MAXIMUM-LIKELIHOOD ESTIMATION OF LITHOSPHERIC THICKNESS ON VENUS.

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Introduction: Gravity and topography data from the Magellan spacecraft remain the best available tools for constraining the structure of the Venusian lithosphere. A number of authors have used these combined data to estimate an effective lithospheric thickness as well as to infer associated surface and subsurface loading mechanisms, both in 1-D [1] and on localized regions of the sphere [2,3]. These studies have typically modeled the admittance function, relating gravity and topography as a function of wavenumber, to derive the relevant physical parameters. However, admittance-based inversions for Venus are in many cases ill-conditioned given the limitations of the data, or are poorly fit by simple flexural models.

To reevaluate the existing gravity and topography datasets for Venus, we employ a new, maximum-likelihood-based estimation technique with the goal of further constraining the planet's tectonic evolution. In doing so, we avoid the intermediary admittance function, solving for the lithospheric parameters of interest directly from the gravity and topography data for the region of interest.

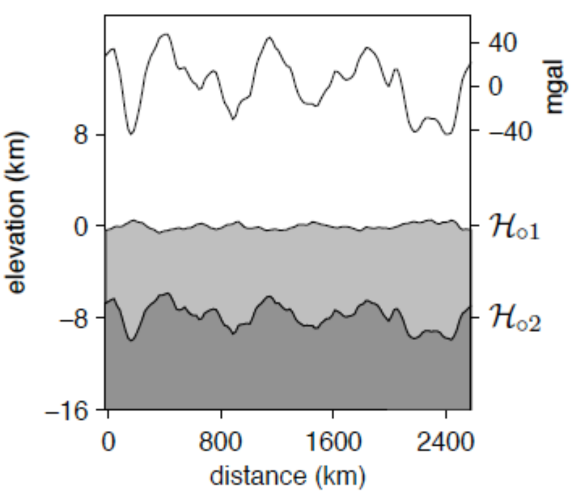


Figure 1: Two-layer lithosphere model setup, with density interfaces at H_1 and H_2, and the resulting Bouguer anomaly at the surface.

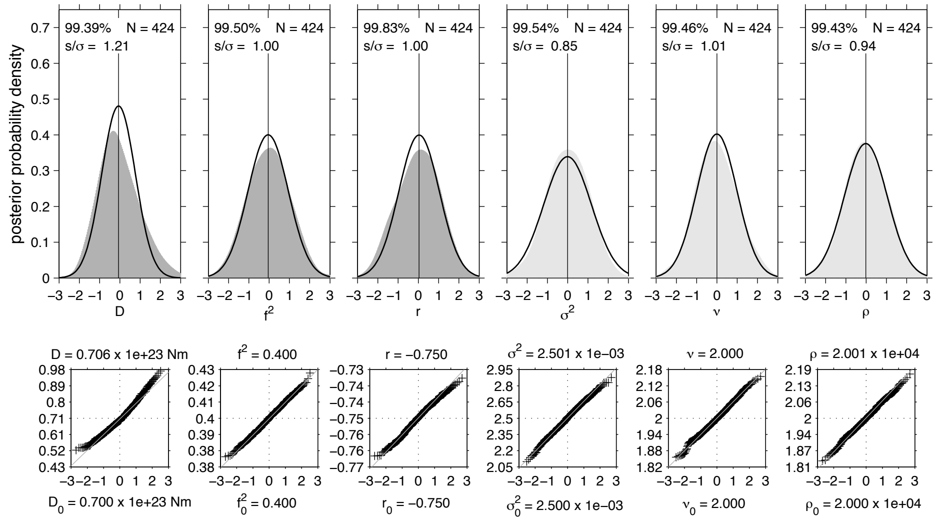
Technique: The maximum-likelihood-based approach proposed by [4] uses a basic two-layer density model, to which isotropic loads are applied at either interface (Fig. 1). The observable final surface and subsurface (estimated from the Bouguer anomaly) topography at each interface are used to determine the form of the initial loading processes, along with the properties of the lithosphere on which they act. The three model parameters of geophysical interest include the traditional flexural rigidity of the lithosphere (D) and top-to-bottom loading ratio (f^2) along with the correlation (r) of the loading processes between the two interfaces. Additionally, the spectrum of the initial loading S_{11} is specified as an isotropic, spectrally red process of the Matérn form,

$$\mathcal{S}_{11}(k) = \frac{\sigma^2 \nu^{\nu+1} 4^\nu}{\pi(\pi\rho)^{2\nu}} \left(\frac{4\nu}{\pi^2\rho^2} + k^2 \right)^{-\nu-1},$$

over wavenumber k, whose shape is determined by the three parameters σ^2, ν, and ρ. In all, these 6 parameters are estimated from the observed surface topography and Bouguer gravity fields, here in the 2-D Cartesian domain. Although the maximum-likelihood approach has been validated for synthetic datasets [4], its application to Venus represents the first implementation using real planetary geophysical data.

