Supplementary material: Past and future dynamics of the Brunt Ice Shelf from seabed bathymetry and ice shelf geometry

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1. Inversion of sub-ice shelf bathymetry from gravity

Bathymetry under ice shelves is critical for understanding their long-term stability, but is hard to determine. Radar techniques do not penetrate the water column, seismic measurements are time consuming with many areas inaccessible, and direct observation using autonomous underwater vehicles, such as NERC's Boaty Mc Boat Face, is risky and only provide a narrow swath of data. An alternative approach is to use gravity signals, collected rapidly and efficiently with airborne systems, to invert for sub-ice shelf bathymetry. Inversion of gravity data relies on the density contrast between water and the underlying rock, which can provide a clear bathymetric signal. Inversion of gravity data for sub-ice or sub-marine topography has been applied since the early surveys of Antarctica in the 1960's (Bentley, 1964), and continues to be applied in both marine and terrestrial settings to this day (Cochrane and Bell, 2012; Fretwell et al., 2013; Sandwell and Smith, 1997). However, it has been shown that some of these inversions provided poor estimates of sub-ice shelf topography (Brisbourne et al., 2014). Such inaccuracies in bathymetry derived from gravity data likely reflect un-modelled sub-surface geological features, which can distort the gravity field, and may have a similar wavelength to the desired bathymetric signal. Despite these limitations, gravity data can provide an important first look at sub-ice shelf bathymetry when other data is limited, or lacking.

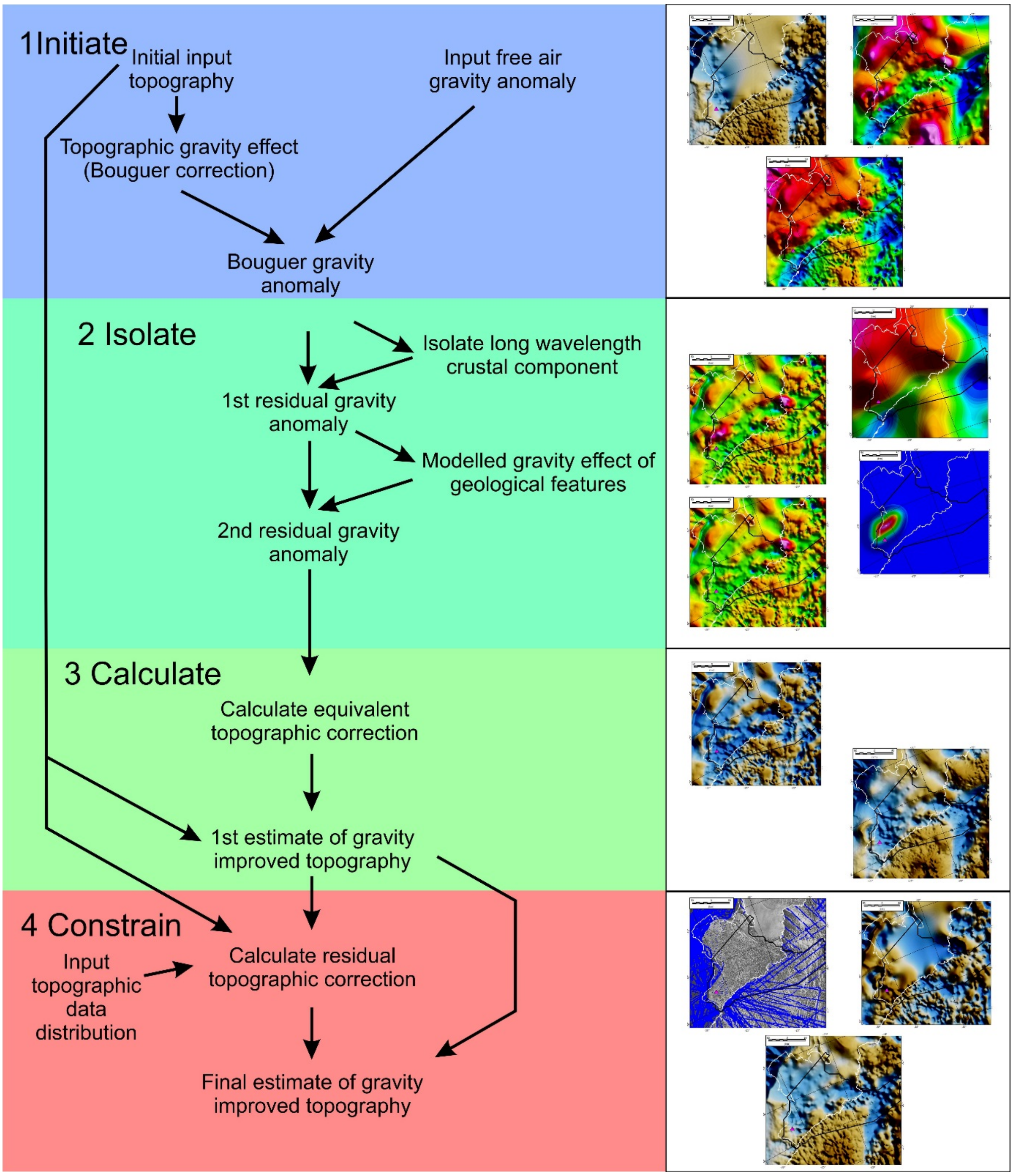
To provide the most robust estimate of sub-ice topography we have developed a four-stage process to derive sub-ice shelf topography from gravity data, while maintaining close correspondence to available direct bathymetric observations (SFig. 1). The detailed steps for calculating the final gravity improved topography are described below.

