ANALYSIS OF MGS/TES TEMPERATURE OBSERVATIONS IN THE WAVENUMBER - FREQUENCY DOMAIN.

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Introduction:

Results of MGS/TES temperature observations have been analyzed in details since MGS has started to observe Mars. Probably the MGS/TES temperature data set is the data set most commonly used to study the Mars atmosphere. In the process of analyses, longitude, latitude and time axes have been divided into several bins, and observational data to be analyzed has been obtained by averaging the original data inside each bin. For example, the typical bin sizes are 30 deg (longitude), 5 deg (latitude) and 12 hours (time). This seems to be a logical choice if spatially large and temporally slow disturbances are focused on. However, this method may increase serious errors and biases in the temperature spectrum if the disturbances lie on high latitudes or if the frequency and wavenumber of the disturbances are high. Such a problem results from assuming asynoptic observations as synoptic observations ([1]). [1, 2] suggested a method for the spectral analysis in the wavenumber-frequency domain of asynoptic data without dividing the data into several synoptic bins. I visualize amplitude distributions of all resolvable waves in the wavenumber-frequency domain by applying this Salby's method to MGS/TES temperature data. The eastward diurnal wave (e.g. diurnal Kelvin waves) and high wavenumber components in low latitudes can be ideally resolved without contaminations. However, the high wavenumber components are weakened due to missing data.

Data Set:

The MGS/TES data set was downloaded from http://static.mars.asu.edu/tes/. Options of "vanilla" [1] used to extract variables (e.g. nadir_temperature_profile, ephemeris_time, local_time etc.) from the data volumes are;

```
quality:major_phase_inversion 0 0
quality:algor_risk 0 0
quality:detector_mask_problem 0 0
quality:calibration_quality 0 0
quality:calibration_failure 0 0
quality:temperature_profile_rating 0 0
IMC_COUNT 0 0
emission_angle 0 10.
```

I used profiles obtained by "detector 2" near the center of the detector array from MY24 L_s=135° through L_s=220° (150 sols).

Preprocessing:

Latitudinal bin: The data has to be binned latitudinally although it does not have to be binned longitudinally and temporally. The latitudinal bin size sets to 4 deg. Such latitudinal binning does not affect the quality of the spectral analysis since I focus on amplitude of disturbances in the zonal wavenumber-frequency domain, and can reduce random errors included in data to be processed.

Missing value: After variables are extracted from the published data tables by the above query, each variable, even latitude and longitude, is stored as a very long one dimensional time series. In the time series of temperature at a pressure level, there remain "missing time", which is the time when the profile was not retrieved for some reasons. This missing time directly corresponds to an observation point (longitude, latitude) where the missing profiles should be located. The temperature data are interpolated latitudinally in the case where the latitudinal range of continuous data missing is less than 30 deg.

The orbital period of the satellite: Basically MGS is a sun-synchronous orbiter. So the orbital period is ~2 hours. For example, it is 117.65 min during the mapping phase according to http://pds-geosciences.wustl.edu/missions/mgs/catalog/mission.txt. However, the orbital period of the satellite changes slightly throughout the mission. The optimal period has to be re-determined from the time series of latitude and ephemeris time in order to use the Salby's method. Furthermore, the zonal transition of *nodes* of the satellite per revolution has to be a constant, which has a serious effect on the zonal phase of reconstructed wave patterns. Therefore, the orbital frequency ν_0 (orbits per sol) is determined so that the observations are well approximated by equations (2) and (4) presented by [1]. Ephemeris time and longitude of each (ideal) observation is expressed by the equations (2) and (4) using the determined ν_0, and each temperature value at the (ideal) observation point and time is determined by temporally and linearly interpolating the detrended actual observations.