Synthetic testing: The maximum-likelihood method has been tested extensively with synthetic data, using simulated random topography and Bouguer gravity generated from the Matérn class with known parameters. Over thousands of such simulations, it has been shown that it is possible to repeatably recover unbiased estimates of the six lithospheric and spectral model parameters. Further, the uncertainty of the estimated parameters has been shown to be nearly normally distributed and in agreement with theoretical predictions. A key issue in simulating synthetic test cases is the correct implementation of the blurring associated with analyzing finite-sample size data sets [4]. The examples shown in Figures 2 and 3 properly take these considerations into account.

Spectral modeling: To test the applicability of the Matérn form for parameterizing topographic power spectra on Venus in particular, we have reduced the maximum-likelihood procedure to operate on a single field (topography or Bouguer gravity), estimating only the three spectral parameters for a range of observed terrain types. Sample patches from the global datasets were extracted based on new and existing regional-scale mapping of major geologic provinces [5].



$E = 1.4e+11$; $\nu = 0.25$; $T_e = 17.8 \pm 0.7$ km ; $f^2 = 0.4 \pm 0.008$; $r = -0.75 \pm 0.007$

$\sigma^2 = 0.0025 \pm 0.0002$; $\nu = 2.000 \pm 0.061$; $\rho = 20000 \pm 672$

Figure 2: Results using synthetic data on a 64x64 grid. Top panels: theoretical (black) and observed (shaded) estimates for each of the six parameters. Bottom panels: Q-Q plots of the observed versus theoretical distributions for each parameter.

In general, the maximum-likelihood method reliably finds solutions for all observed geologic terrain-types – a key affirmation of the use of these parameters in the more complicated six-dimensional lithospheric flexure problem. Further, there is some consistency in the derived spectral parameters among similar mapped terrain types, indicating a correspondence between our spatial classification of observed topographic morphology and the modeled spectral shapes (Fig. 3).

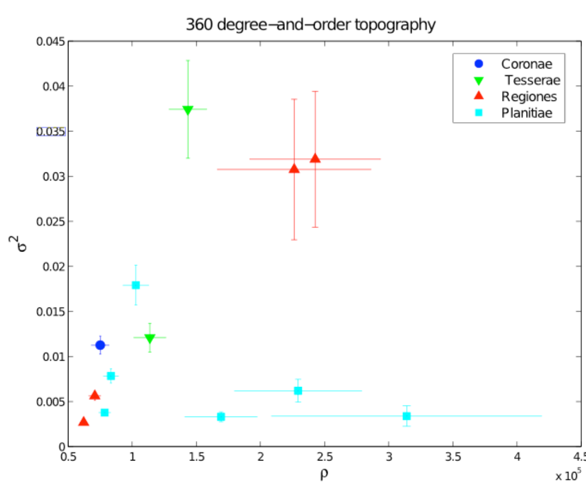


Figure 3: Estimation of spectral shape parameters, ρ and σ² in the Matérn form, for representative tectonic provinces on Venus.

Lithospheric modeling: More recent tests have begun to employ the full 6-parameter lithospheric model to sample regions of the Venusian surface. Early results demonstrate reliability of finding minimized solutions for representative Venus data, given initial parameter values within a reasonable range. We are working to fully characterize the range of acceptable parameters for the Venusian lithosphere as modeled, particularly for the three Matérn parameters. We will discuss the results of these studies in detail, along with tectonic interpretations of the derived parameters.

References: [1] McKenzie, D. and Nimmo, F. (1997) *Icarus, 130*, 198-216. [2] Simons, M., Solomon, S. C. and Hager B. H. (1997) *Geophys. J. Int., 131,* 24–44. [3] Anderson, F. S., and Smrekar, S. E., (2006) *J. Geophys. Res. (111)* E8. [4] Simons F. J. and Olhede, S. C. (2013) *Geophys. J. Int., in press*. [5] Eggers, G. L., Lewis, K. W., and Simons, F. J. (2012), *AGU Fall Meeting,* P23C-1948.