POLAR SCIENCE FOR PLANET EARTH

Seabed topography beneath the Larsen C Ice Shelf from seismic soundings

AM Brisbourne, AM Smith, EC King, KW Nicholls, PR Holland and K Makinson

WAIS 2013

- Motivation
- Fieldwork & Data
- Results & Implications
- Conclusions

Currently in review: *The Cryosphere Discuss., 7, 4177-4206, doi:10.5194/tcd-7-4177- 2013.*

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

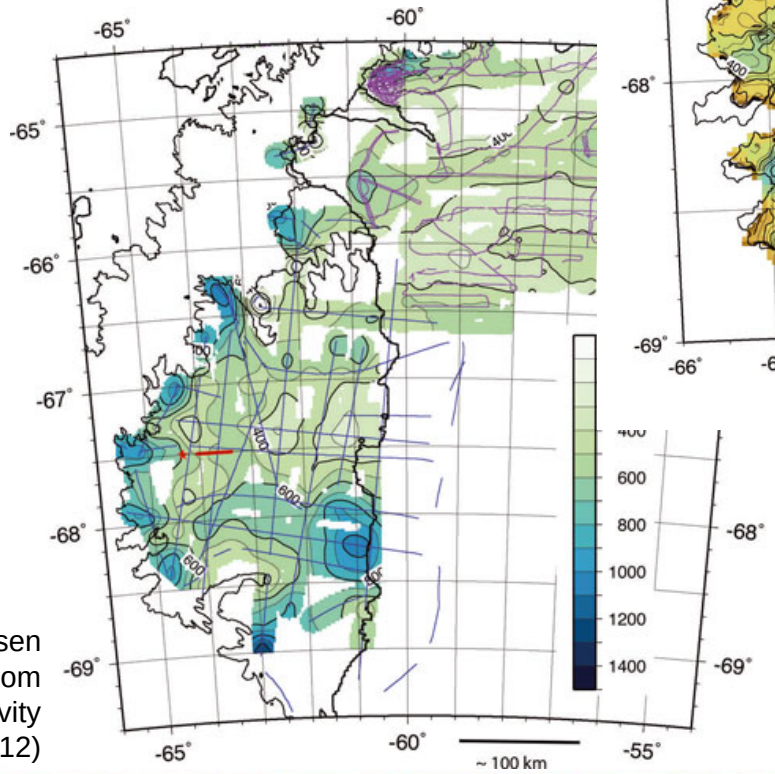
Motivation

Sub-shelf bathymetry model required for oceanographic circulation modelling to address ice-ocean thermal transfer

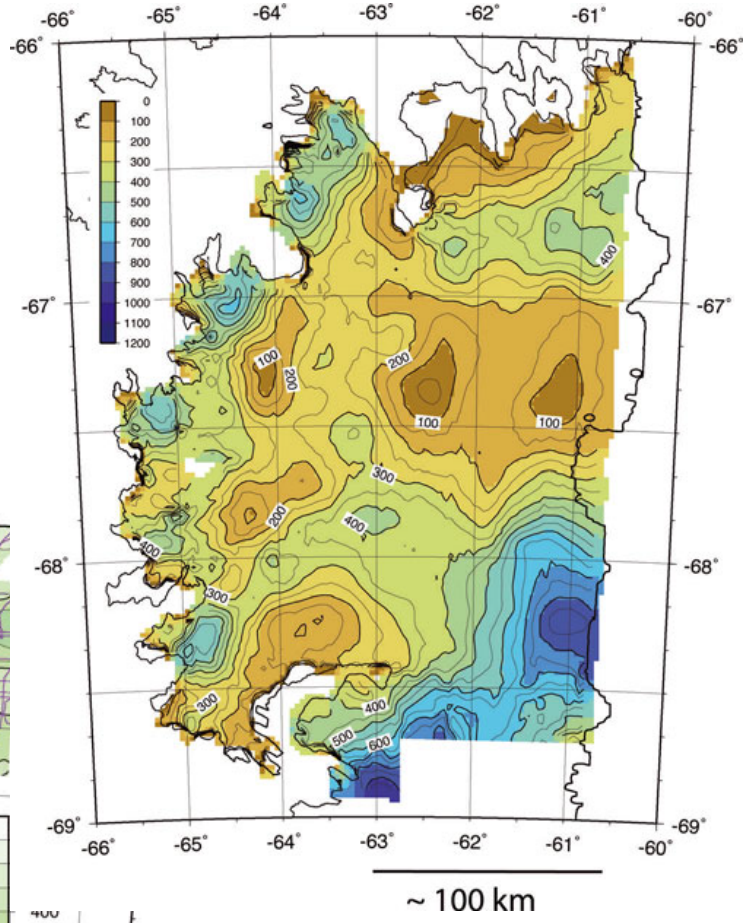
- Validation with seismic spot-measurements of bathymetry

C&B 2012: - Inversion of IceBridge 2009 free-air gravity data

- 1D geology across entire region, single density contrast assumed
- Mean depth to seabed is controlled by previous in-situ measurements
- Localized over-deepenings
- Two broad troughs



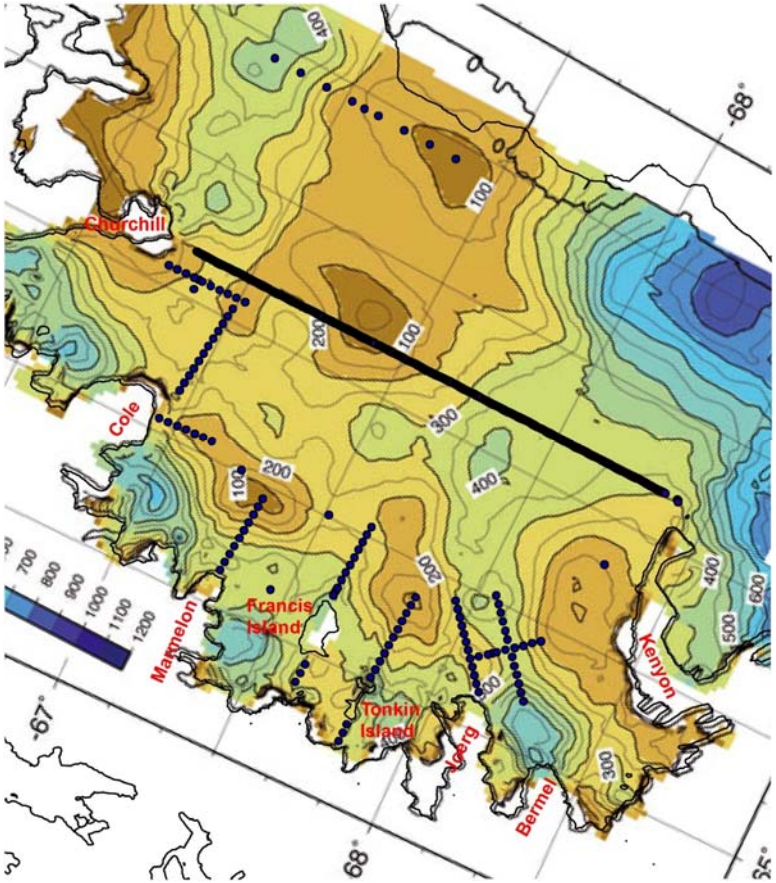
Bathymetry beneath the Larsen Ice Shelf determined from inversion of airborne gravity data (Cochran and Bell, 2012)



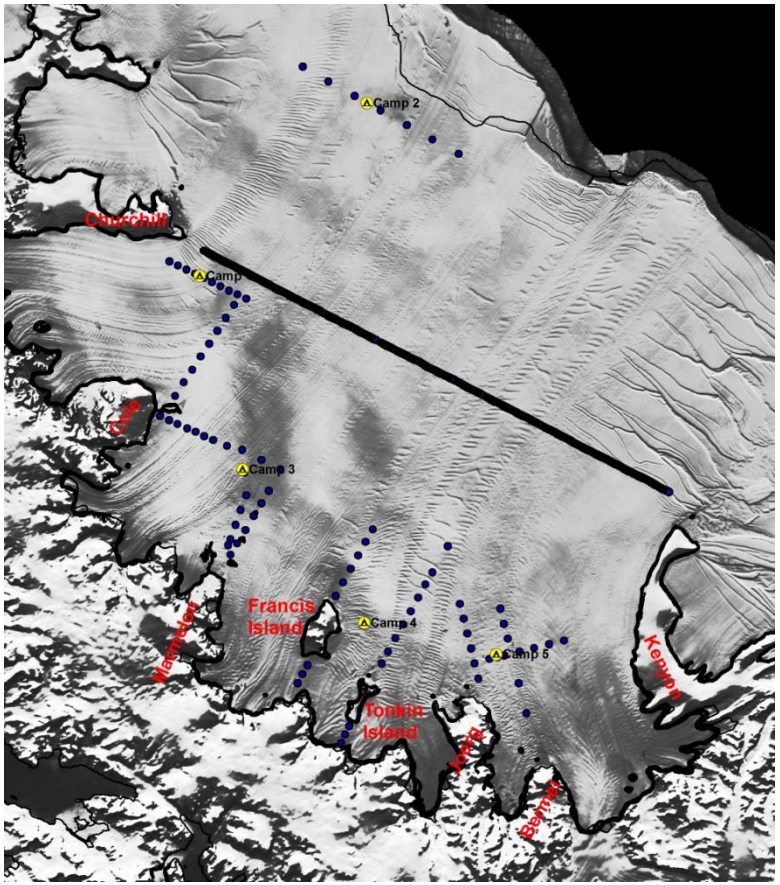
Thickness of the water cavity beneath the Larsen Ice Shelf contoured at 50m intervals. (Cochran and Bell, 2012)