[1] Analysis tool for MGS/TES data (http://software.mars.asu.edu/vanilla/)

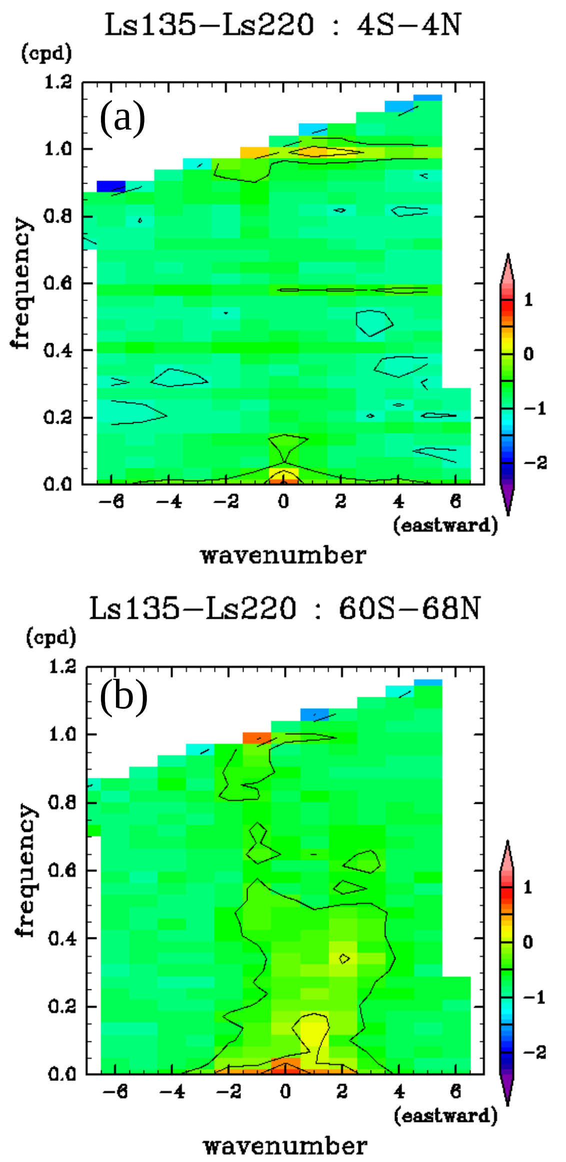

Figure 1.Distributions of amplitude (K) averaged latitudinally and vertically. The colors and contours indicate $\log_{10}$(mean amplitude). The contour interval is 0.5.

Results:

Figure 1a. shows an amplitude distribution averaged latitudinally and vertically in low latitudes (4°S-4°N) between 2 hPa and 1 hPa. What is averaged latitudinally and vertically is not the time series of temperature but the amplitude distributions in the wavenumber-frequency domain at some latitudes and pressure levels. Therefore, waves with short vertical wavelength are not removed by averaging if their vertical wavelengths are long enough to be resolved by MGS/TES. Eastward diurnal components are successfully resolved by the Salby's method. The diurnal Kelvin modes with large amplitude are clearly seen. High wavenumber components seem to be also resolved. There are clearly some signals over all wavenumbers at ~0.4 or ~0.6 cpd. However, it should be carefully discussed whether these signals are real or not because their amplitude may be too small to be resolved by MGS/TES.

Figure 1b shows the same amplitude distribution as that displayed in Figure 1a except for the latitudes (60°N-68°N) and the vertical levels (5 hPa - 1 hPa). The small wavenumber long period modes with positive (eastward) phase speed are probably baroclinic waves. There seems to be the wavenumber 1 mode that can propagate into higher altitudes than the baroclinic waves can reach. The wavenumber -1 short period modes are possibly an artifact that was induced by the missing value handling described in the previous section.

Figure 2 shows a longitude-time diagram of temperature fluctuations at 0°N on synoptic grid points reconstructed from Figure 1a. The diurnal modes are dominant and there don't seem to be the slow modes. The stationary disturbances exist around the Tharsis Mons. The weak signals seen at ~0.4 and ~0.6 cpd in Figure 1a are not clear.

Figure 3 shows longitude-time diagram of temperature fluctuations at 64°N on synoptic grid points reconstructed from Figure 1b. The diurnal modes are not as clear as in Figure 3. In contrast, The quasi-stationary wavenumber 2 mode is clearly seen. Wavenumber 1-2 modes with the period of 2-10 sols are also dominant.

Summary:

Wave modes detected in this study are basically consistent with the previous researches (e.g. [3], [4], [5], [6]). Although these previous researches focused on the specific season, mode or latitude, this study can encompass the possible wavenumber-frequency ranges. Other modes that have not been discovered by the previous studies might be detected in the future. It has already turned out by preliminary works that amplitudes of high wavenumber modes are reduced by 15-25% in this season due to linear interpolation of the missing values. Therefore, it may be concluded by the future work that the weak signals at ~0.4 and ~0.6 cpd in Figure 1a are real.

