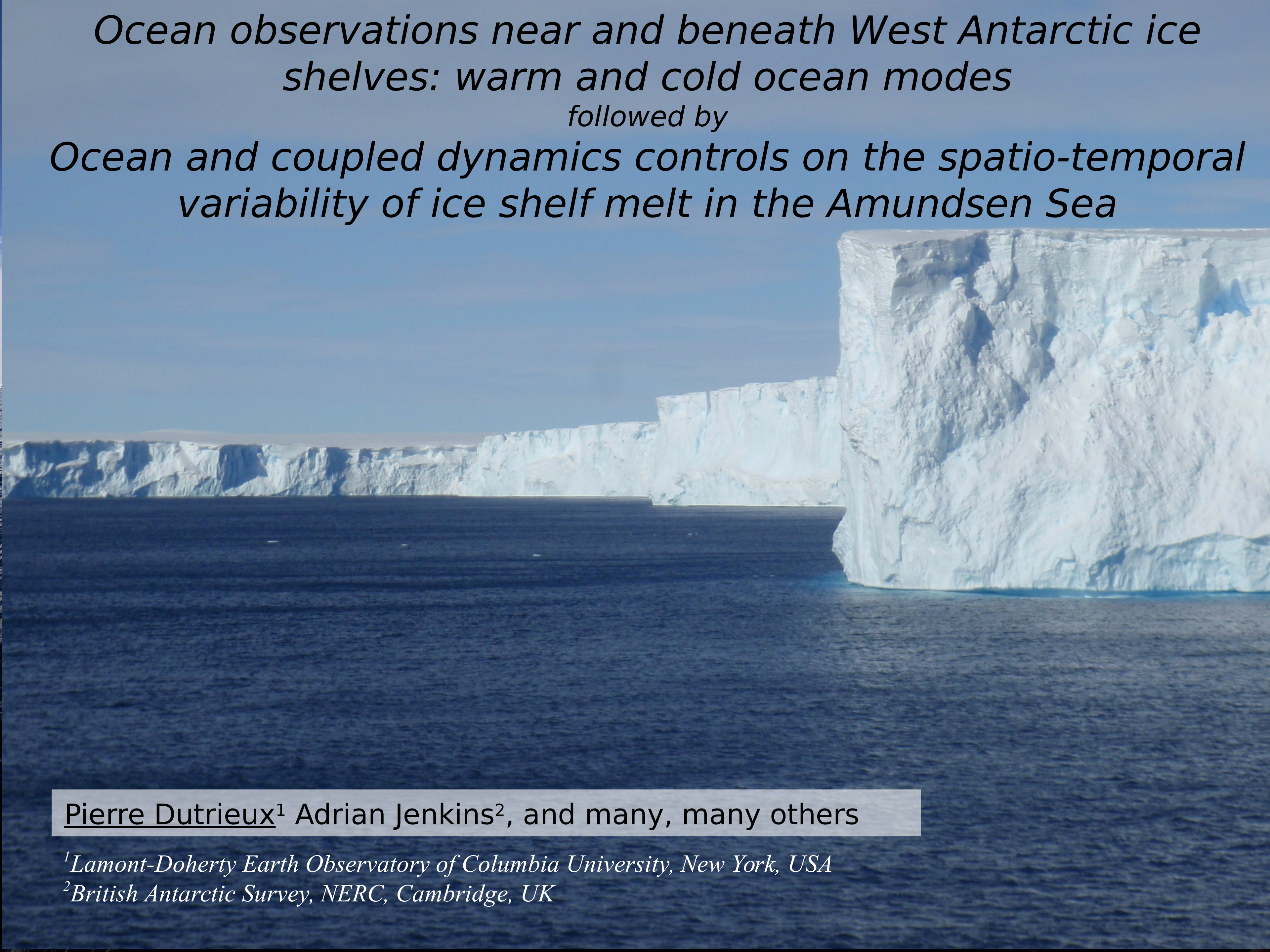
Ocean observations near and beneath West Antarctic ice shelves: warm and cold ocean modes

followed by

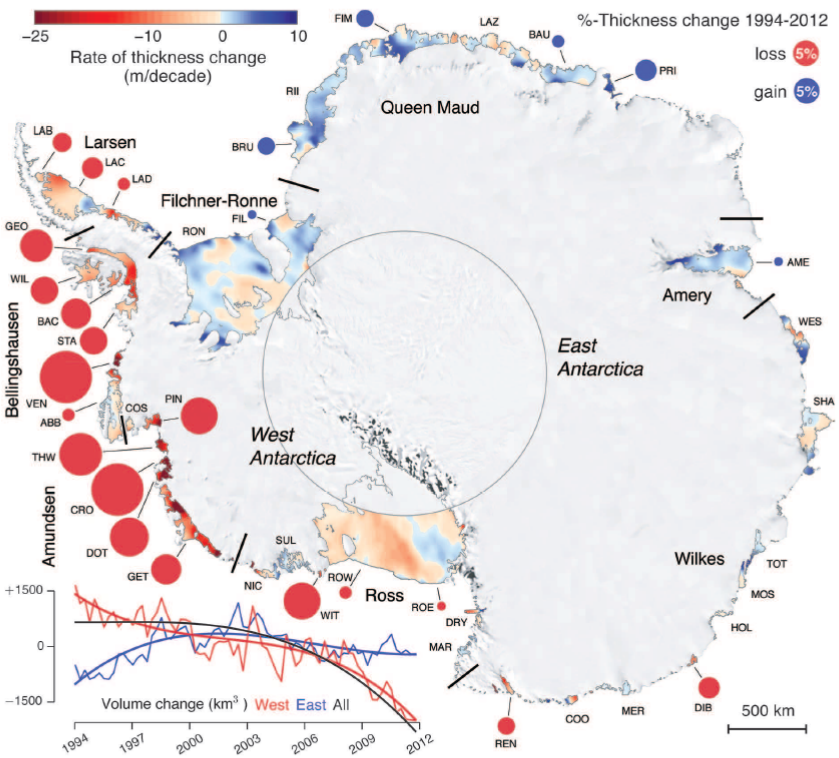
Ocean and coupled dynamics controls on the spatio-temporal variability of ice shelf melt in the Amundsen Sea



Pierre Dutrieux[1] Adrian Jenkins[2], and many, many others

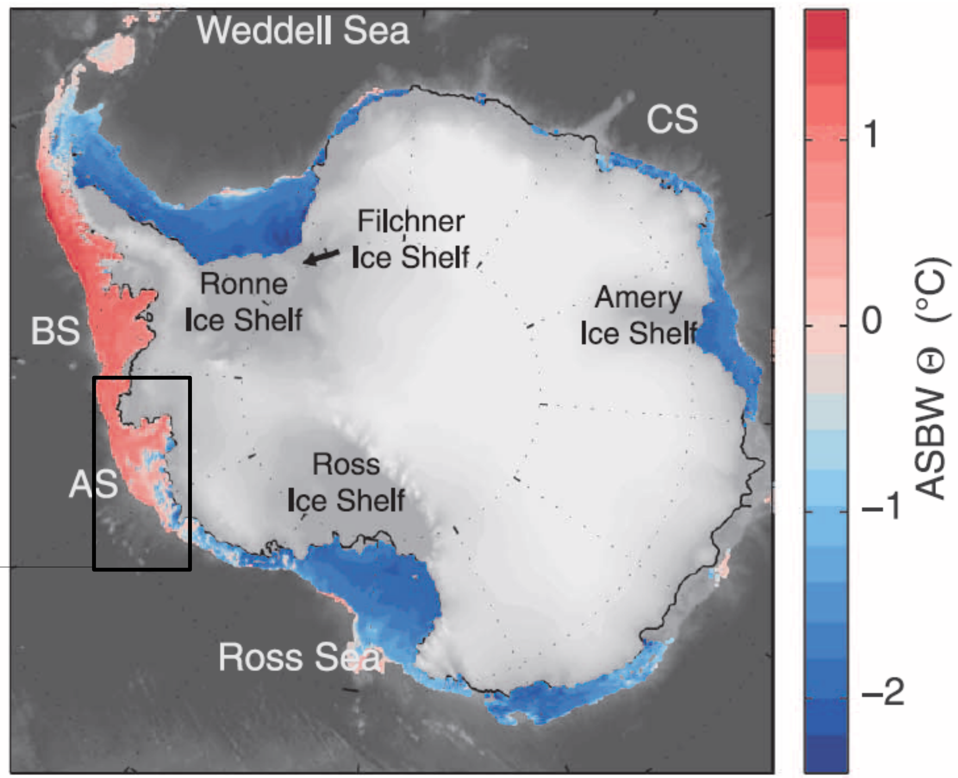
[1]*Lamont-Doherty Earth Observatory of Columbia University, New York, USA*

[2]*British Antarctic Survey, NERC, Cambridge, UK*

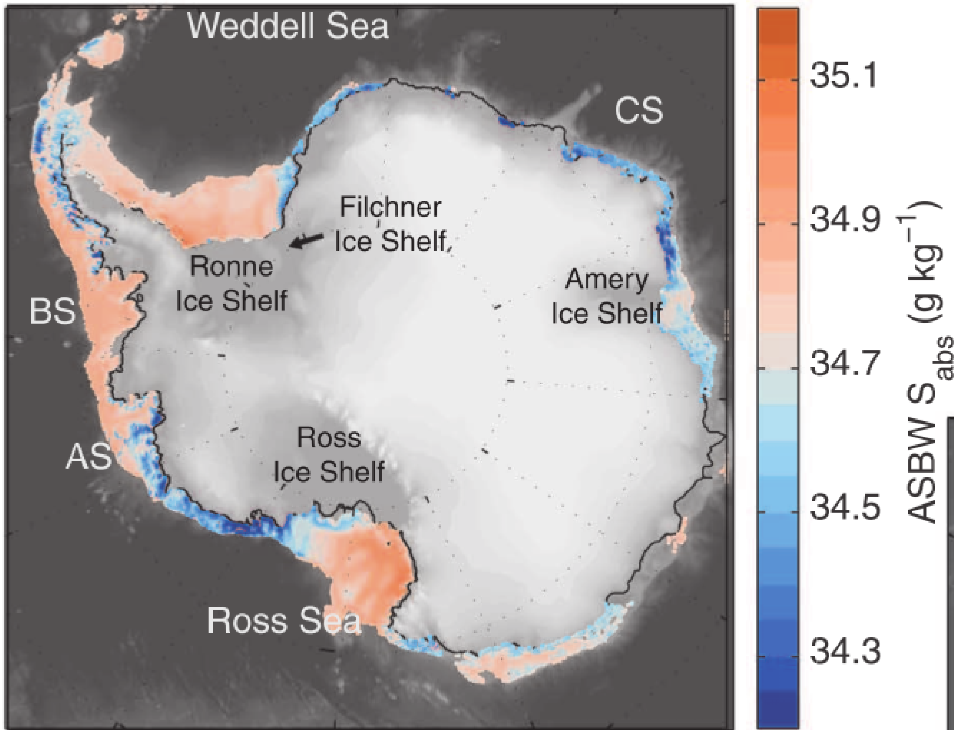


18 years ice shelf thickness change
[*Paolo et al,* 2015]

