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

C21A-0708

Bernd Kulessa[1], Alex Brisbourne[2], Peter Kuipers Munneke[1] Suzanne Bevan[1], Adrian Luckman[1], Bryn Hubbard[3], Adam D. Booth[4], David Ashmore[3], Paul Holland[2], Andrew Shepherd[4], Noel Gourmelen[5], Steve Palmer[6]

[1]College of Science, Swansea University, UK (b.kulessa@swansea.ac.uk); [2]British Antarctic Survey, UK; [3]Aberystwyth University, UK; [4]University of Leeds, UK; [5]University of Edinburgh, UK; [6]University of Exeter, UK

1. Motivation and aim:

Surface melt is common on Larsen C Ice Shelf in the summer[1], 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 explosive[2-5] or hammer and plate[6] 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 method[7] that assumes continuous refraction of seismic 'diving waves' in the firn (except Point 0k (Valley), characterised instead by a two layer case of firn over massive ice[9]).**
- **Density-depth profiles were converted into firn air content assuming a two-phase medium of pure ice (917 kg m^{-3}) and air.**
- **At four sites (J1-08, J2-08, J4-8 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.**

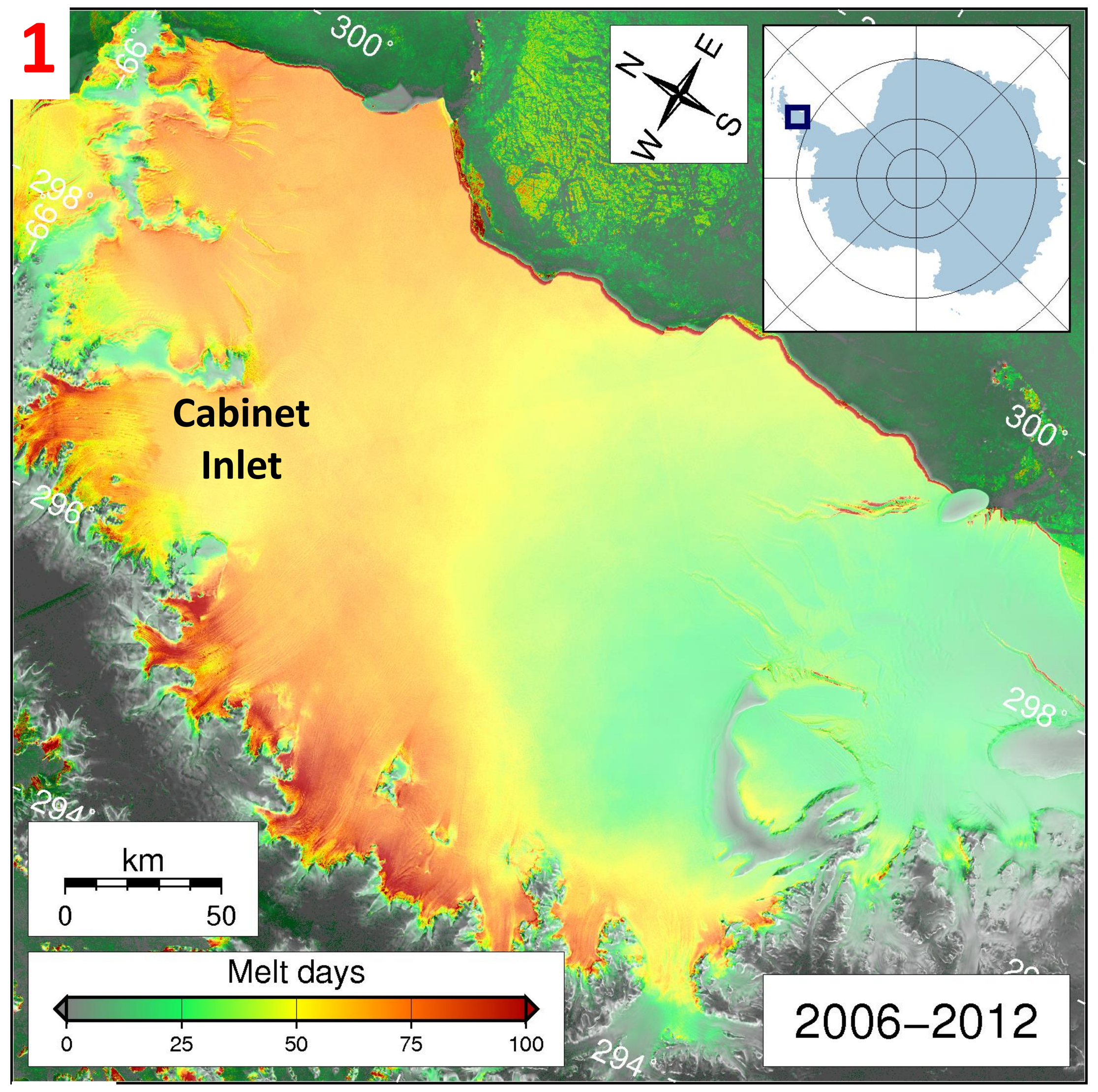
3. Patterns of firn air content, thickness and density:

