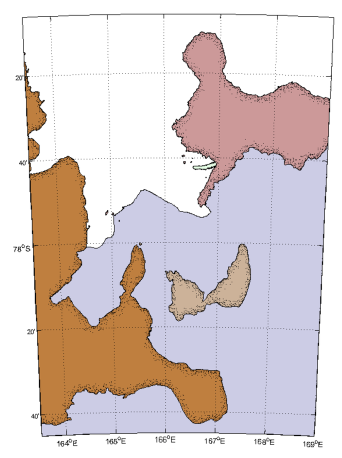
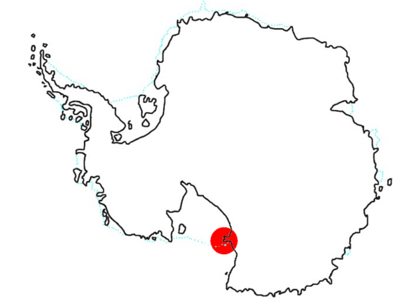
Independent Flow Regimes in the Southern McMurdo and Ross Ice Shelves – New Evidence from Velocity Analysis of Landsat Images and Numerical Modelling

R. J. Gamble, G. S. Wilson, P. J. Langhorne, R. L. Enlow & V. J. Challis.

Departments of Physics, Geology, Mathematics,University of Otago, New Zealand.

rgamble@physics.otago.ac.nz





1. Introduction

Between Minna Bluff and White Island there is a shear margin at the interface joining the Southern McMurdo and Ross Ice Shelves of Antarctica. The Ross Ice Shelf is fed by numerous glaciers to the south, and flows north out to sea, while the Southern McMurdo Ice Shelf flows west between Minna Bluff and Black & White Islands.

Previous observations ([1],[2]) indicate a 100 fold difference in velocity between Southern McMurdo (less than $10\mathrm{ma}^{-1}$) and Ross (typically $500\mathrm{ma}^{-1}$ or more) ice shelves, and gravity measurements [3] suggest a sharp rise in the basal topography north of the eastern tip of Minna Bluff, leading to the suggestion that the ice shelf is grounded in this region.