Seismic survey 2012-13

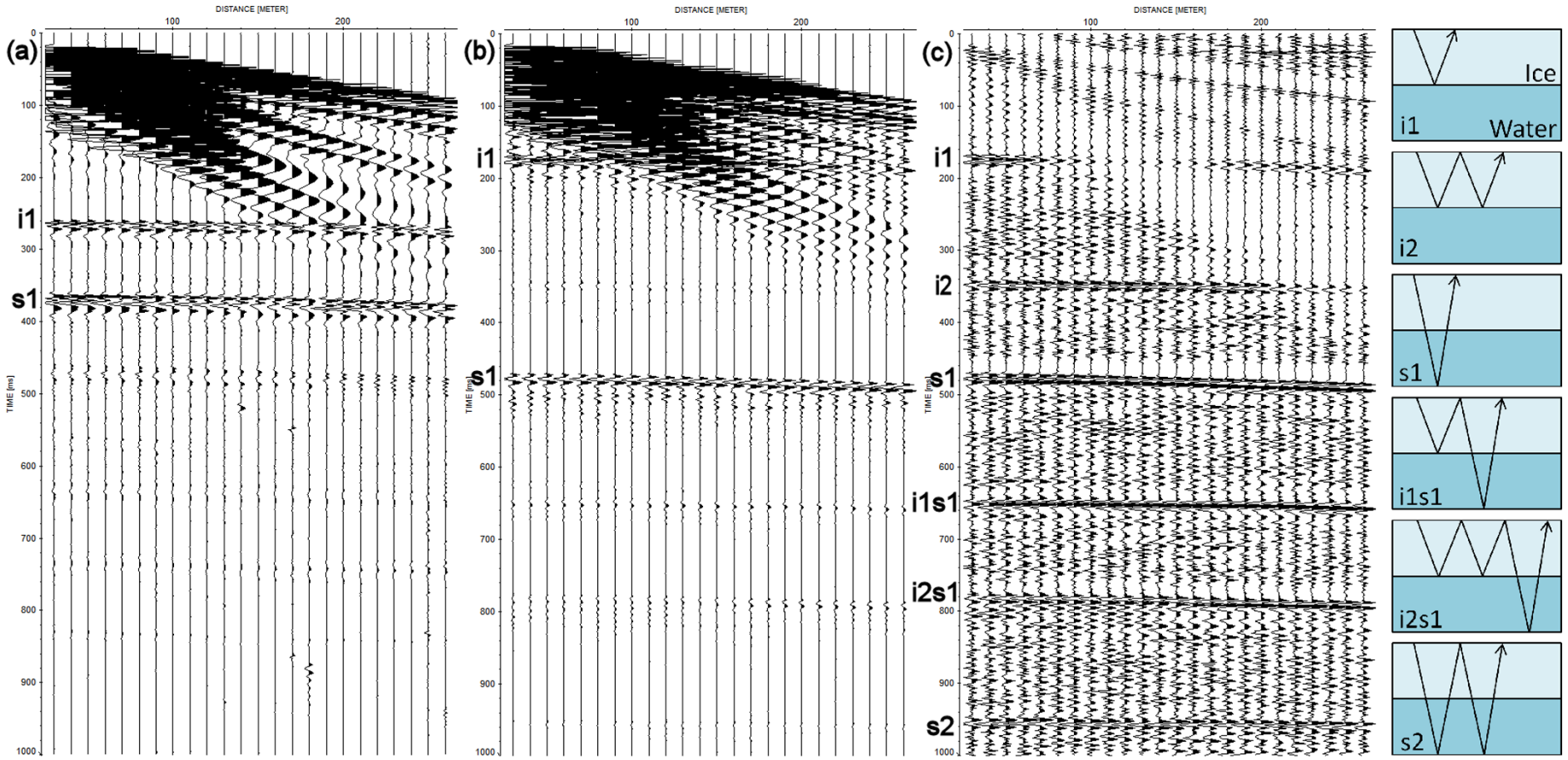
Planned

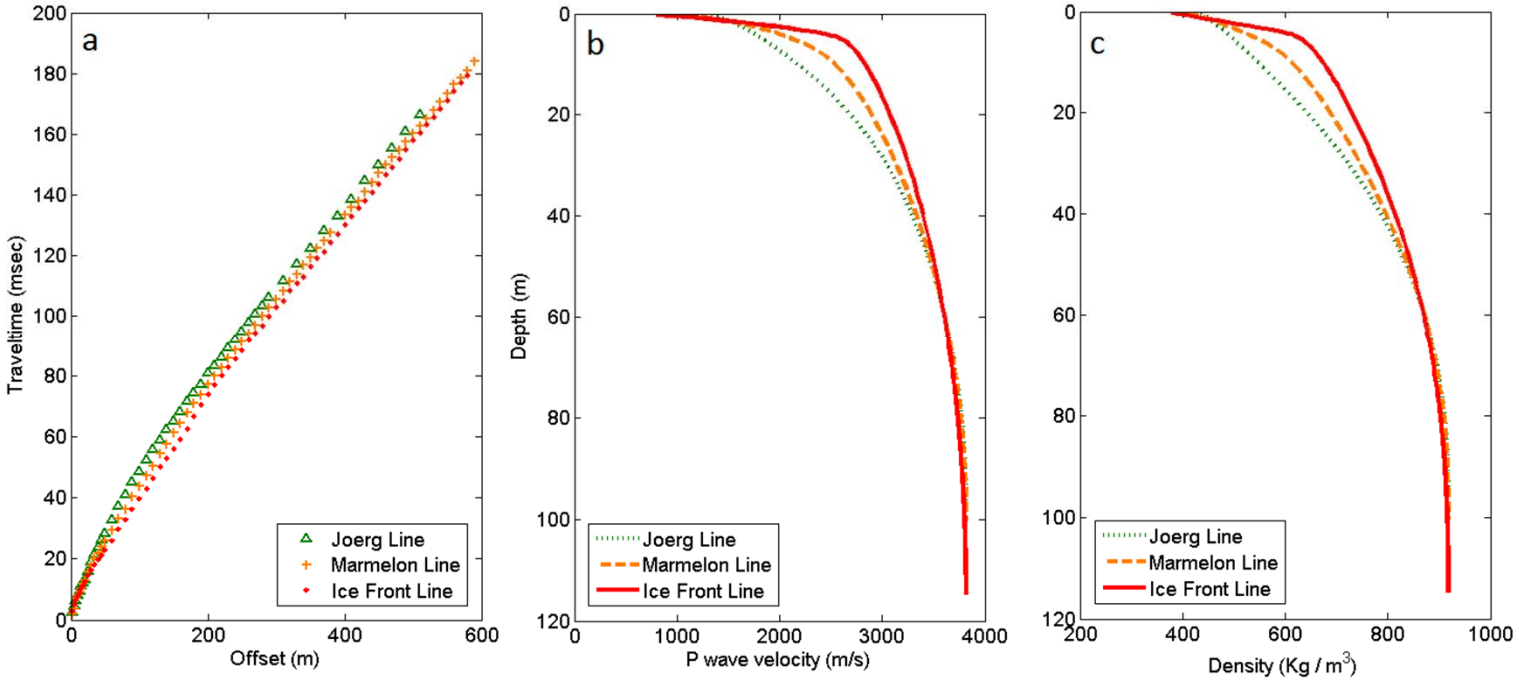


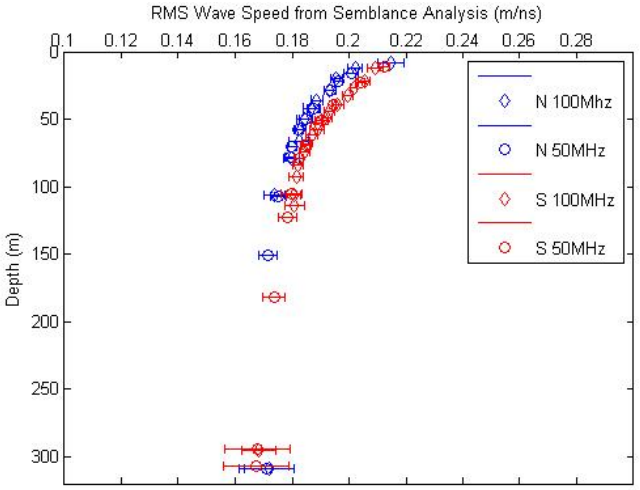
Undertaken



Data quality and ice base / seabed reflection strength highly variable



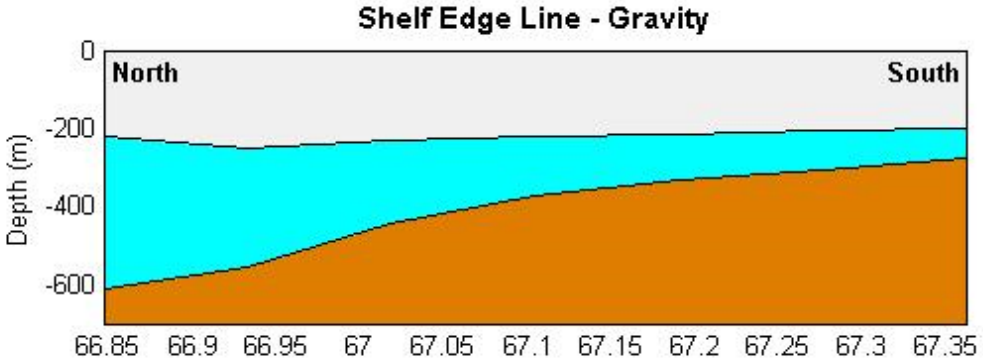


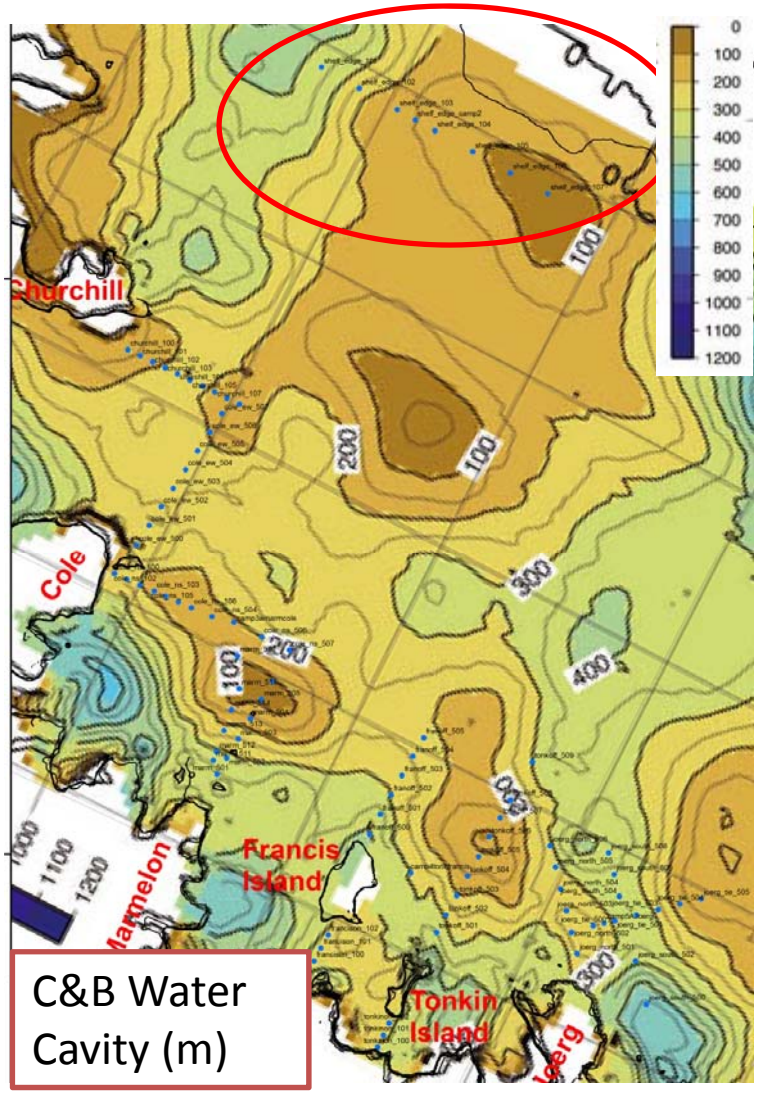


Seismic velocities:

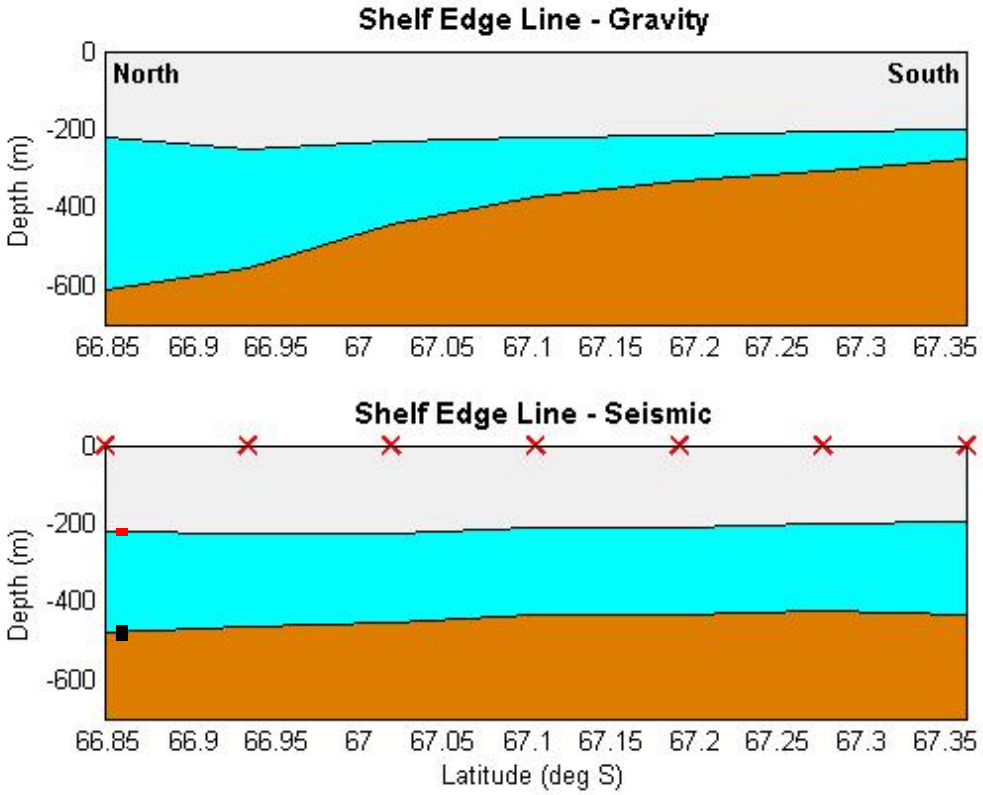
- Consistent variation in seismic velocities
- Water velocity measured directly with CTD
    - Mean water velocity: 1445m/s
- Cavity thickness is independent of the ice velocity
- Well-constrained linear fit: thickness and surface elevation

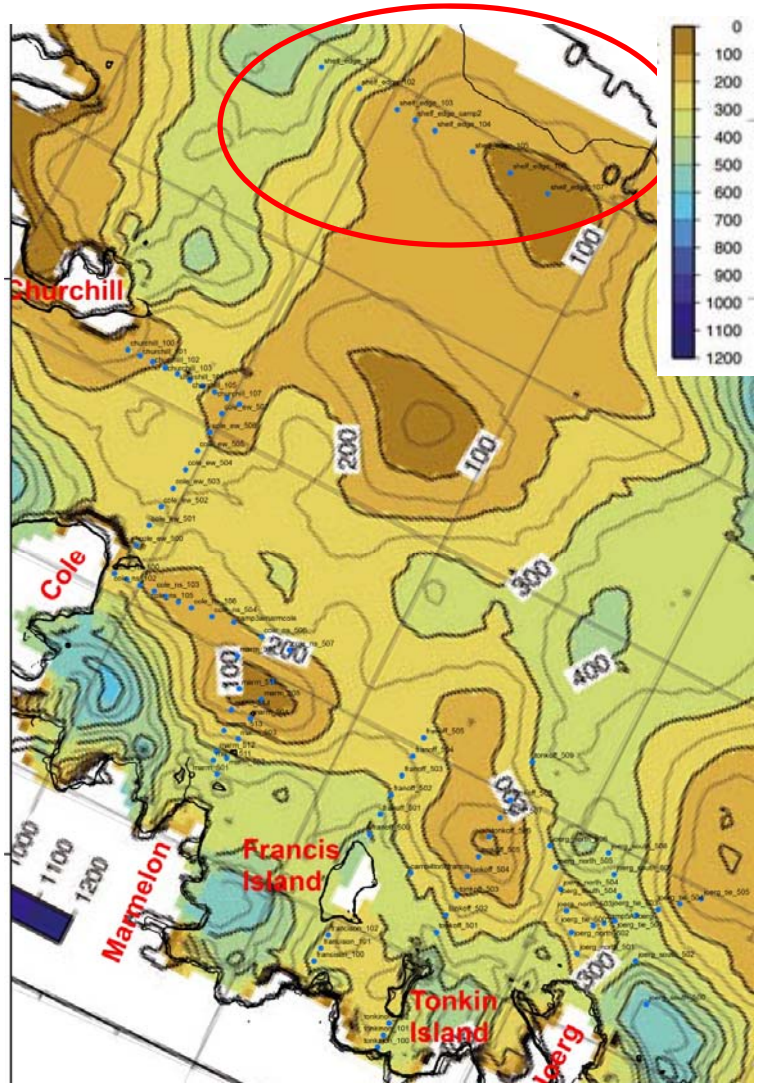
Results





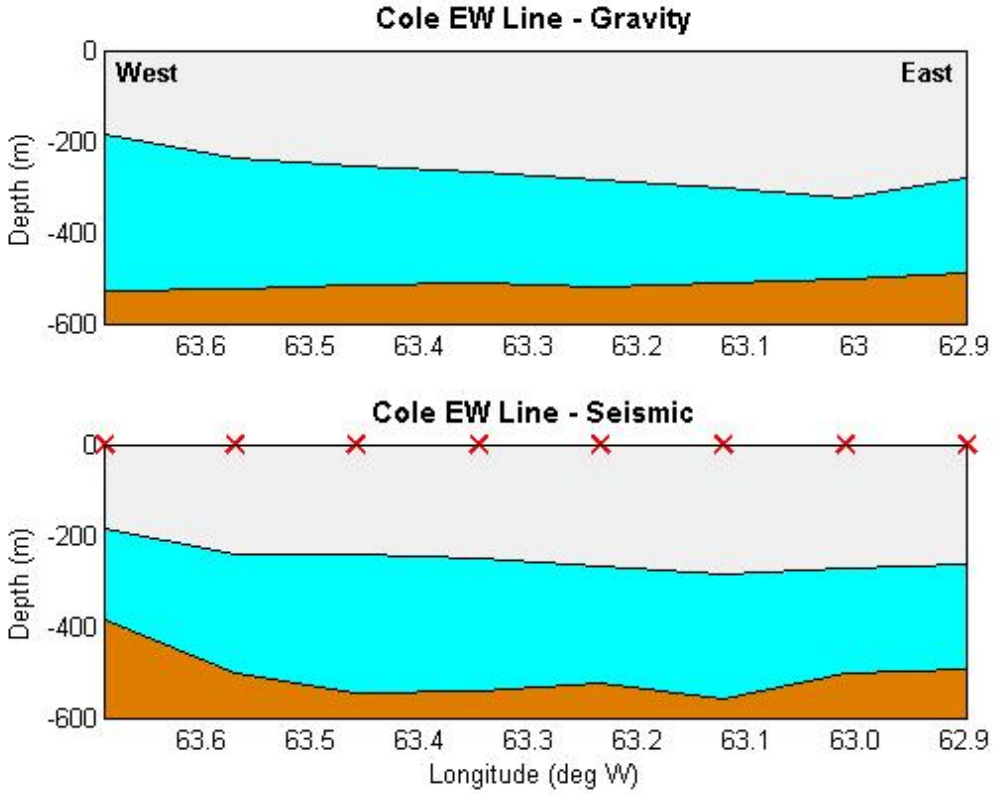
C&B Water Cavity (m)