Step 1. Initiate. The 3D gravity effect of the initial known topography, interpolated from radar, seismic and swath bathymetry measurements, is calculated. This Bouguer correction is subtracted from the observed grid of free air gravity anomalies. The resulting Bouguer anomaly contains signals caused by variations in crustal thickness, shallow geological bodies with distinct densities, and errors in the input topographic data.

Step 2. Isolate. The long wavelength gravity anomaly, assumed to be due to crustal thickness variation, is isolated using a low pass filter. This long wavelength anomaly is subtracted from the Bouguer anomaly, leaving the 1st residual gravity anomaly, which contains signatures due to shallow geological bodies with distinct densities, and errors in the input topographic data. If distinct geological features can be recognised 3D models of their gravity signatures are calculated and subtracted leaving the 2nd residual gravity anomaly, theoretically only due to errors in the input topographic data.

Step 3. Calculate. The 2nd residual gravity anomaly is converted from mGal to equivalent rock thickness using the Bouguer slab formula, assuming a density of 2.67 and 1.028 gcm^{-3} for rock and water respectively. This equivalent topographic correction is added back to the initial topography to provide the 1st estimate of gravity improved topography.

Step 4. Constrain. Discrepancies between the 1st estimate of sub-ice shelf topography and the input topography where it is well constrained relate to un-modelled geological factors. We interpolate this error field between the points where topography is well constrained to provide a residual topographic correction. This is added to the 1st estimate of gravity improved topography to provide the final estimate of gravity improved topography.



Supplementary Figure 1. Flow diagram showing inversion of bathymetry from gravity. Right-hand panel shows example grids at each stage (red-green-pink colours = gravity, blue-brown colours = topography).

Specific notes for this study: The Bouguer correction was calculated using a 3D Gauss-Legendre quadrature (GLQ) method (von Frese et al., 1981), assuming a uniform observation altitude of 450 m, coincident with the 2017 survey altitude over the ice shelf. Results are therefore not valid onshore where surface elevations are above 450 m. Standard densities for the Bouguer correction of 915, 1028 and 2670 kgm^{-3} for ice, water and rock respectivley were used.

The residual crustal anomaly was isolated using a 150 km low pass Gaussian filter. This appeared to remove any linear regional trend in the observed gravity anomaly, suggesting the long wavelength signal due to the extreme change in crustal thickness between the East Antarctic continent and the oceanic crust of the Weddell Sea have been accounted for.

For areas outside the high-resolution 2017 data anomalies appear in the Bouguer gravity field which are likely artefacts of the low resolution of the reconnaissance free air gravity data.

References

Bentley, C.: The structure of Antarctica and its ice cover. In: Research in Geophysics Vol. 2, Solid Earth and Interface Phenomena, Odishaw, H. (Ed.), MIT Press, Cambridge, Mass., 1964.

Brisbourne, A. M., Smith, A. M., King, E. C., Nicholls, K. W., Holland, P. R., and Makinson, K.: Seabed topography beneath Larsen C Ice Shelf from seismic soundings, The Cryosphere, 8, 1-13, 2014.

Cochrane, J. R. and Bell, R. E.: Inversion of IceBridge gravity data for continental shelf bathymetry beneath the Larsen Ice Shelf, Antarctica, J. Glaciology, 58, 540-552, doi: 510.3189/2012JoG3111J3033, 2012.

Fretwell, P., Pritchard, H. D., Vaughan, D. G., Bamber, J., Barrand, N., Bell, R., Bianchi, C., Bingham, R., Blankenship, D., and Casassa, G.: Bedmap2: improved ice bed, surface and thickness datasets for Antarctica, The Cryosphere, 7, 2013.

Sandwell, D. T. and Smith, W. H. F.: Marine gravity anomaly from Geosat and ERS 1 satellite altimetry Journal of Geophysical Research, 102, 10039-10054, 1997.

von Frese, R. R. B., Hinze, W. J., Braile, L. W., and Luca, A. J.: Spherical earth gravity and magnetic anomaly modeling by Gauss- Legendre quadrature integration, J. Geophys, 49, 234-242, 1981.