Revising gravity terrain corrections in Tasmania

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SUMMARY

Terrain corrections for determination of the complete Bouguer anomaly are empirically evaluated with respect to a number of different techniques, parameters and digital terrain model data sets, for areas in western and northern Tasmania.

For the most part, while terrain corrections calculated from very high resolution terrain models (1.2 metres or better) are presumed to deliver the most accurate results, those computed for the same area using only a Statewide 25 metre-cell digital terrain model to within two metres of gravity stations correspond remarkably well. Internally consistent comprehensive terrain correction of acceptable yet maximal accuracy can therefore be calculated for all Tasmanian gravity stations, even if very high resolution DTMs are unavailable.

Fully automatic terrain correction computation from two metres to 167 kilometres from gravity stations will result in significantly improved removal of topographic effects over extant manual corrections, which were limited to 22 kilometres.

Key words: terrain correction, complete Bouguer anomaly, Tasmania, digital terrain models, LiDAR

INTRODUCTION

Despite increasing prevalence and capability of 3D potential field modelling software, qualitative interpretation of gravity data remains common among mineral explorers, as does quantitative modelling that does not explicitly account for topography (employing the planar Bouguer gravity assumption). This creates an ongoing need for gravity data and images that are free of direct topographic effects. In Tasmania, the necessity of a terrain correction (complete Bouguer anomaly calculation) for each station in order to isolate the geological signal in gravity data, for both simple quantitative and qualitative interpretation, has long been recognised (Direen 2000). Subsequently terrain corrections have been calculated routinely for all gravity stations acquired in Tasmania, both commercially and by government agencies. This has been performed predominantly by manual methods (Leaman 1998), to a standard radius of 22 km. The topography of Tasmania is such that gravity station corrections well in excess of 10 mGal are not uncommon, while other stations within a few kilometres may be less than 0.5 mGal, underscoring the need for accurate terrain effect characterisation. The particular importance of the terrain correction in western Tasmania in general and for mineral exploration in particular has been highlighted by case studies such as that of Roberts and Mudge (1997).

In recent years, considerable advances have been made in the availability of very high resolution terrain data, as well as in computing capacity. A digital terrain model (DTM) at 25 metre cell size is available for the entire state, and this has been augmented by LiDAR-derived DTMs, typically at one metre resolution or better, across a significant portion of the state. These developments have enabled practical fully automatic computation of terrain corrections in to and including Hammer zone B (Hammer, 1939) i.e. two metres, where LiDAR data are present. However, availability of such high resolution DTMs remains far from universal. This raises issues concerning the consistent application of terrain corrections across the Statewide gravity database.

This paper compares terrain correction methods for test areas in Tasmania, empirically examining the effect of different parameter choices and DTM data sets, and the implications for the statewide gravity data set.

METHOD AND RESULTS

A subset of Tasmanian gravity data from western Tasmania (Figure 1) was examined, containing 24909 stations at spacings ranging from tens of metres to several kilometres (Figure 2). The region analysed is a representative portion of the State centred on an area of recent gravity acquisition (Yu 2014). It encompasses large topographic variations in both wavelength and range terms, from around 100 metres below sea level (offshore) to over 1100 metres above sea level.

Water body surfaces including hydroelectric scheme impoundments are generally included within the terrain models used. This will result in the introduction of errors in uncritical application of automatic terrain corrections to stations adjacent to lakes. Recently-derived DTMs will also be inapplicable in the case of the dozens of station locations in the Tasmanian database that have been submerged by hydroelectric developments since the gravity data were acquired. It should however be noted that efforts to create a 'bare earth' digital elevation model of Tasmania, including lake bottoms, are under way at the University of Tasmania (M. King, pers. comm.); these should be incorporated in future terrain correction calculations.

The Bouguer reduction density, 2.67 t/m^3, was employed in all terrain correction computations.