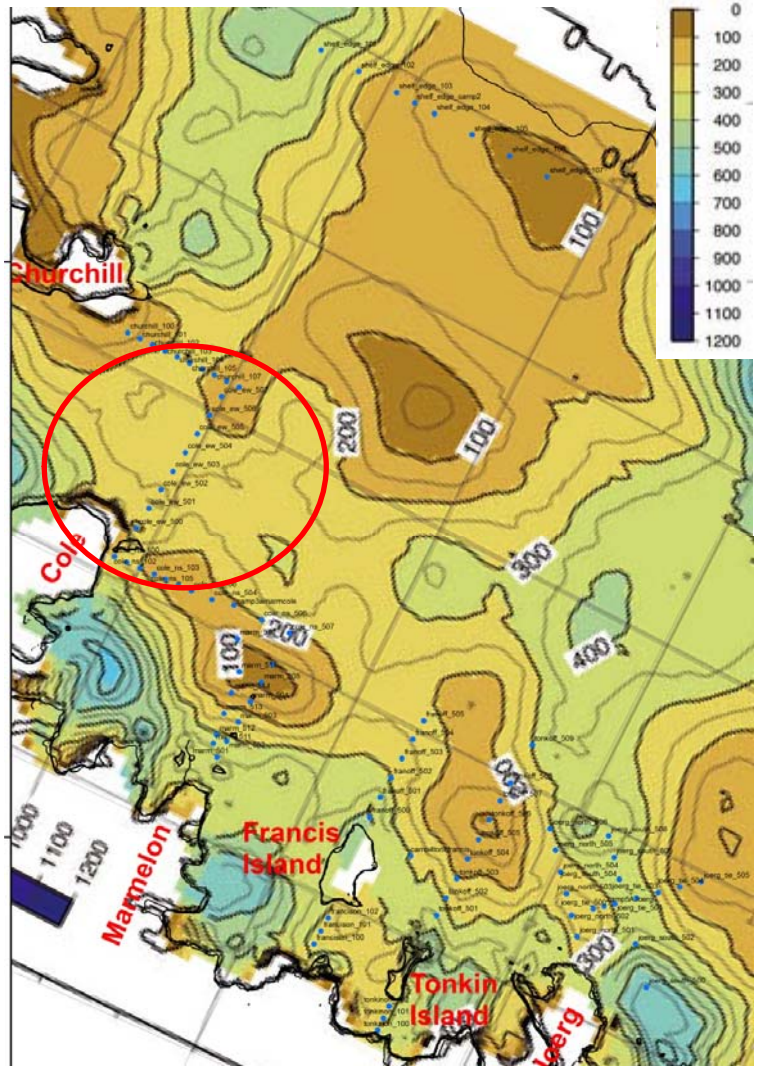




Uncertainties:

Ice and cavity thickness:	**±5m to ±10m**
Seabed depth:	**±10m to ±20m**


Cole EW Line - Gravity
West
East
Depth (m)
0
-200
-400
-600
63.6
63.5
63.4
63.3
63.2
63.1
63
62.9
Cole EW Line - Seismic
Depth (m)
0
-200
-400
-600
63.6
63.5
63.4
63.3
63.2
63.1
63.0
62.9
Longitude (deg W)


0
100
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600
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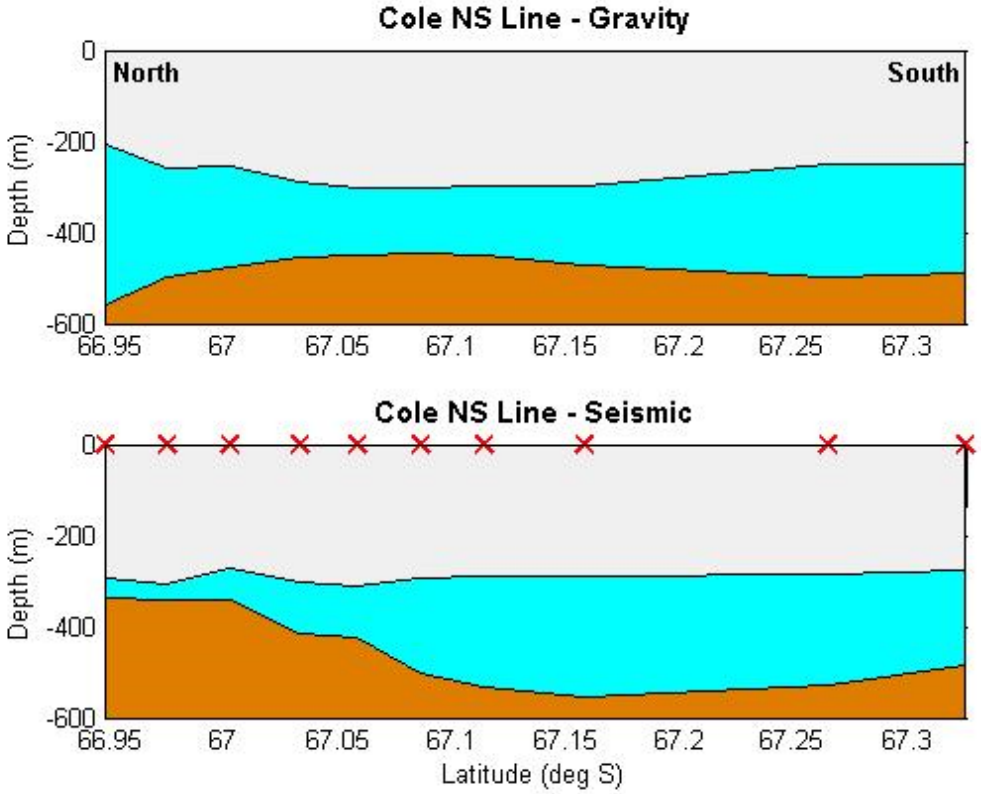
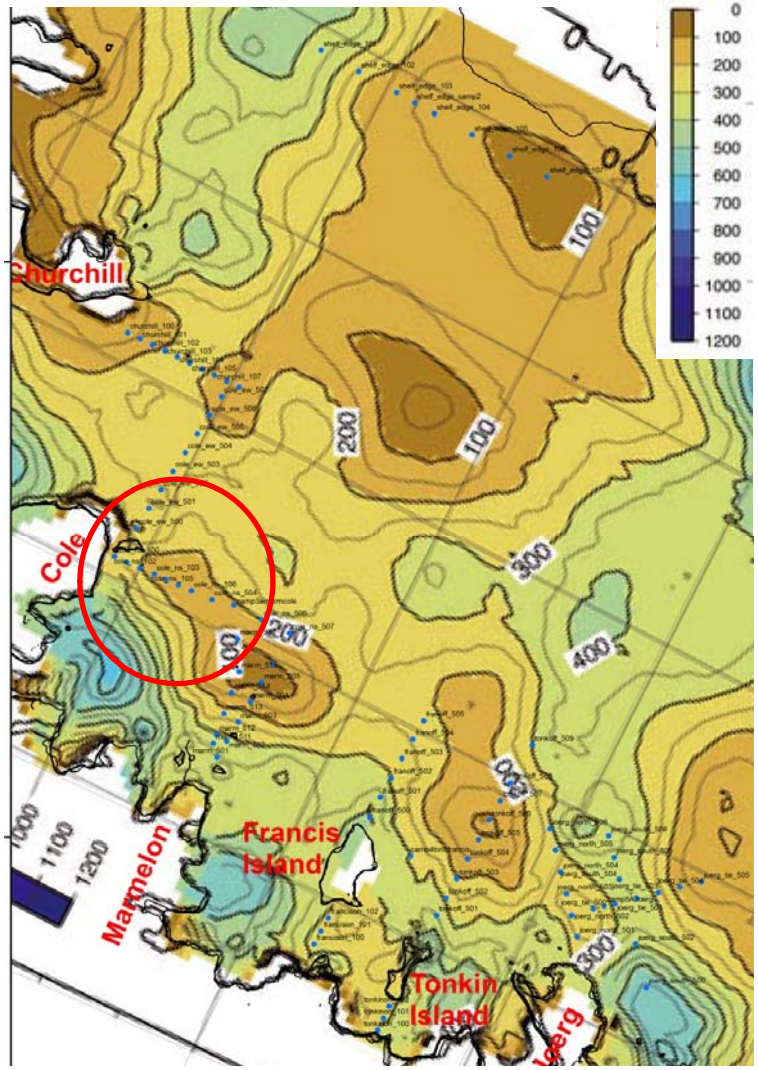
1100
1200
Churchill
Cole
Francis Island
Marmelon
Tonkin Island


