# WAVENUMBER-FREQUENCY SPECTRA OF ATMOSPHERIC TEMPERATURE, ZONAL AND MERIDIONAL WINDS IN LOW LATITUDES ON MARS

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**Introduction:**

Atmospheric waves in the Martian atmosphere have been studied since Zurek (1976; 1980; 1981) started theoretical studies on atmospheric thermal tides embedded in observations by the Viking Landers. In 1990's, Wilson and Hamilton (1996) analyzed Viking/IRTM data to clarify thermal tides and simulated them. Hollingsworth et al. (1997) suggested the existence of "storm zone" such as storm tracks in the terrestrial atmosphere by numerical simulations of baroclinic waves. Since 2000's, various atmospheric waves have been detected in atmospheric temperature data observed by Thermal Emission Spectrometer onboard Mars Global Surveyor (MGS/TES).

However, what has been well investigated are relatively large scale waves with wavenumber 1-3 such as baroclinic wave in the winter hemisphere and planetary wave in middle and high latitudes. Atmospheric waves except for migrating and non-migrating thermal tides have not been reported in low latitudes, although atmospheric waves excited by diabatic heating associated with dust events and water ice clouds are expected to exist. In this study, we calculate wavenumber-frequency spectrum of atmospheric temperature T, zonal and meridional winds U and V, and detect all of resolvable atmospheric waves in low latitudes on Mars.

**Data:**

We use Mars Analysis Correction Data Assimilation (MACDA, Montabone et al. 2014), which was downloaded from http://browse.ceda.ac.uk/browse/badc/mgs/data/macda/v1-0. The spatial and temporal resolutions are 72×36×25 grids and 2/24 sol. Data from $L_s$=141° in MY24 through $L_s$=86° in MY27 are used in this study. The latitudinal and vertical range of data used for the spectral analysis is 15°S-15°N and 300-100 Pa, respectively.

**Method:**

Wavenumber-frequency spectrum in low latitudes are calculated by the standard method used in the terrestrial meteorology (Takayabu and Nitta 1993, Wheeler and Kiladis 1998). The data length in time is 150 sols. We define the wavenumber-frequency spectrum of symmetric and asymmetric modes that are a function of latitude to distinguish symmetric and asymmetric structures of disturbances as follows:

$$Z_S(\phi) = \frac{Z(\phi) + Z(-\phi)}{2}$$

$$Z_A(\phi) = \frac{Z(\phi) - Z(-\phi)}{2}.$$

where $\phi$ and $Z$ are latitude and one of T, U and V, respectively. Suffixes $A$ and $S$ indicate the symmetric and asymmetric modes, respectively.

For each 150 sols segment of time series of a variable (T, U and V) at each vertical level and each longitude, the mean and linear trend is removed in time and the ends of the segment are tapered to zero using the cosine function. Then, we obtain a longitudinal wavenumber-frequency spectrum using FFT. After that, we latitudinally and vertically average wavenumber-frequency spectrum of each mode.

**Results:**

*The symmetric mode:* Figure 1 shows wavenumber-frequency spectra of the symmetric modes of the three variables that are averaged vertically and latitudinally in the northern fall ($L_s$=180$\pm\sim 50°$). The spectra divided by the background spectra obtained using the 1-2-1 filter (Wheeler and Kiladis 1999) are also shown in Fig. 1. Positive (negative) wavenumbers mean waves that propagate eastward (westward). The background spectrum is not as clear in the spectrum of T as it seen in wavenumber-frequency spectra of the equatorial atmosphere of Earth (Wheeler and Kiladis 1999). Because the spectrum of V is not red in Fig. 1, it is difficult to define the background. However, the spectrum of U is similar with the wavenumber-frequency spectra of OLR of the equatorial atmosphere on Earth.

Signals representing Kelvin waves with the phase velocity comparable with the phase velocity of the diurnal Kelvin wave described by Zurek (1988) and Wilson (2000) are clearly seen in the spectrum of atmospheric temperature. Similar waves with these Kelvin waves are also recognized in the U spectrum and slower than them. The phase velocity of these waves may be comparable with the zonal mean zonal wind. There is no Kelvin wave signal in the spectrum of V. This is because the Kelvin wave has no meridional component of wind disturbances.

Of interest is signals with the frequency of 0.4 and 0.6 cpd that are uniform in the direction of wavenumber, which are seen in all spectra of T, U and V. The signal with 0.6 (0.4) cpd is relatively strong in positive (negative) wavenumbers. The superposition of these waves should appears to be quasi-standing waves with the frequency of 0.5 cpd. Furthermore, this quasi-standing waves are expected to localize longitudinally because the spectrum is spatially white approximately.