- **Patterns of firn air content derived from seismic surveys (3a) are broadly similar to those estimated previously[8] 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 estimates[8] (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 summer[9]. 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).**

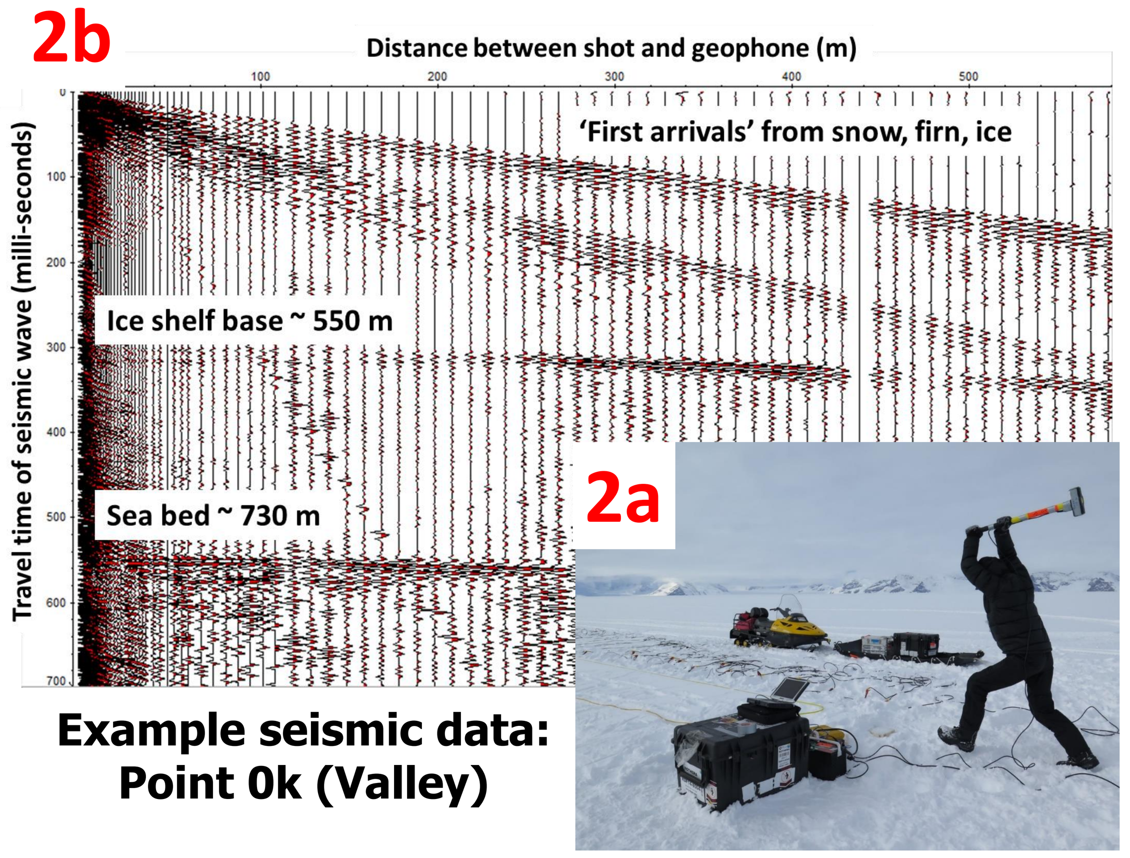
4. Comparison of measured and modelled firn densities:

- **Seismic and borehole (firn core, neutron probe) acquisitions were not precisely co-located in either 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 firn model simulates the depth-density 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 leeward (sea-ice-influenced) microclimate of the shallow boundary layer, leading to excess melt and/or lack of snowfall.**