Acknowledgement:

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References:

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[5] Hinson D. P. et al. (2003) JGR, 108, E1, 1-13.
[6] Hinson D. P. and H. Wang (2010) Icarus, 206, 1, 290-305.

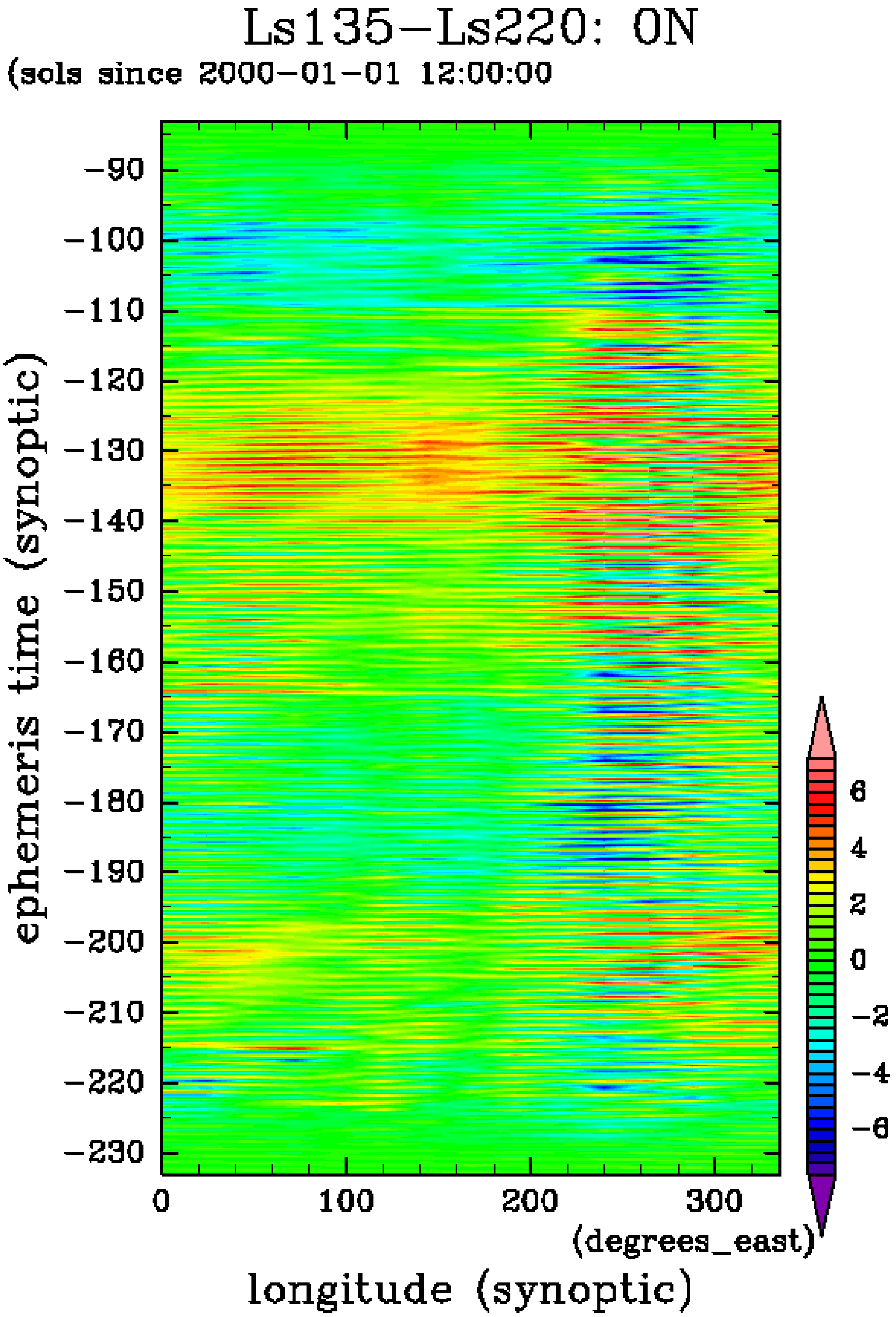

Figure 3. A longitude-time diagram of vertically averaged temperature fluctuations (K) at 0°N on synoptic grid points reconstructed from Figure 1a. Unit of ephemeris time is sol. Weakening of signals near the start and the end of the period is an artifact resulting from cosine tapering of the time series.

