ATLA REGIO REVISITED: INSIGHTS ON THE LITHOSPHERIC STRUCTURE OF VOLCANIC RISES ON VENUS. J. S. Maia and M. A. Wieczorek, Observatoire de la Côte d'Azur, Laboratoire Lagrange, Université Côte d'Azur, Nice, France (julia.maia@oca.eu)

Introduction: Venus presents a large variety of highlands which, based on their gravitational signatures and geologic characteristics, have been divided into two groups: the crustal plateaus, characterized by small positive gravity anomalies and highly tectonized terrains, and the volcanic rises, with associated volcanism and larger gravity anomalies [1]. By exploring the relation between gravity and topography, we investigate the interior structure of Atla Regio, a large volcanic rise on Venus that presents three large shield volcanoes and a major rift system. We chose to focus on Atla because the feature has one of the largests gravity signals on the planet and the gravity model has a very good resolution in this area.

With the advent of the Magellan mission, several studies investigated the interior structure of Atla making use of the early developed Magellan gravity models [*e.g.*, 2, 3, 4], leading to the widely accepted interpretation that the topography of Atla is (at least partially) supported by an active mantle plume. Although these works used the state-of-the-art methods of their times, in the past two decades there have been important improvements in the analyses techniques used with gravity data and the development of new lithospheric loading models. The goal of the present study is to explore these new methods and compare the results with those obtained in the Magellan era. Particularly, here we focus our comparison with the study by Phillips [4], since it is one of the most recent and thorough geophysical investigations of Atla Regio.

Methods: We make use of the VenusTopo719 dataset by [5] for the topography and the final Magellan-era 180th degree spherical harmonic gravity solution MGNP180U [6]. For comparison, [4] adopted the preliminary Magellan gravity model MGNP60I whose highest resolution is spherical harmonic degree 60, much lower than the resolution of our adopted model. Figure 1 shows maps of the gravity and topography at Atla.

An important similarity between the two studies is that both are performed in the spectral domain, making use of the spectral admittance and correlation (the wavelength-dependent ratio between gravity and topography). Since we are studying a specific region of the planet, the information we are interested in is the localized spectral content of the region of interest. In [4] the localized spectra were estimated by computing the Fourier transform of the data in the Cartesian domain followed by averaging the spectra over wavenumber bands of constant magnitude. Our study makes use of a more sophisticated localization technique developed by [7], where the data is localized simultaneously in the spatial and spectral domains using spherical coordinates.

The observed localized admittance is then compared to theoretical admittance curves based on a geophysical model which allow us to constrain the interior structure and lithospheric thickness of the region. We adopt the model from [8] that was used to stufy Martian volcanoes and was later applied to the plateaus on Venus [9]. This model treats the lithosphere as a thin elastic shell subjected to loads both on the surface and in the subsurface and the amount of lithosphere deflection depends on the elastic thickness T_e and the magnitude of the loads. The subsurface layer is modeled as a low density mass-sheet, which can be interpreted as a mantle plume. The layer is parametrized in terms of the surface to subsurface load ratio f where the loads are perfectly correlated. Since we are investigating the case where the subsurface load has a relative low density, f is always negative. $f = 0$ corresponds to the top-loading scenario.

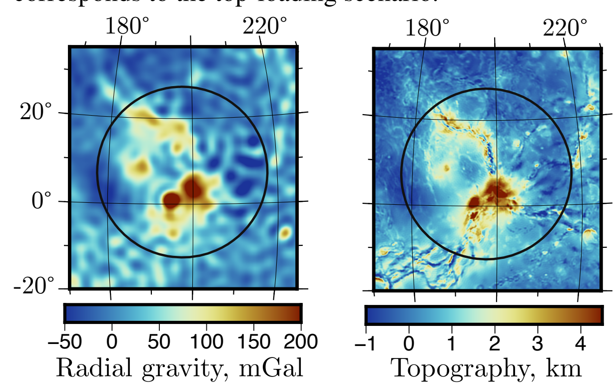

Figure 1: (left) Radial free-air gravity anomaly and (right) topography at Atla Regio. The circles correspond to the limits of the adopted localization window. Projection: Lambert azimuthal equal-area.

In addition to the parameters described above, our modeling primarily contained two other free parameters: the crustal thickness T_c and the crustal density ρ_c. We systematically varied these 4 parameters to estimate theoretical gravity fields followed by computing the predicted localized admittances. Then, we calculate the root-mean-square misfits between predicted and observed admittances to constrain the lithospheric properties of the region. For each parameter we estimate the accepted range of values by defining a threshold based on the average of the admittance uncertainties. It turned out that the inversions were not sensitive to the crustal thickness and crustal density, hence we chose to fix these parameters to $T_c = 20\,\mathrm{km}$ and $\rho_c = 2800\,\mathrm{kg\,m^{-3}}$.