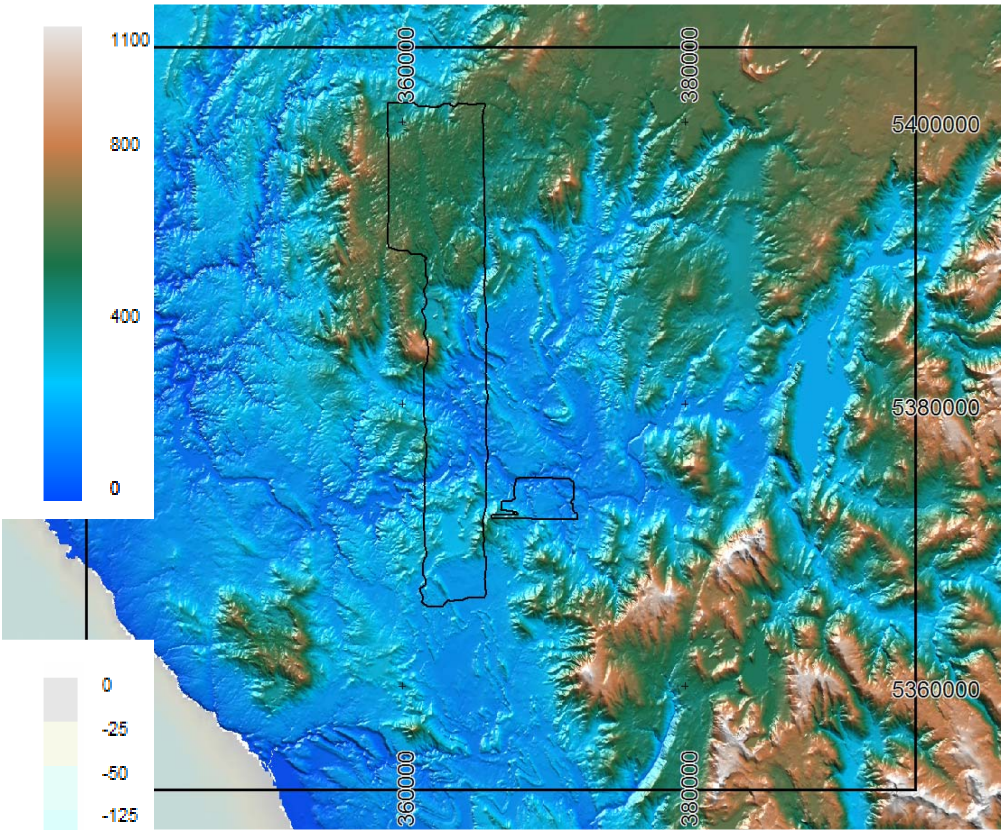

Figure 1: Terrain model (25 metre cells) of area in western Tasmania containing gravity stations analysed (see Figure 2 for their locations). The irregular polygon with lighter line weight indicates the area of a 1 metre cell digital terrain model (DTM) derived from LiDAR data (Metals X, 2009). Offshore bathymetry from Geoscience Australia (200 metre cells). Coordinates in this and all subsequent figures are MGA zone 55, all topographic values in metres above sea level.

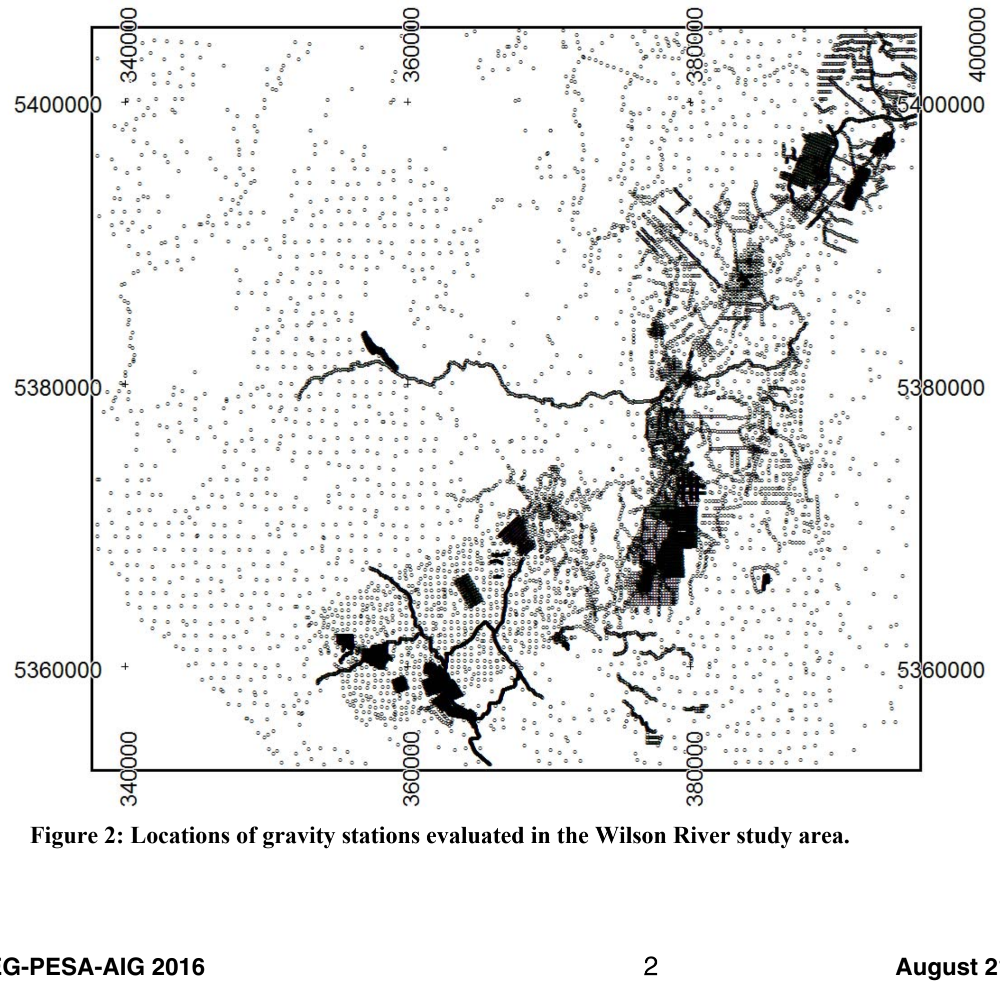

Figure 2: Locations of gravity stations evaluated in the Wilson River study area.

