. [6] Smith, S. A. et al. (1987) *JAS, 44,* 1404-1410. [7] Tsuda, T. et al. (1991) *JGR, 96,* 17265-17278. [8] Tsuda, T. and K. Hocke (2002) *JMSJ, 80,* 925–938.