The most substantial difference between our model and the one used in [4], which follows the method introduced by Forsyth [10], regards the internal load parametrization. While we assume that the loads are correlated, as might be expected for an active volcanic region, their model assumes that the loads are statistically independent, which might be more appropriate for continental-like highlands. Consequently, in our case the analysis is mostly focused on the admittance spectra, since the model correlation is always equal to 1 (or -1) by definition, whereas in the alternative approach both the admittance and correlation should be investigated.

Results: We initially tried to fit a single theoretical admittance curve to the entire admittance spectrum. However, no set of parameters was found to satisfactorily fit the data across all spherical harmonic degrees. Nevertheless, acceptable fits can be found when the spectrum is segmented into multiple wavelength ranges and each range is fitted independently [4]. By doing this, we effectively are assuming that the compensation mechanism varies piecewise as a function of wavelength.

We divided the spectrum in three ranges: the first comprising the longest wavelengths, from spherical harmonic degree 3 to 10, the second ranging from degree 20 to 35, and the third from degree 45 to 70. The highest degree investigated is defined based on the degree strength of the region and the size of the window used in the localization procedure. The wavelengths comprised in each range were chosen empirically but they turned out to be quite consistent with what have been used in previous studies. For example, [4] was also unable to find acceptable solutions with only one mode of compensation, so he chose to divide it into two intervals, one ranging from degree 10 to 36 and the second from degree 36 to 60.

Figure 2 shows the observed admittance and correlation at Atla Regio along with the best-fitting predicted admittance for each investigated range. As we can see, f seems to increase with decreasing spherical harmonic degree (or increasing wavelength). This implies that internal loading progressively becomes more important as the wavelength increases.

This effect can also be clearly observed when considering the misfits. We found that for the lower degrees the load ratio has only an upper bound of $f < -0.72$, while for the mid-range $-0.2 < f < -0.09$ and for the higher degrees $-0.11 < f < -0.04$. A similar behaviour was obtained in [4], where the lower degree range was associated with a more important bottom-loading component than the higher degree part of the spectrum.

In the case of the elastic thickness, for the low-degree range we were unable to constrain this parameter, in the mid-degree range we obtained an upper bound of 48 km and regarding the high degrees constrained the elastic thickness within $24 < T_e < 36$ km. A similar result was found by [4], for low degrees he obtained an upper bound of 140 km while a much better constraint was found in the high-degree range, with $40 < T_e < 50$ km.

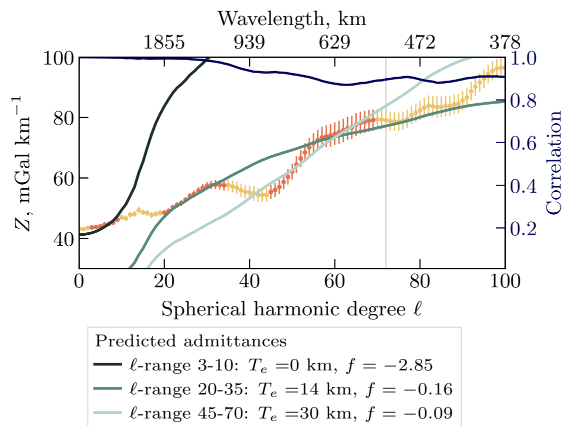

Figure 2: Observed and best-fit admittance curves of Atla Regio for the three investigated spectral bands. Red points indicate the degrees used when calculating the misfit in each band.

Conclusion and perspectives: Overall, we find a large importance of subsurface loading in the support of topography for the lowest degrees and, based on the higher degree part of the admittance spectrum, we can infer that the elastic thickness varies from roughly 20 to 40 km. These results are broadly similar to what was found by [4]. Hence, it seems that the differences in the model assumptions regarding the phases of the surface and subsurface loads do not have a major impact on the final results. Nevertheless, in order to better assess this influence, the models should be compared under the same conditions, i.e., using the same datasets and analyses techniques. Thus, the next step in our study will be to implement a model with uncorrelated subsurface loads [5]. We also plan to compare these loading models with dynamic flow models [11] which introduce a dynamic support component associated with mantle convection.

Another important point that should be addressed is to better understand how f varies with wavelength. For the moment, studies have dealt with this issue by splitting the spectra in multiple ranges, but this solution is somewhat arbitrary. It would be preferable to determine a function $f(\ell)$ that would allow us to fit the entire spectrum with a single model. Finally, we intent to expand this study to all Venusian volcanic rises.

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