Automatic versus manual terrain corrections

Two different automatic terrain correction algorithms, TERRAIN (Roach, 1994; based on the method of St John and Green, 1967) and RasterTC© (Cogbill, 1990) were run for the gravity data set, initially for distances from 75 metres to 22 km from station locations. These gave very similar results (Yu, 2014), giving rise to confidence that both codes are valid. These results may be compared with the pre-existing manual terrain correction values (Figure 3). While the expected strong correlation between automatic and manually calculated values is present, a significant systematic tendency for the manual terrain corrections to be underestimates is also apparent, by up to 4.5 mGal. A minority of stations exhibit automatically calculated terrain correction values less than those obtained manually (below the red line in Figure 3). These are ascribed largely to the automatic calculations' omission of local terrain effects, between the station and a radius of 75 metres.

Inner zone terrain effects

Obviously it is desirable, indeed critical in many cases for calculation of the terrain correction to include effects of topographic variation less than 75 metres from the station (Leaman 1998). Equally obviously, this is facilitated by very high resolution terrain models. Such a data set exists in the Wilson River area (Figure 1), derived from LiDAR data (Metals X, 2009). This was used to compute the terrain effect to within two metres for all 253 gravity stations covered by the LiDAR survey, and thus quantify the importance of the inner zone contribution. The results (Figure 4) demonstrate that the terrain between 2 and 75 metres contributes an average of 0.126 mGal for this dataset, in what is fairly typically undulating country for Tasmania. This may be considered acceptable for region-scale applications. However, contributions up to 0.788 mGal are observed. This is well within the range of signal likely to be significant in a mineral exploration context, and confirms the importance of the inner zone terrain correction (TC), at least in Tasmania. It should therefore be determined if available data sets permit. However, consistency across the entire database needs to be maintained.

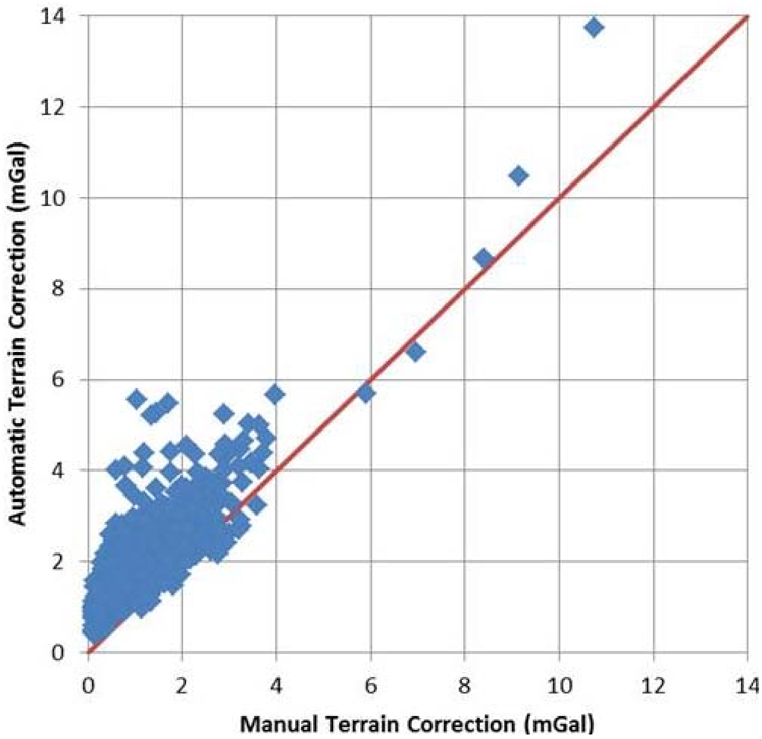

Figure 3: Comparison of terrain correction values (blue diamonds) obtained using manual and automatic methods on a 25 m DTM for station locations in the study area. Red 1:1 line for reference. After Yu (2014).