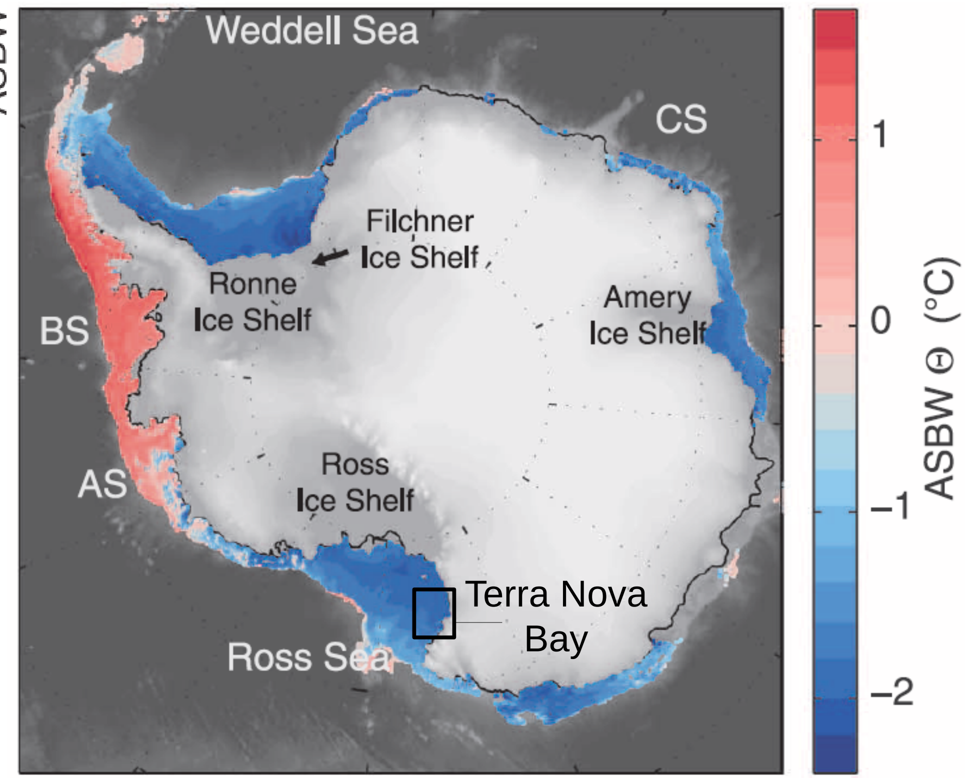
Amundsen Sea



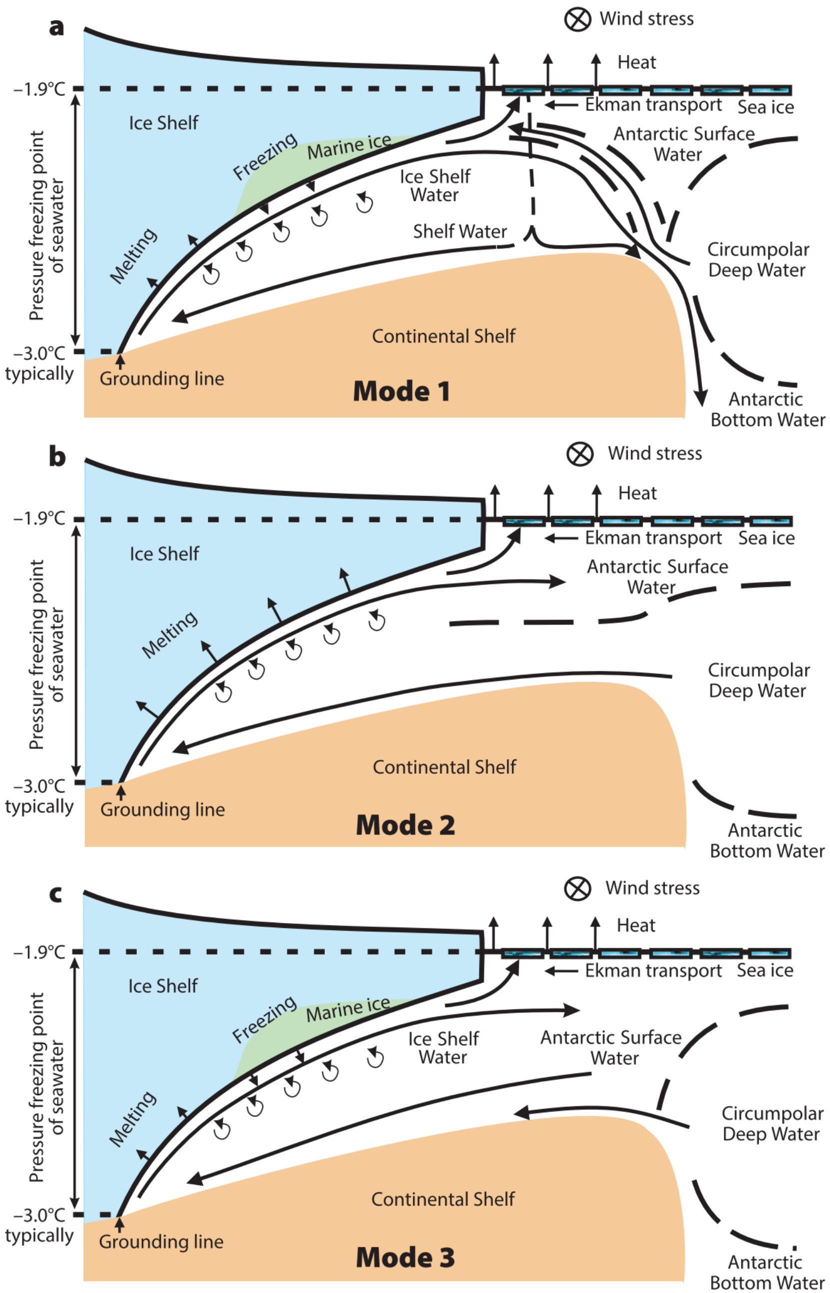
Near seabed water temperature
[Schmitdko *et al,* 2014]



Near seabed salinity
[Schmitdko *et al,* 2014]

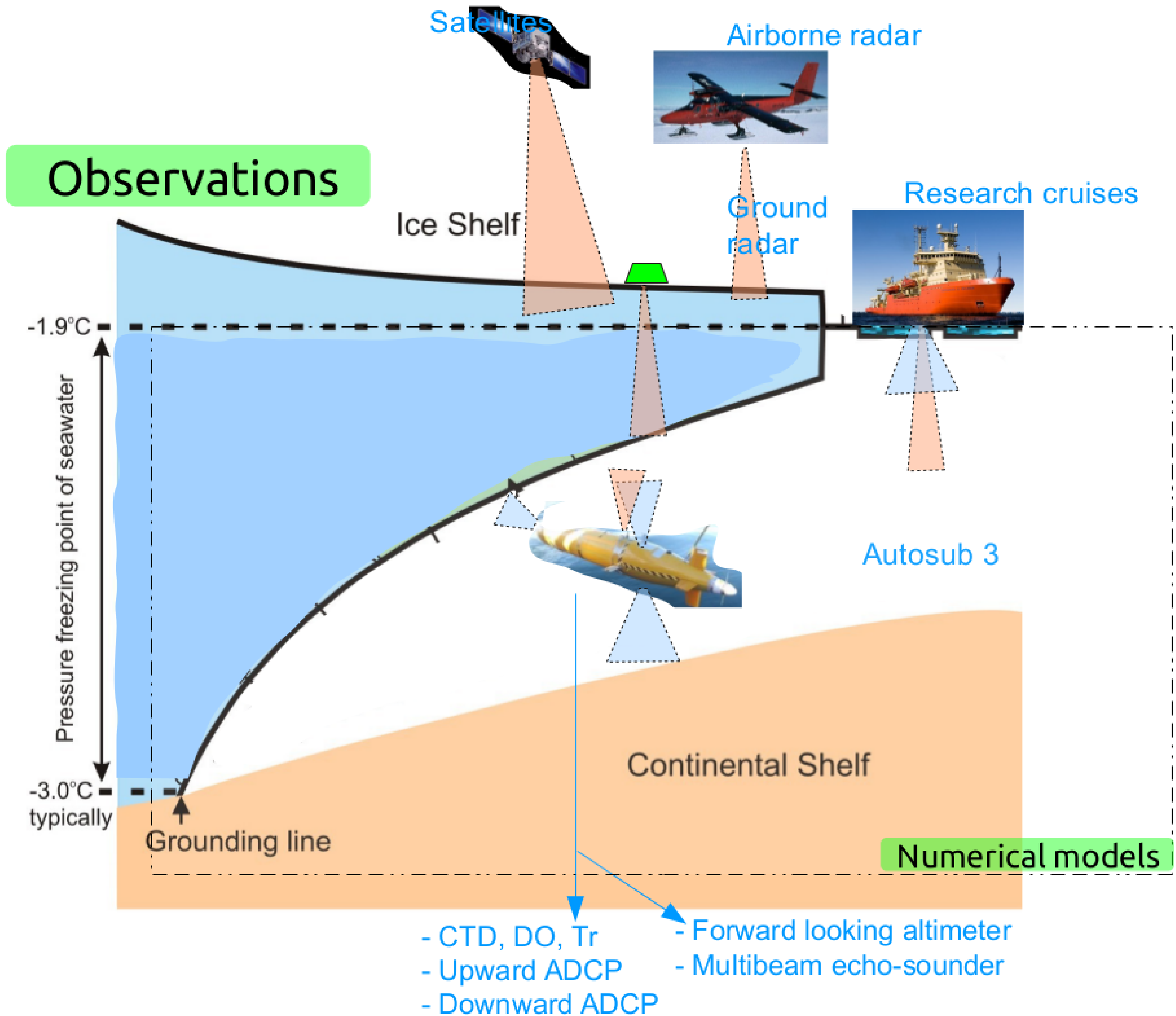


Near seabed water temperature
[Schmitdko *et al,* 2014]



←Terra Nova Bay ice shelves

←Amundsen Sea ice shelves

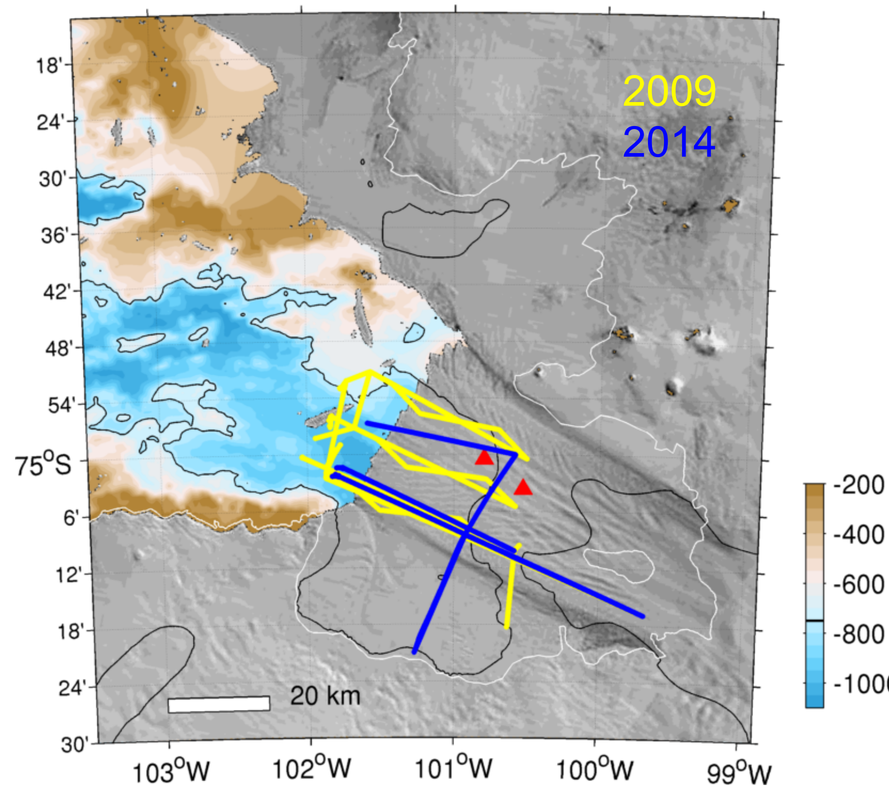


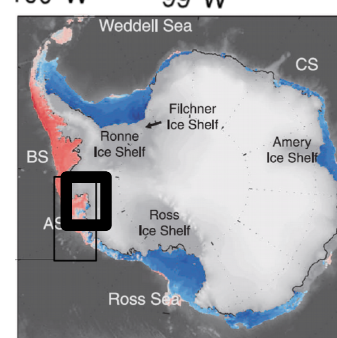
Satellites
Airborne radar
Observations
Ice Shelf
Ground radar
Research cruises
-1.9°C
Pressure freezing point of seawater
Autosub 3
Continental Shelf
-3.0°C
typically
Grounding line
Numerical models
- CTD, DO, Tr
- Upward ADCP
- Downward ADCP
- Forward looking altimeter
- Multibeam echo-sounder

