Firn structure of Larsen C Ice Shelf, Antarctic Peninsula, from seismic and borehole surveys and firn model simulations

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1. Motivation and aim: Surface melt is common on Larsen C Ice Shelf in the summer, to the extent that melt ponds form in several inlets, like Cabinet Inlet (Fig. 1). Firn compaction, meltwater ponding and hydrofracturing are strongly implicated in the rapid disintegration of Larsen B ice shelf in 2002. The NERC-funded MIDAS project (2014-17) aims to identify the impact of surface melt and ponding on the stability of Larsen C ice shelf. Here we characterise firn structure from in-situ measurements and modelling.

2. Methods and approach:
- We conducted seismic refraction surveys at 17 sites (see below for sources and dates of data acquisition) with explosive5-6 or hammer and plate4 sources (2a), and used the first energy arrivals (2b) to calculate profiles of p-wave velocity (2c) and then firn density (2d) with depth, adopting a well-publicised method7 that assumes continuous reflection of seismic ‘diving waves’ in the firn (except Point 0k (Valley), characterised instead by a two layer case of firn over massive ice8).
- Density-depth profiles were converted into firn air content assuming a two-phase medium of pure ice (917 kg m⁻³) and air (2a).
- At four sites (J1-08, J2-08, J3-08 and Y2-08, see locations in Fig. 3a) firn density was estimated gravimetrically from firn cores (∼30 m depth) and neutron probe data (∼10 m depth).
- Densities were simulated with a 1-D firn compaction model, forced with data from the regional climate model RACMO2.

3. Patterns of firn air content, thickness and density:
- Patterns of firn air content derived from seismic surveys (3a) are broadly similar to those estimated previously9 from airborne radar data and hydrostatic equilibrium considerations (3b). The patterns are consistent with elevated degrees of firn compaction in the north and landward inlets compared to the south. Spatial gradients in firn air content derived from seismic surveys (3a) are, however, less pronounced than previous estimates9 (3b).
- Cabinet Inlet in the extreme northwest is a focus of firn compaction (2d, 3a, 3b). Here a buried layer of massive refrozen ice was discovered in the 2014-15 austral summer6. Firn is less than 10 m thick in Cabinet Inlet, and more than 40 m in the southeast (3c), and firn densities are greatly elevated (2d).

4. Comparison of measured and modelled firn densities:
- Seismic and borehole (firn cores, neutron probe) acquisitions were not precisely co-located in space or time (3a). For the seismic surveys located closest to the four borehole locations (3a) the profiles of firn density with depth derived from seismic surveys generally provide a reasonable fit with those from firn cores and neutron probe data (Fig. 4).
- The firm model simulates the density-depth profiles in the inlets well (4a). Discrepancies between measured and modelled depth-density profiles become progressively greater towards the ice-shelf front (4b-4d). RACMO is interpreted to simulate incorrectly the particular favourable microstructure of the shallow boundary layer, leading to excess melt and/or lack of snowfall.

References:

10. The ‘Fig’ in the list of references indicates the location of the figures in the paper.