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Planetary-scale waves on Venus found in the cloud-top temperature

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Abstract

Periodic variations in the Venusian cloud-top temperature with periods of several Earth days were studied using Akatsuki LIR data. Based on the periods and the latitudinal structures, the oscillations were identified as planetary-scale waves such as Kelvin wave and Rossby wave.

1. Introduction

Planetary-scale waves are thought to play crucial roles in the atmospheric dynamics of Venus. Periodic fluctuations with periods of several Earth days were found in ultraviolet photometric data taken by Venus orbiters, and those oscillations are considered as planetary-scale waves such as hemispherically-symmetric Rossby wave and equatorial Kelvin wave [1]. We should note, however, that the brightness does not directly represent physical quantities such as the velocity and the temperature. This ambiguity limits the comparison of the results with models. Similar periodicities were found also in the cloud-tracked velocity [2], although the latitudinal structures are still unclear.

Here we analyse thermal images of the cloud top taken by the Longwave Infrared camera (LIR) onboard JAXA's Akatsuki [3] to study planetary-scale waves. The wave structures in the temperature complement those in the cloud-tracked velocity. Akatsuki is on an elliptical equatorial orbit and can take global images almost any time. The complete localtime coverage of LIR enables extremely continuous sampling; this is advantageous to precise spectral analysis.

2. Method

Zonal propagation of a planetary-scale wave is expected to be reflected in the periodic variation of the brightness temperature of the clout top. However, the temperature change from one image to another is difficult to detect because of the relatively large systematic error of the measurement (~3 K). A numerical study shows that the temperature amplitudes are expected to be ~1 K [2]. Therefore, we focus on the temporal variation of the temperature gradient in the east-west direction in each image, which is affected only by the relative error between pixels (~0.3 K).

The observed altitude region depends on the emission angle: the larger the emission angle, the higher the peak altitude of the contribution function. Therefore, pixels having the same emission angle should be sampled in the calculation of the longitudinal gradient of the temperature. The same emission angle needs to be used for all latitudes.

The procedure is as follows. (1) Images are sampled roughly at 12 hour intervals. (2) In each image, along a particular latitudinal circle, the averages of the brightness temperature on the eastern and western sides of the Venus disk in the emission angle range of 40-60° are calculated. (3) The longitudinal gradient of the temperature is calculated from the difference between the eastern side and the western side. (4) The time series of the temperature gradient obtained for each latitude is spectrally analysed after subtracting the long-timescale component obtained by fitting a polynomial function to the data, and distinct peaks are identified in the spectra. (5) The latitudinal profiles of the amplitude and the phase are obtained for each periodic component, and the amplitudes of the temperature are further calculated assuming that the waves have a zonal wavenumber of unity.

3. Results

An example of the time series spanning 142 days from 18 May 2017 is shown in Figure 1, in which variations with various time scales are superposed. Figure 2 shows an example of the power spectrum. The leftmost peak is a remnant of the long-timescale component, and the peak around 0.1 day^{-1} is attributed to the orbital motion of the spacecraft. In addition to these, several peaks are found at periods of several days. Distinct periodicities of 3.5, 4.9 and

5.2 days are identified. The amplitudes and the phases of these periodic components were obtained.

The procedure above was repeated for latitudes from 50°S to 50°N with an interval of 10°. The latitudinal structures of the amplitude and the phase for the 3.5-day and 4.9-day components are shown in Figures 3 and 4. The former is attributed the a Kelvin wave and the latter is considered as a Rossby wave.

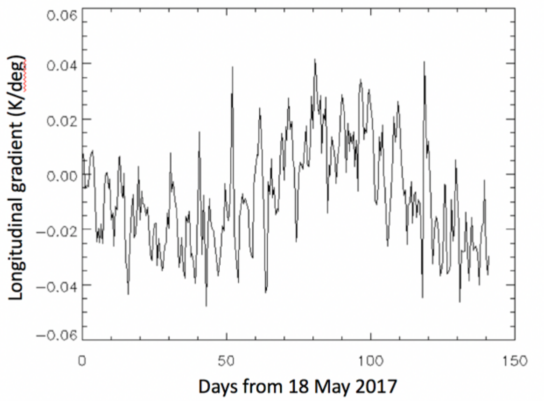

Figure 1: Time series of the longitudinal gradient of the temperature at 30°N.

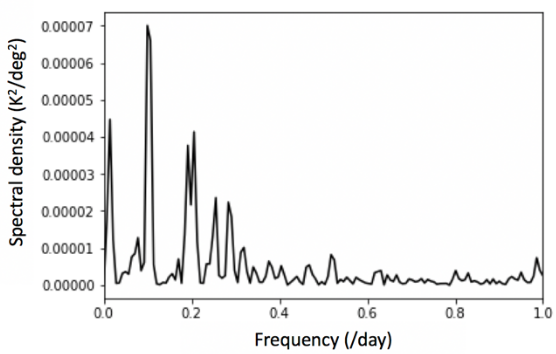

Figure 2: Power spectrum of time series of the longitudinal gradient of the temperature at 30°N.

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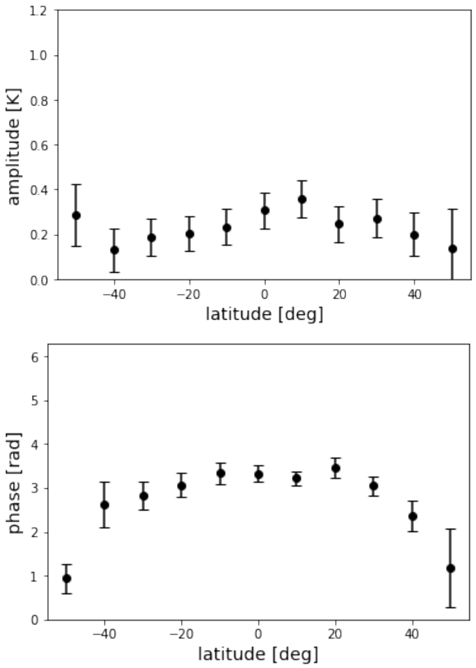

Figure 3: Latitudinal structures of the amplitude and the phase of the 3.5-day wave.

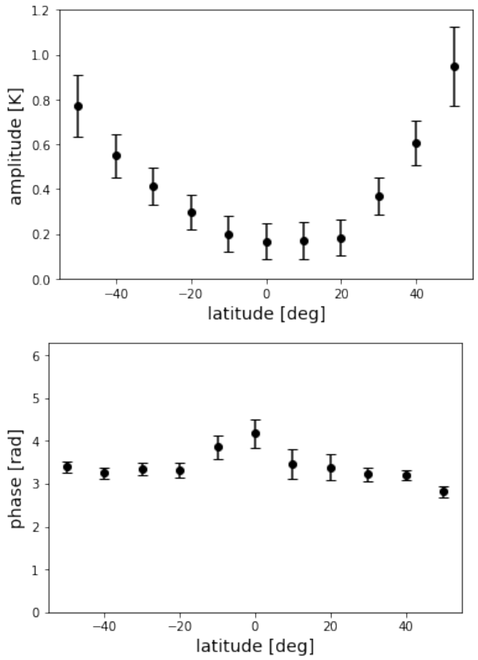

Figure 4: Latitudinal structures of the amplitude and the phase of the 4.9-day wave.