Gravitational signatures of atmospheric thermal tides on Venus

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Introduction: The Sun raises two types of tides on Venus. One is a gravitational tide, mainly involving the solid body, the other is a thermal tide in the atmosphere. The gravitational tide is larger, and has already been detected. Accurate measurements of the smaller amplitude thermal tide will require improved gravitational measurement configurations to be deployed in orbit around Venus.

Sufficiently accurate measurements of time variable gravity at Venus will provide important new constraints on the atmospheric dynamics. In particular, we examine the feasibility and utility of measuring the gravitational signature of atmospheric mass transport on Venus, via the thermal tide.

We are interested in answering two questions concerning the gravitational signature of thermal tides on Venus. First is the measurement accuracy required to discern the pattern, and second concerns which aspects of the atmospheric structure and dynamics can best be constrained by those measurements.

To address the first question, we present simulations of the spatio-temporal variations in atmospheric pressure on the solid surface of Venus, as driven by the thermal tide, using the high accuracy *Institut Pierre-Simon Laplace* (IPSL) general circulation model [1, 2]. We use this pressure pattern to estimate changes in the external gravitational potential.

Based upon these simulations, we now have an assessment of the gravitational measurement accuracy required to characterize the thermal tide. As expected, the thermal tide gravitational signature is too small to have been detected by past missions (PVO and Magellan). However, gravity measurement by future missions, using improved accuracy Doppler data, should easily suffice.

We are just beginning to answer the second question, by repeating the simulations with Venus atmospheric simulations, with diagnostic changes in key parameters. It appears that the height distribution of radiative absorptions within the atmosphere will emerge as a key parameter..

Mean thermal tide: The sidereal orbit period of Venus is 224.701 days, while the rotation period is -243.025 days. As a result, the radiation pattern repeats every 116.752 days, which is the Venus solar day.

We estimate the spatio-temporal pattern of mass transport associated with the thermal tide, using the following recipe. We first examine a global grid of surface pressure values, at 100 uniformly spaced time steps over the solar day. This pattern has two main signatures. One is related to local surface topography and the other mainly follows the sub-solar point, moving East by 3.6 degree each time step. We remove the time average value in each spatial cell. It is a large effect, and is constant in the Venus-fixed frame.

We then back-rotate the remaining pressure anomaly pattern at each time step, and average the values in a Sun-fixed frame. **Figure 1** shows the resulting spatial pattern. The coordinate origin is the sub-solar point.

To compute the gravitational signature of this mean thermal tide, we take several more steps. First is to convert the pressure anomaly pattern dP (Pa) into a surface mass density pattern σ (kg/m^2). That involves division by the mean surface gravity value (8.87 m/s^2). We then expand the surface density pattern into a spherical harmonic series

$$\sigma[\theta,\phi] = \frac{M}{4\pi R^2} \sum_{n,\ m,\ k} \sigma_{n,m,k}\ Y_{n,m,k}[\theta,\phi]$$

The external gravitational potential is also written in terms of a harmonic series

$$\Phi[r,\theta,\phi] = \frac{GM}{r} \sum_{n,m,k} \left(\frac{R}{r}\right)^n\ \Phi_{n,m,k}\ Y_{n,m,k}[\theta,\phi]$$

The connection between dimensionless coefficients for potential and surface density is

$$\Phi_{n,m,k} = \frac{\sigma_{n,m,k}}{2n+1}$$

Figure 2 shows the computed RMS amplitude spectrum for the potential associated with the thermal tide. It is well approximated by the power law

$$A[\Phi;n] = \frac{7.49 \times 10^{-9}}{n^2\ (2n+1)}$$

A comparison between this signal spectrum and anticipated error spectra for a number of different measurement configurations, suggests that the thermal tide will easily be measured by future Venus spacecraft [3]

References: **[1]** Lebonnois, S et al. (2010), JGR 115, E06006. **[2]** Lebonnois, S. et al. (2016), Icarus, 278, 38-51. **[3]** Bills, B.G. et al. (2019) Icarus, in review.