‘Warm’ case: observations in the Amundsen Sea

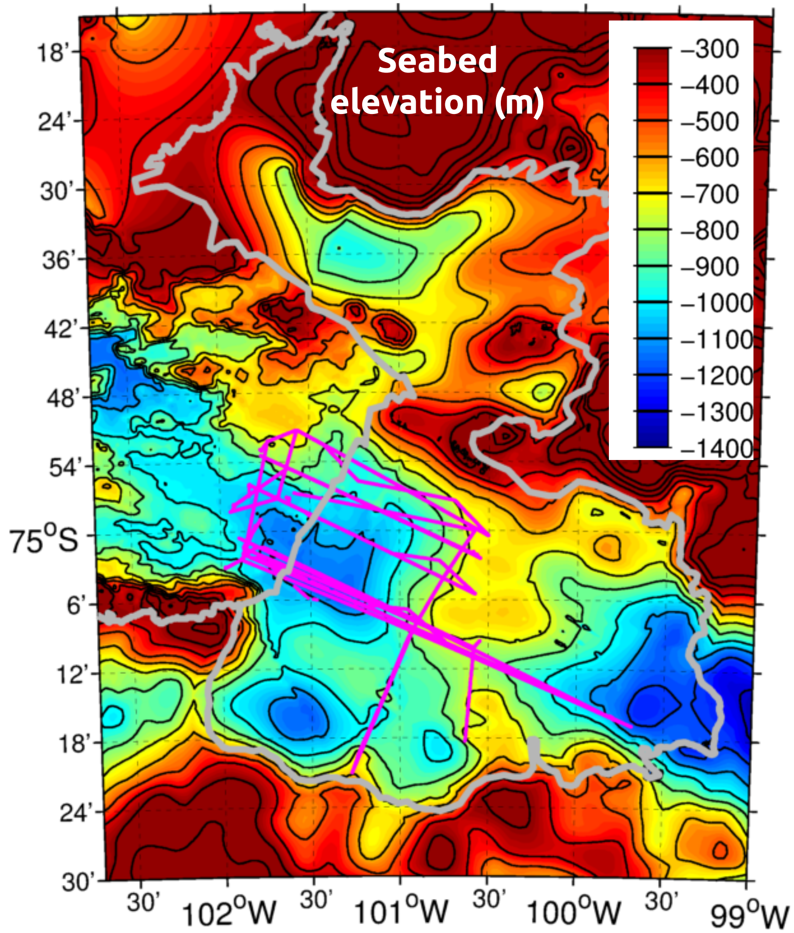
Photo © Maria Stenzel

2009 and 2014 missions

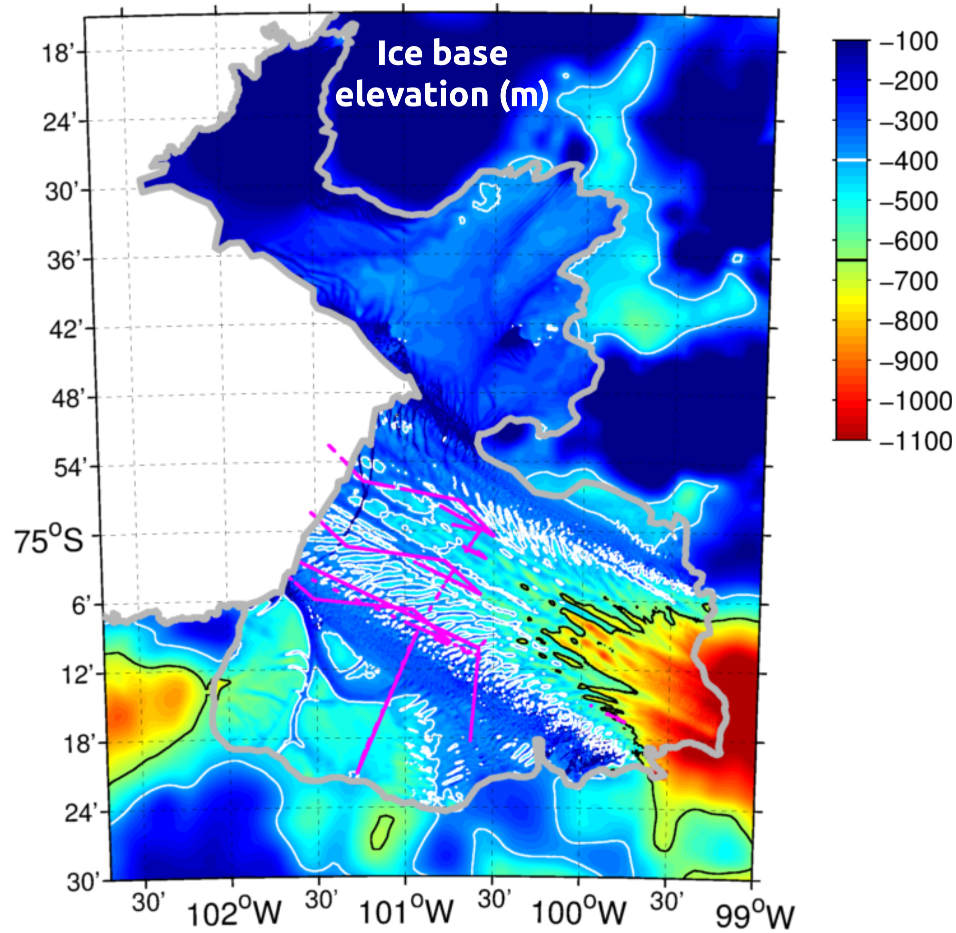




Upgraded geometry



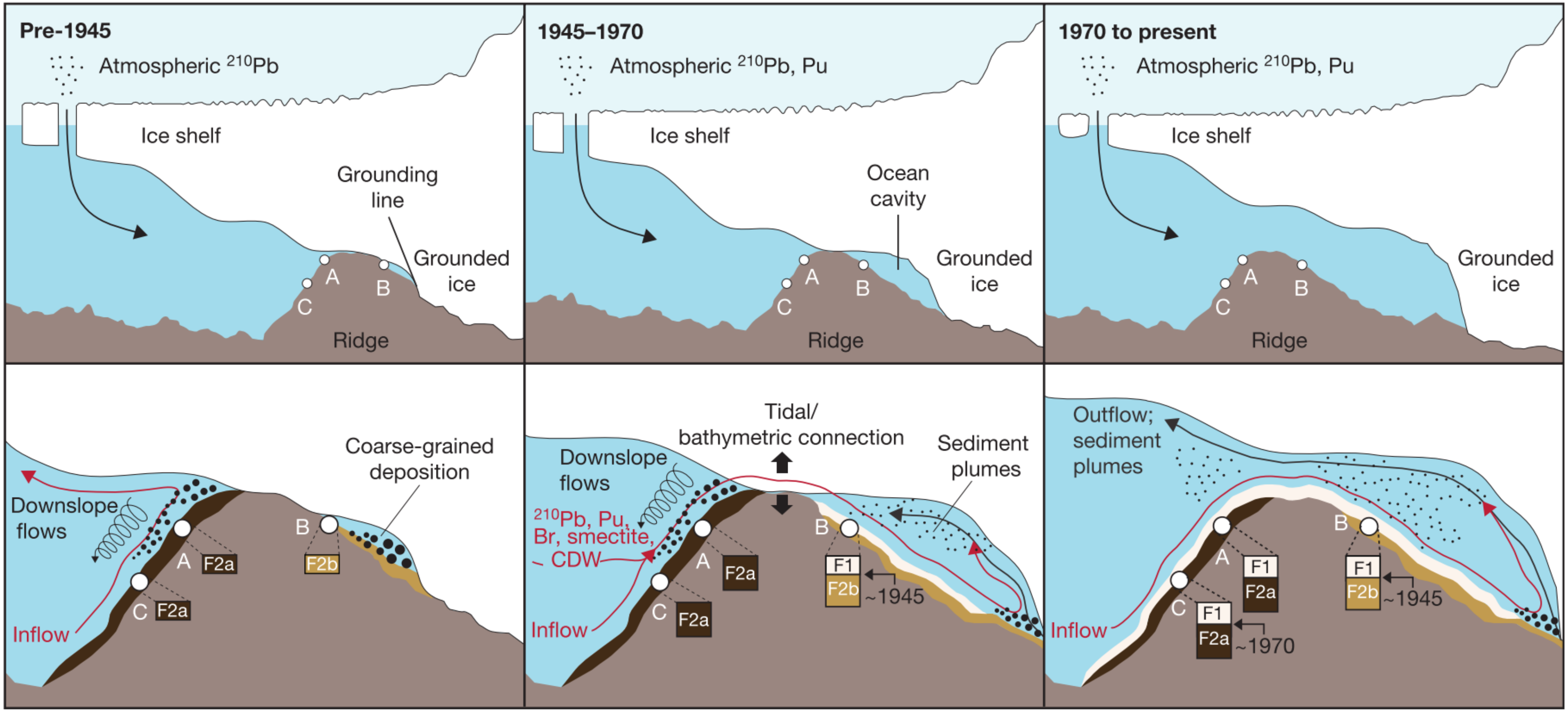
✔Icebridge Gravimetry
✔Autosub 2009 and 2014
✔BEDMAP2
✔Shipborne observations (F. Nitsche)



✔WorldView DEM 2012
✔Autosub 2009 and 2014
✔BEDMAP2

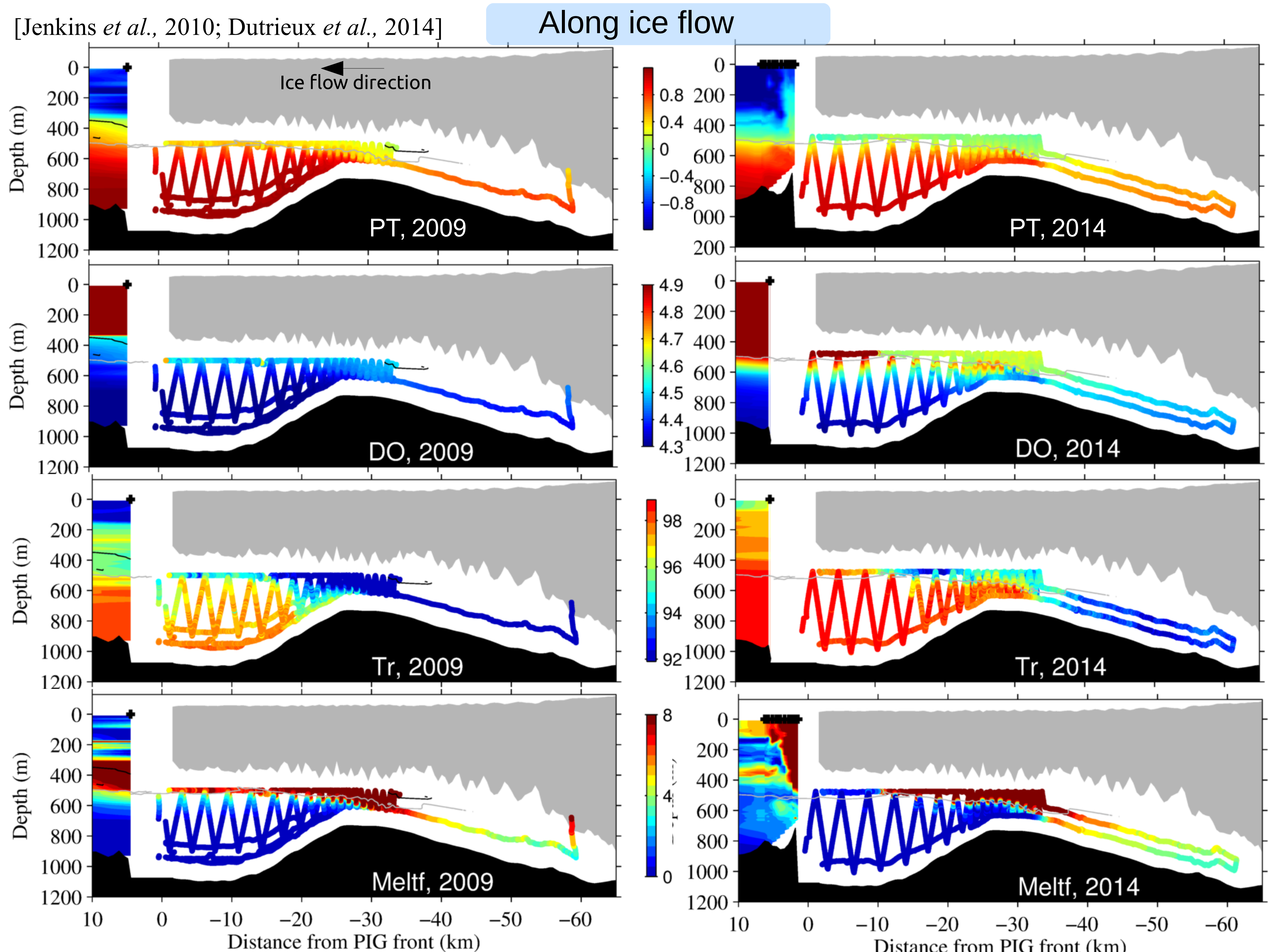
[Dutrieux *et al,* 2014; Muto *et al,* 2016; McMillan *et al,* 2017]

