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Review

# Toward mapping the effective elastic thickness of planetary lithospheres from a spherical wavelet analysis of gravity and topography

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ABSTRACT

The effective elastic thickness ($T_e$) of the lithosphere controls the flexural response to transverse loading and can be used in conjunction with rheological models to remotely estimate surface heat flux of terrestrial planets. In the vast majority of studies, $T_e$ estimation is carried out in a two-step process: (1) the joint spectra (admittance and/or coherency) of gravity anomalies (free air and/or Bouguer) and topography are calculated within finite-size windows, and (2) the spectra are inverted using a model for the loading of an infinite elastic plate or shell. In recent years, research in the spatio-spectral analysis of Cartesian grids and improvements in lithospheric loading models have allowed the mapping of $T_e$ on the Earth at unprecedented resolution. Nevertheless, the limitations imposed by working with Cartesian data and models are hampering further advances in terrestrial $T_e$ studies. The planetary community, on the other hand, has traditionally used spatio-spectral methods that work directly on the sphere, thereby avoiding the undesirable distortions and biases inherent in Cartesian studies. However, the models and methods developed for the Earth have never been applied to planetary data, therefore also limiting further advances in the mapping of planetary $T_e$. This paper reviews the latest developments in $T_e$ studies and proposes to combine advances in both terrestrial and planetary studies to allow the mapping of $T_e$ of terrestrial planets using a spherical wavelet analysis of gravity and topography data. We begin with a review of the recent literature on the challenges and debates concerning $T_e$ estimation from joint gravity and topography spectra. We then briefly review the implementation of the continuous planar and spherical wavelet transforms (CPWT and CSWT) and demonstrate that both transforms possess exactly the same resolving power, however the CSWT does not suffer from effects associated with non-periodic boundaries. We further re-derive, in a consistent manner, the expressions for the admittance and coherency from flexural equations for the loading of thin elastic plates and shells and show that they result in similar spectra, except at the longest wavelengths where the shell membrane stresses dominate. We then estimate global grids of Earth's continental$T_e$ by inverting the planar and spherical admittance and coherency functions, both separately and jointly, using either free air or Bouguer gravity anomalies. The correspondence between the Cartesian and spherical approaches and the similarity of $T_e$ results for the Earth's continents indicate that the spherical methods are robust. Results obtained from the joint inversion of admittance and coherency show that simple lithospheric loading models fail to capture the complexity of the data, with adverse effects on the estimated parameters. Finally, we extend the analysis to the Moon and other terrestrial planets and discuss limitations and future applications of the fully spherical techniques.



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## 1. Introduction

Isostasy describes the condition that vertical loads must be mass-compensated at some depth within the lithosphere (Watts, 2001). The equilibrium can be achieved either locally by lateral variations in density structure, or regionally via the support of an elastic lithosphere. In the regional model, the lithosphere is treated as a thin elastic plate bending under applied surface and internal loads. The flexural rigidity $D$, a rheological property that governs the resistance of the plate to bending, is given by

$$D = \frac{ET_e^3}{12(1 - \nu^2)}, \tag{1}$$

where $E$ is Young's modulus, $\nu$ is Poisson's ratio and $T_e$ is the thickness of the effective elastic plate. Knowledge of the flexural rigidity is crucial in many aspects of lithospheric dynamics, as it provides valuable information into the factors influencing plate deformation and evolution.

A common method to map out variations in flexural rigidity is based on a two-step process through which the statistical relationships between gravity and topography data are formed and inverted using equations for the flexure of an elastic plate or shell with uniform properties. The method has traditionally been cast as an inverse problem in the spectral domain by fitting the ratio of gravity and topography spectra to model-derived spectra using a chi-squared misfit criterion. Despite its apparent simplicity, the method has produced vastly different and sometimes inconsistent results in continental regions due to specific choices of gravity anomalies (Bouguer or free air), spectral ratio (admittance or coherence), model assumptions (surface and/or subsurface loading), and spectral estimation methods. Furthermore, even though the planetary community has dealt with this problem in spherical coordinates for at least three decades (e.g., Turcotte et al., 1981), terrestrial studies of $T_e$ have traditionally been cast using a Cartesian approach through which planar grids are extracted from spherical data using a map projection, and Cartesian spectral analysis is applied within sliding, finite-size