Cole NS Line - Gravity
North
South
Depth (m)
0
-200
-400
-600
66.95
67
67.05
67.1
67.15
67.2
67.25
67.3
Cole NS Line - Seismic
Depth (m)
0
-200
-400
-600
66.95
67
67.05
67.1
67.15
67.2
67.25
67.3
Latitude (deg S)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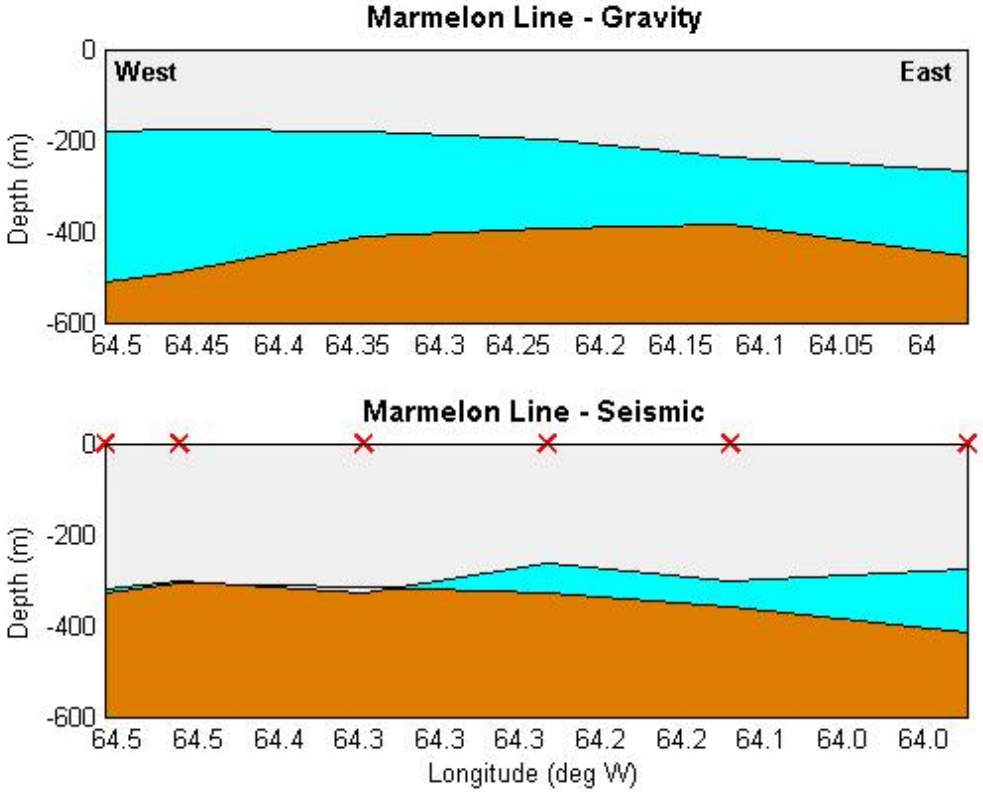
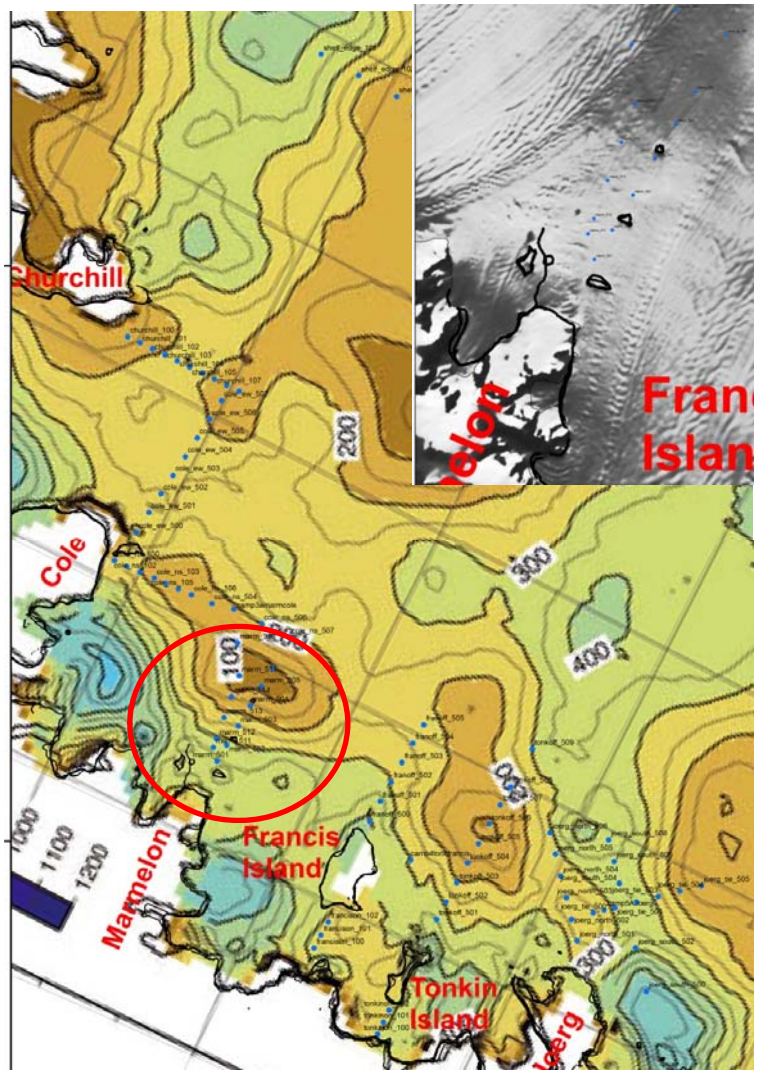
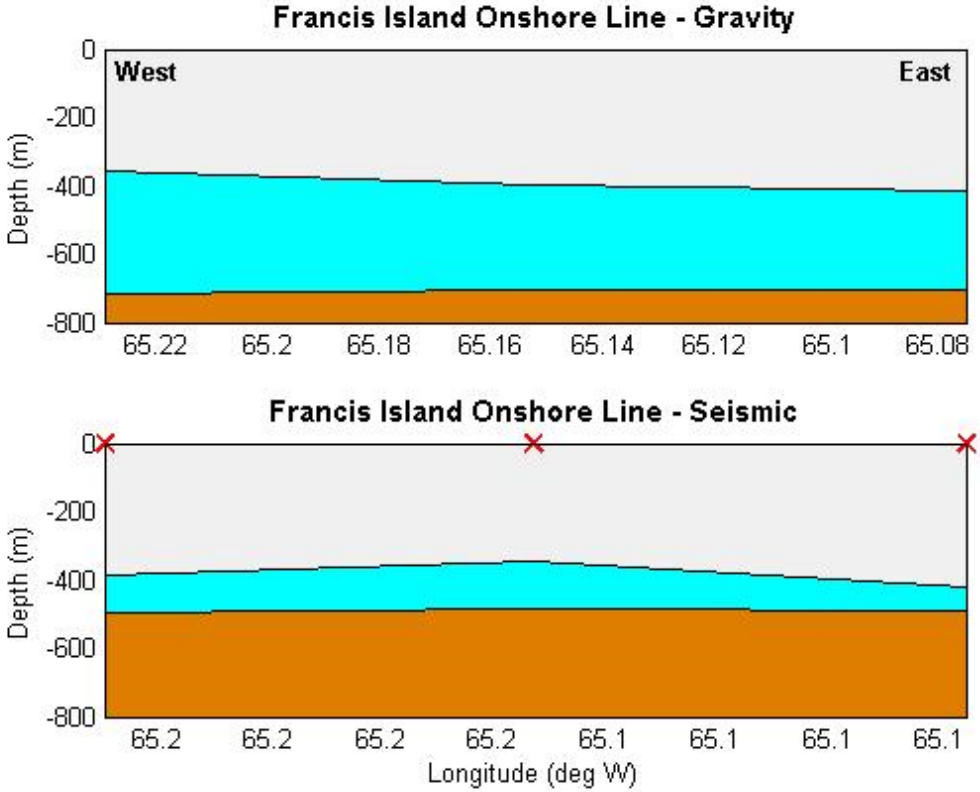
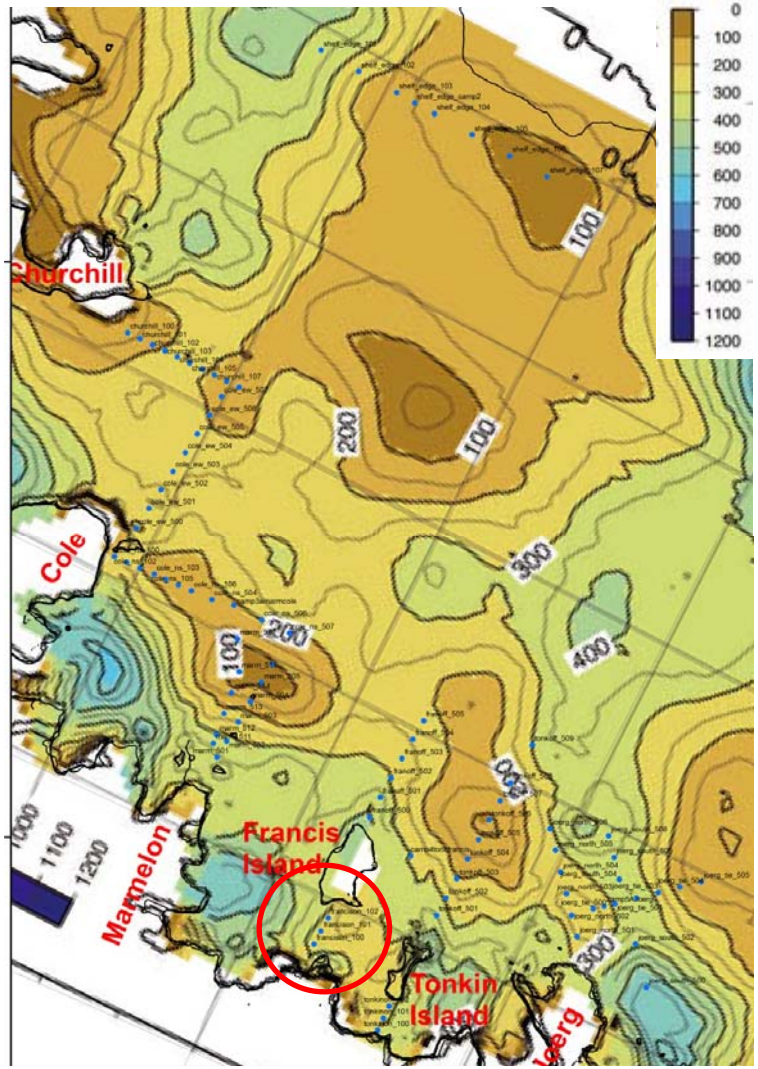
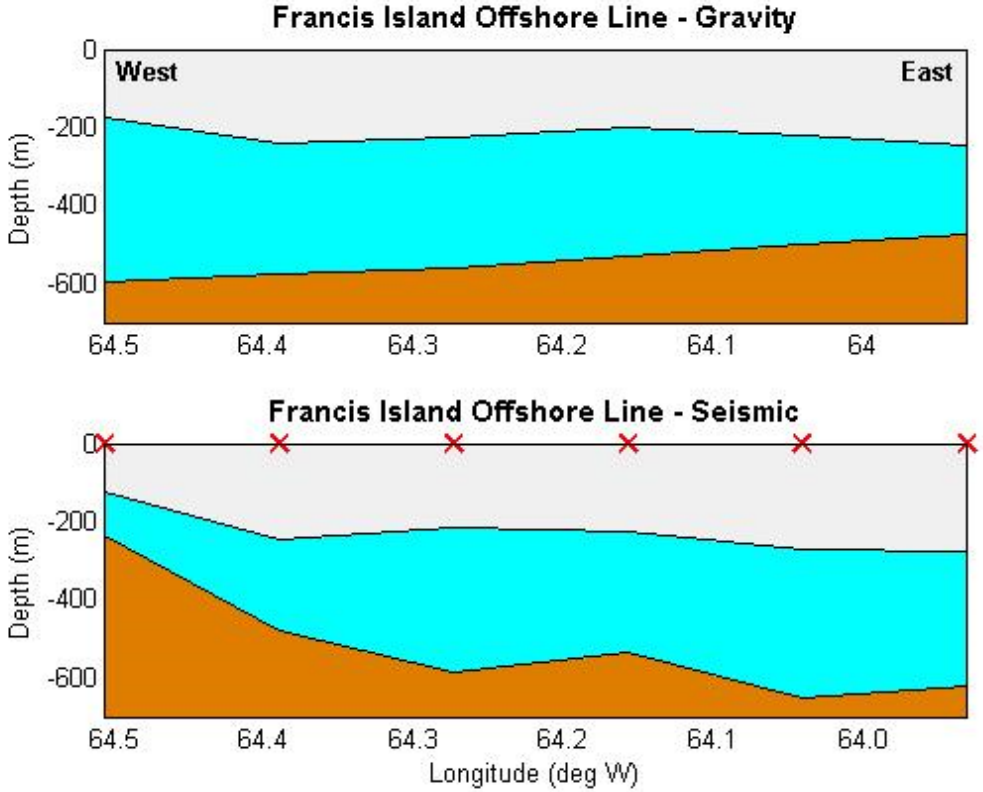
1100
1200
Churchill
Cole
Marmelon
Francis Island
Tonkin Island

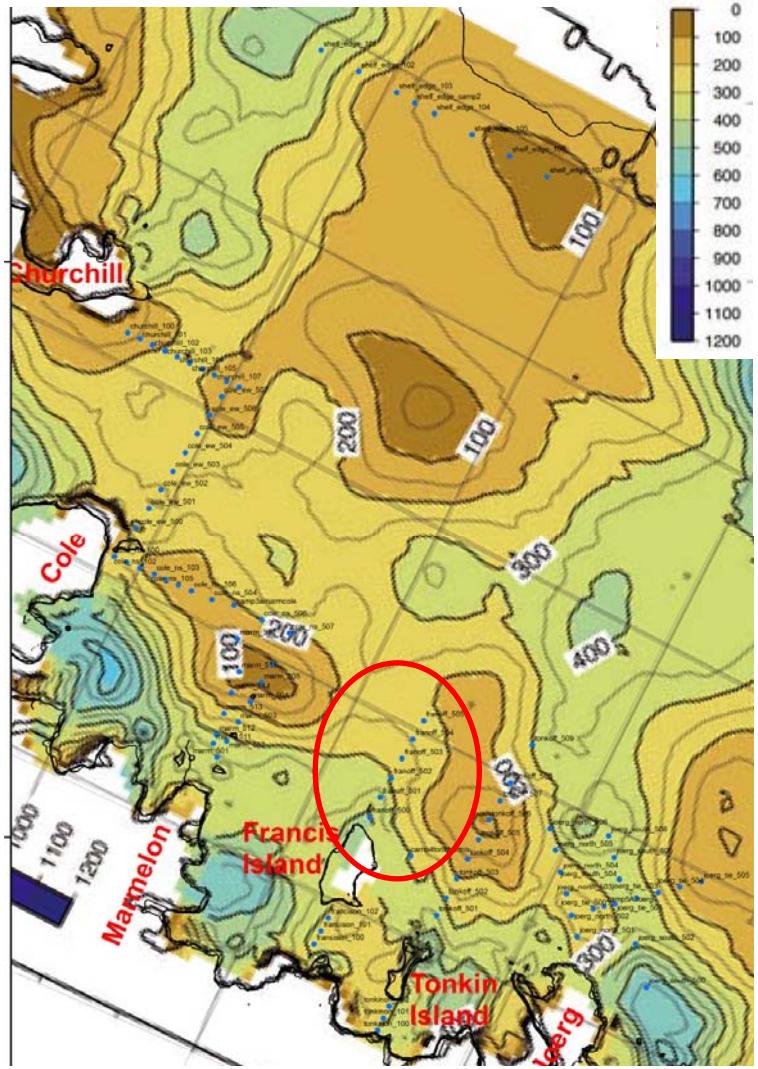

Marmelon Line - Gravity
West
East
Depth (m)
0
-200
-400
-600
64.5 64.45 64.4 64.35 64.3 64.25 64.2 64.15 64.1 64.05 64
Marmelon Line - Seismic
Depth (m)
0
-200
-400
-600
64.5 64.5 64.4 64.3 64.3 64.3 64.2 64.2 64.1 64.0 64.0
Longitude (deg W)


Churchill
Cole
Francis Island
Marmelon
Tonkin Island
200
300
400
100
1000
1100
1200


Francis Island Onshore Line - Gravity
West
East
Depth (m)
0
-200
-400
-600
-800
65.22
65.2
65.18
65.16
65.14
65.12
65.1
65.08
Francis Island Onshore Line - Seismic
Depth (m)
0
-200
-400
-600
-800
65.2
65.2
65.2
65.2
65.1
65.1
65.1
65.1
Longitude (deg W)


Churchill
Cole
Marguelon
Francis Island
Tonkin Island
0
100
200
300
400
500
600
700
800
900
1000
1100
1200


Francis Island Offshore Line - Gravity
West
East
Depth (m)
0
-200
-400
-600
64.5
64.4
64.3
64.2
64.1
64
Francis Island Offshore Line - Seismic
Depth (m)
0
-200
-400
-600
64.5
64.4
64.3
64.2
64.1
64.0
Longitude (deg W)