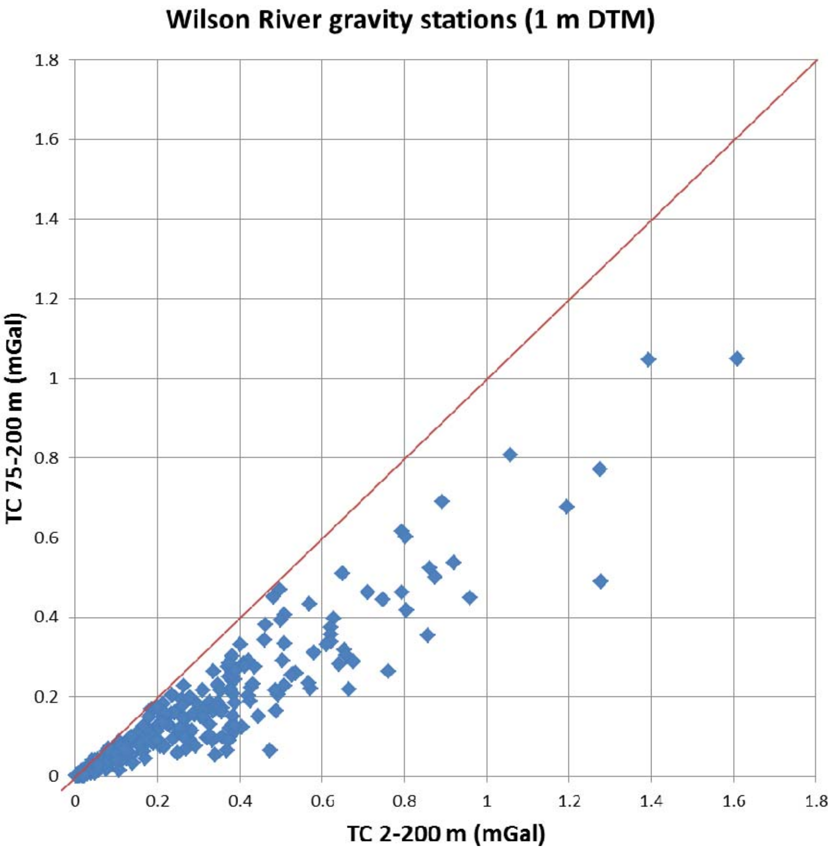

Figure 4: Comparison of inner zone terrain effects, computed for gravity stations within a 1 metre DTM. Red 1:1 line for reference.

Though acquisition of LiDAR data in Tasmania has proceeded rapidly in recent years (mainly for forestry purposes, supplemented significantly by sea level rise risk assessment in addition to geological mapping, local government and other applications) and may approach Statewide coverage in future, the 25 metre cell DTM remains the best available for most of Tasmania. The ability of this DTM to characterise the inner zone TC (down to two metres) was therefore investigated. TCs were computed to within two metres for the same set of 253 gravity stations outlined above, but using only the 25 metre DTM. The results showed surprisingly close correspondence to the TCs obtained via the 1 metre DTM (Figure 5). The average difference is 0.051 mGal (standard deviation 0.094 mGal), or in relative terms 3.7%. Less than a dozen stations of the 253 exhibited a difference of more than 0.25 mGal between the 25 metre and 1 metre DTM-derived TCs. The slightly positive nature of the average value is indicative of terrain (or at least terrain model) roughness at wavelengths less than resolvable by the 25 metre DTM, compared to the smooth surface interpolated by the RasterTC© code (Renka, 1984; Cogbill, 1990). Nevertheless, the error introduced by using the coarser DTM is less than would be the case if the inner zone component were omitted altogether inside 75, 50 or even 25 metres.

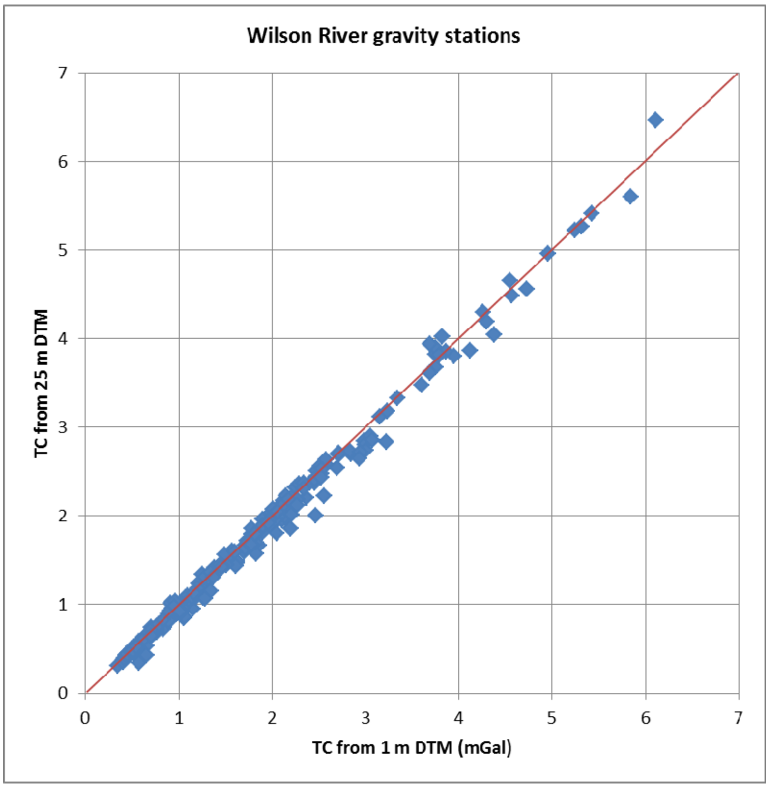

Figure 5: Comparison of terrain correction values (blue diamonds) obtained using the same parameters (2 m to 22 km) but DTMs of different resolution for station locations in the Wilson River area. Red 1:1 line for reference.

This potentially important result was checked by performing the same analysis on another area containing a very high resolution DTM; the Meander Valley region of northern Tasmania (Figure 6), also an area of recent new gravity data acquisition (McAdam 2015).

The results show an even tighter correspondence between TC values calculated using the very high resolution DTM (1.2 metre cells in this case) and those obtained using the 25 metre DTM only (Figure 7). In this instance the average difference is 0.012 mGal (standard deviation 0.025 mGal), or 0.68%.

