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The Cryosphere
Discussions

Interactive comment on "Tectonic and oceanographic controls on Abbot Ice Shelf thickness and stability" *by* J. R. Cochran et al.

AM Brisbourne (Referee)

aleisb@bas.ac.uk

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SUMMARY:

This paper presents the results of the inversion of Operation IceBridge data over the Abbot Ice Shelf, inverting the free-air gravity anomaly for sub-ice shelf bathymetry. Radar and altimeter data are used to constrain ice shelf thickness. Densities are fixed according to existing geological knowledge, as well as known surface elevations beneath grounded ice and line-ties. These results are then used to address the oceanographic and tectonic setting of the Abbot Ice Shelf and their effects on ice shelf stability. The major control is attributed to ice-shelf thickness rather than sub-shelf bathymetry. The paper is well written and structured.

Although adjacent to Pine Island and Thwaites Glaciers, and in the topical Amundsen-Bellinghausen Sector, the Abbot Ice Shelf has been somewhat overlooked. The consequent sparseness of direct observations (geology and bathymetry) in the area limit the constraints which can be applied to the inversion of gravity data for bathymetry, and as such call into question the reliability of these results for assessing the oceanographic control on the ice shelf. These shortcomings have not been addressed in full or realistically quantified here, although the conclusions have been weighted such that the uncertain results are not overly relied upon.

The absence of a sediment layer in the inversion has significant implications for the derived bathymetry. However, the interpretation of the tectonic setting from the gravity inversion is more reliable as this influences the large-scale features of the gravity field and therefore can be better constrained by the known bedrock densities, depths and grounding line positions. The interpretation of the tectonic setting fits within the regional context as I understand it.

The discrepancy between the OIB draft and that of Bedmap2/Griggs and Bamber is probably the most significant result presented. Indeed, this puts the ice-shelf base close to the mixed layer/thermocline boundary, and results in melt-rate sensitivity to seasonal variation. However, how the sub-ice shelf bathymetry influences oceanographic flow is still very much an open question due to the uncertainties resulting from the lack of knowledge of sediment thickness (see major comments).

To me, the title of the paper implies that active tectonics control the Abbot Ice Shelf thickness. This is of course not the case. It is the remnant features of a tectonic episode 100 Ma which produce the rifted basin structure. This has then presumably been modified by sediment infill which is also not tectonically controlled. "Topographic and oceanographic ..." would be more fitting. However, as stated above, the topographic influence is still very much uncertain.

MAJOR COMMENTS:

A number of highly relevant recent studies have been overlooked which have significant implications for the reliability of the gravity inversion as presented here.

(1) Missing reference: Rignot, E., J. Mouginot, and B. Scheuchl (2011), Antarctic grounding line mapping from differential satellite radar interferometry, Geophys. Res. Lett., 38, L10504, doi:10.1029/2011GL047109.

- In the absence of any direct measurements of sub-ice shelf bathymetry all available information must be used to constrain the gravity inversion. Use of the interferometric InSAR grounding line allows points of zero-depth sub-ice cavity to be constrained, especially where small-scale features below the resolution of the gravity data are present. Most notably, at the southern end of lines 6 and 7 of this study, grounded ice can be inferred and used to constrain the inversion where at present the gravity results indicate floating ice.

(2) Missing reference: Muto, A., Anandakrishnan, S., and Alley, R., Subglacial bathymetry and sediment layer distribution beneath the Pine Island Glacier ice shelf, West Antarctica, modeled using aerogravity and autonomous underwater vehicle data, Ann. Glaciol., 54, 27–32, 2013.

- The study of Muto et al. utilises a more closely-spaced 3D dataset with AUV bathymetry data. However, PIG's proximity (which is referred to elsewhere in the manuscript) means this work cannot be overlooked. More specifically, the presence of faults is inferred, associated with high gradients in the gravity data. Of even more significance is the thickness of sediment (200-1000m) associated with a ridge, not dissimilar to the structural features presented here. The exclusion of sediment in the density profile in Abbot must therefore be justified when such significant thicknesses, and therefore bathymetric differences, have been reported in the regional setting.

(3) Missing reference: 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, doi:10.5194/tc-8-1-2014, 2014.

- Although without ground truth data it is speculation to include a layer of sediments, this recent evaluation of the gravity inversion method using seismic soundings demonstrated that ignoring the presence of sediments can invalidate any derived bathymetry.

(4) Missing reference: Mueller, R. D., Padman, L., Dinniman, M. S., Erofeeva, S. Y., Fricker, H. A., and King, M. A., Impact of tide-topography interactions on basal melting of Larsen C Ice Shelf, Antarctica, J. Geophys. Res.-Oceans, 117, doi:10.1029/2011JC007263, 2012.

- The study of Mueller et al. highlighted the significance of bathymetry on topographic effects on tidal melting of ice shelves. Errors introduced in the Larsen study mentioned above were demonstrated to significantly affect basal melt-rates. Although tides are likely less relevant in this region, the effects of tidally-forced melting should be outlined where sub-ice shelf cavity thickness is so variable.