0
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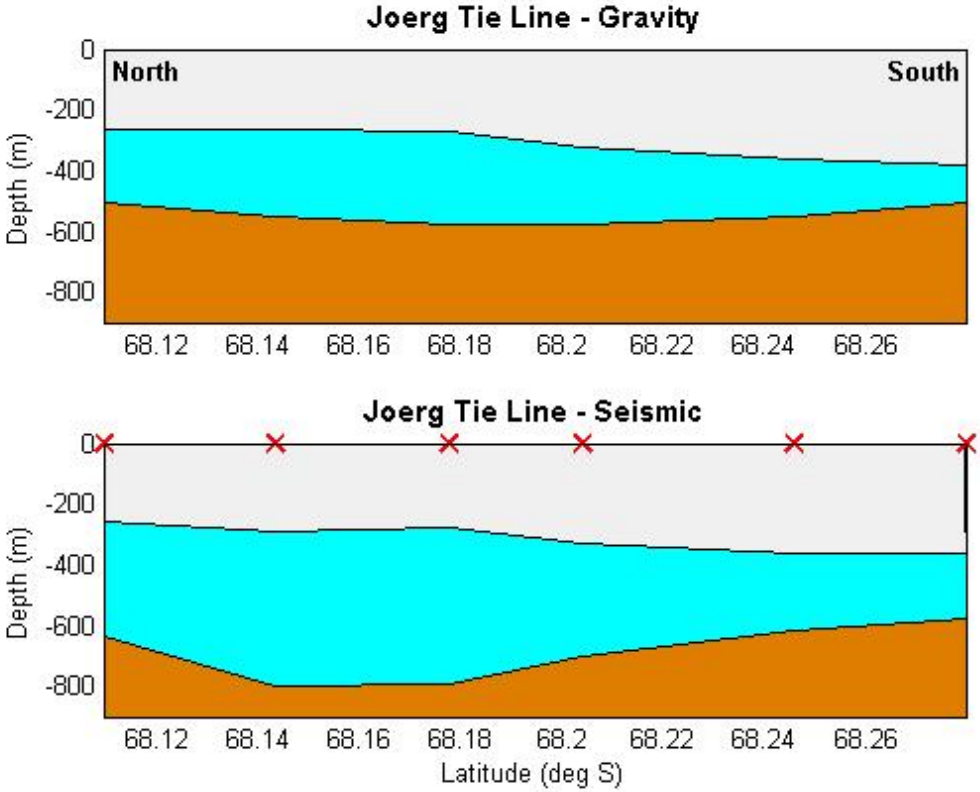
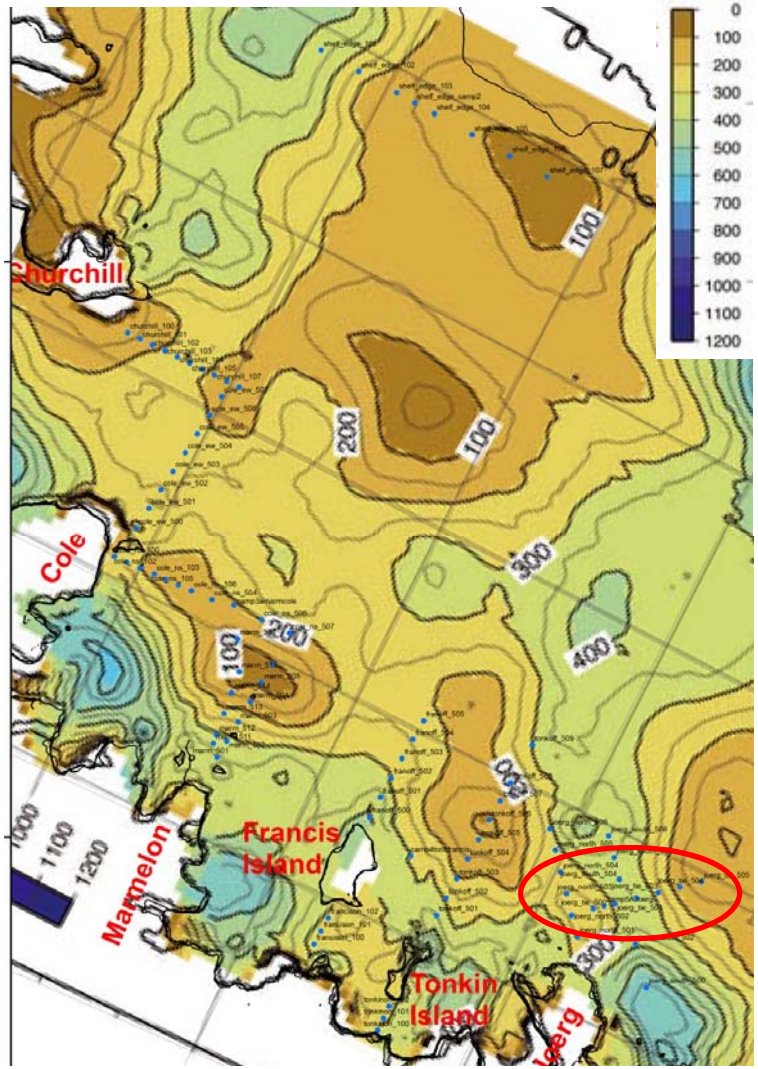
Churchill
Cole
Marguelon
Francis Island
Tonkin Island


Joerg Tie Line - Gravity
North
South
Depth (m)
0
-200
-400
-600
-800
68.12
68.14
68.16
68.18
68.2
68.22
68.24
68.26
Joerg Tie Line - Seismic
Depth (m)
Latitude (deg S)


Churchill
Cole
Marmelon
Francis Island
Tonkin Island
Joerg
0
100
200
300
400
500
600
700
800
900
1000
1100
1200

Summary

Uncertainties in seismic results:

Ice and cavity thickness:

±5m to ±10m

Seabed depth:

±10m to ±20m

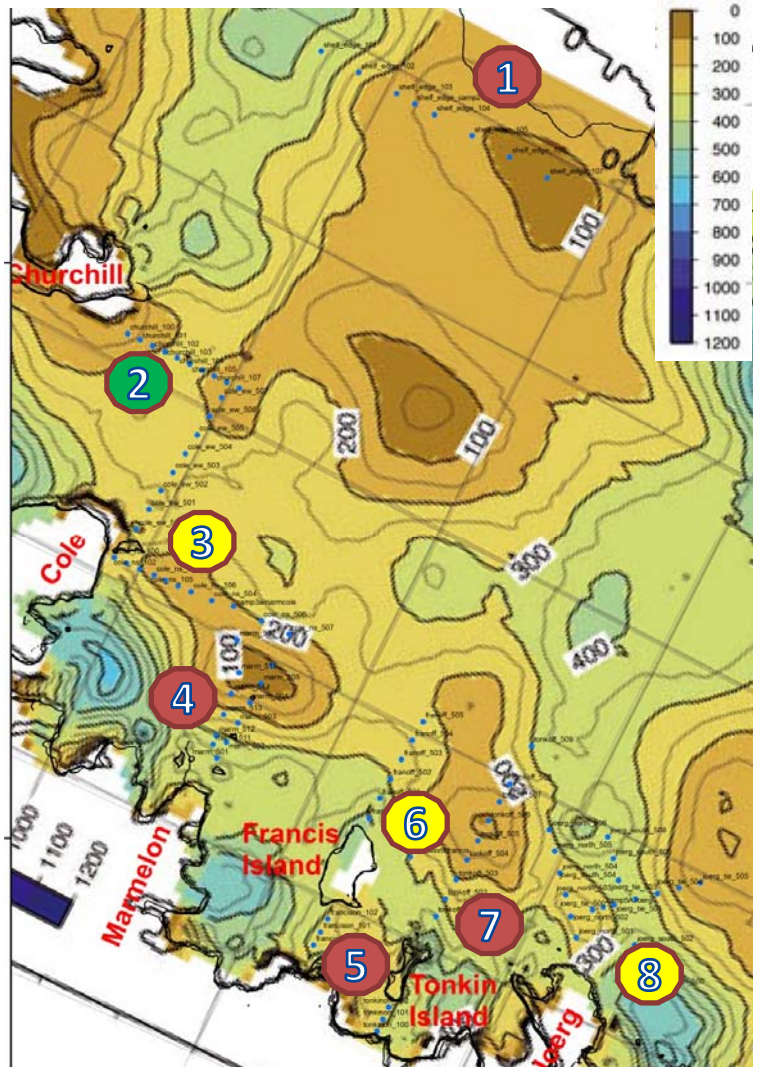
Cochran and Bell (2012)

Error in bathymetry:

162m rms

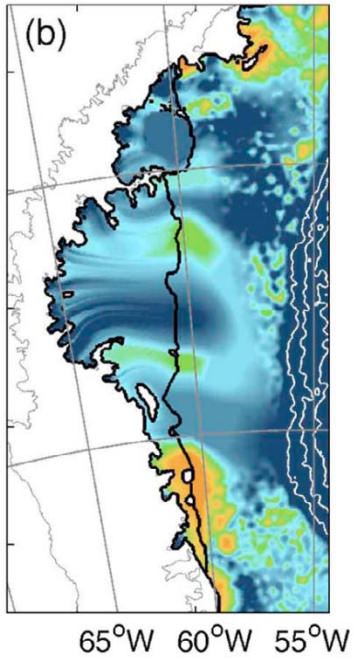
Error in cavity thickness:

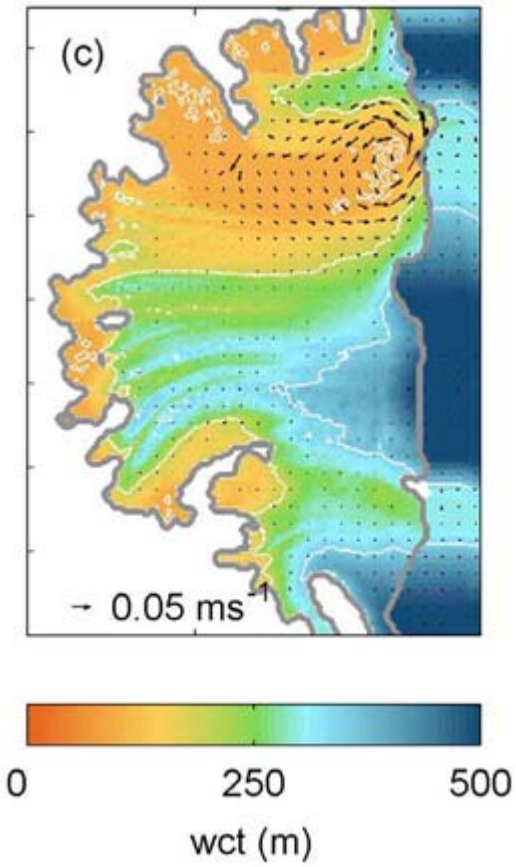
143m rms

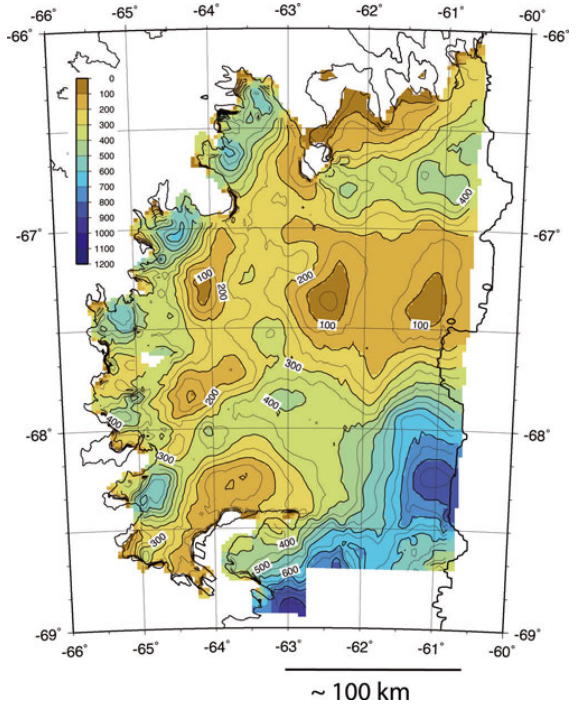


Implications

Impact of tide-topography interactions on basal melting of Larsen C Ice Shelf, Antarctica (Mueller et al., 2012)