It may be inferred that the improved correspondence between 25 metre and ~1 metre DTM-derived TCs in the Meander Valley can be largely ascribed to most stations in the data set being on the relatively flat valley floor. However, even when these are excluded (by the simple expedient of analysing only stations above 450 metres elevation), the average difference rises only to 0.030 mGal. This actually represents a fidelity improvement in relative terms (0.39%) despite generally rougher terrain adjacent to the station.

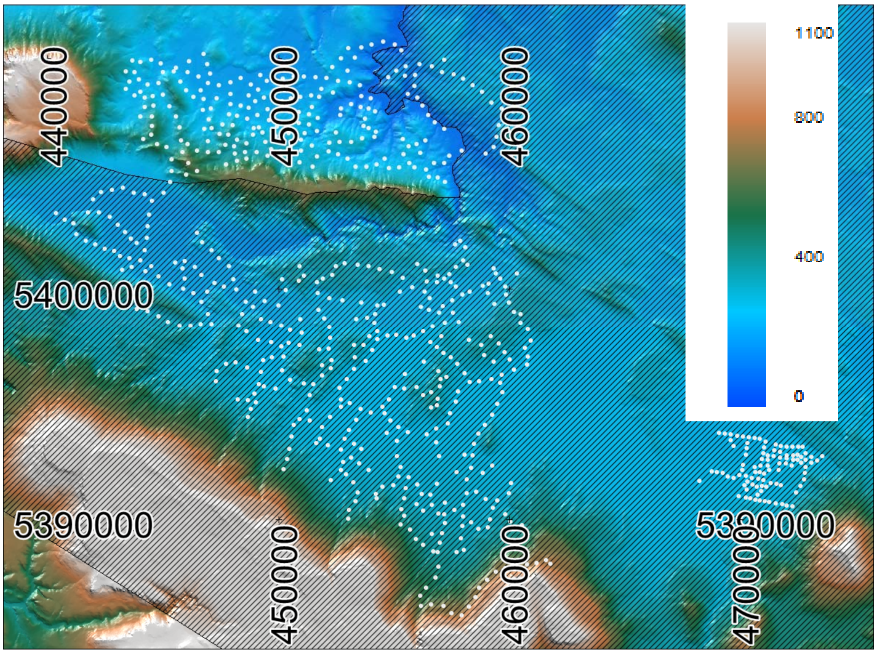

Figure 6: Gravity stations (white dots) within the hatched area (indicating 1.2 m DTM coverage) were evaluated in the Meander Valley area. Z-scale in metres ASL.

The Wilson River DTM is from one of the earlier commercial LiDAR surveys in Tasmania (Metals X, 2009), when techniques for obtaining ground elevation models from LiDAR point cloud data in heavily vegetated areas were still being refined. As such, artefacts are known to be present in thickly forested parts of the Wilson River DTM (fortunately these contain very few gravity stations, for obvious reasons). The Meander Valley DTM is of significantly more recent derivation (2014) and covers what is generally a more lightly vegetated area, thus the DTM is of substantially better quality. This may also have contributed to the apparent improved correspondence between 25 metre and 1 metre DTM terrain corrections for the Meander Valley data set.

Summarising, it is self-evident that more accurate terrain models deliver more accurate terrain corrections. Nevertheless, these results taken together confirm that 25 metre-cell DTMs are capable of delivering usable terrain correction to within two metres of gravity stations. The error introduced in doing so may range as high as 0.4 mGal in extreme cases, but is likely to be of the order of 0.05 mGal or less in most areas. Importantly for regional data integration, little of this is expressed as systematic bias. It is outweighed by the greater error introduced by the alternative of omitting the inner zone contribution altogether in the common situation where no very high resolution DTM is available. The entirety of this would constitute a systematic bias due to the additive nature of the terrain correction.

