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Isostatic response of the Australian lithosphere: Estimation of effective elastic thickness and anisotropy using multitaper spectral analysis

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Abstract. Gravity and topography provide important insights regarding the degree and mechanisms of isostatic compensation. The azimuthally isotropic coherence function between the Bouguer gravity anomaly and topography evolves from high to low for increasing wavenumber, a diagnostic that can be predicted for a variety of lithospheric loading models and used in inversions for flexural rigidity thereof. In this study we investigate the isostatic response of continental Australia. We consider the effects of directionally anisotropic plate strength on the coherence. The anisotropic coherence function is calculated for regions of Australia that have distinctive geological and geophysical properties. The coherence estimation is performed by the Thomson multiple-Slepian-taper spectral analysis method extended to two-dimensional fields. Our analysis reveals the existence of flexural anisotropy in central Australia, indicative of a weaker N–S direction of lower T_e. This observation is consistent with the suggestion that the parallel faults in that area act to make the lithosphere weaker in the direction perpendicular to them. It can also be related to the N–S direction of maximum stress and possibly the presence of E–W running zones weakened due to differential sediment burial rates. We also demonstrate that the multitaper method has distinct advantages for computing the isotropic coherence function. The ability to make many independent estimates of the isostatic response that are minimally affected by spectral leakage results in a coherence that is more robust than with modified periodogram methods, particularly at low wavenumbers. Our analysis elucidates the reasons for discrepancies in previous estimates of effective elastic thickness T_e of the Australian lithosphere. In isotropic inversions for T_e, we obtain values that are as much as a factor of 2 less than those obtained in standard inversions of the periodogram coherence using Bouguer gravity and topography but greater than those obtained by inversions that utilize free-air rather than Bouguer gravity and ignore the presence of subsurface loads. However, owing to the low spectral power of the Australian topography, the uncertainty on any estimate of T_e is substantial.

1. Introduction

1.1. Admittance and Coherence Calculations

Mountain belts are generally underlain by "roots" that are less dense than the surrounding mantle. In the most extreme, fully compensated case, they are in a state of near-Airy isostasy that corresponds to a lithosphere with no strength or zero thickness [*Turcotte and Schubert*, 1982]. In this case the free-air gravity anomaly is small and approaches zero for the longest wavelengths, and the Bouguer gravity anomaly is nonzero, reflecting the crustal root. Generally, the Bouguer anomaly is strongly correlated with the topography at long wavelengths. In other scenarios the lithosphere has more rigidity or strength and can support topographic loads without much of a compensating crustal root. For wholly uncompensated topography the free-air anomaly, not the Bouguer anomaly, will be correlated with topography [*Lambeck*, 1988; *Fowler*, 1990; *Blakely*, 1995]. In general, the correlation of the Bouguer anomaly to topography is wavelength-dependent. The wavelength range at which the transition from compensated to uncompensated topography occurs is diagnostic of the lithospheric rigidity. Thicker or more rigid lithospheres tend to undergo the transition from highly compensated to uncompensated topography at longer wavelengths than thinner or weaker lithospheres [e.g., *Karner*, 1982; *Forsyth*, 1985].

Admittance and coherence functions, spectral measures of the isostatic response of gravity to topography, can be used to invert for an effective elastic thickness T_e or flexural rigidity D [*Timoshenko and Woinowsky-Krieger*, 1959], assuming surface and/or subsurface loading of an elastic plate overlying a fluid substrate. This has been done for both oceanic and continental plates in a variety of settings [e.g., *McKenzie and Bowin*, 1976; *McNutt and Parker*, 1978;