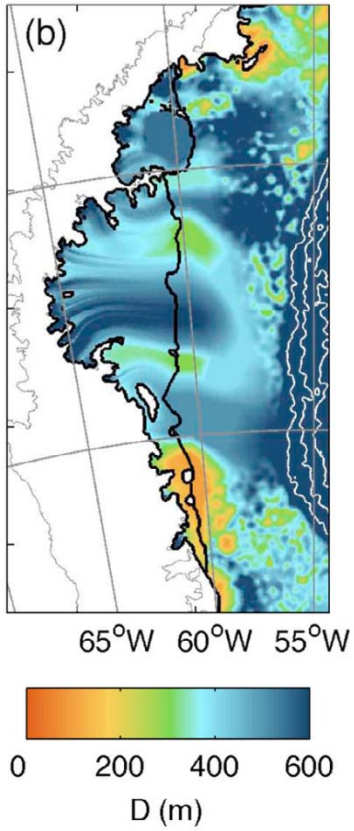


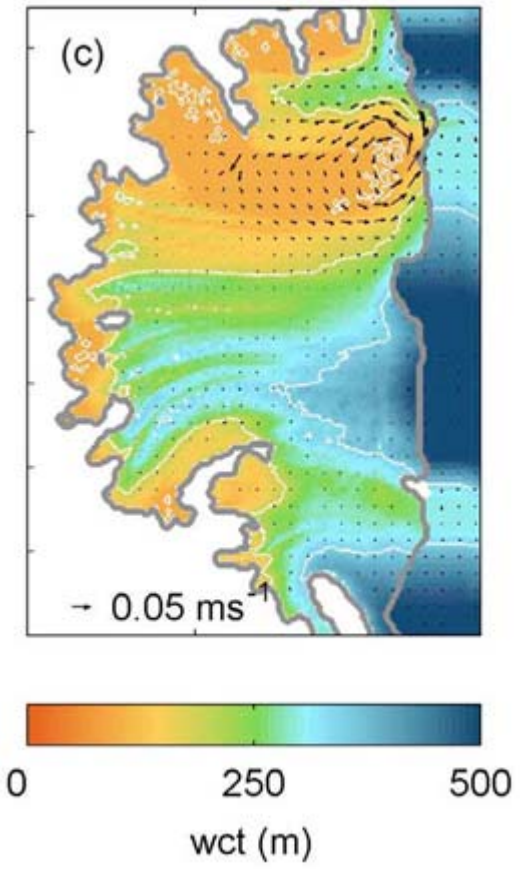


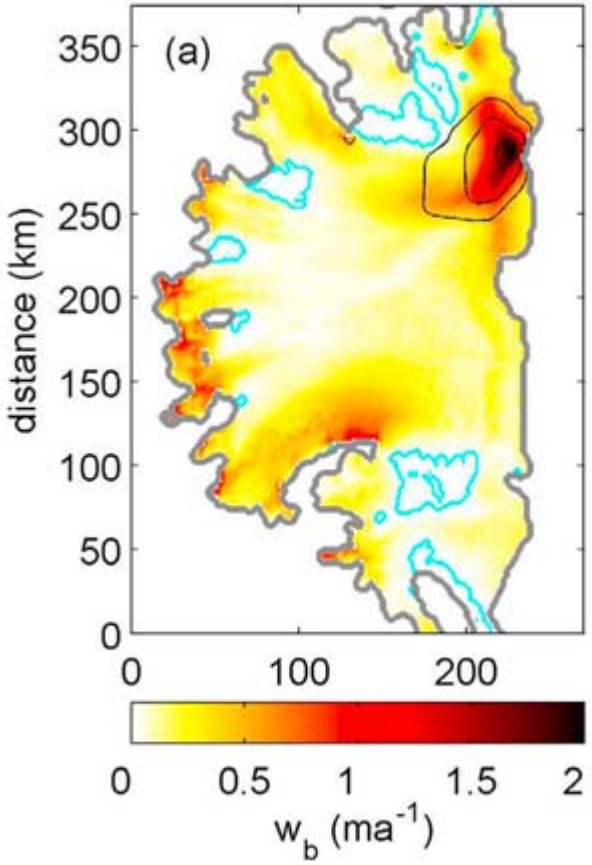


Implications

Narrowing of cavity in north increases basal melt rate to ~2 m/a

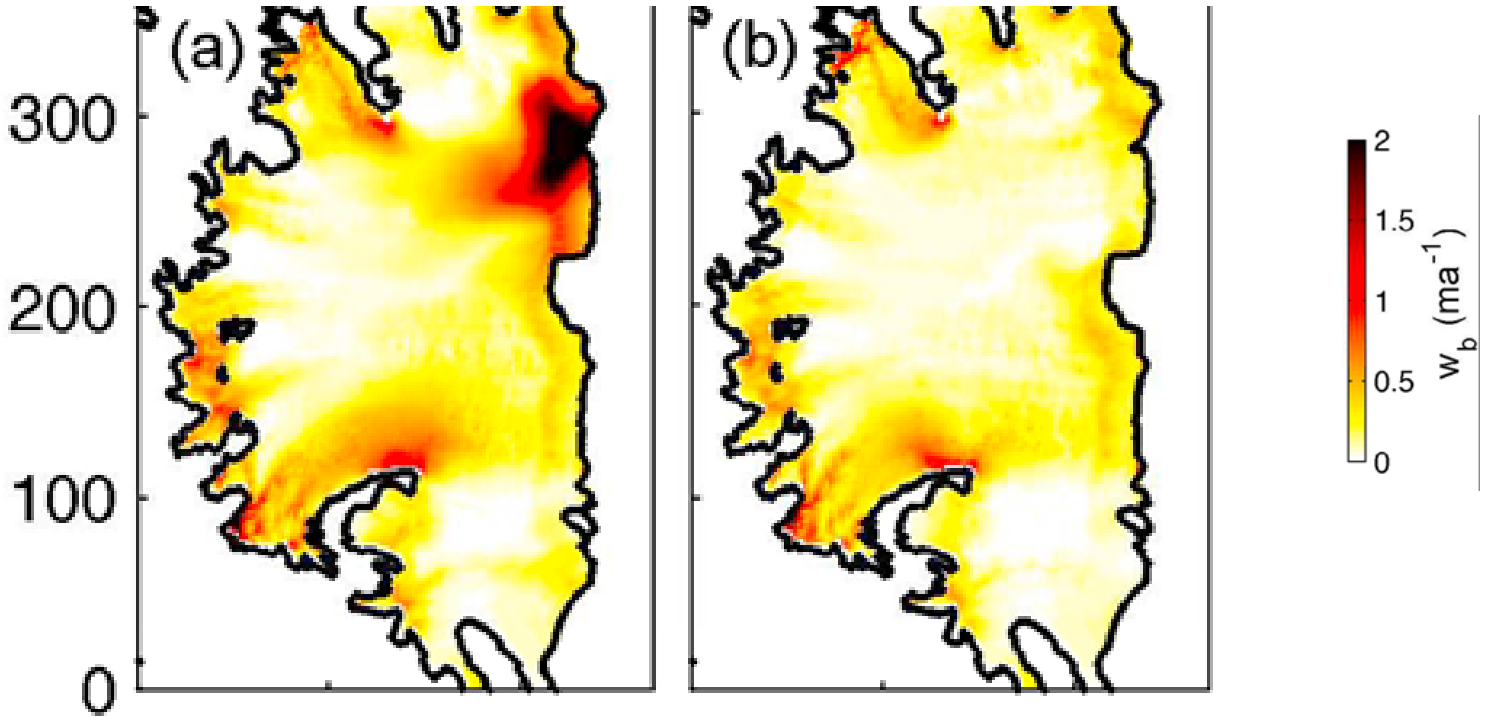




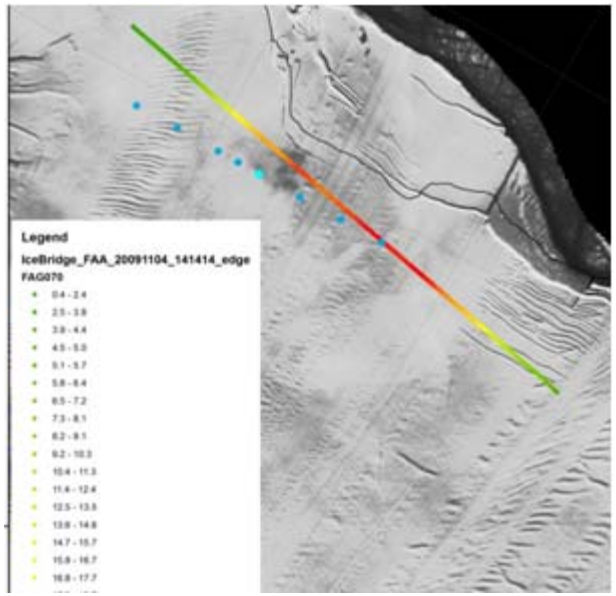


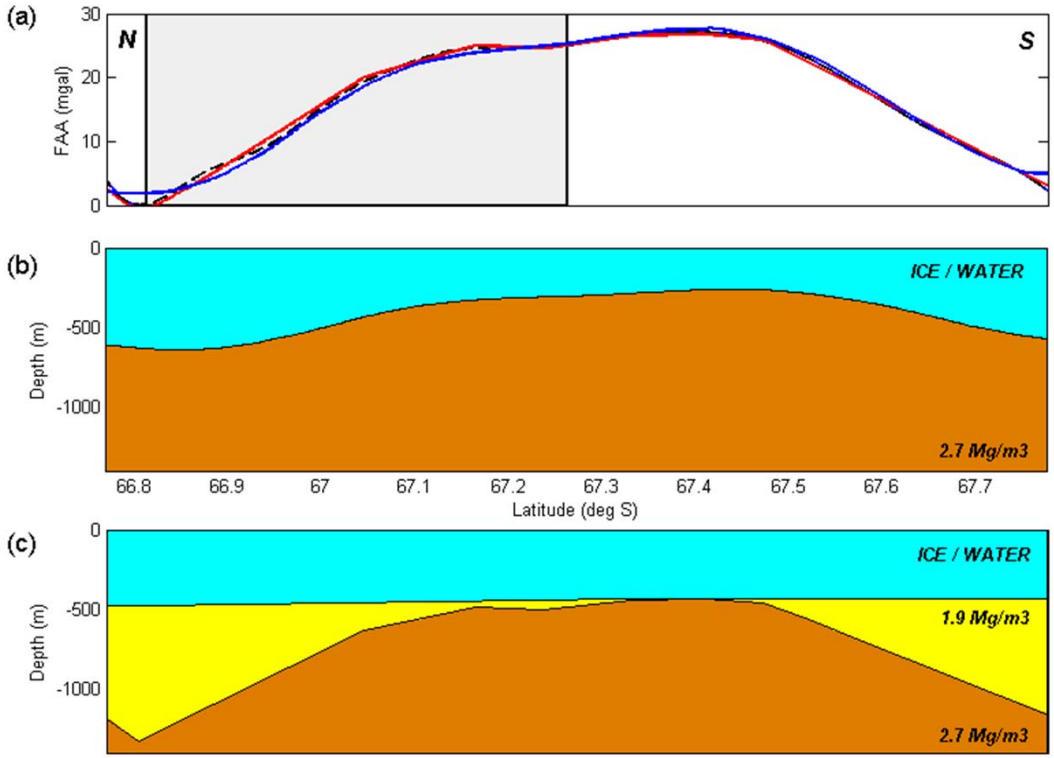
Implications

Minimum-350m cavity removes high basal melt rate from northern sector



Modelling FAA (Talwani et al., 1959)





Conclusions

- Bathymetry across Larsen C Ice Shelf successfully acquired using active seismics
  - Uncertainties of <20m in cavity thickness
  - Good agreement between seismically-measured ice thickness and previous studies
  - Seismic velocity variation consistent with varying degrees of firn compaction and melt
- Major discrepancies between bathymetry derived from free air gravity anomaly inversion compared to seismically-measured
  - Most notably: Shelf edge; Marmelon Point; Francis Island; Tonkin Island
  - 162m rms error in bathymetry (143m cavity thickness) derived from airborne gravity inversion
- Significant implications for sub-shelf circulation models
  - At eastern edge of LIS, no features to inhibit or concentrate water circulation
  - Significance of cavity model errors of this magnitude demonstrated by Mueller et al (2012)
  - Significant barriers to ocean circulation around peninsulas near the grounding line, consistent with partitioned north-south circulation from the ice front (Nicholls et al, 2012)

References:

Brisbourne, A. M., Smith, A. M., King, E. C., Nicholls, K. W., Holland, P. R., and K. Makinson (2013), Seabed topography beneath Larsen C Ice Shelf from seismic soundings, *The Cryosphere Discuss.*, **7**, 4177-4206 (doi:10.5194/tcd-7-4177-2013)

Cochran, J. R. and R. E. Bell (2012), Inversion of IceBridge gravity data for continental shelf bathymetry beneath the Larsen Ice Shelf, Antarctica, *J. Glaciol*., **58** (209), 540-552, (doi:10.3189/2012JoG11J033)