Upgraded scenario for ice shelf retreat

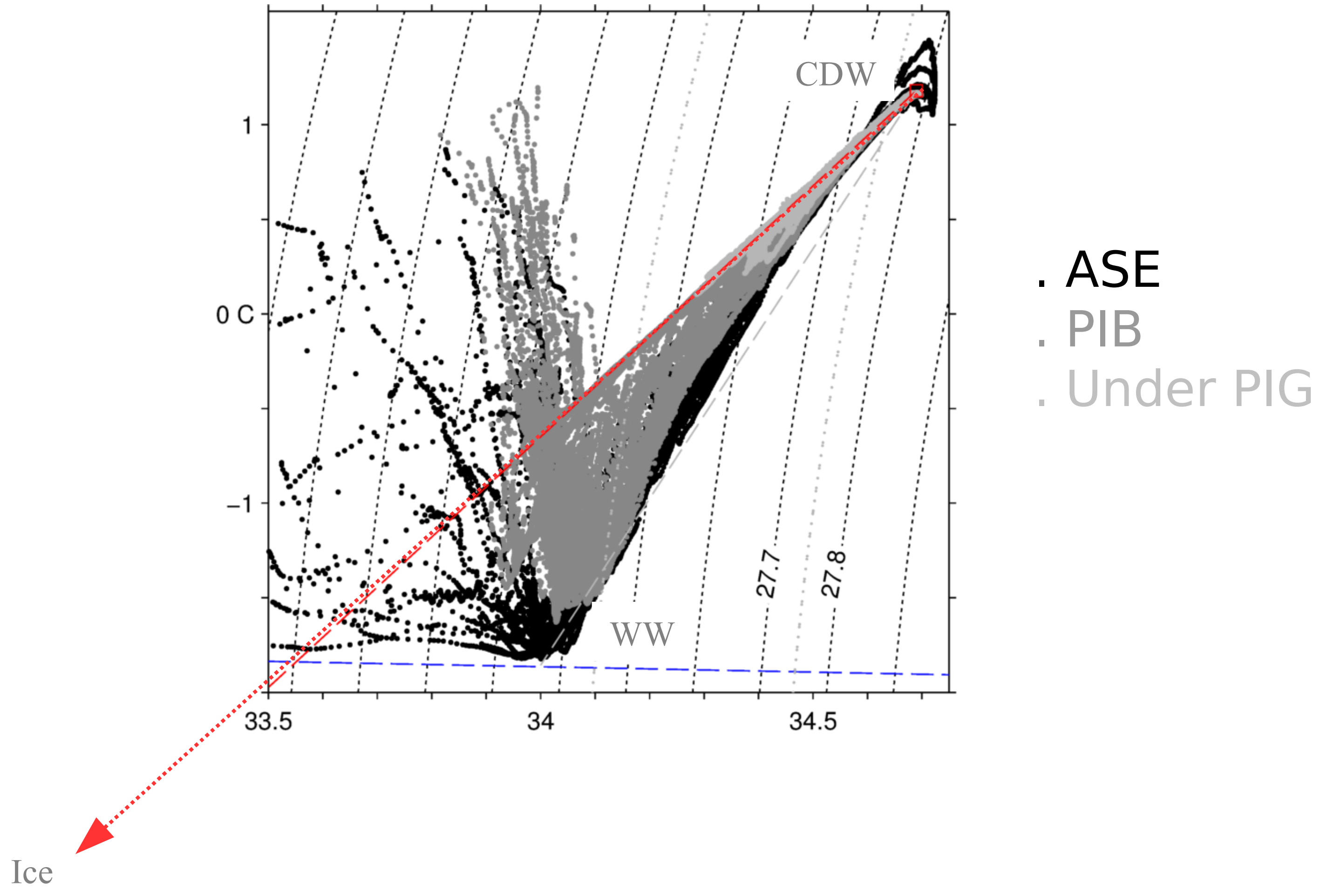


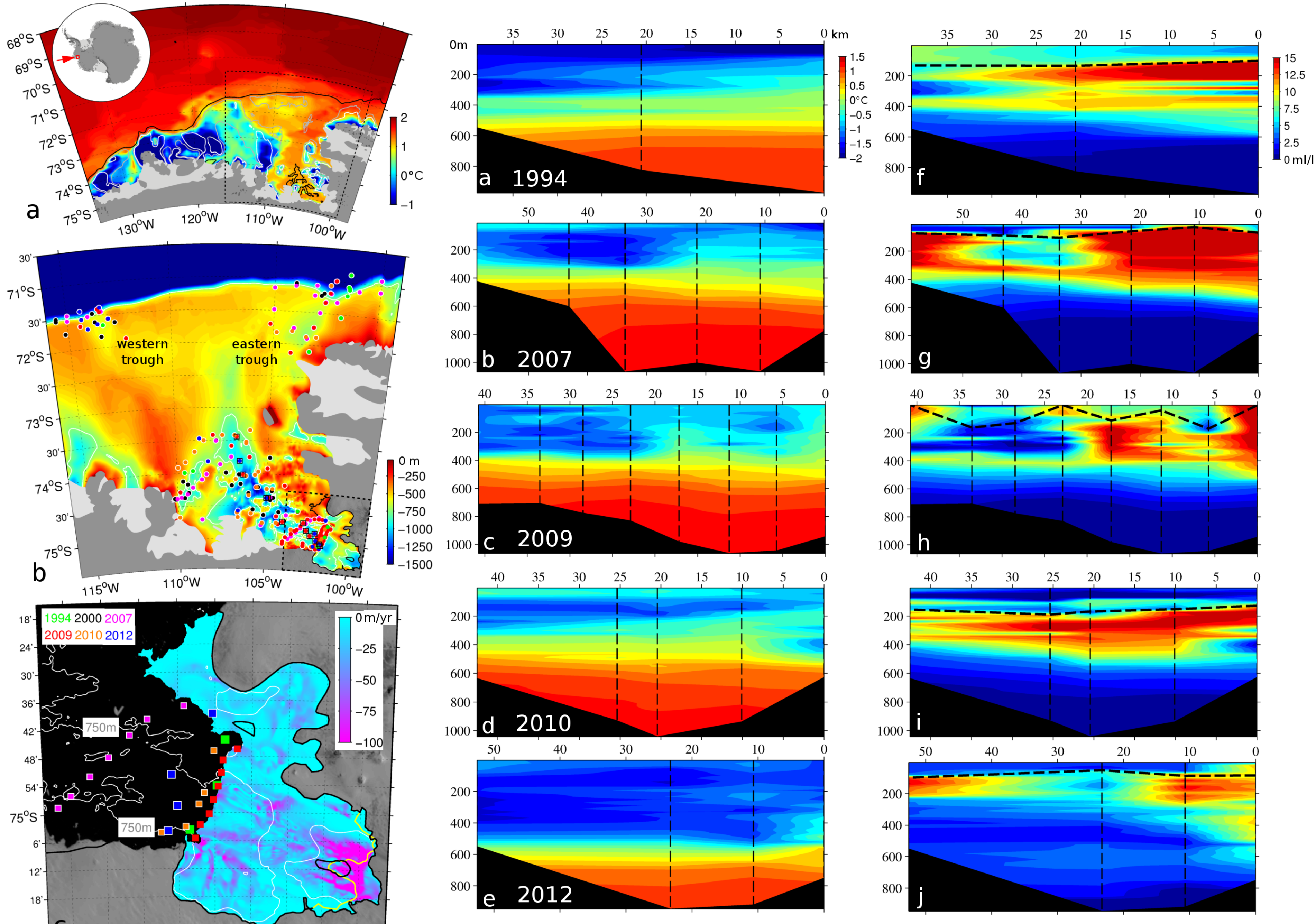
[Smith *et al,* 2016]

[Jenkins *et al.,* 2010; Dutrieux *et al.,* 2014]

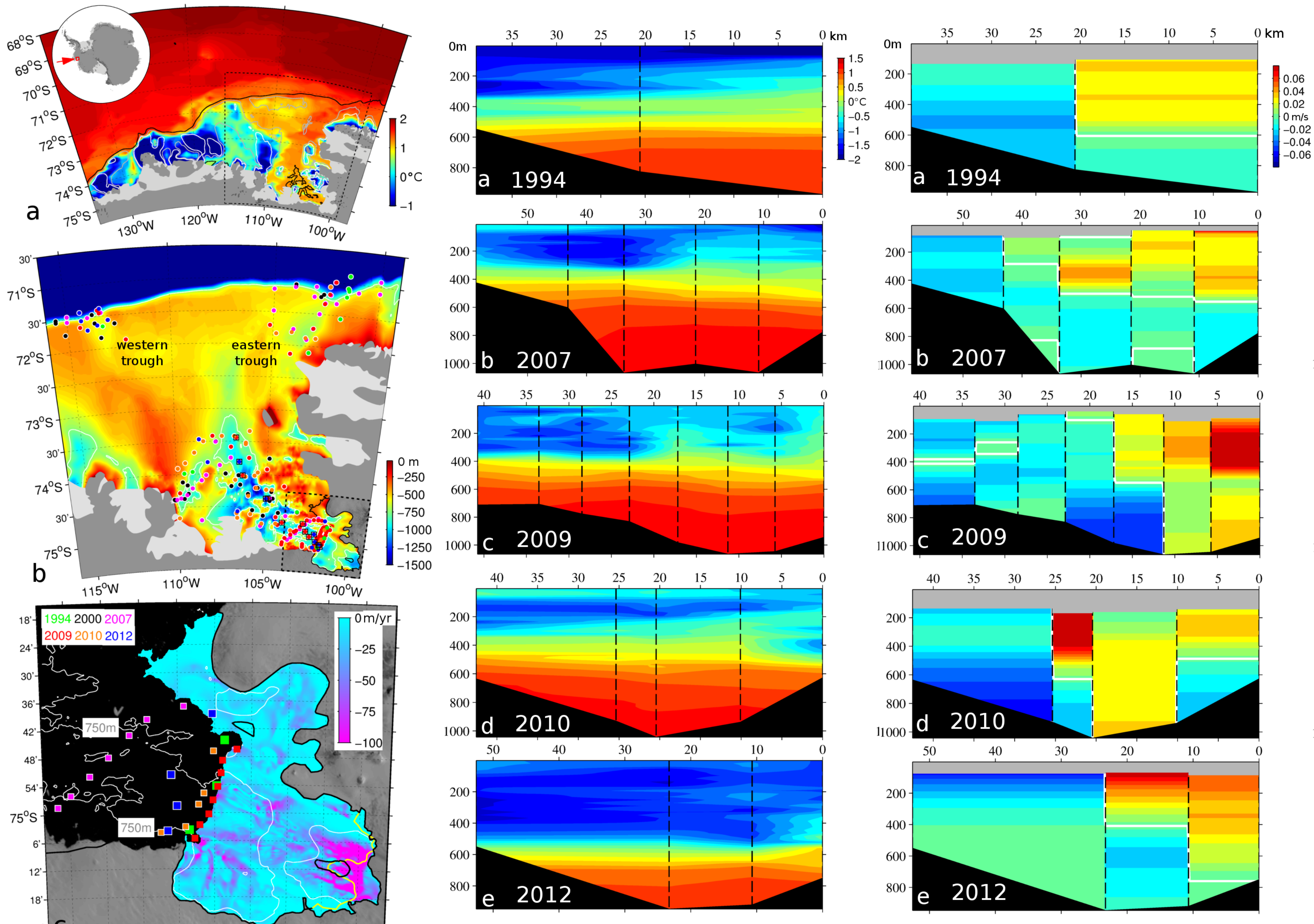


Ice shelf/ocean interaction signature





[Dutrieux et al., 2014]



[Dutrieux et al., 2014]

Net melt volume loss rates from the main trunk:

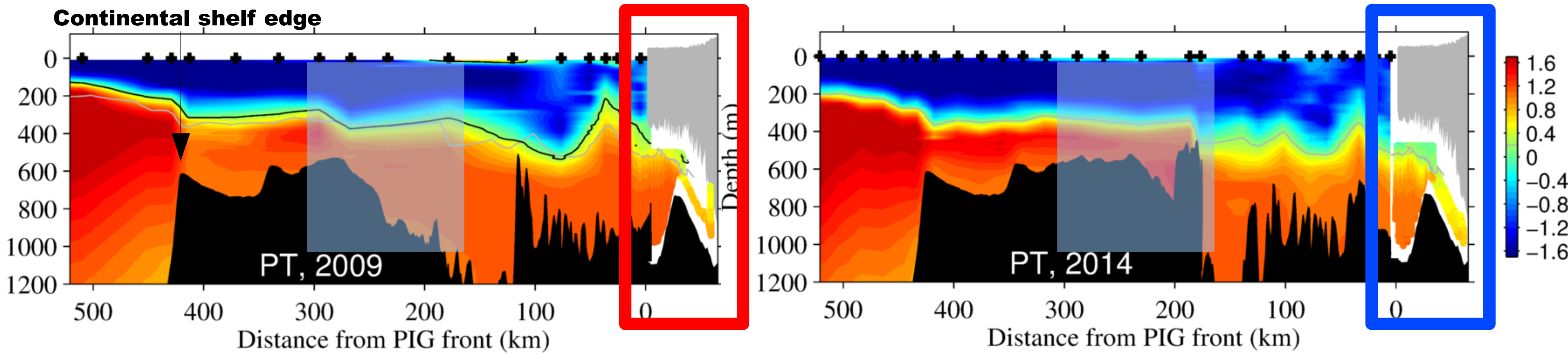
1994: -51±7 km³/yr

2009: −80±10 km³/yr

2010: -75±10 km³/yr

2012: -37±5 km³/yr !