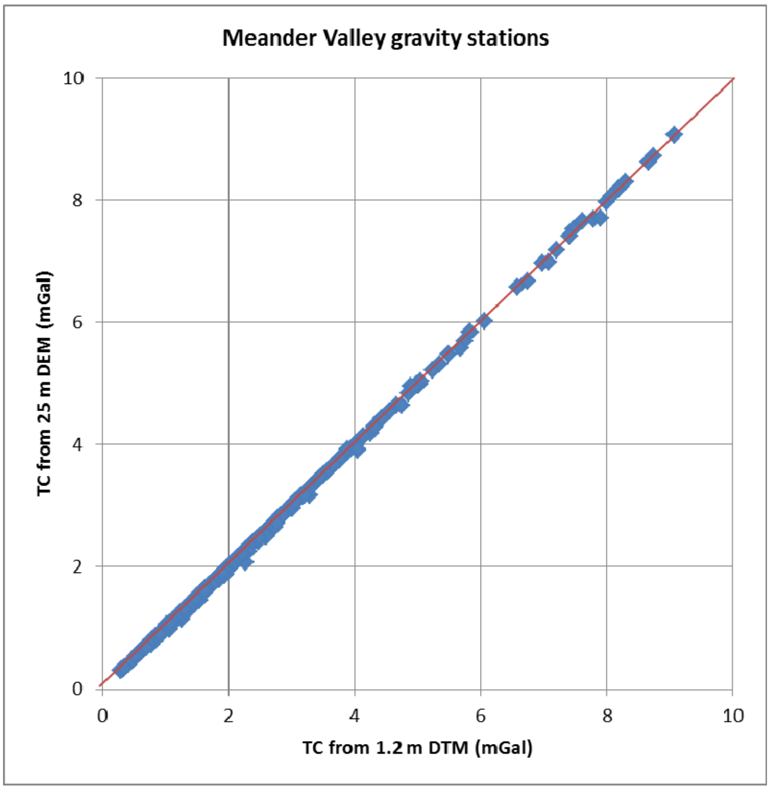

Figure 7: Comparison of terrain correction values (blue diamonds) obtained using the same parameters (2 m to 22 km) but DTMs of different resolution for 500 station locations in the Meander Valley. Red 1:1 line for reference.

Effect of outer terrain correction radius

Hitherto, terrain corrections calculated for gravity stations in Tasmania have been limited to a radius of 22 km (zone M, Hammer 1939), within which Earth's curvature can be safely neglected in most cases. Since this practice was established, a radius of 167 km has become a widely adopted standard (Nowell, 1999). The effect of this difference was evaluated by comparing terrain corrections for the Wilson River test data set with outer radii of 22 and 167 km respectively. Corrections for Earth's curvature were only incorporated in the latter case, for distances beyond 22 km. In addition to the DTM data sets described above, an extract from the 9-second (~250 metre cell size) Australian Bathymetry and Topography Grid (Whiteway 2009) was employed (Figure 8).

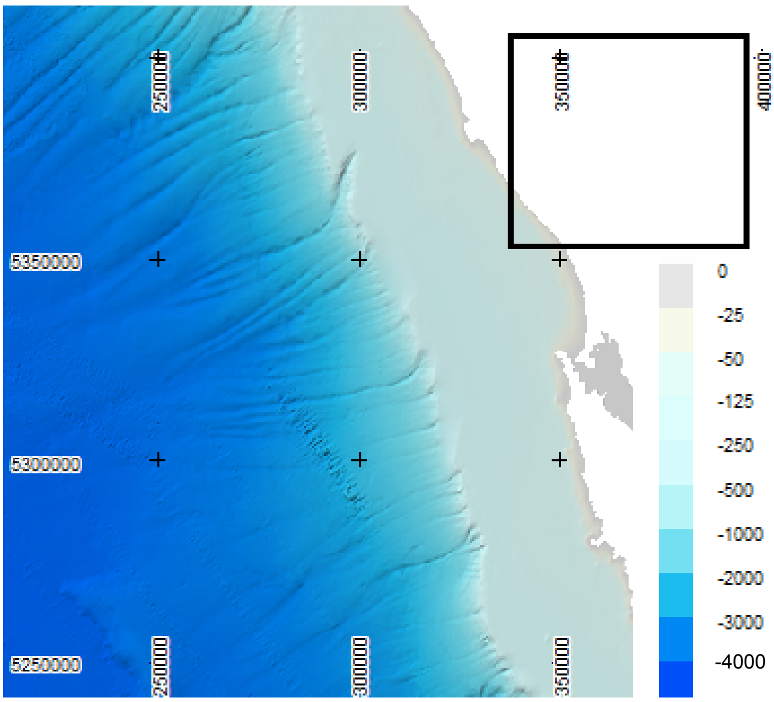

Figure 8: Continental shelf bathymetry (z scale in metres) in the vicinity of the Wilson River study area (black rectangle).

Results of the comparison are shown in Figure 9. Limiting the TC computation radius to 22 km results in underestimation of the terrain effect by an average of 1.27 mGal for the test data set, compared to the 167 km radius standard. As described by Nowell (1999), station height becomes the dominant control on the terrain correction for distances beyond 22 km. Thus the effect of calculating TC to the larger radius is clearly greatest for the most elevated stations (compare Figure 9 with Figure 1). The influence from longer wavelength terrain changes such as the continental slope is not immediately apparent, even at the wavelengths of tens of kilometres encompassed by the test area, as even these large features approach insignificance with increasing distance from the gravity station beyond 22 kilometres, where the curvature correction dominates. However, removal of the first-order, station height control (via subtraction of topography crudely rescaled to match the range of the 22 km-167 km terrain correction contribution) reveals that the continental slope does exert a discernible influence, albeit only as a regional gradient in the order of less than 0.03 mGal per kilometre (Figure 10).