Mueller, R. D., L. Padman, M. S. Dinniman, S. Y. Erofeeva, H. A. Fricker, and M. A. King (2012), Impact of tide-topography interactions on basal melting of Larsen C Ice Shelf, Antarctica, *J. Geophys. Res*., **117**, C05005, (doi:10.1029/2011JC007263)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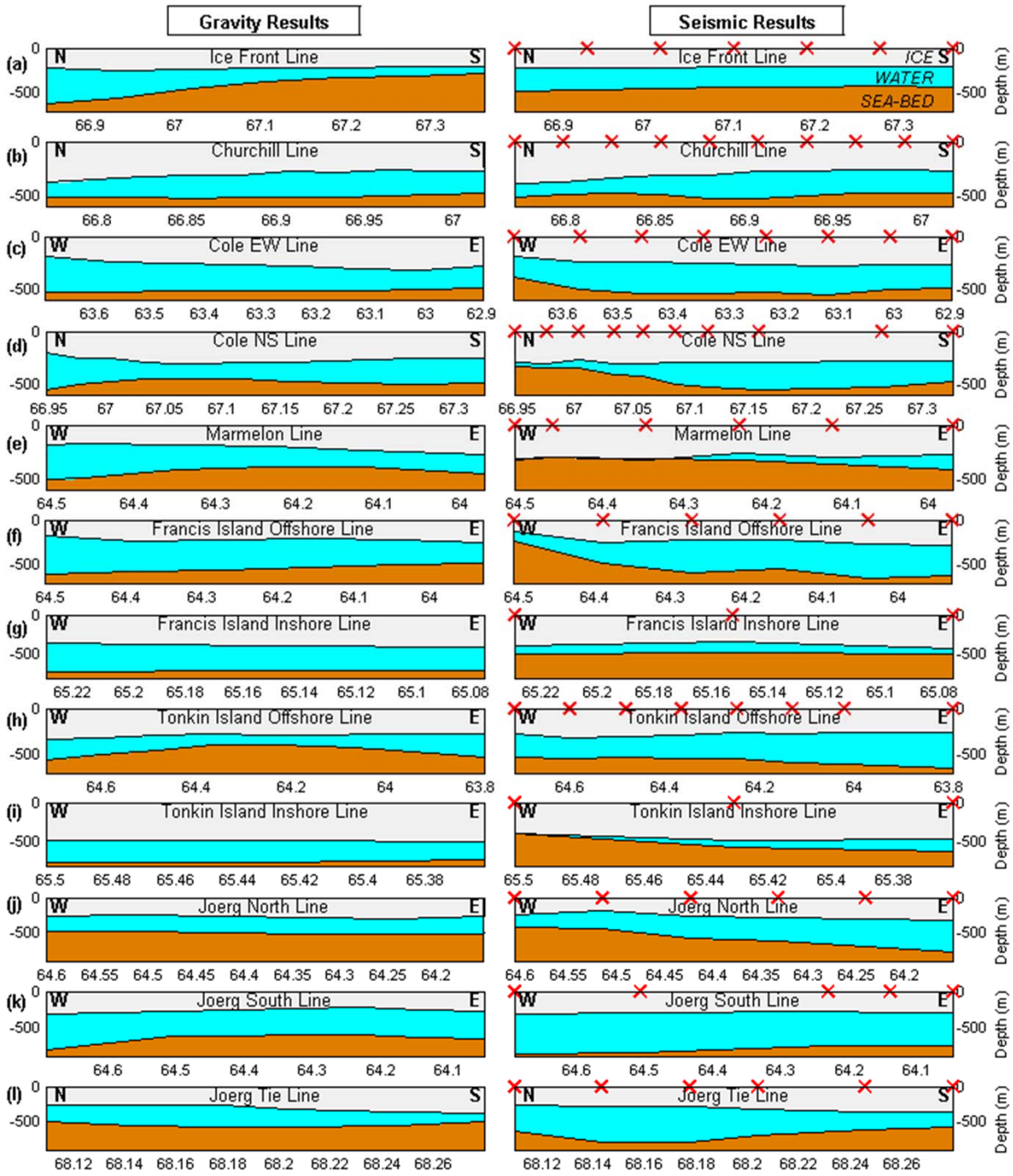
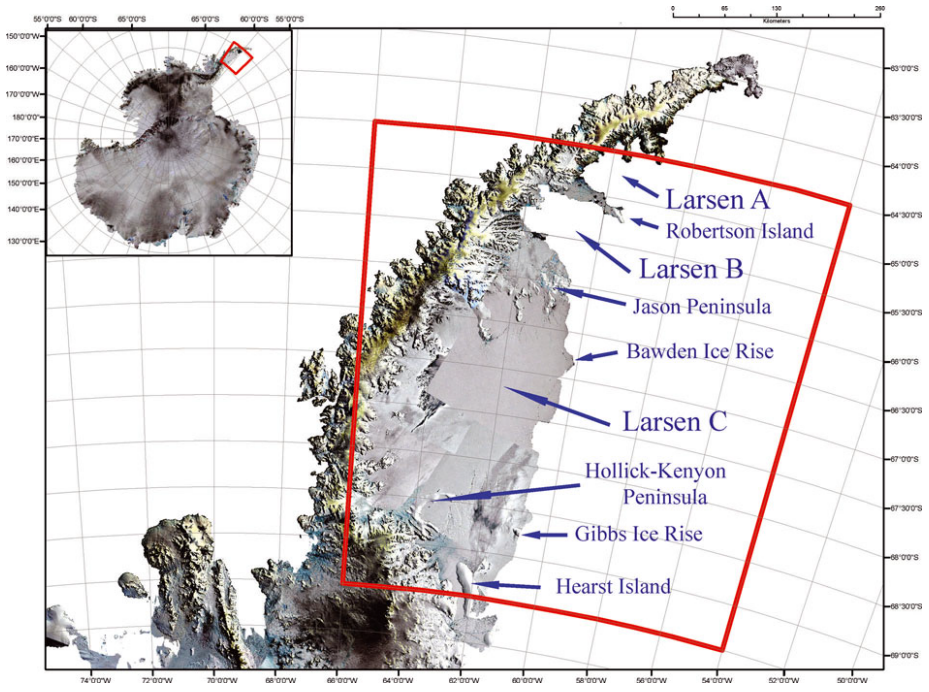
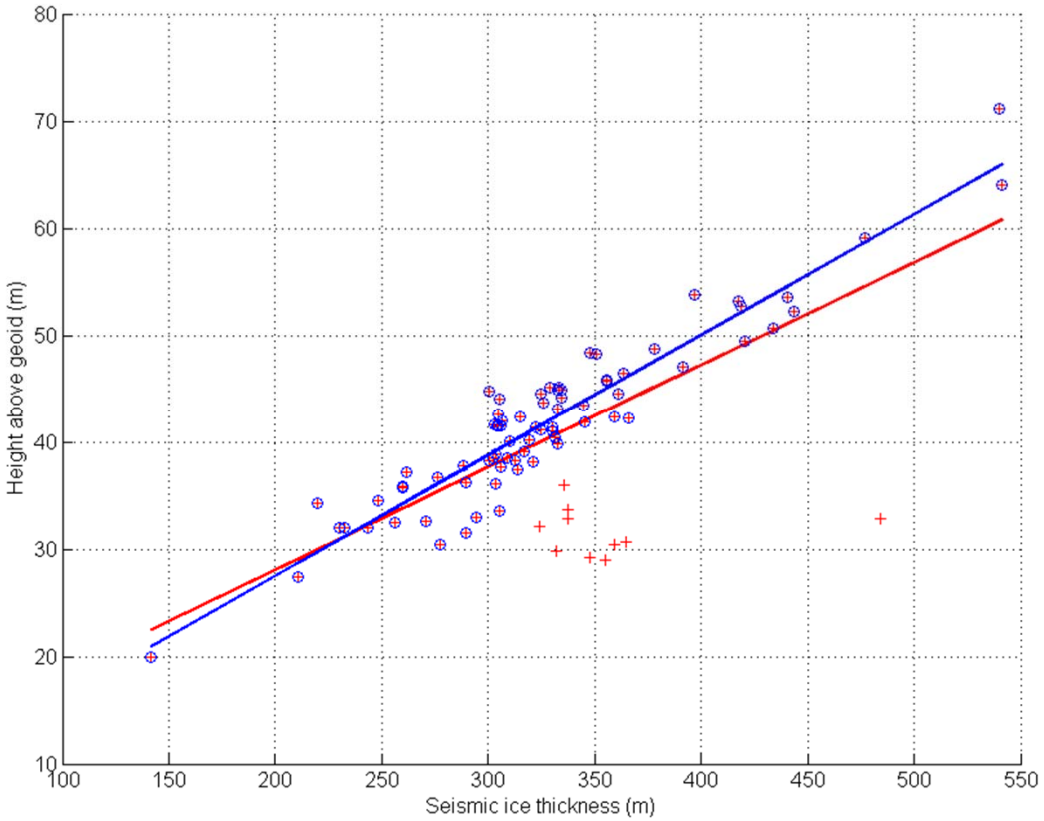

Gravity Results
Seismic Results
(a)
Ice Front Line
N
S
66.9 67 67.1 67.2 67.3
ICE
WATER
SEA-BED
(b)
Churchill Line
66.8 66.85 66.9 66.95 67
(c)
Cole EW Line
W
E
63.6 63.5 63.4 63.3 63.2 63.1 63 62.9
(d)
Cole NS Line
66.95 67 67.05 67.1 67.15 67.2 67.25 67.3
(e)
Marmelon Line
64.5 64.4 64.3 64.2 64.1 64
(f)
Francis Island Offshore Line
(g)
Francis Island Inshore Line
65.22 65.2 65.18 65.16 65.14 65.12 65.1 65.08
(h)
Tonkin Island Offshore Line
64.6 64.4 64.2 64 63.8
(i)
Tonkin Island Inshore Line
65.5 65.48 65.46 65.44 65.42 65.4 65.38
(j)
Joerg North Line
64.6 64.55 64.5 64.45 64.4 64.35 64.3 64.25 64.2
(k)
Joerg South Line
64.6 64.5 64.4 64.3 64.2 64.1
(l)
Joerg Tie Line
68.12 68.14 68.16 68.18 68.2 68.22 68.24 68.26
0
-500
Depth (m)

Motivation – Sub Ice Shelf Bathymetry

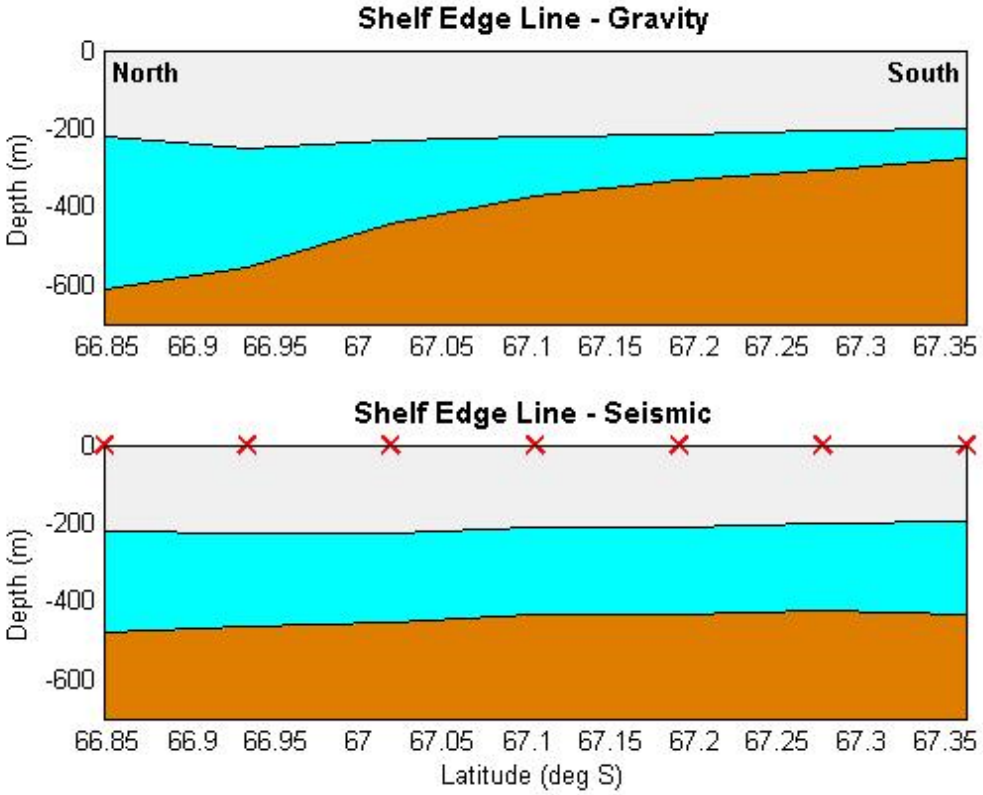
- Ice shelves act as a buttress to the flow of inland ice; Acceleration of ice drainage following loss of Larsen B
- Derivation of sub-shelf bathymetry model for oceanographic circulation modelling to address ice-ocean thermal transfer
- Inversion of IceBridge gravity data for continental shelf bathymetry beneath the Larsen Ice Shelf, Antarctica (Cochran and Bell, 2012)
- Use seismic spot-measurements to verify inversion model

