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The Cryosphere Discussions

Interactive comment on "Bedmap2: improved ice bed, surface and thickness datasets for Antarctica" *by* P. Fretwell et al.

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We are very thankful to the three reviews of the paper, each has made useful and constructive comments that will clarify and improve the publication and dataset. We are especially appreciative of the generous words supporting and emphasising the importance of this work. The comments from Gael Durand from the modeller's perspective are especially useful - we hope that the Bedmap2 dataset will be downloaded and utilized by a wide spectrum of users, the glaciological modelling community is an important part of our targeted audience, so getting detailed and constructive comments from one within this community is essential.

Below are comments and responses to the two referees and the short comment:

Specific comments to Referee 1 (Ben Smith).

1. The Topogrid routine used to fit the data. In the test on Scottish STRM data, the algorithm clearly fared best compared to the other options considered, so it seems a reasonable choice. However, the algorithm is fairly complicated and, as implemented in ARC, has a long list of options. It would be worth describing Topogrid in a bit more detail than "based upon a thin-plate spline" and it would be good to detail the options selected to give the best results, both for Scotland and for Antarctica.

We have added extra text to the manuscript:

Topogrid is an adapted thin plate spline with an iterative finite difference interpolation that imposes constraints upon the elements to prevent spurious sinks being formed in the output dataset (Hutchinson 1989). It is a routine widely used in bathymetric applications (Jakobsson et al. 2000) and digital cartography (e.g. British Antarctic Survey Misc series maps have all used this technique). There are a number of options available within the Topogrid function in ArcGIS, for our test and final grids we used no drainage enforcement, set the primary data type to "spot" and, after experimentation, left the maximum number of iterations and roughness penalty as the default as both these options had a minimal effect on the final output.

And added the extra reference: Hutchinson,M.F. 1989. A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. Journal of Hydrology:106, 211-232.

2. Second, the process of generating synthetic data is not entirely clear from the text. Unlike in the BEDMAP-1 paper, the regression coefficients for the thin-ice model are not given here, nor is there a description for how the trough thicknesses for the mountain glaciers were determined. I assume that they were interpolated along the length of the profile from whatever ice thickness measurements could be found, but I can't find where the text say so. It would be good to see 1-2 more sentences describing the thin-ice data, and another two or three about how the profiles were determined.

We have clarified these points by adding the following sentences:

In areas within 10 km of rock outcrop and greater than 10 km from radar data, we employed the thin ice model following the procedure laid out in Bedmap1. Identical regression coefficients (y = 223.98Ln(x) - 1108.4), originally calculated from bed data near rock outcrop in Prince Charles Land and Dronning Maud Land were applied. The following modifications were made to the original thin ice model: (1) the vector data used to describe the rock outcrops was taken from an updated digital dataset (Scientific Committee on Antarctic Research, 2012); (2) we refined the modelled ice thickness by calibrating the rate at which thickness increases with distance for different mountain areas for which radar data were available. This change particularly affected mountainous coastal areas where uncalibrated ice thickness from the thin-ice model tended to be excessive.

The second synthetic dataset was required to define major glaciers passing through mountain ranges for which ice-thickness measurements are too sparse to ensure their existence in the gridded product (cf., Lythe et al., 2001). The absence of such topographic troughs in the Bedmap2 products would have severely limited the value to the ice-sheet modelling community. The synthetic glacier profiles are linear interpolations, typically along the centre line of the glacier, between the nearest upstream and downstream data points, or a downstream data point at the grounding line calculated by hydrostatic equilibrium from the surface height. The specific glaciers for which such data was included are shown in Fig. 2. These differ from those in Bedmap1 because some glaciers have since been surveyed and because we added new ones in mountainous areas of East Antarctica and the Antarctic Peninsula.

Minor points

1. All instances of where the use of the term data is in the singular have been changed to plural. 2. An extra description has been added (in parenthesis) to define the term bull's eye: "(erroneous artefacts around isolated data points where lack of nearby

data causes the gridding algorithm to over emphasise a single point)". 3. CHANGE GRAPH?????? 4. Long has been changed to longitudinal.

Comments to Referee 2 (Ted Scambos).