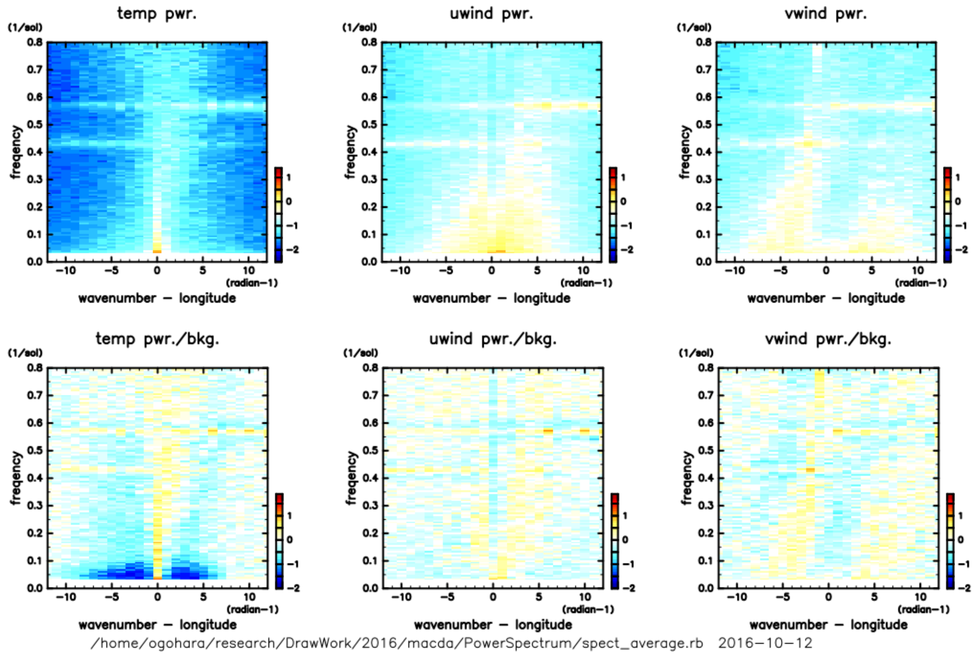


**Figure 1 (top) The wavenumber-frequency spectra of the symmetric modes of the three variables that are averaged vertically and latitudinally in the northern fall. (bottom) The spectra divided by the background spectra obtained using the 1-2-1 filter.**

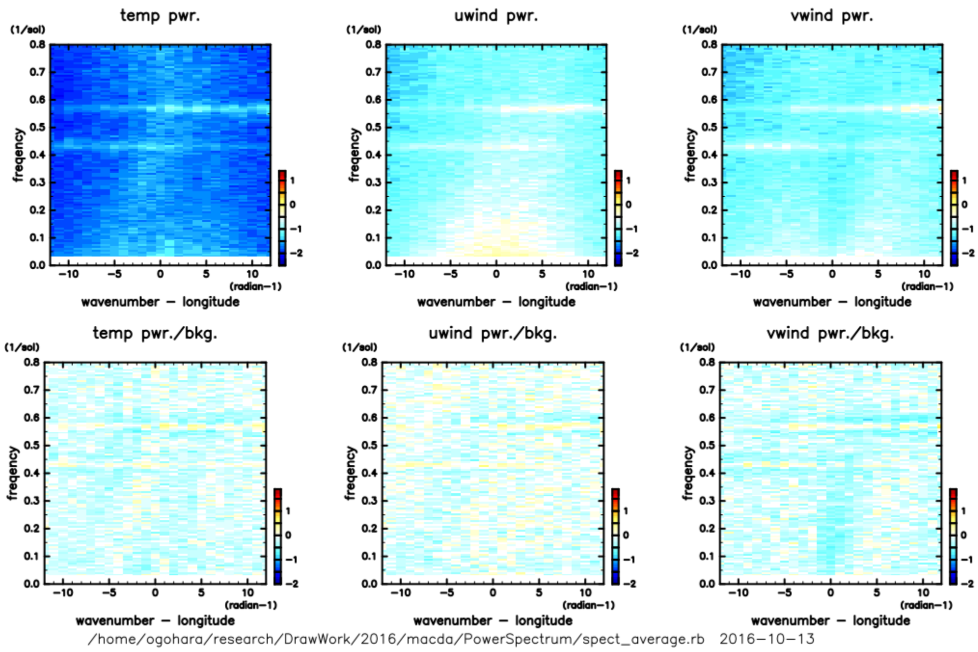


**Figure 2 The same figure of the asymmetric modes as Fig. 1.**

*The asymmetric mode:* Figure 2 shows wavenumber-frequency spectra of the asymmetric modes of the three variables that are averaged vertically and latitudinally in the same season as Fig. 1. The power spectra are weaker than those of the symmetric mode. It is not surprising that there is no Kelvin wave in the spectra of the asymmetric mode because Kelvin waves are symmetric about the equator. The fast eastward waves seen in the spectra of T and U in Fig. 1 have disappeared. The appearance of the spectrum of T is similar to that of the symmetric mode of V shown in Fig. 1 although the absolute values of the power spectra are clearly different.

In spite of many differences between the symmetric and asymmetric modes, wave with the frequency of 0.4 and 0.6 cpd seen in Fig. 1 still remain in Fig. 2 The power and location of their spectral peaks in the wavenumber-frequency domain do not change largely

**Summary:**

We derived wavenumber-frequency spectra of the symmetric and asymmetric modes of T, U and V from the MACDA data set, and detected some outstanding atmospheric waves in low latitudes on Mars. One is the traditional Kelvin waves (Zurek 1988 and Wilson 2000). This type of waves are fast eastward waves, especially clear in the spectrum of the symmetric mode of T. Another is 0.4 and 0.6 cpd waves seen in most of wavenumbers in both modes of the three variables. The superposition of these waves should appear to oscillate with the frequency of 0.5 cpd and localize within a narrow longitudinal band.

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