2014: -65±5 km³/yr



- Ocean circulation tightly controlled by cavity geometry under the ice shelf;
- Vigorous melt-induced circulation, reaching upwards of 50 cm/s;
- Variable ocean heat content modulates ice shelf melt;

‘Warm’ case: observations in the Amundsen Sea

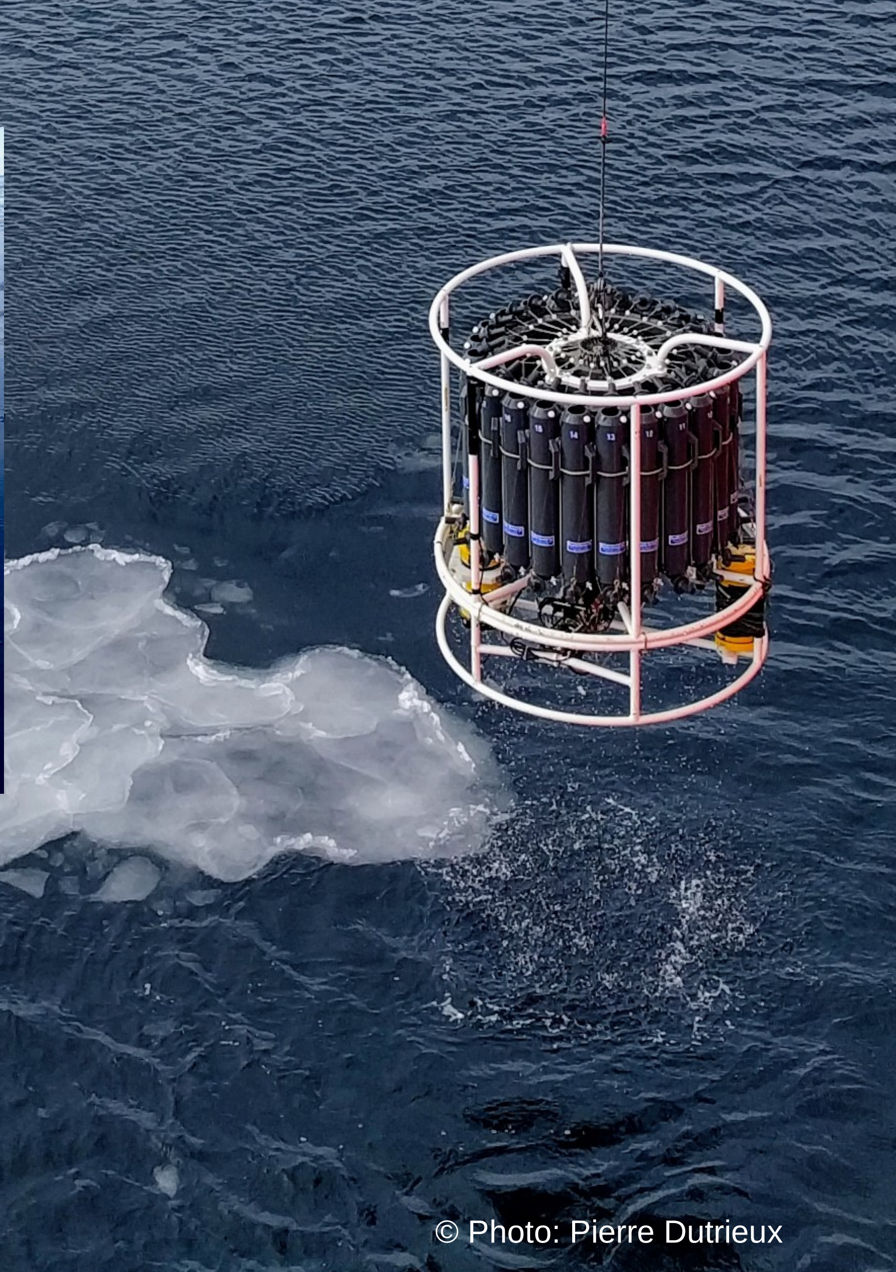
Photo © Maria Stenzel

‘Cold’ case: observations in Terra Nova Bay
ANA07 cruise

© Photo: Pierre Dutrieux

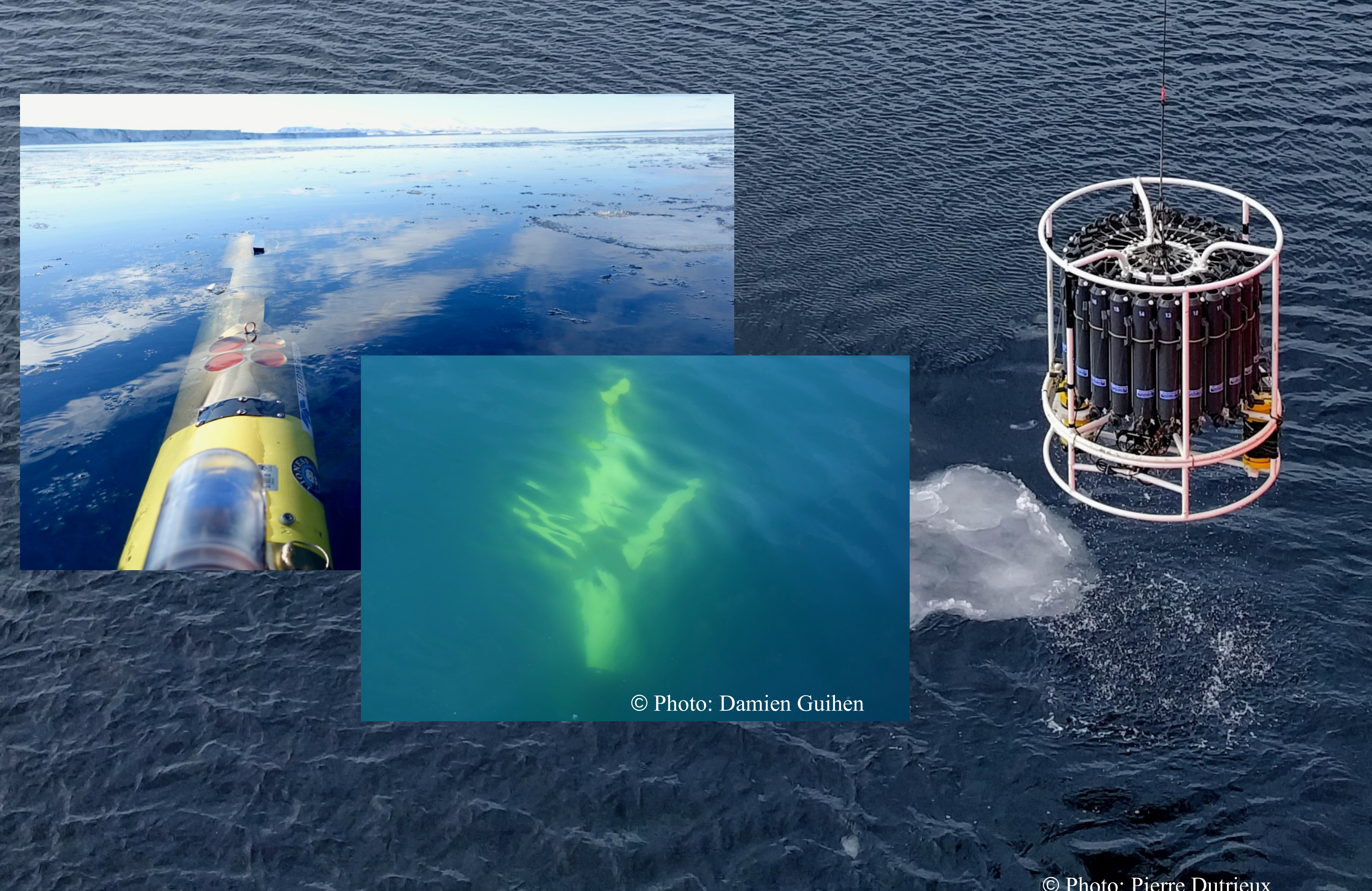
‘Cold’ case: observations in Terra Nova Bay
ANA07 cruise