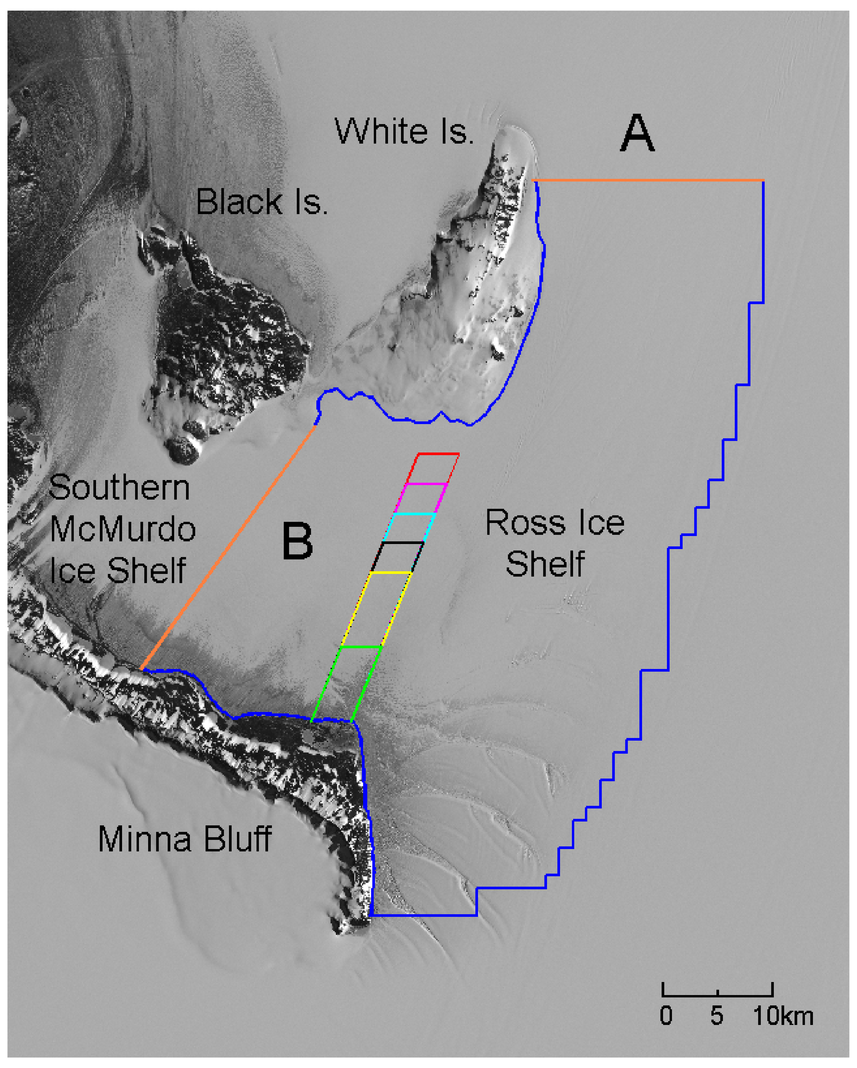


Figure 1: *Satellite photograph of the region showing the outline of the model (blue), and outlines of different grounding levels that were tested. These grounding outlines are colour coded to correspond to figures 3 & 4. The two sections of the model boundary with modified conditions are labelled 'A' and 'B'.*

A remote sensing and numerical modelling study has been undertaken to investigate the flow regime and interaction between the Southern McMurdo and Ross ice shelves of Antarctica.

Satellite images of the region were compared to derive ice shelf velocity data for the system. This data was used, in conjunction with GPS derived data [1], as boundary conditions for a finite element model of the system.

Interaction between the ice shelves was limited by varying the size of an artificially introduced obstruction to simulate grounding in the suspected region.

2. Remote Sensing

Three LANDSAT 7 satellite images of the region were ordered, allowing three different image pairs to be compared. (The images have 12.5 m/px resolution, and were taken 16/1/2000, 27/12/2001 and 5/12/2002.)

Autonomous feature tracking techniques were applied to each pair of images, resulting in 3 sets of vector displacements for the region. The data sets suffered from two types of problem: lack of detail to provide a reliable match, and mismatching of features. An initial attempt to remove mismatched features was to include only those data points whose matching quality was above a set level. However this tended to remove accurate data points while leaving inaccurate ones.

A better method was devised which compared the data values at a given location between the three data sets. Because erroneous vectors point in random directions, only those vectors whose magnitudes and directions agreed to within a certain tolerance were kept.

A final data set was created by taking the average of those data points which satisfied the above criteria (figure 2).