1

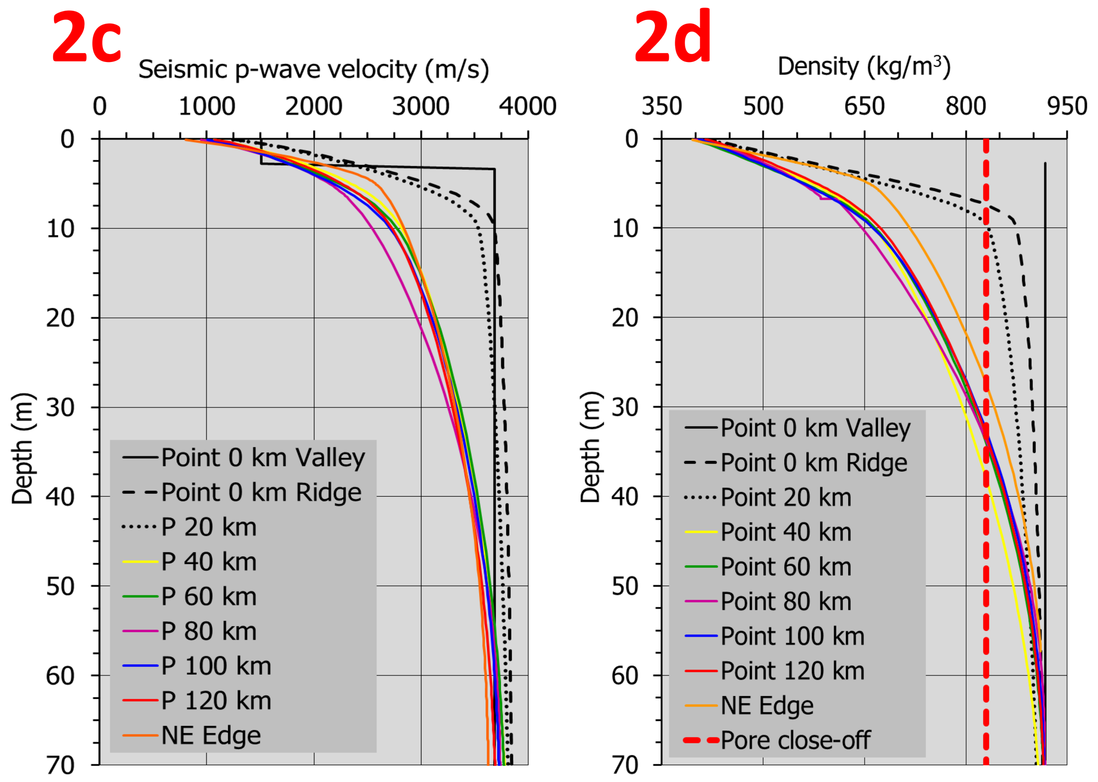


2b



Example seismic data: Point 0k (Valley)