© Photo: Damien Guihen



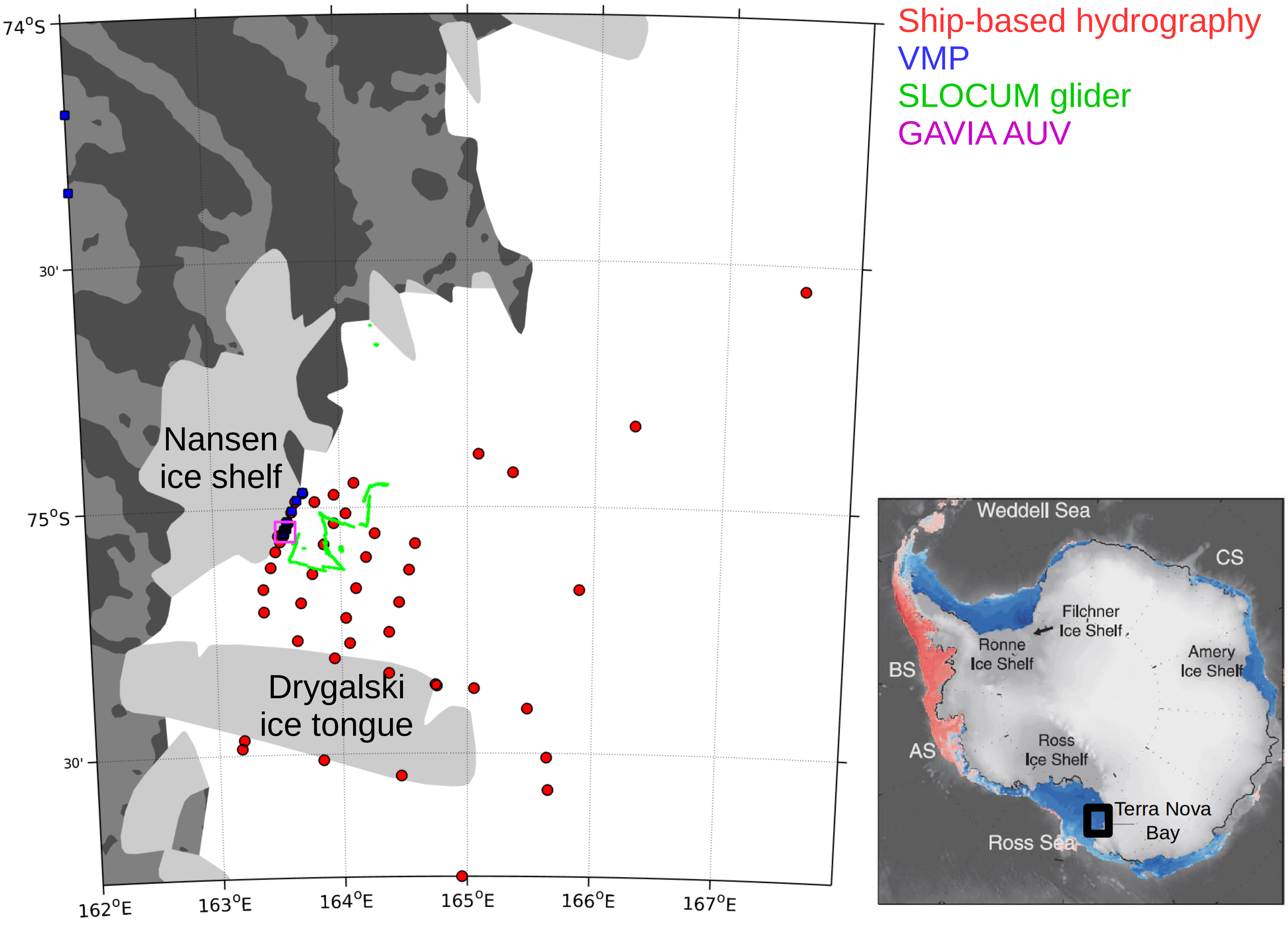
© Photo: Pierre Dutrieux

‘Cold’ case: observations in Terra Nova Bay
ANA07 cruise

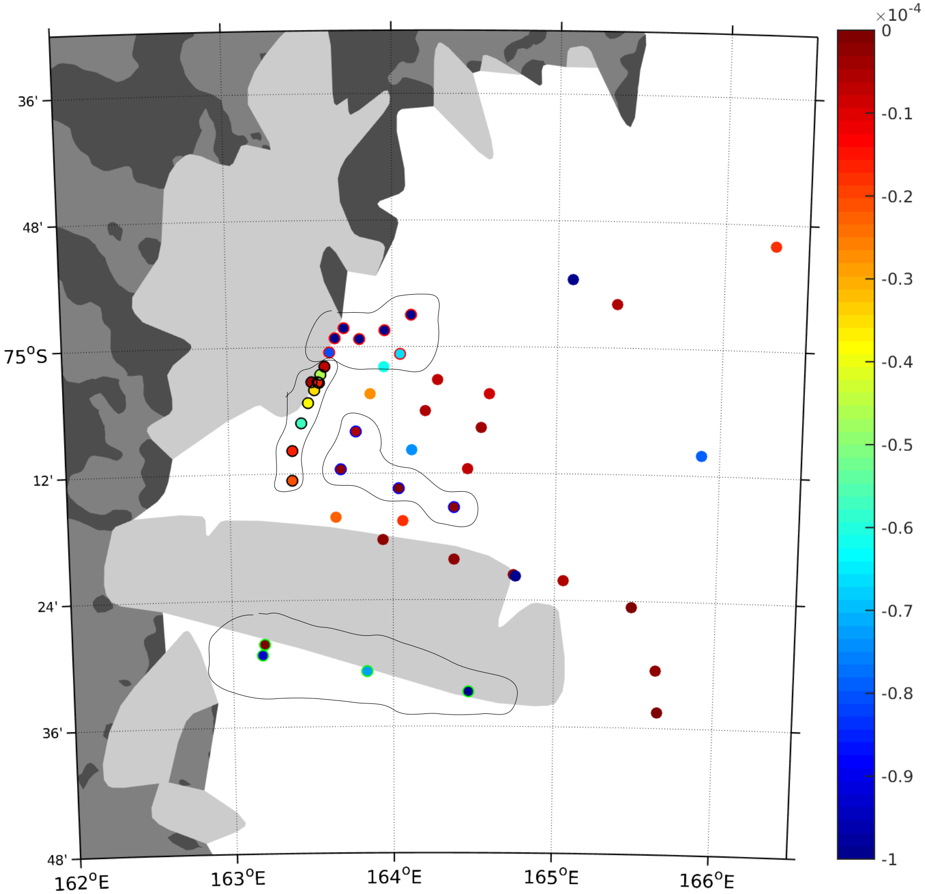


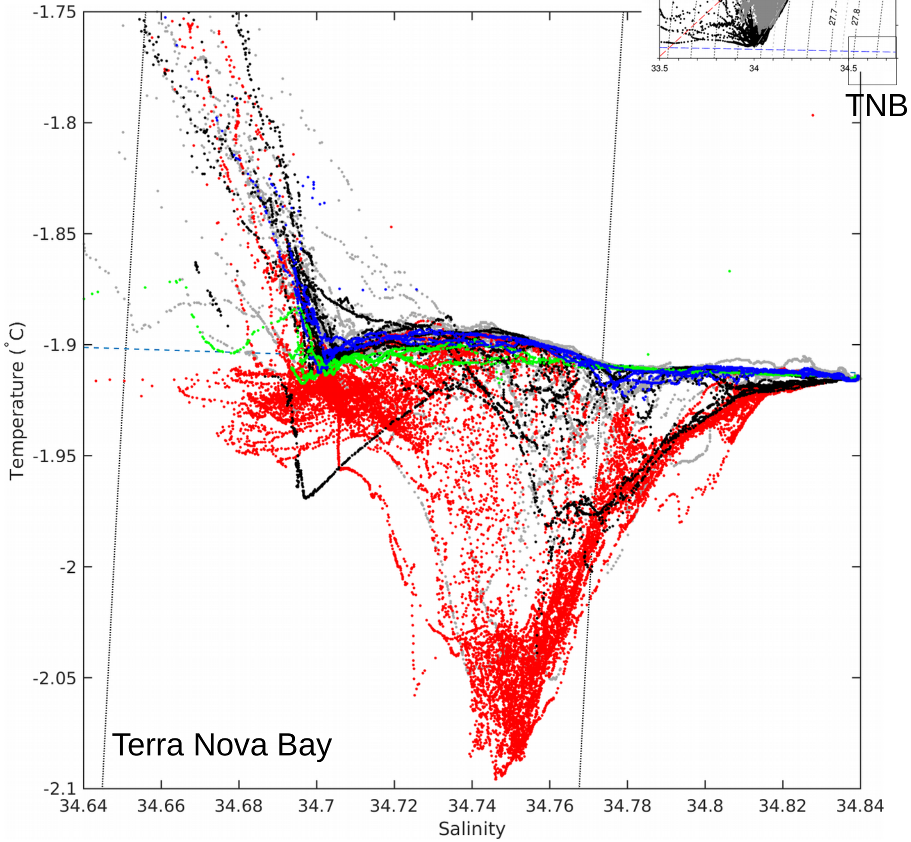
© Photo: Pierre Dutrieux

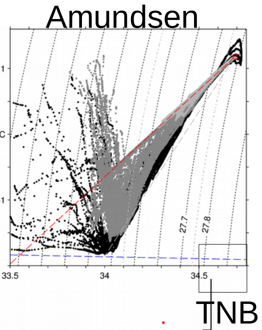
‘Cold’ case: observations in Terra Nova Bay
ANA07 cruise

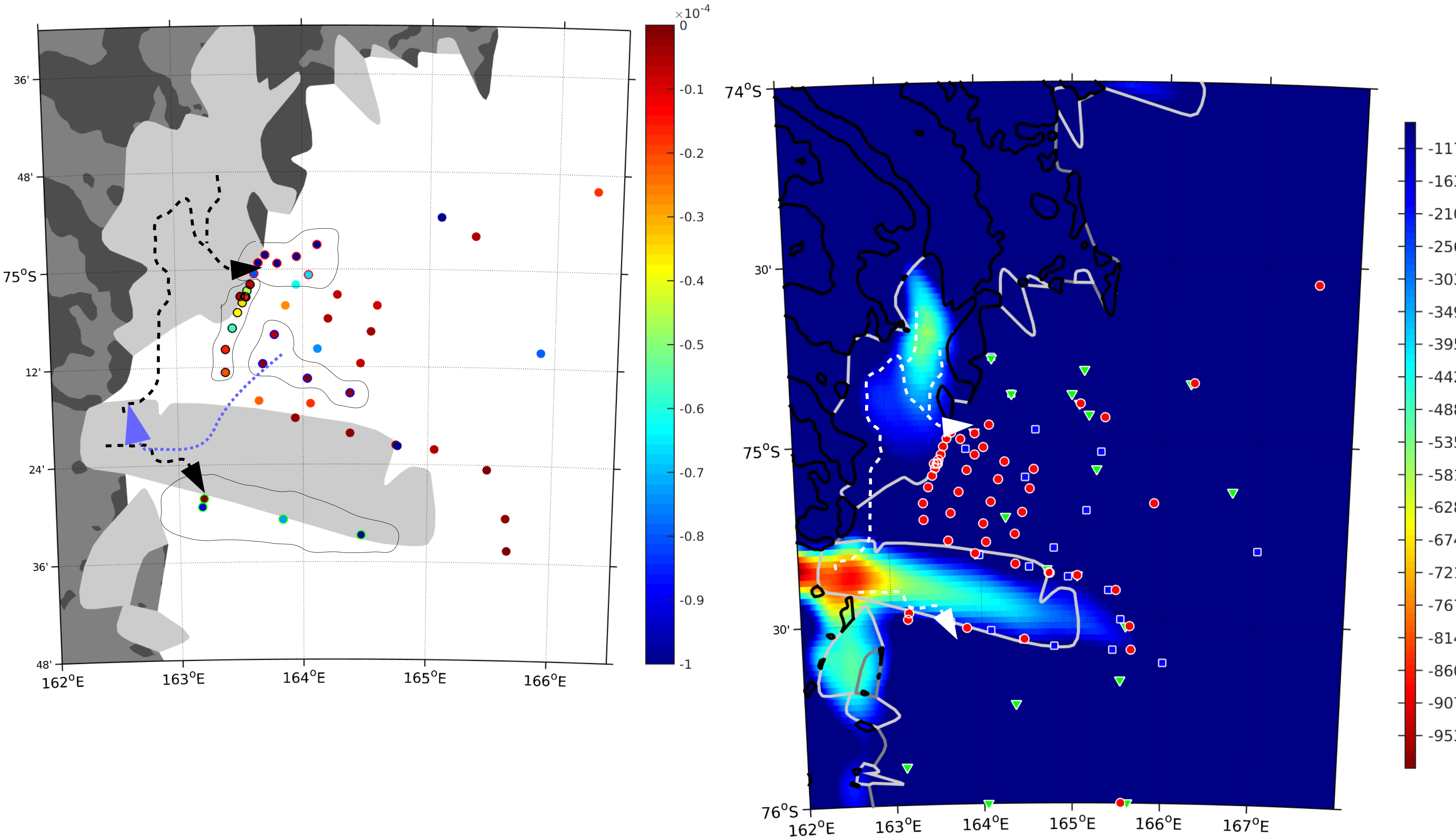

Ship-based hydrography
VMP
SLOCUM glider
GAVIA AUV
74°S
30'
75°S
30'
162°E
163°E
164°E
165°E
166°E
167°E
Nansen ice shelf
Drygalski ice tongue
Weddell Sea
CS
Filchner Ice Shelf
Ronne Ice Shelf
Amery Ice Shelf
BS
AS
Ross Ice Shelf
Terra Nova Bay
Ross Sea

Ice shelf melt water, spatial distribution and circulation



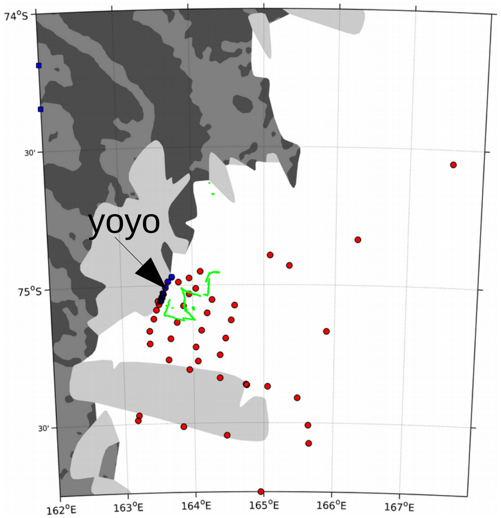




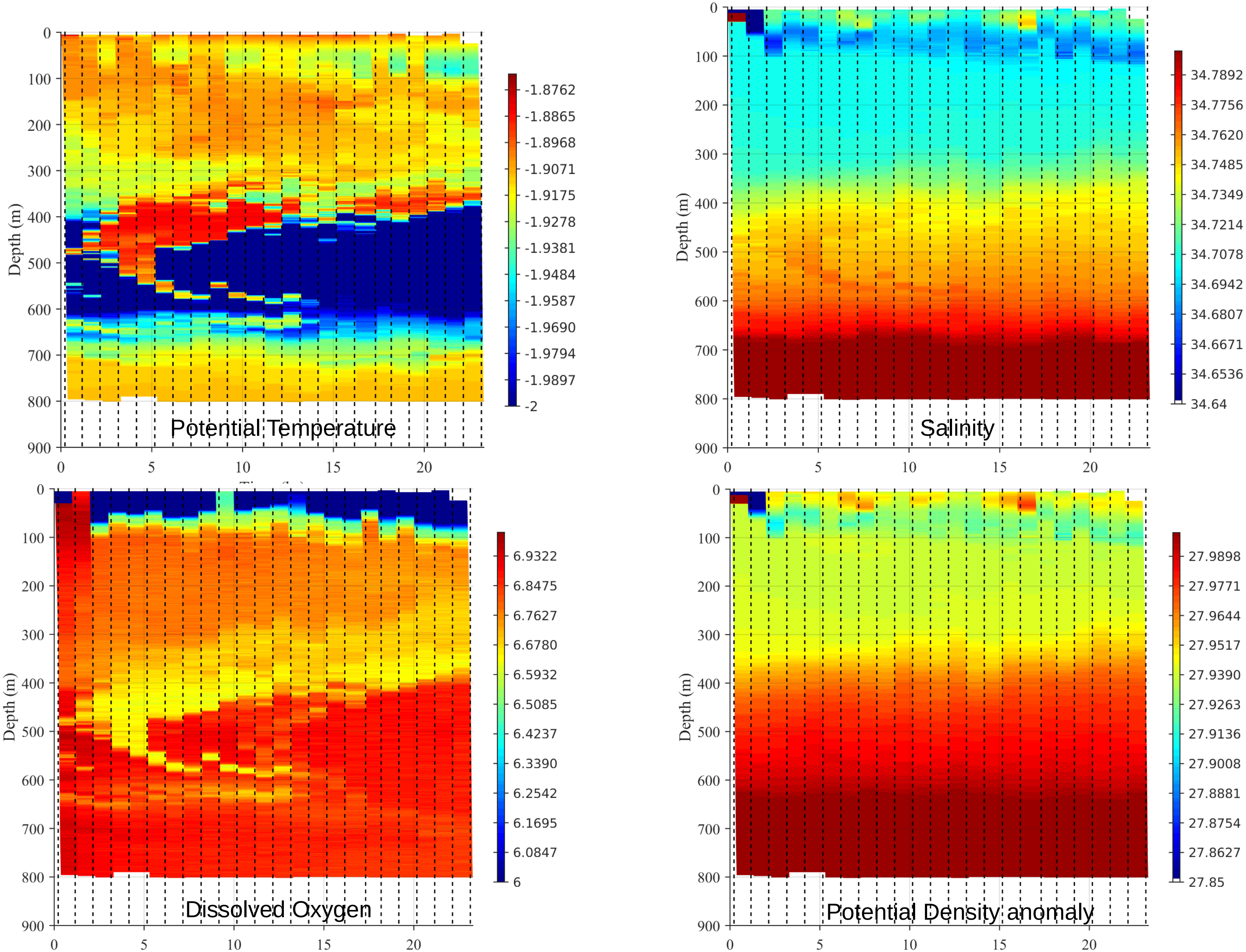


36'
48'
75°S
12'
24'
36'
48'
162°E
163°E
164°E
165°E
166°E
×10^-4
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
74°S
30'
75°S
30'
76°S
162°E
163°E
164°E
165°E
166°E
167°E
-117.
-163.
-210.
-256.
-303.
-349.
-395.
-442.
-488.
-535.
-581.
-628.
-674.
-721.
-767.
-814.
-860.
-907.
-953.