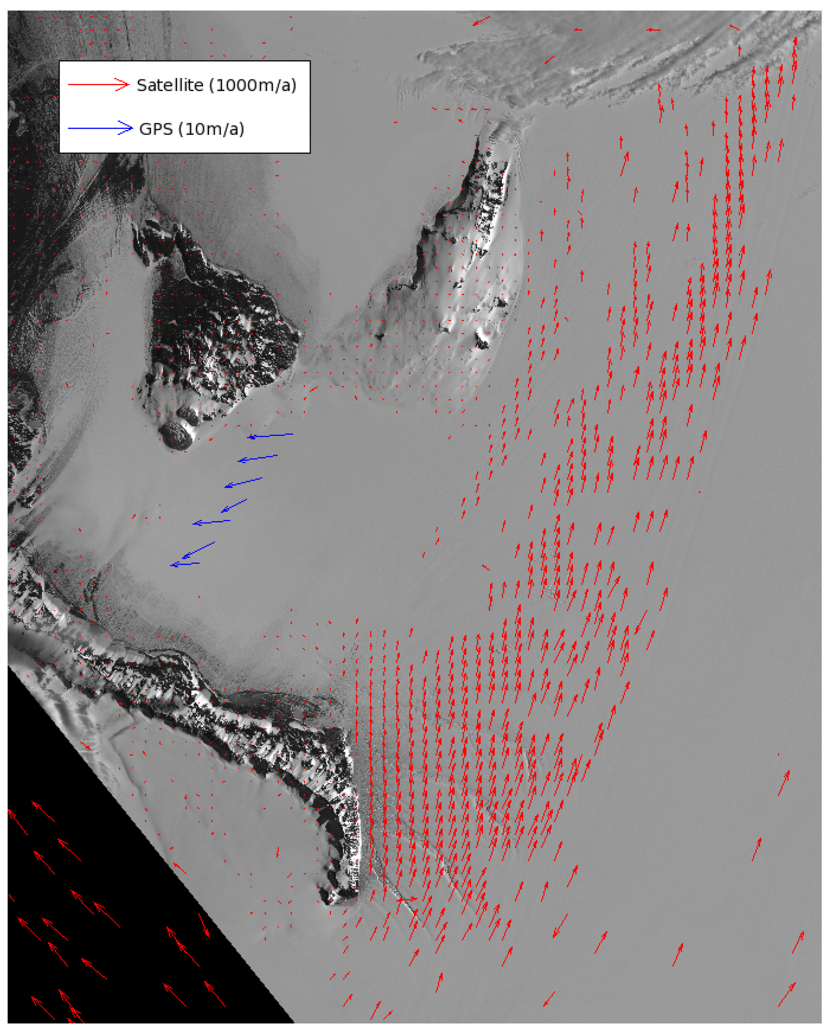


Figure 2: *Final velocity data set after removal of erroneous data points (red). Select data points from GPS measurements [1] are also shown (blue).*

Result: While the technique was only successful in places where there is sufficient image detail to obtain a clear match, the data obtained still clearly shows that two distinct flow regimes exist.

A distinct shear zone runs from the tip of Minna Bluff to White Island to accommodate the large difference in velocities present. East of this shear zone, northward ice velocities in excess of $500\mathrm{ma}^{-1}$ are observed, reducing to $200\mathrm{ma}^{-1}$ adjacent to Minna Bluff. Immediately west of the shear zone, flow rates into the Southern McMurdo Ice Shelf are $20\mathrm{ma}^{-1}$ to the northwest, and diminish in magnitude further west.

3. Numerical Modelling

A finite element model of the region was created, using velocity data obtained from satellite (above) and GPS measurements [1] as boundary conditions.

The ice shelf is modelled as a constant thickness (plane strain) slab with mechanical properties as given by Glen's flow law:

$$\dot{\epsilon}_{ij}(t) = A\tau^{n-1}\tau'_{ij}$$

Boundary conditions are set by specifying the velocity (or later, force) at the edges of the model - land boundaries had velocity values of zero imposed, while ice boundaries were chosen to coincide with available velocity data.

First, a simple model was constructed which specified velocities at *all* ice boundaries. No grounding was used in this model. This produced velocity values on the interior of the region whose directions and magnitudes both agreed well when compared to the measured values.

This model is problematic, because the velocities on *all* boundaries are set, and the interior values must therefore accommodate for this. Ice that is flowing into the model (along the southern boundary) may flow in two different directions - west into the Southern McMurdo Ice Shelf (boundary **B**) or continue north toward Ross Island (boundary **A**). The proportion of ice that flows in either direction is fixed by specifying the ice velocities at these two boundaries.

A second model was therefore created, which imposes a zero force restraint on these two boundaries, and also simulated grounding north of Minna Bluff by artificially introducing an immobile obstruction which protruded north of the tip of Minna Bluff. This then does not predetermine the proportion of ice that flows into the Southern McMurdo Ice Shelf; it is instead determined by the geometry of the region and the amount of grounding that is introduced.

The model was then run with different amounts of artificial grounding, and the velocity profiles at boundaries A and B were compared to known data to determine which grounding scenario is appropriate (figures 3 & 4).