We agree with Ted's point about the poor quality of data beneath ice shelves and the problems this may cause. To rectify this in the section on sub-ice shelf bathymetry we have added the extra sentences: The sea-bed topography beneath ice-shelves is, in many areas, poorly constrained. Although the most recent data compilations have been integrated into Bedmap2, many areas still require better data for effective modelling. Better data in these sub-shelf areas are important for our understanding of Holocene ice retreat and the retreat of the LGM Antarctic Ice Sheet. The other minor points and typos pointed out by Ted have been amended in full. Response to the Short Comment from Gael Durand. After reading Gael's comments in full we checked the files available from the ftp site and have adjusted and improved the final files for the modelling community. Below are the original comment and our specific responses to the four points made.

1. Opening the geotiff files provided it appears that S, H and B does not have the same origin (but the same 1-km resolution). Locations of the cells of the various rasters are therefore different. This forbids any trivial operation between raster without interpolation (see comment 3). I would recommend to have strictly the same extend, or at least the exact same positions of cells from one raster to the other.

Incorrect versions of the ice thickness and bed topography files were posted on the ftp site which meant that the three datasets (bed, thickness and surface topography) were misaligned. We have recreated the thickness and bed files so that the alignment is exact, as we intended.

2. Models requires that S>B. But on (some?) nunatak S<B which of course make no sense, and would crash any ice flow model if directly plugged in. I think this needs to be fixed and S should be superior or equal to B.

This error has been fixed by correcting the bed dataset, ensuring that within all areas of rock outcrop the bed height exactly matches the surface height.

3. On grounded regions S-H-B should be equal to 0. Making this simple operation using QGIS gives the following map for the Pine Island region (Green 0, blue < 0, 0< red<10, white > 10). Positive values indicate floating ice region, so red and white are fine. But blue values mean that the lower ice surface is below the bedrock, this has no sense. This may comes from interpolation because raster cells are not perfectly aligned. Using the output directly will crash any ice flow model.

These errors resulted from the misalignment described above, and have now been corrected to make surface, thickness and bed elevation consistent over grounded ice. Additionally, for Lake Vostok, new bathymetry data has been incorporated to give the lake cavity beneath the ice (references for this data are already included).

4. Most ice-sheet models assume hydrostatic equilibrium of the ice shelf. In the map below is plotted ISeq = H + rho_w/(rho_w-rho_i)*S, rho_w being the ocean water density (1030) and rho_i ice density (917). ISeq should be equal to 0 if hydrostatic equilibrium is respected. As can be seen on the map (white is grounded or hydrostatic equilibrium) below none of the ice shelf is in equilibrium, and any ice-sheet model will have to readjust the thickness accordingly. As stated in the manuscript, the ice shelf thickness available in bedmap 2 is a physical ice thickness rather than ice-equivalent thickness. But ice sheet modelers would need a firn correction. Could this be provided as well?

Gael is correct in surmising that our dataset is one of physical ice thickness not ice-equivalent thickness, our purpose was always to provide a model of actual thickness. However, to help modellers we will provide for download the grids of firn thickness and density that we used to assess correct grounding of grounded ice and correct flotation of floating ice.

We will also include other additional datasets on the website. These include a “masks

layer” and the grounding-line used in our compilation. Each comes with a readme file.

To ensure that further small errors have not crept into the dataset, we tested for the following:

1. Consistency and coincidence – check that all cells sit exactly over the top of each other

2. Outcrop – check that the surface and bed heights match exactly in areas of rock outcrop

3. Grounded – check that in grounded areas the bed plus thickness equals surface

4. Shelf – check that on the shelves surface minus thickness is always greater than bed

5. GL – check that there are step artefacts in thickness over the grounding line in areas of outflow glaciers

6. Vostok – check that there is a cavity between the ice bottom and the bed

Old versions of the data should be replaced with the new, corrected bedmap2 grids.

As well as the points from reviewers, some other minor corrections have been made to the manuscript and datasets: inclusion of missing data from the Sulzberger Ice Shelf and updates to the references that have changed (acceptance of papers in press at the time of initial submission) since our original submission. It is also worth noting that the site for downloading the dataset has now changed. This new web-address (www.antarctia.ac.uk/bedmap2) represents the final archiving of the data. Although we do not predict any future changes, if they are needed additions, comments or changes will be hosted here.

Peter and Hamish on behalf of the Bedmap2 authors.

Interactive comment on The Cryosphere Discuss., 6, 4305, 2012.