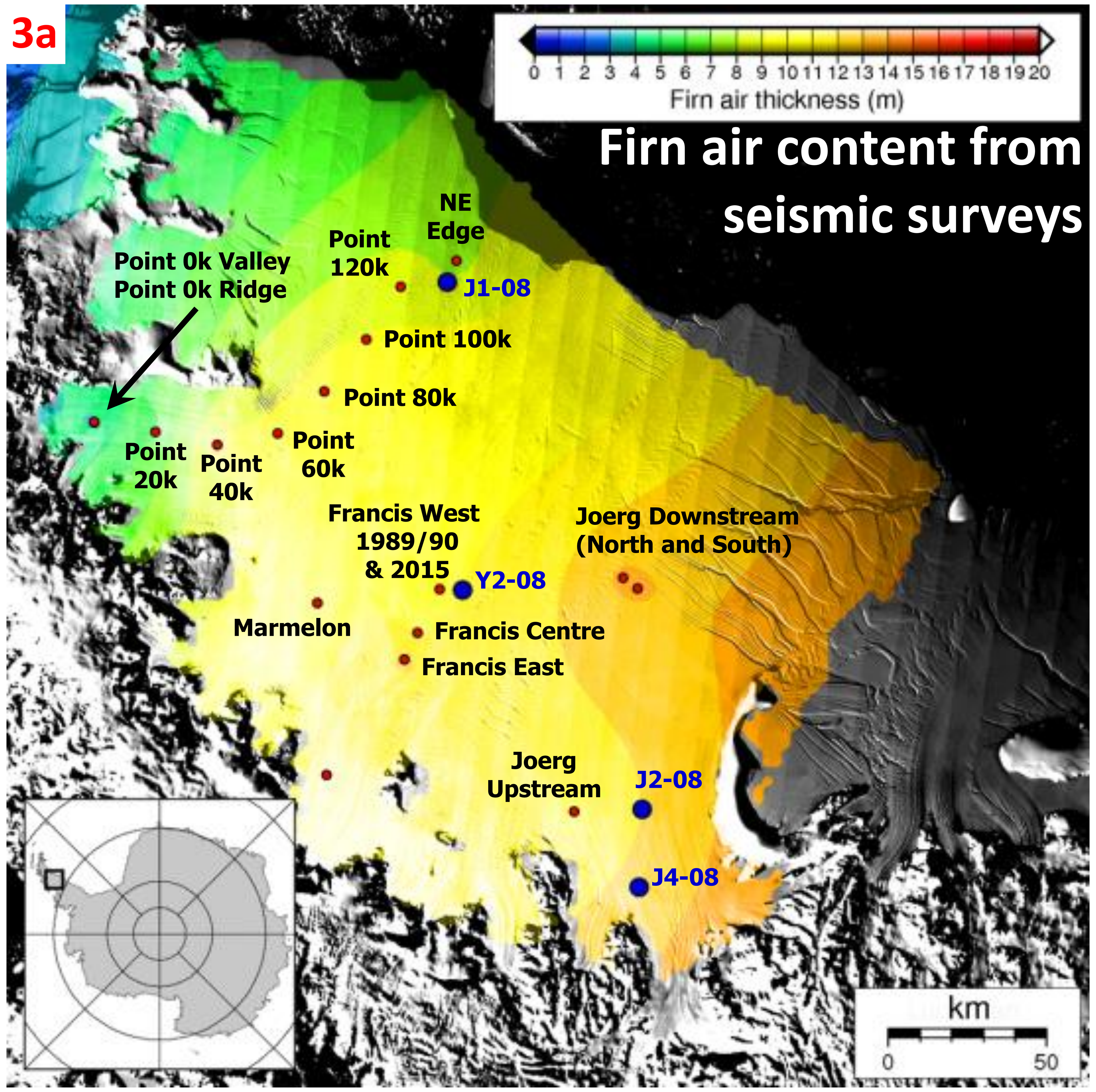
2c **2d**



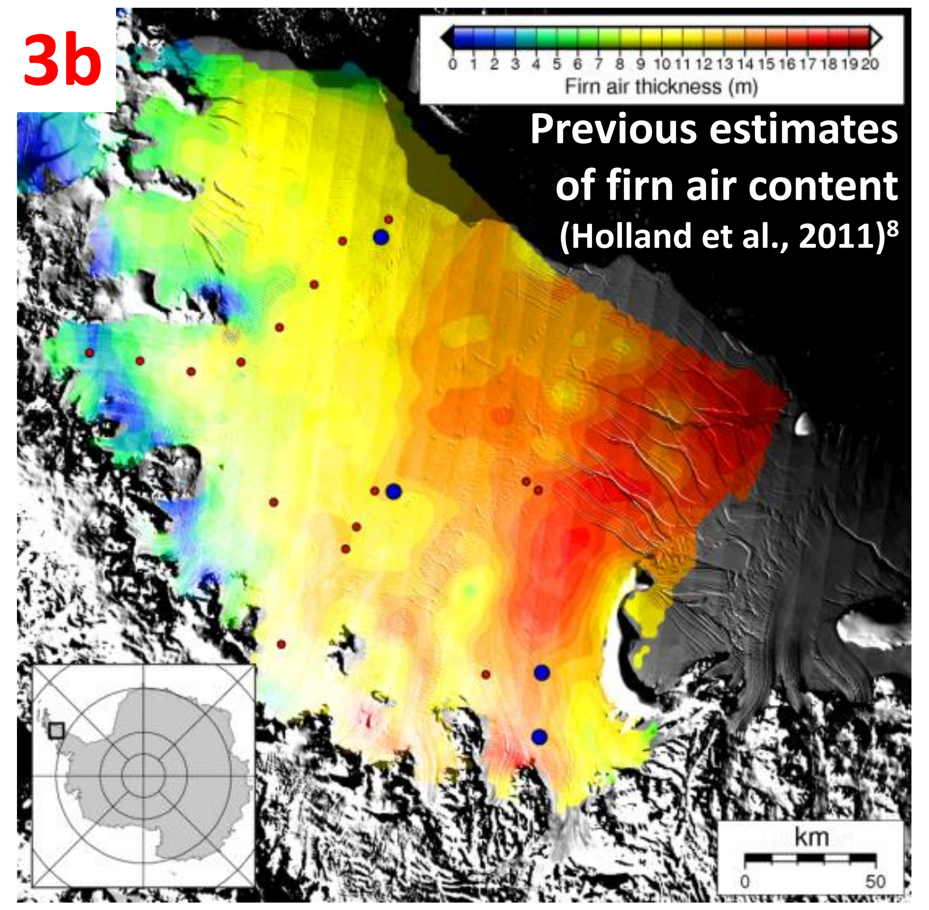
Depth profiles of p-wave velocity and density along transect from Point 0k to NE-Edge