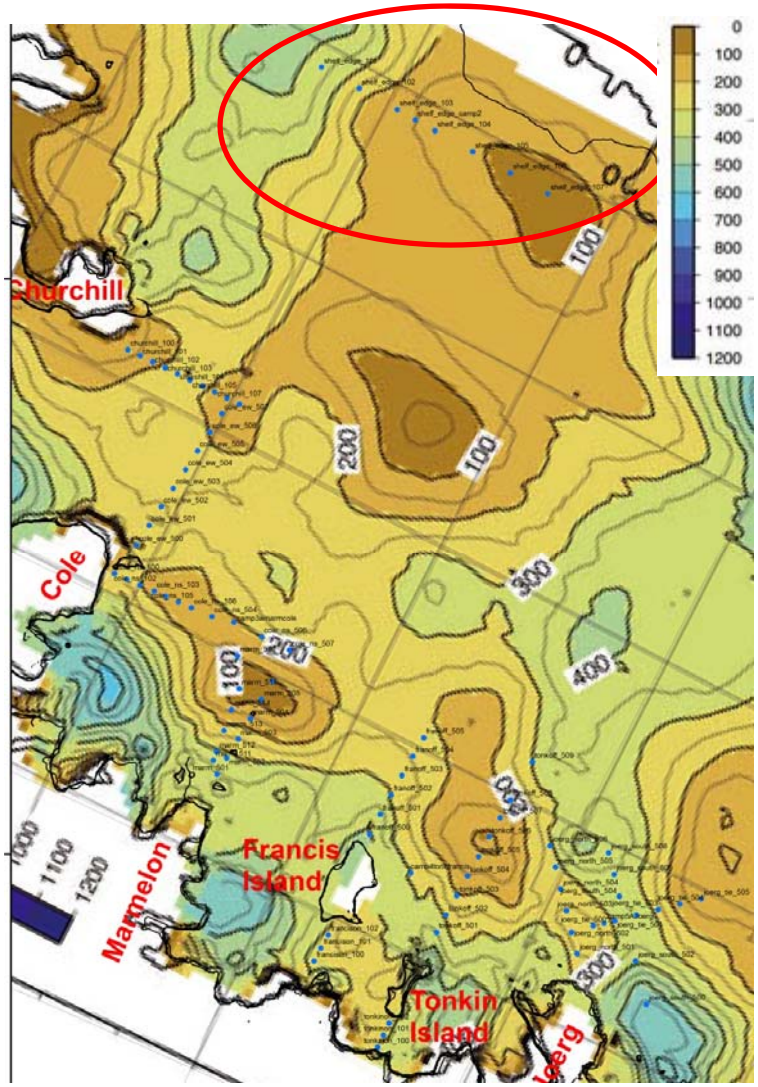


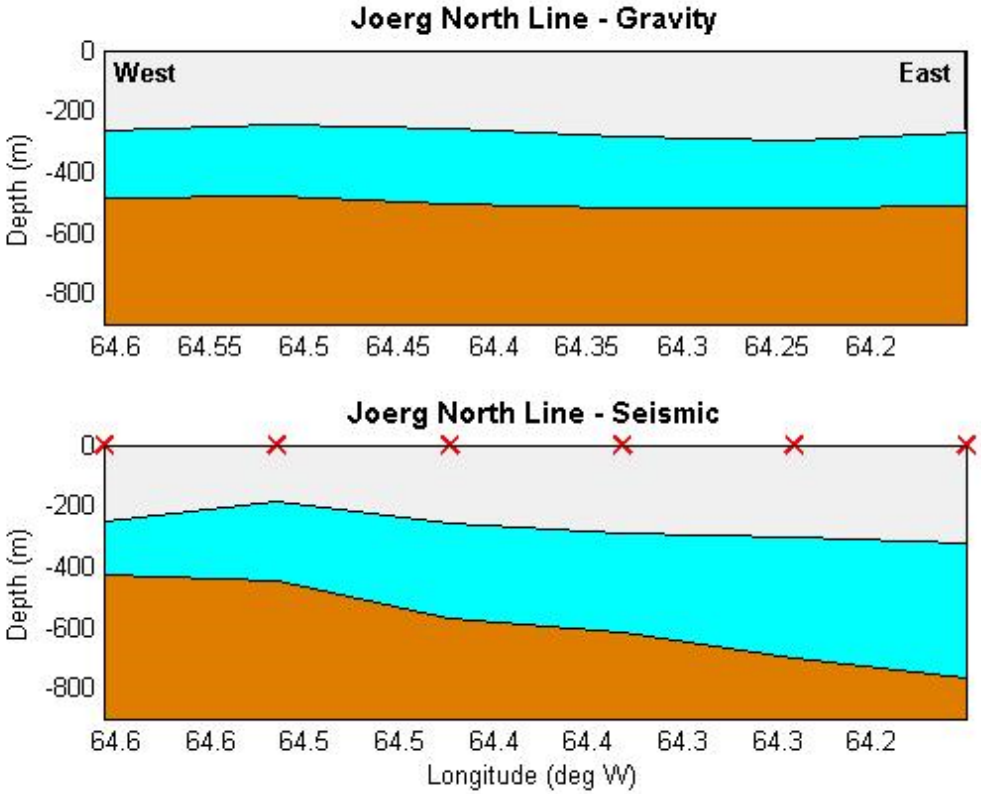
Ice Draft and Seismic Thickness

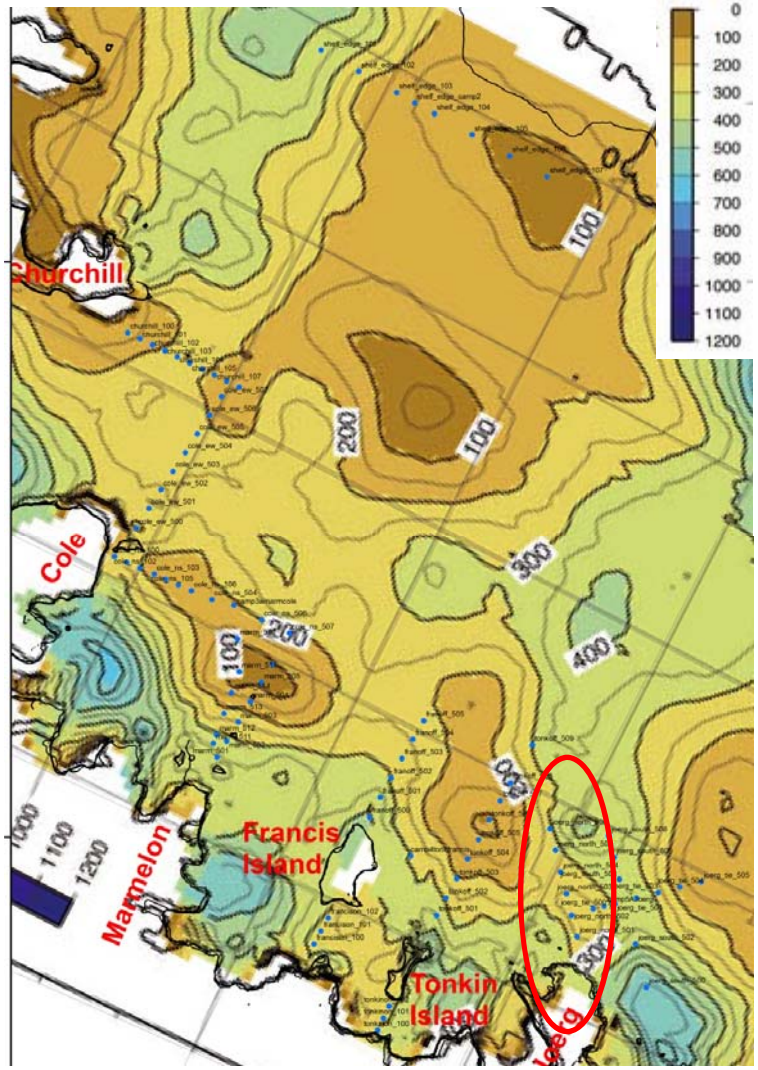


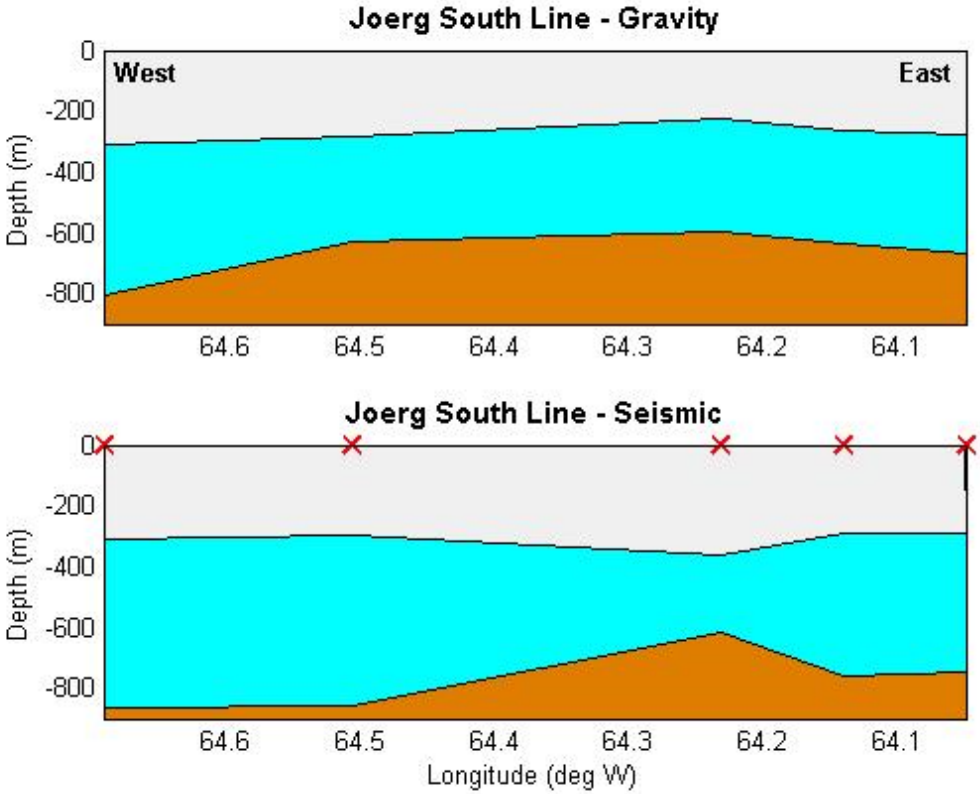
Fit: $h = 0.113\ H + 5.003$ (± 0.005 / ± 1.525; $R^2 = 0.89$)

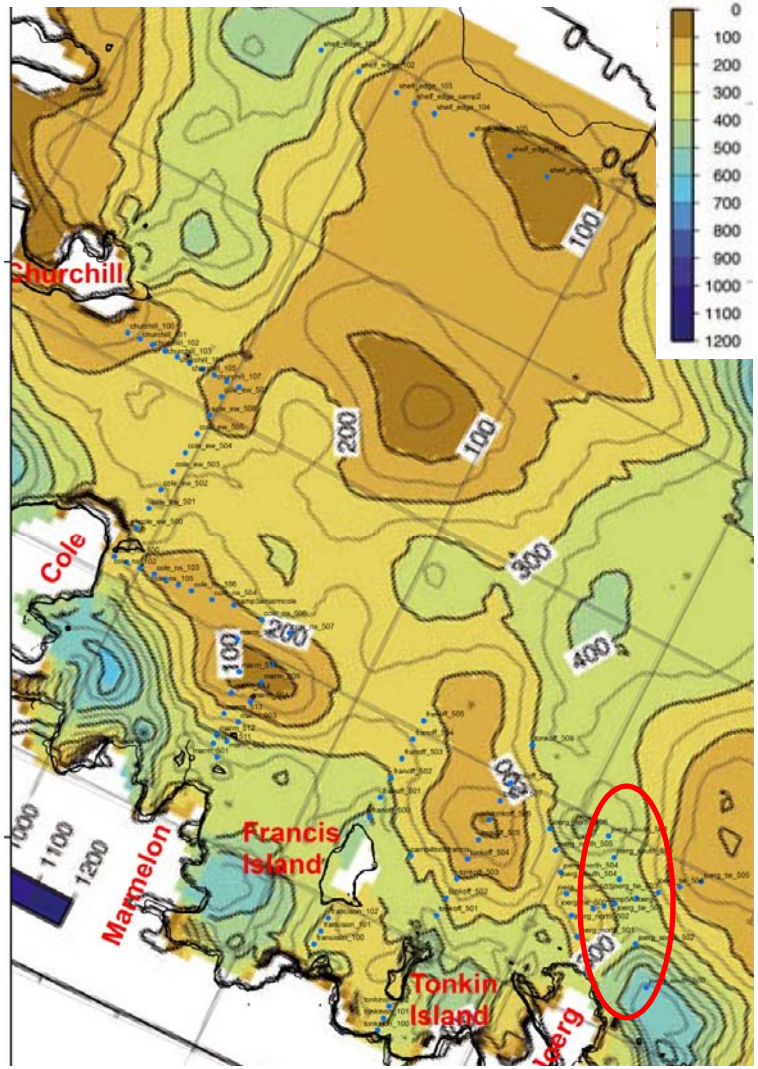

Shelf Edge Line - Gravity
North
South
Depth (m)
0
-200
-400
-600
66.85
66.9
66.95
67
67.05
67.1
67.15
67.2
67.25
67.3
67.35
Shelf Edge Line - Seismic
Depth (m)
Latitude (deg S)


Churchill
Cole
Marmelon
Francis Island
Tonkin Island
100
200
300
400
1000
1100
1200

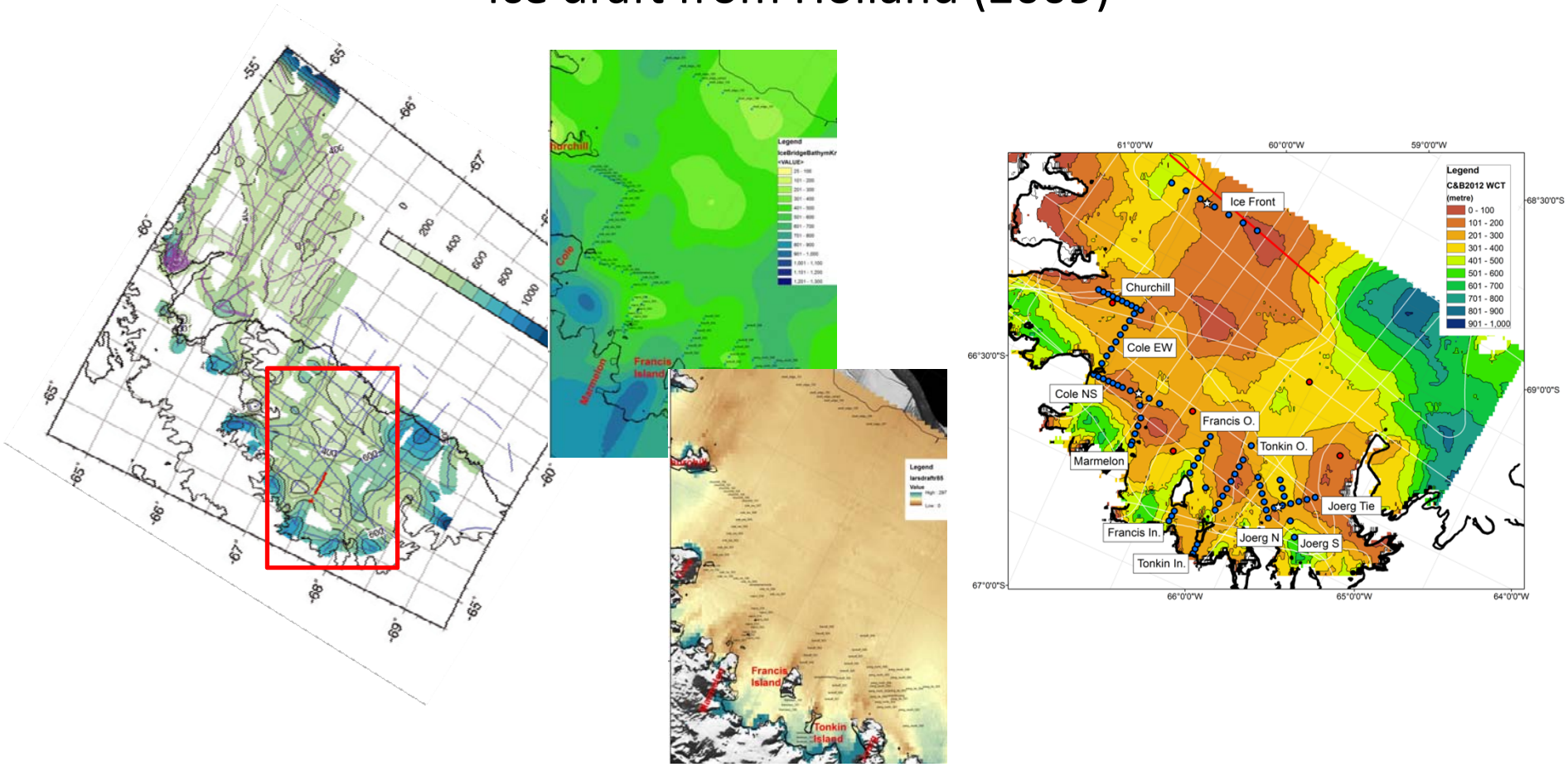

Joerg North Line - Gravity
West
East
Depth (m)
0
-200
-400
-600
-800
64.6
64.55
64.5
64.45
64.4
64.35
64.3
64.25
64.2
Joerg North Line - Seismic
Depth (m)
0
-200
-400
-600
-800
64.6
64.6
64.5
64.5
64.4
64.4
64.3
64.3
64.2
Longitude (deg W)


0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Churchill
Cole
Marmelon
Francis Island
Tonkin Island
100
200
300
400


Joerg South Line - Gravity
West
East
Depth (m)
0
-200
-400
-600
-800
64.6
64.5
64.4
64.3
64.2
64.1
Joerg South Line - Seismic
Depth (m)
0
-200
-400
-600
-800
64.6
64.5
64.4
64.3
64.2
64.1
Longitude (deg W)


0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Churchill
Cole
Marmelon
Francis Island
Tonkin Island

Gravity Inversion Bathymetry
C&B (2012) vs kriged IceBridge data;
Ice draft from Holland (2009)



Marine Ice (Holland, 2009) overlaying MODIS image (Haran, 2003)

- Strong correlation between marine ice distribution (yellow bands) and uncertainty / difficulty in identifying seismic base of ice (red sites) at a qualitative level
- DInSAR grounding line (Rignot, 2011)
- Would require normalisation of site by site amplitudes to be validated