Temporal variability



Temporal variability, repeat and yoyo



- In Terra Nova Bay, minimal heat content reduced to effect of pressure on freezing point;
- Meltwater distribution traced as supercooled water, focused on ice shelves calving fronts;
- Tidal/inertial/high frequency modulation of meltwater outflow;
- Gale wind event impacts sea-ice formation and upper ocean properties;

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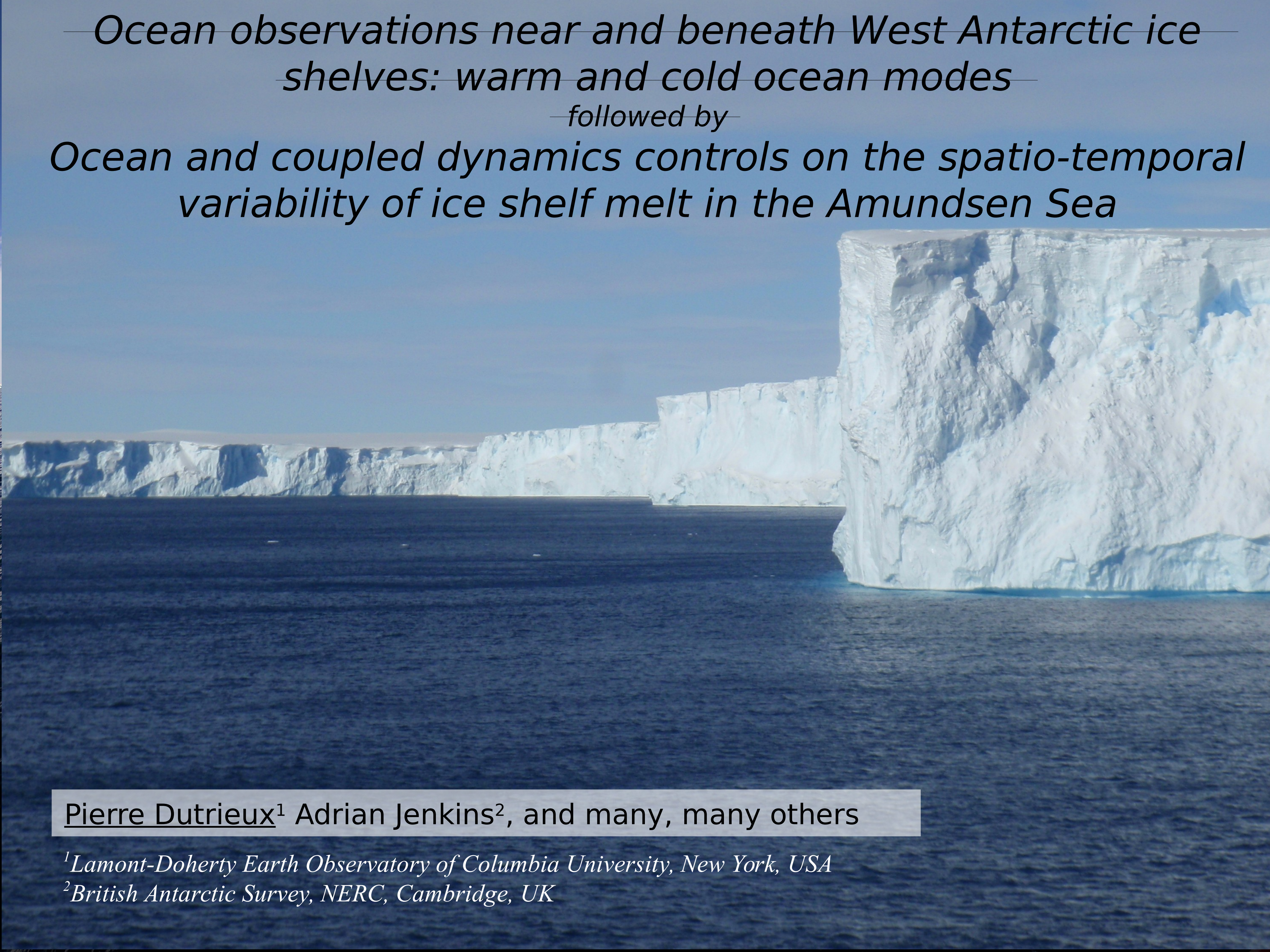
~~*followed by*~~

Ocean and coupled dynamics controls on the spatio-temporal variability of ice shelf melt in the Amundsen Sea



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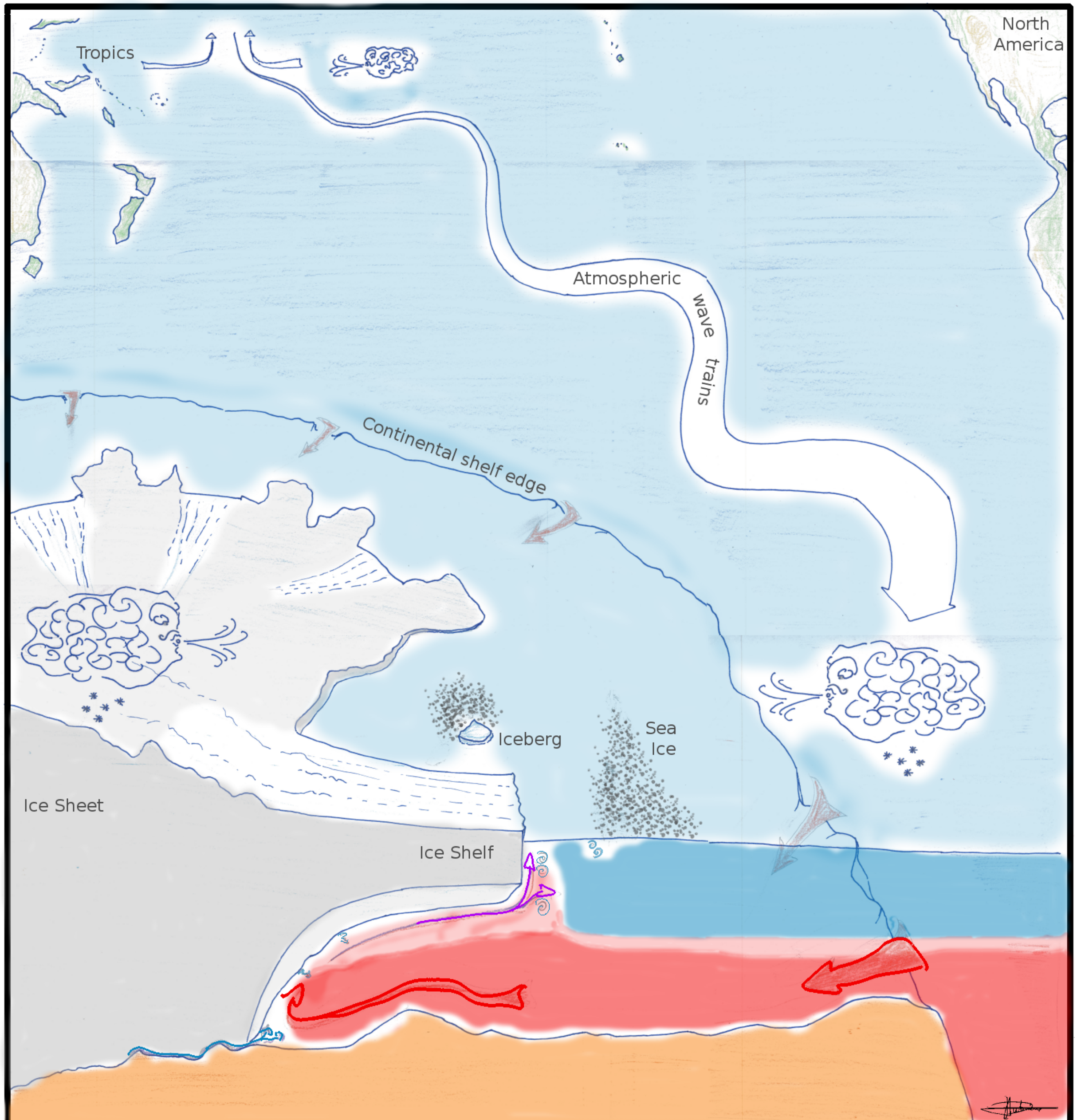
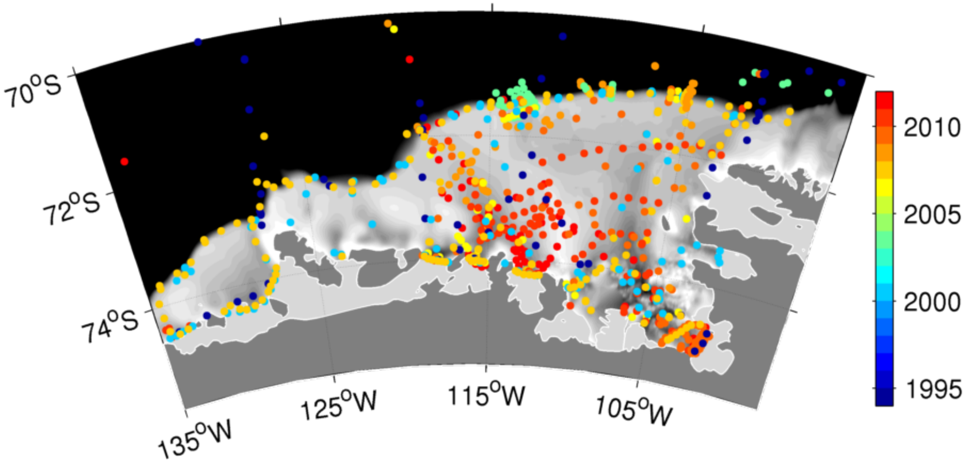
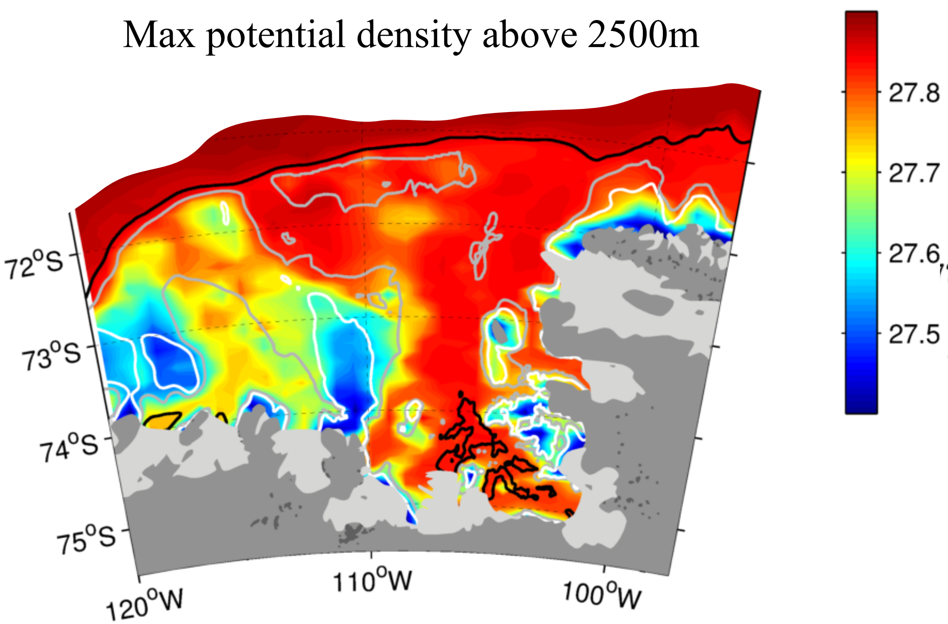


Tropics
North America
Atmospheric wave trains
Continental shelf edge
Iceberg
Sea Ice
Ice Sheet
Ice Shelf