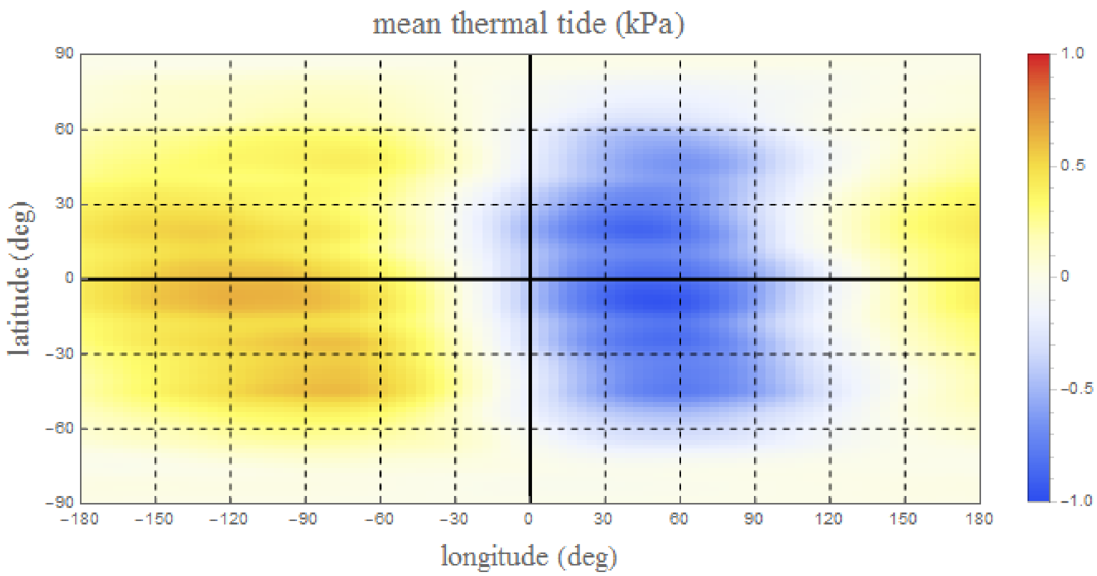

Figure 1. Spatial pattern of surface pressure associated with Venus mean thermal tide.

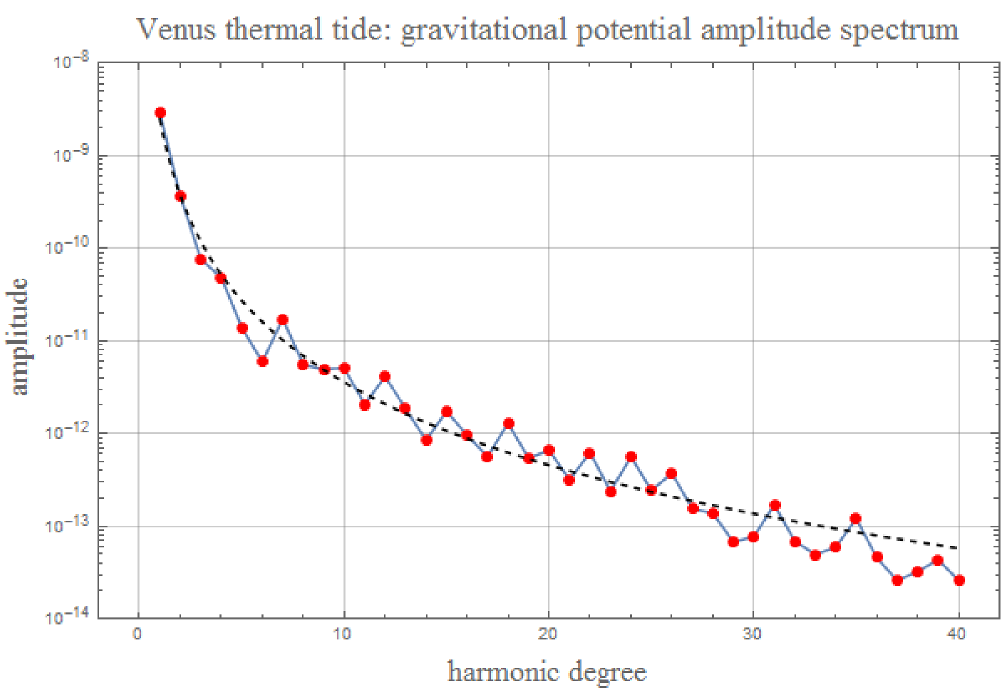

Figure 2. RMS amplitude spectrum of gravitational potential associated with mean thermal tide.