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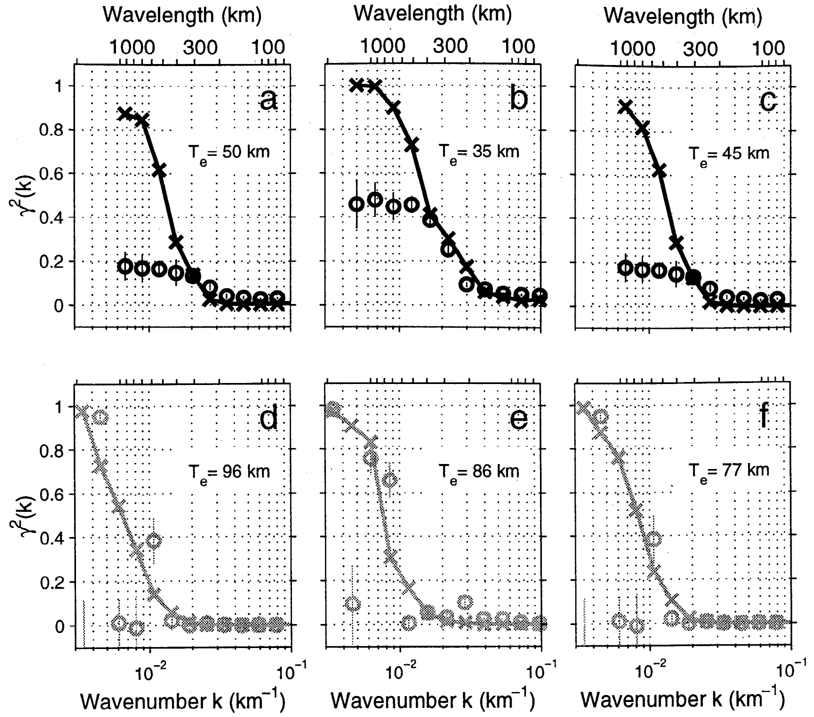

Figure 10. Isotropic T_e inversions of the three boxes lettered a through c in Plate 2. (a–c) Inversion with multitaper coherence estimates. Circles, measurements with 2σ error bar; crosses, prediction. (d–f) Same for periodogram measurements. The inversion for both coherence measurement methods is identical: topographic loading and one interface of subsurface loading are considered [*Forsyth*, 1985; *Zuber et al.*, 1989], the interface being the local average Moho depth of 50 km for Figures 10a and 10d, 45 km for Figures 10b and 10e and 35 km for Figures 10c and 10f.

elastic thickness are relatively profound. The values for T_e that we obtain here are as much as a factor of 2 lower than those found by *Zuber et al.* [1989].

7. Discussion

7.1. Anisotropic Mechanical Properties

A zeroth-order model for an elastically anisotropic lithosphere is one in which the average plate strength is made up of one direction which is "stronger" than the isotropic average, and another, "weaker" direction.

7.1.1. Stress state. The stress state of the continent is an important factor in the creation of anisotropic coherence functions [*Lowry and Smith*, 1995]. Flexural isostasy proposes that it is the stress distribution within the plate that supports the weight of the loads. In-plane tectonic (deviatoric) stresses (which are adequate representations of the lithospheric stress state [*Turcotte and Schubert*, 1982]) are predominantly associated with plate tectonics, through mechanisms of ridge push, slab pull, continental convergence, viscous drag at the base of the lithosphere or curvature changes with latitude [*Lambeck et al.*, 1984; *Coblentz et al.*, 1995, 1998]. Other processes are also at play, and moreover, the stress state may be inherent to the mechanical and thermal properties of the lithosphere [*Lambeck et al.*, 1984]. In viscoelastic models, stress relaxation rates may vary with direction. *Stephenson and Lambeck* [1985] proposed that regional compressive stresses help support near-surface loads in preferred directions. However, *Lowry and Smith* [1995] have shown that directions of both maximum compressive and extensional tectonic stress lower the T_e values in the same direction due to the shifting of the yield envelope which reduces the depth-integrated fiber stresses and hence the T_e. Unfortunately, very few extensive in situ stress measurements are available for Australia. Borehole break-out measurements, where available, are notorious for their scatter [*Hillis et al.*, 1998, 1999]. However, on the basis of focal mechanisms of the infrequent earthquakes in the area the direction of maximum compressive stress for central Australia scatters around N–S [*Lambeck*, 1983; *Lambeck et al.*, 1984; *Stephenson and Lambeck*, 1985; *Zoback*, 1992; *Spassov*, 1998]. For a N–S maximum compressive stress orientation we expect a T_e reduction in the same direction.

7.1.2. Moho depth. In an inversion for T_e, both surface and subsurface loading can and should be considered. However, subsurface interface depths need to be maintained throughout the region under study. Although the effect of uncertainties in the locations of the internal density stratification on the coherence is reported to be minor [*Forsyth*, 1985, Figure 9], azimuthal crustal thickness variations (such as those that characterize central Australia) will introduce a variation of mechanical properties with direction. The