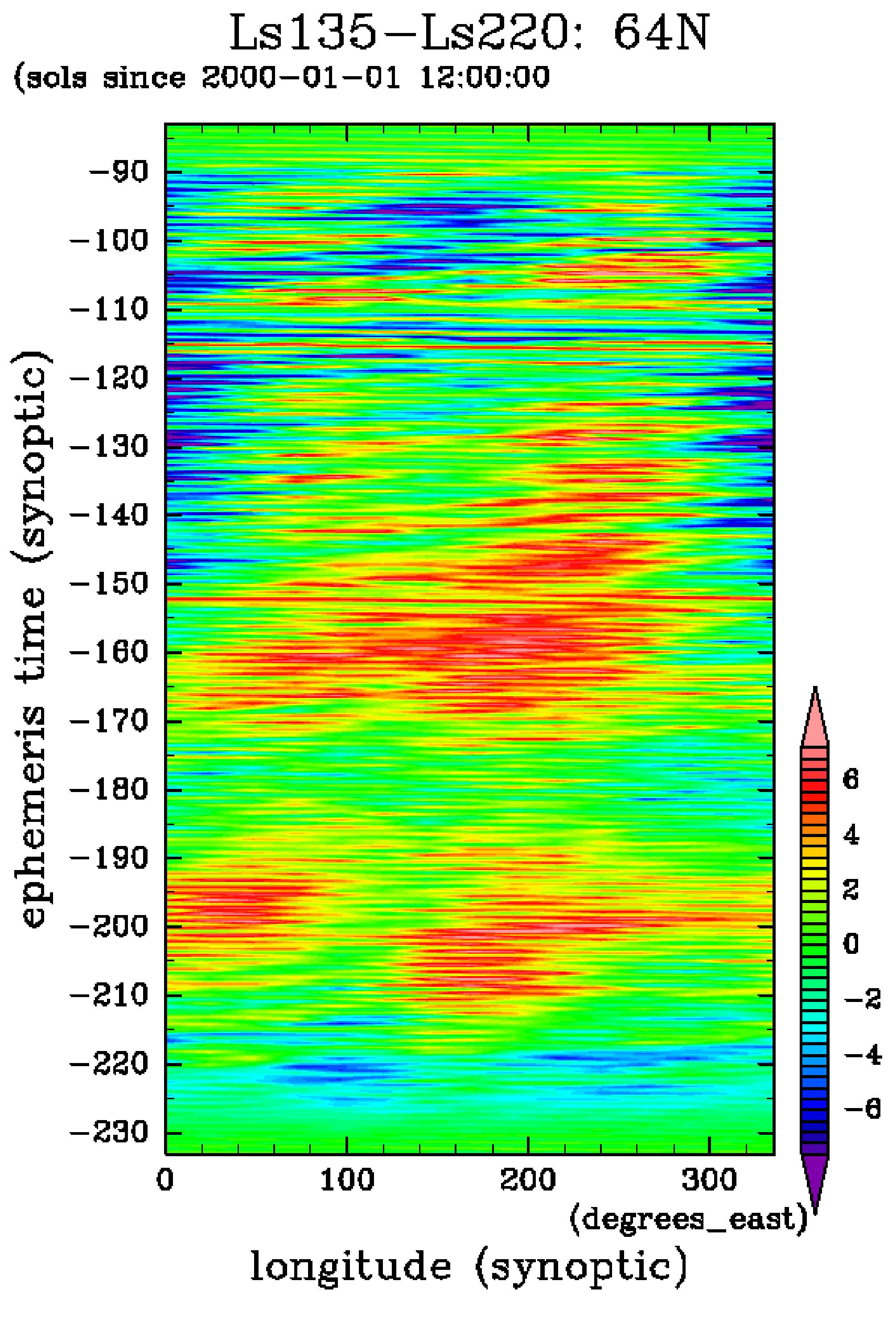

Figure 4. A longitude-time diagram of vertically averaged temperature fluctuations (K) at 64°N on synoptic grid points reconstructed from Figure 1b. Unit of ephemeris time is sol. Weakening of signals near the start and the end of the period is an artifact resulting from cosine tapering of the time series.