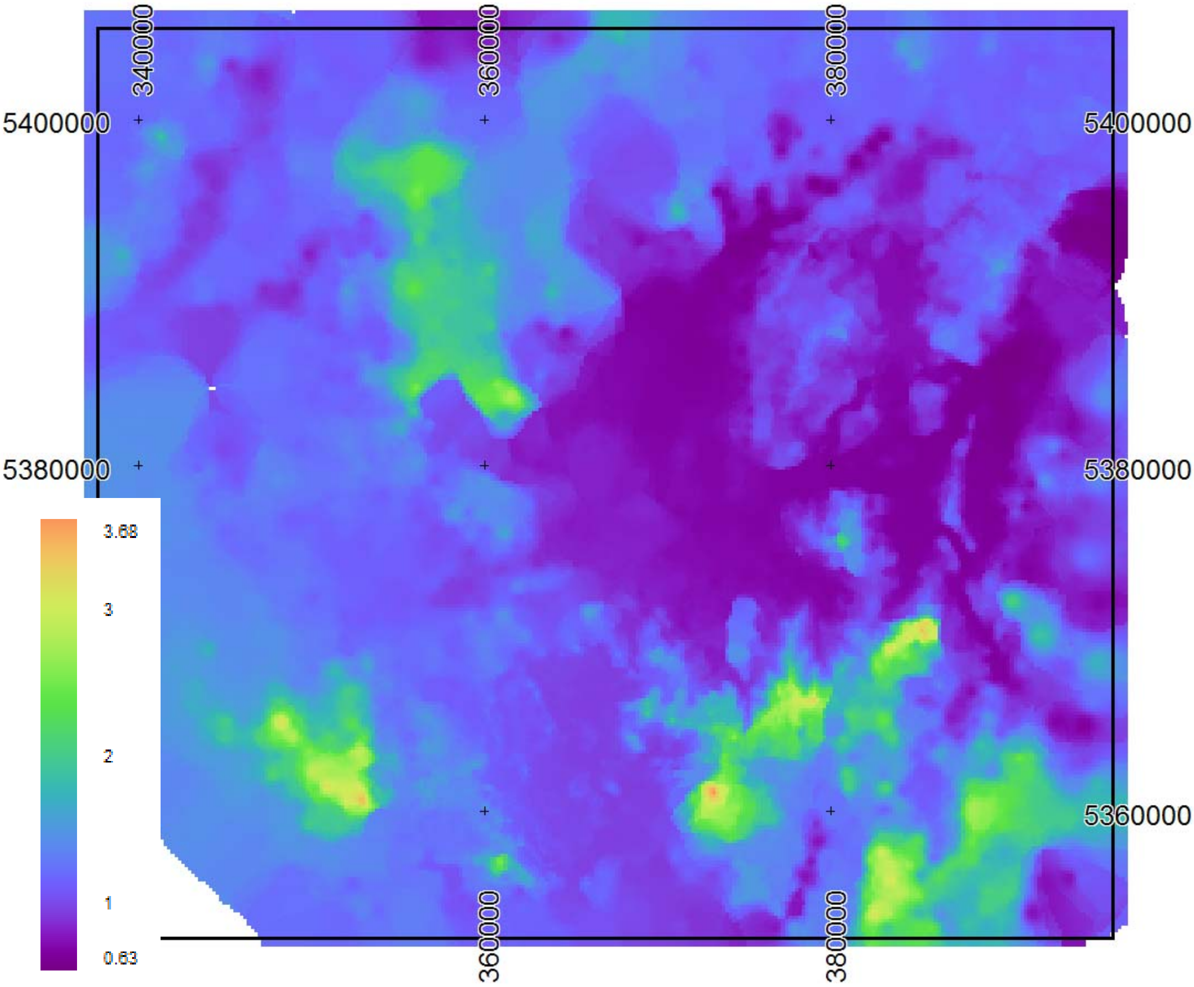

Figure 9: Difference between terrain corrections for 167 km and 22 km radii (i.e. effect of terrain between 22 km and 167 km from stations) gridded using inverse distance weighting. Z-scale in mGal.

Impact of revision

The effect of all the proposed terrain correction revisions (fully automatic computation, 167 km radius with Earth curvature correction beyond 22 km) on the complete Bouguer anomaly is indicated in Figure 11. Gravity stations where the terrain correction change is greatest are strongly associated with local lows in the pre-revision gridded Bouguer gravity. These local lows can thus be seen to be at least partly spurious. It may be inferred that significant components of these lows are due to under-correction of terrain, and will be attenuated or eliminated by the revised terrain correction.

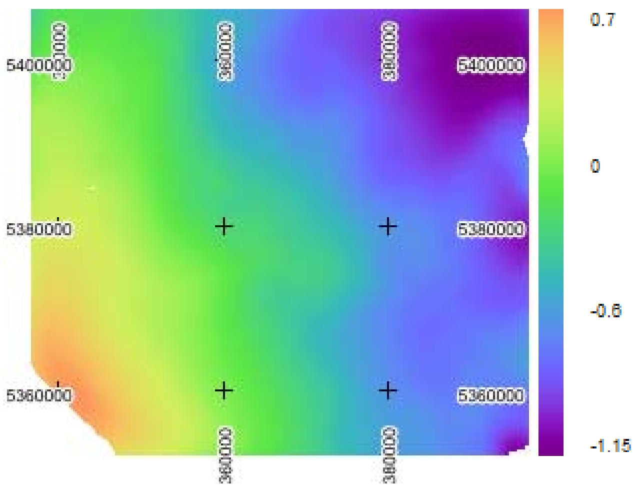

Figure 10: Effect of terrain between 22 and 167 km from stations after suppression of approximate station height contribution and 22 km low-pass filter. Z-scale in mGal.