Sources and Dates of Data Acquisitions	
Points 0k to 120k: 2014/15[6]	Francis West, Centre and East: 1989/90[4,5]
NE Edge, Marmelon, Joerg Upstream: 2012/13[2]	Francis 2015: 2015/16[6]
Joerg Downstream, North and South: 2008/09[3]	Core / neutron probe data: 2008/09, 2009/10

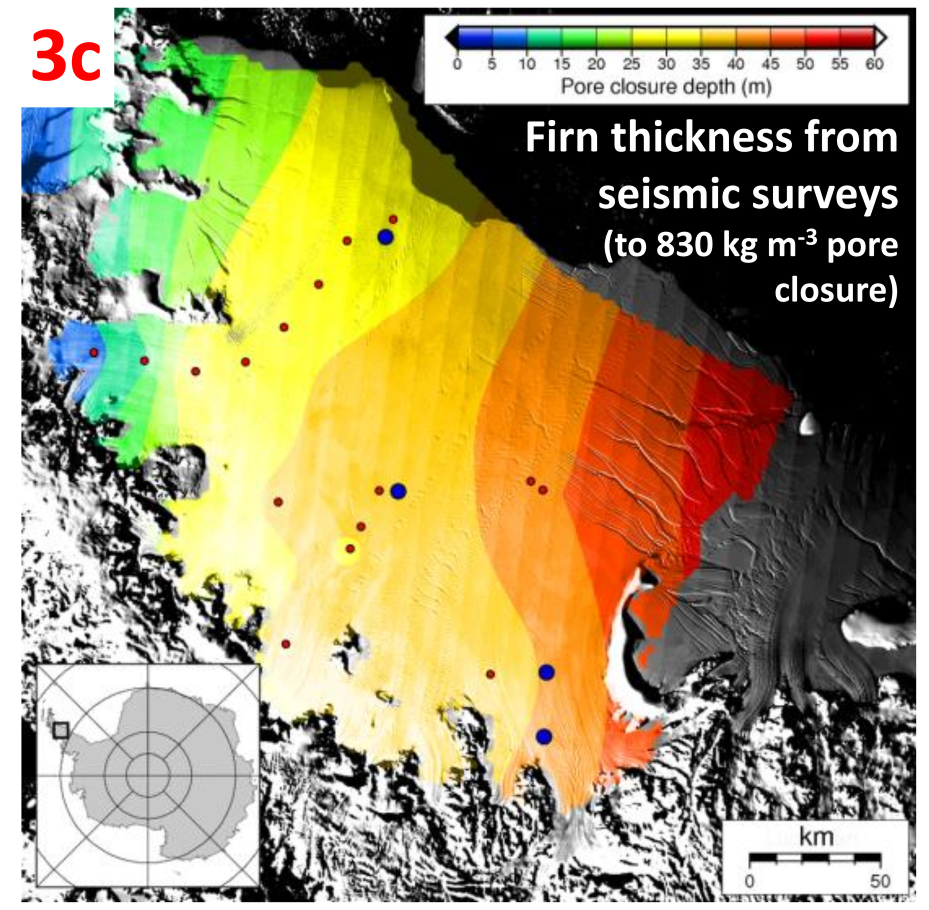
3a



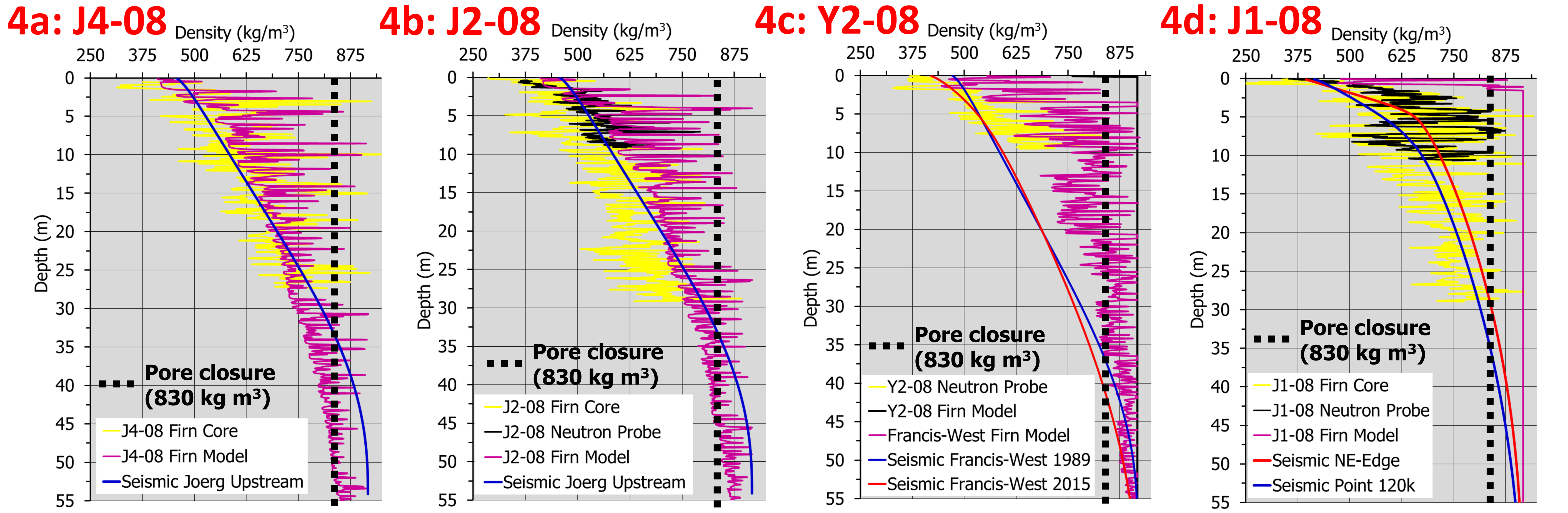
3b



3c



4a: J4-08 **4b: J2-08** **4c: Y2-08** **4d: J1-08**



Comparison of depth-density profiles from seismic and borehole (gravimetric firn core analysis, neutron probe) data (note that seismic and borehole acquisitions are not precisely co-located), with simulations from the 1-D firn model.

References

[1]Luckman, A., A. Elvidge, D. Jansen, B. Kulessa, P. Kuipers Munneke, J. King, and N. E. Barrand (2014), Surface melt and ponding on Larsen C Ice Shelf and the impact of föhn winds, *Ant. Sci.*, 26, 625-635.
[2]Brisbourne, A. M. et al. (2014), Seabed topography beneath Larsen C Ice Shelf from seismic soundings, *The Cryosphere*, 8(1), 1-13.
