Supporting Information: Detailed seismic bathymetry beneath Ekström Ice Shelf, Antarctica: Implications for glacial history and ice-ocean interaction

Emma C. Smith[1], Tore Hattermann[2], Gerhard Kuhn[1], Christoph Gaedike[3], Sophie Berger[1], Reinhard Drews[4], Todd A. Ehlers[4], Dieter Franke[3], Raphael Gromig[1] *, Coen Hofstede[1], Astrid Lambrecht[5], Andreas Läufer[3], Christoph Mayer[5], Ralf Tiedemann[1,6], Frank Wilhelms[1,7], Olaf Eisen[1,6]

[1]Alfred-Wegener-Institut Helmholz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany

[2]Norwegian Polar Institute, Troms, Norway

[3]BGR, Federal Institute for Geosciences and Natural Resources, Geozentrum Hannover, Hannover, Germany

[4]Department of Geosciences, University of Tübingen, Tübingen, Germany

[5]Geodesy and Glaciology, Bavarian Academy of Sciences and Humanities, Munich, Germany

[6]Department of Geosciences, University of Bremen, Bremen, Germany

[7]Department of Geosciences, University of Göttingen, Göttingen, Germany

*Now at: Max Planck Institute for the Science of Human History, Jena, Germany

Contents of this file

1. Text S1 to S2

Introduction This supporting information contains details of seismic data processing steps and uncertainty calculations for the seismic bathymetry. They are not crucial to the understanding of the main text, but will be of interest to some readers and those who may want to perform similar analysis.

S1: Seismic Data Processing

The following is a full description of the seismic vibroseis data processing steps:

1. Raw seismic vibroseis data were read from SEG2 field records into the Paradigm *EPOS* processing system.

2. Data were cross-correlated with the appropriate input vibroseis sweep to produce shot gathers.

3. Geometry was applied to locate the source and receiver positions and calculate common midpoint (CMP) positions.

4. Data were manually checked and compared to field logs to identify low quality shots and noisy or dead channels, which were then removed from further processing.

5. The data was bandpass filtered (survey dependent) and a notch filter at 206 Hz was applied, to remove known spurious noise from the geophones.

6. Data are then re-sorted into common midpoint (CMP) gathers.

7. CMP gathers with fold > 3 are used for velocity analysis, to determine the seismic-wave velocity (V_{stack}) of different layers within the sub-surface. This is done by fitting a normal moveout (NMO) velocity curve to the CMP gathers and in some areas using constant velocity stacks.

8. This velocity field produce by the above analysis is used for NMO correction of CMP gathers.

9. NMO corrected CMP gathers are stacked to produce one stacked trace for each CMP location, this results in stacked time sections for each seismic line. It is the reflection horizons on these sections that are used to create the bathymetry map of the sea floor.

S2: Error Calculations for Seismic Derived Sea-floor Depths

Uncertainties in the sea-floor depth come from four sources, these will be analysed below: (i) accuracy of the horizon picking, (ii) velocities used for depth conversion of these horizons, (iii) errors in the REMA DEM used for surface elevation corrections and (iv) depth errors from unmigrated data.

The error in horizon picking can be quantified by assessing the possible travel time mis-pick and converting this into a depth error. In the area of the main grid, the 2017 and 2018 surveys are high fold and the horizons are clear meaning picking of the peak of a reflection is possible to better than ± 1.5 ms. In the 2010 and 2011 surveys, the lower frequency Failing Y-1100 vibroseis source was used, which has a longer wavelength and lower resolution, such that picks are possible to ± 3 ms. However, with the exception of the far north eastern protrusion from the main seismic grid, picks from the 2017 and 2018 surveys were used preferentially in the gridding, therefore a picking error corresponding to ± 1.5 ms is appropriate for this region, giving a depth error of ± 7.6 m for the sea floor. The 2014 survey data is single fold, this doesn't affect the pick of the ice base, which is still possible to ± 1.5 ms, as it is largely horizontal. However, picks of the sea floor, in areas of rough topography are only possible to ± 15 ms, in the extreme case. This corresponds to a possible depth error of ± 27.2 m at the sea floor in the areas covered by these lines. As a result, the bathymetry map is significantly more accurate in the area of the main grid than the single lines that extend south across the grounding line.

The error in seismic velocity of the ice can be quantified by looking at the minimum and maximum velocities determined during velocity analysis (see S1). This yields a range

of ice velocities from 3597 ms^{-1} to 3606 ms^{-1}. The range of water column velocities determined from CTD measurements was 1448 ms^{-1} to 1453 ms^{-1}, giving a depth error at the deepest part of the sea floor from velocity errors of $\pm$ 4 m.

Seismic energy reflected from the sea floor is assumed to have reflected at the midpoint of the source and received, known as the CMP (see S1). However, for dipping interfaces this is not strictly true introducing an error, which is greatest for the deepest and steepest dipping interfaces. Using the dip-correction equations of ? (?), an error of $\pm$ 2.4 m was calculated for the steepest dipping and deepest section of the sea floor.

The quoted error for the REMA DEM is $\pm$ 0.75 m in this region.

Combining these four error sources leads to a cumulative error at the sea floor of $\pm$ 14.8 m in the main data grid and $\pm$ 34.4 in the areas of the 2014 seismic lines, these values are stated in the main article.

References

Yilmaz, O. (1987). Chapter 4: Migration. In S. E. Doherty (Ed.), *Seismic data analysis: Processing, inversion, and interpretation of seismic data (i)* (pp. 463–653). Society of Exploration Geophysicists.