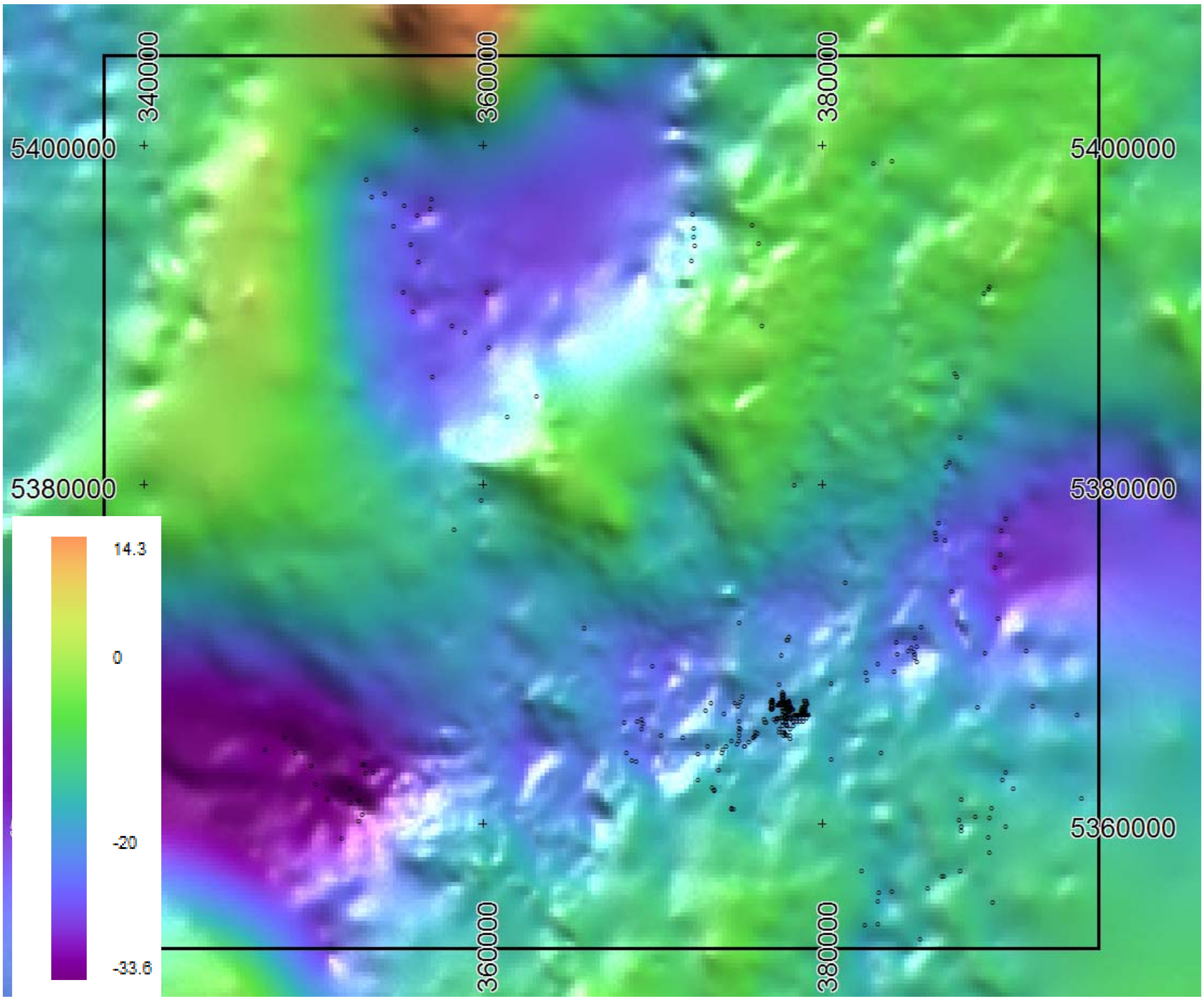

Figure 11: Pre-revision residual complete Bouguer anomaly (image, mGal) overlaid with stations where the difference between old and revised TC exceeds 5 mGal.

CONCLUSIONS

Results from different terrain correction computation codes are in close agreement, increasing confidence in their validity. Comparison with previous manual terrain corrections show a systematic tendency for the latter to underestimate the terrain effect. This has been compounded by manual terrain corrections being practically limited to 22 km radius. This contributes to under-correction of topography by up to over 3 mGal in the most elevated areas of Tasmania, relative to the current TC standard radius of 167 km. Comprehensive revision is indicated, however the accuracy attainable for older stations is limited by positional uncertainty.

If care has been taken in field station positioning (Leaman 1998) and approaches that incorporate accurate interpolation between DTM points in close proximity to gravity stations are used, 25 metre-cell DTMs are adequate to approximate the full terrain correction beyond 2 metres from the station in most situations and applications. Nevertheless, for maximum accuracy, higher resolution DTMs such as are obtainable from LiDAR data should be employed if available.

These insights are being applied to a revision of terrain corrections for all gravity stations in Tasmania. This is expected to deliver significant improvement in the quality and utility of the gravity coverage.

ACKNOWLEDGMENTS

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