[3]Jansen, D., B. Kulessa, P. R. Sammonds, A. Luckman, E. C. King, and N. F. Glasser (2010), Present stability of Larsen C ice shelf, Antarctic Peninsula, *J. Glaciol.*, 56(198), 593-600.
[4]King, E. C., E. P. Jarvis, and E. A. Mowse (1993), Seismic characteristics of an airgun fired over snow, *Cold Reg. Sci. Tech.*, 21(2), 201-207.
[5]Jarvis, E. P., and E. C. King (1995), Seismic investigation of the Larsen Ice Shelf, Antarctica: in search of the Larsen Basin, *Ant. Sci.*, 7(02), 181-190.
[6]Kulessa et al., unpublished data (NERC MIDAS project, 2014-17)
[7]Kirchner, J.F., and Bentley, C.R. (1990), RIGS III: Seismic short refraction studies using an analytical curve fitting technique, *Ant. Res. Series*, 42, 109–126, AGU, Washington, D.C.
[8]Holland, P. et al. (2011), The air content of Larsen Ice Shelf, *Geophys. Res. Lett.*, 38, L10503.
[9]Friday poster C53A-0759 by Hubbard et al., Massive Ice Layer Formed by Refreezing of Ice-shelf Surface Melt Ponds: Larsen C Ice Shelf, Antarctica.