(5) Missing reference: Dutrieux, P., De Rydt, J., Jenkins, A., Holland, P. R., Ha, H. K., Lee, S. H., Steig, E. J., Ding, Q., Abrahamsen, E. P., and Schröder, M.: Strong Sensitivity of Pine Island Ice-Shelf Melting to Climatic Variability, Science, 343, 174-178, 2014.

- This study outlines in detail ice shelf sensitivity of PIG in the same regional setting as Abbot (published after the initial submission of this manuscript but essential for inclusion in any revised manuscript).

SPECIFIC COMMENTS:

P5511/L18: Use of the term "facilitated" completely underplays the importance of bathymetry to potential basal melt rates. See Mueller (2012) reference above.

P5512/1: References to Brisbourne (2014)/Muto (2013) etc. The limitations of this technique need to be addressed in detail here.

P5512/L5: References needed for the temperature profiles.

P5513/L8: Explain here why the base of the ice was not imaged.

P5513/L10: What mask was used to define floating ice? How far from the grounding line? The presence of the many islands must render the floating ice assumption invalid for a significant proportion of the ice shelf.

P5514/L1: I fail to understand the significance of large positive and negative free-air anomalies, other than the fact that they occur over topographic highs or lows and are simply a result of the presence of absence of rock. Does the trade-off in density and elevation, especially when relative elevations are not specified, make this discussion redundant?

P5515/L4: Other useful reference: Leat, Storey and Pankhurst (1993) Geochemistry of Palaeozoic-Mesozoic Pacific rim orogenic magmatism, Thurston Island area, West Antarctica, Antarctic Science. 5(3) 281-296

P5515/L19: “Pink” granite. Does this mean felsic, which would perhaps be a more useful description?

P5515/L16: Volcanics are exposed on southern and central parts of Thurston Island (Pankhurst).

P5516/L11: Is it therefore reasonable to define a fault in the density model prior to inversion due to the high gradient? Otherwise, what is the nature of this boundary?

P5517/L29: Peter I Island – readers cannot locate this with only the information within the manuscript.

P5518/L26: Significant sediment deposits are found beneath Pine Island (Muto, 2013). The evaluation here of 100m of sediment at 2.2 g cm-3 pales into insignificance when compared to 800m at 2.013 g cm-3 inferred at PIG. I would argue that the thicknesses assumed here in the assessment of uncertainties are very low, and the densities very high, resulting in reported uncertainties which are much lower than in reality.

P5519/6: The uncertainties of $\sim$70 m in Cochran and Bell (2012) have been proven to be significantly underestimating the potential errors when sediment is ignored (Brisbourne, 2014).

P5520/L2: The geology of the King Peninsula/Cosgrove is not discussed. What are the implications for the results?

P5522/L9: Why was no firn correction applied?

P5523/L24: Possible reference: Bradshaw, J. D., 1989, Cretaceous geotectonic patterns in the New Zealand Region

P5531/Fig1: The entire figure needs clearing up as stated by reviewer Padman. Consider including the Rignot dInSAR grounding. Why not include bathymetry to the continental shelf edge and data points for bathymetry measurements which are very sparse in this region, as referred to in the text?

P5536/Fig4: Leat, Storey and Pankhurst (1993) in Antarctic Science highlight dykes parallel to the coast on TI, related to extensional stresses associated with the mid-Cretaceous rifting. Their presence validates the interpretation of an extensional regime south of TI and so should be included in Fig. 4 and referred to within the body of the text.

P5537/Fig5: These two figures are an opportunity to present a realistic cross section, rather than such an idealised one, allowing the reader to associate anomaly gradients with density or bathymetry variation. Figure 4 presents a series of faults cross-cutting Lines 3 and 6. None of these faults are presented in Fig 5. On Line 6 the proposed faults are more or less coincident with the density boundaries although the vertical nature of the density boundaries do not fit with a half-graben model. On line 3 there are no density boundaries coincident with the proposed faults. Some of the faults produce a gravity anomaly gradient due to the density contrast across it resulting from surface-topography (basin). Not all the faults on Line 3 are however coincident with either basins or density contrasts though. The high-density boundary at the south of the King Peninsula is in fact dipping in the opposite direction to the inferred fault.

P5539/Fig7: To be of use this figure needs to present the “corrected” Bedmap2 draft as discussed. Also, the scaling is such that the subtleties in the draft are not obvious. A scale weighted more to the 200-300m range is much more insightful and relevant to the oceanographic discussion.

P5539/Fig7: To address the point raised by reviewer Padman, I would not like to see a map of seafloor depth as due to the uncertainties involved this would be highly misleading.

MINOR COMMENTS:

P5511/17: “difficult” is rather subjective. “Time-consuming (or challenging?) to achieve good spatial coverage” may be more accurate.

P5513/L15: mismatches in draft? – clarify what the mismatch is in.

P5514/L12: “This positive gravity anomaly ...” rather than “This band of positive gravity ...”

P5515/L24: change “as exposed on” to “from”

P5526/L7: "seismic" not "seiamic"

P5529/L26: “in a” not “ina”

P5532/Fig2: Lines 11 and 12 are not labelled but are referred to in the text. Peter I Island could be labelled here if the map were extended but this may be prohibitive.

Interactive comment on The Cryosphere Discuss., 7, 5509, 2013.