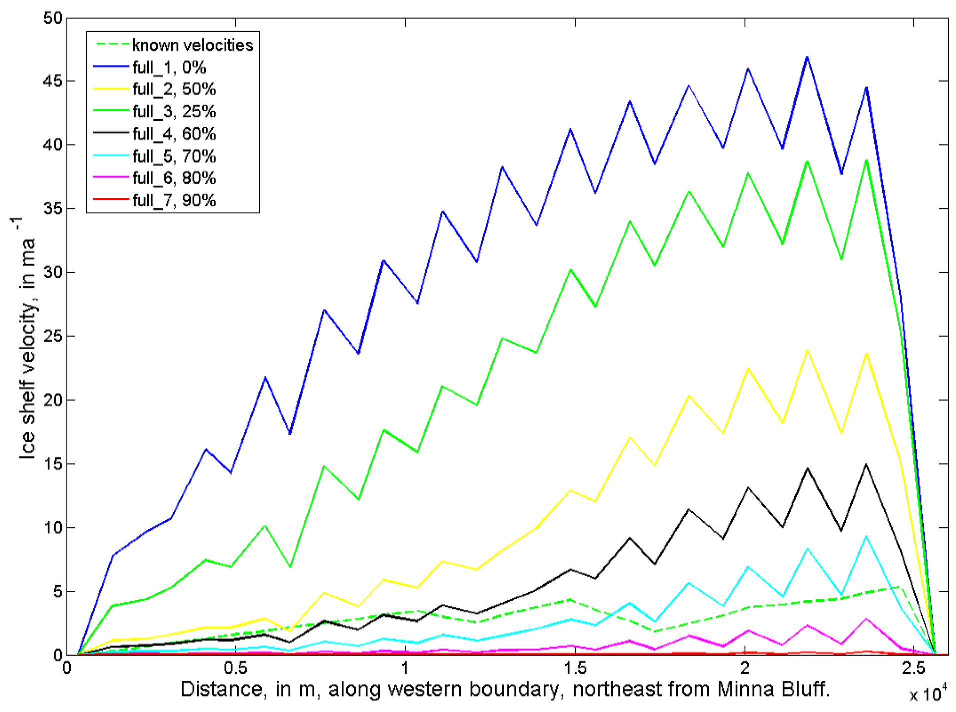


Figure 3: *Velocity profiles for boundary **B**, comparing model results for different grounding levels with known values (dotted).*

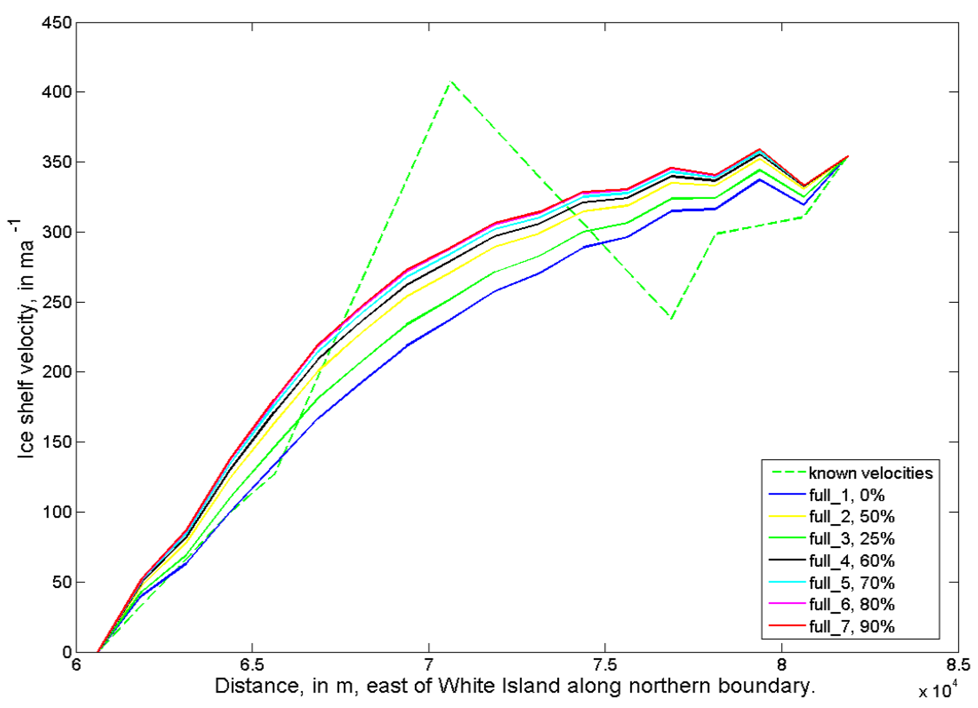


Figure 4: *Velocity profiles for boundary **A**, comparing model results for different grounding levels with known values (dotted).*

Result: It was found that the best fit to the data occurs where a large amount of grounding exists (occupying 60 – 70% of the total width between Minna Bluff and White Island).

4. Conclusions

- Velocity measurements reveal the existence of two very different and independent ice flow regimes.
- Numerical models with various levels of simulated grounding give the best match to known velocity data when the flow interaction between the two ice shelves is severely limited by a large grounding region between Minna Bluff and White Island.

References

[1] Clifford, A. E., 2005. *The Physiography, Flow Characteristics and Vulnerability of the Southern McMurdo Ice Shelf, Antarctica.* MSc thesis, University of Otago, New Zealand. 238pp, + CD.

[2] Merry, C. J. & Whillans, I. M., 2001. *Analysis of a Shear Zone where a Tractor Fell into a Crevasse.* Cold Regions Science and Technology, **33**, (1):1-17.

[3] Wilson, G. S. et al, 2004. *K001W: Continued Geophysical Surveys in Support of ANDRILL Targets Beneath the McMurdo Ice Shelf.* Immediate Science Report, Antarctica New Zealand 2003/4.

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