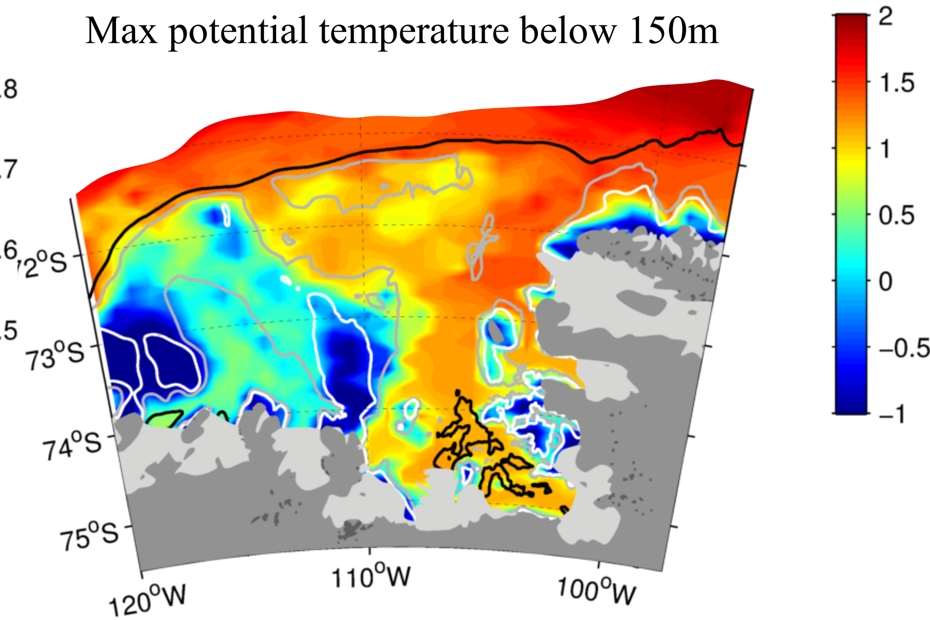
The Amundsen Sea

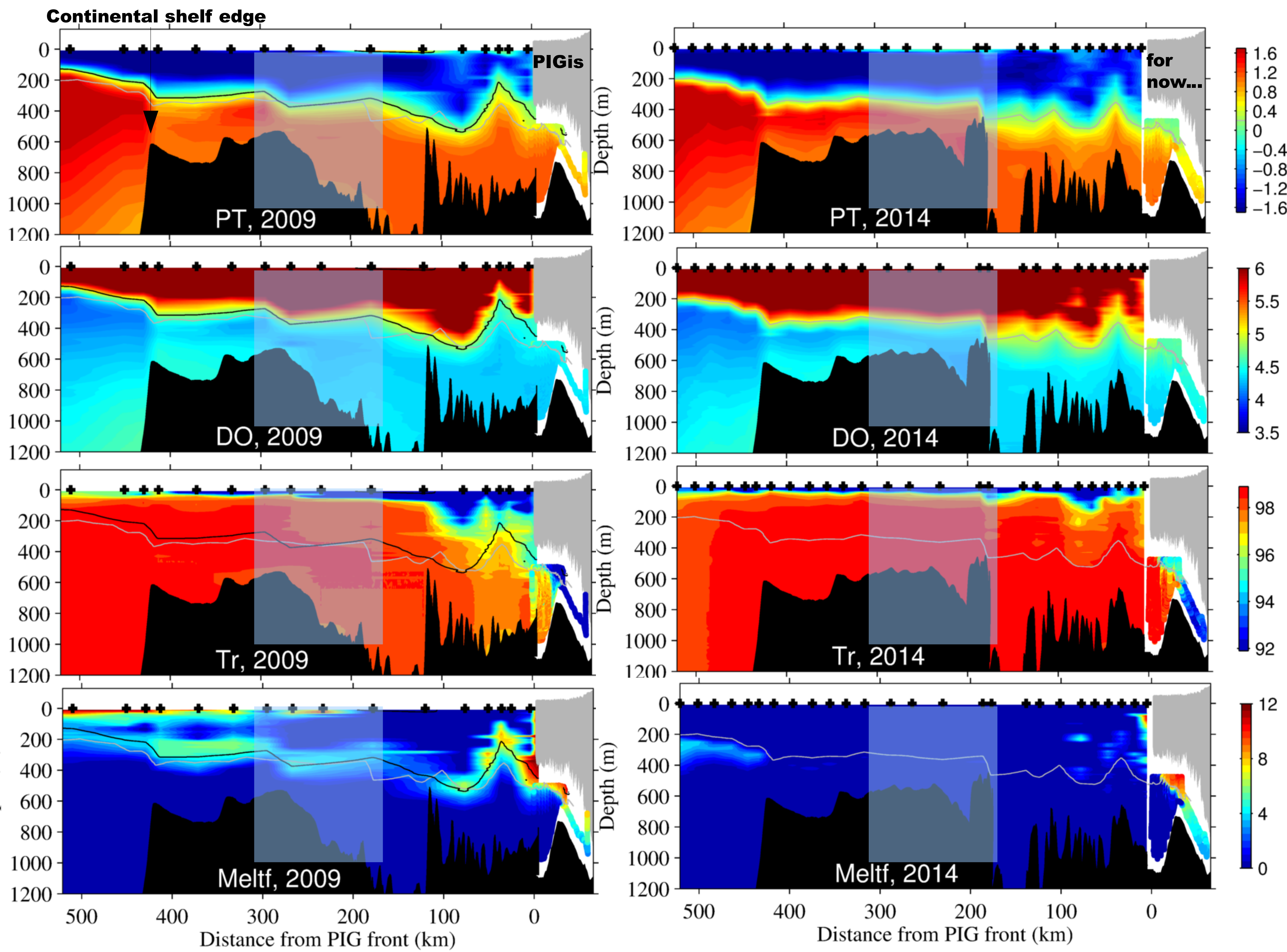


Max potential density above 2500m

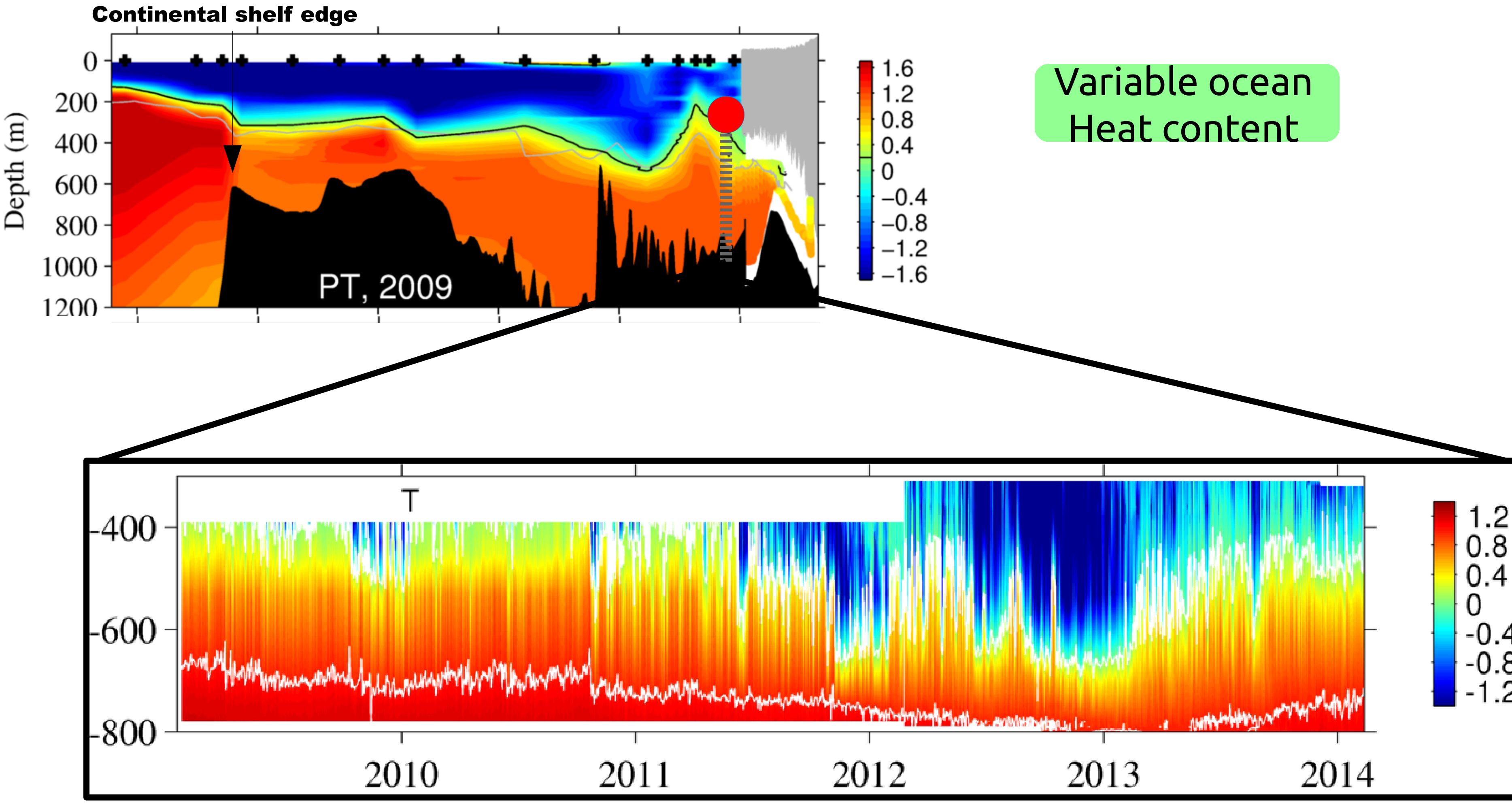


Max potential temperature below 150m



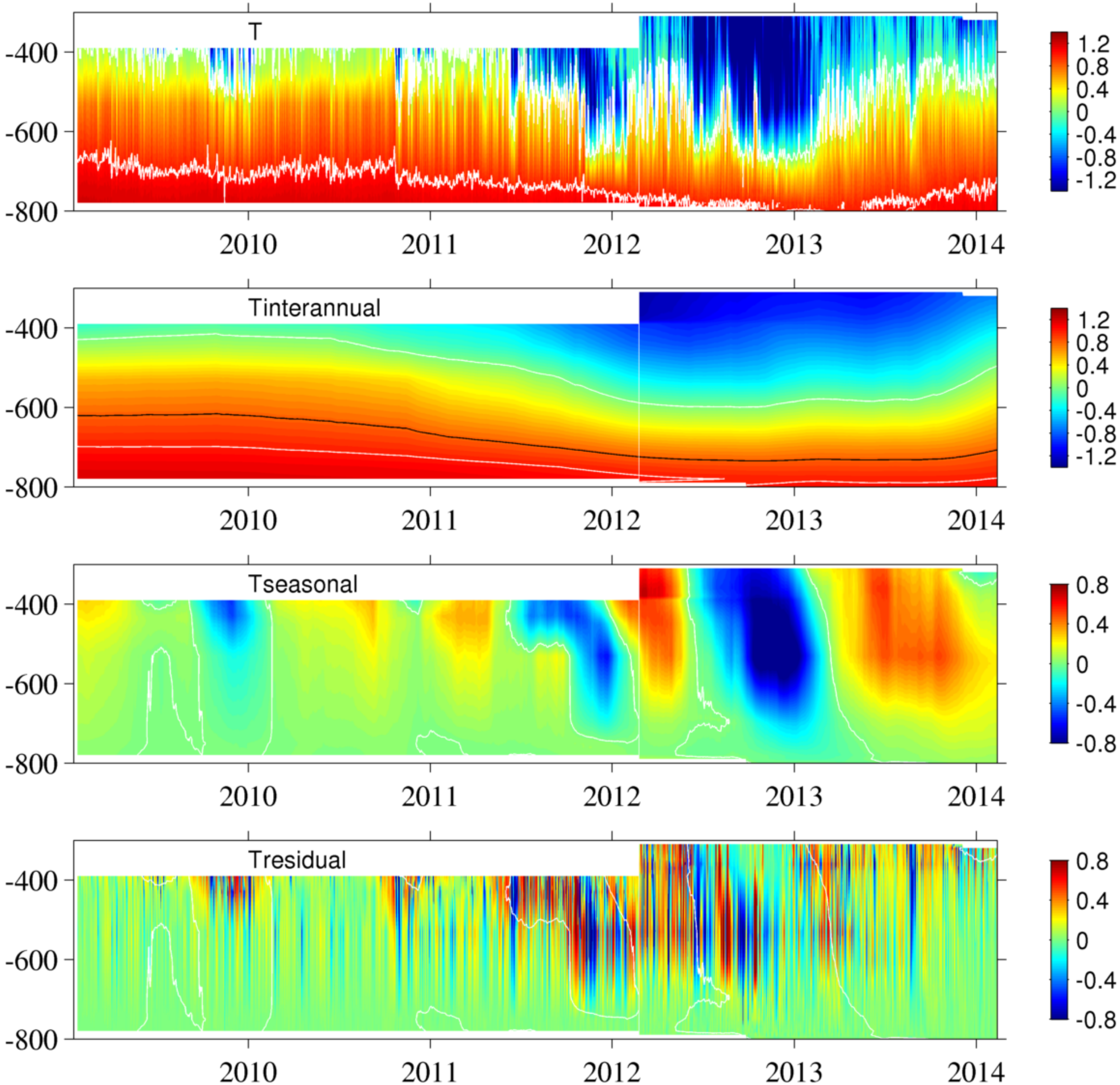


Continental shelf edge
PIGis
for now...
PT, 2009
PT, 2014
DO, 2009
DO, 2014
Tr, 2009
Tr, 2014
Meltf, 2009
Meltf, 2014
Depth (m)
Distance from PIG front (km)

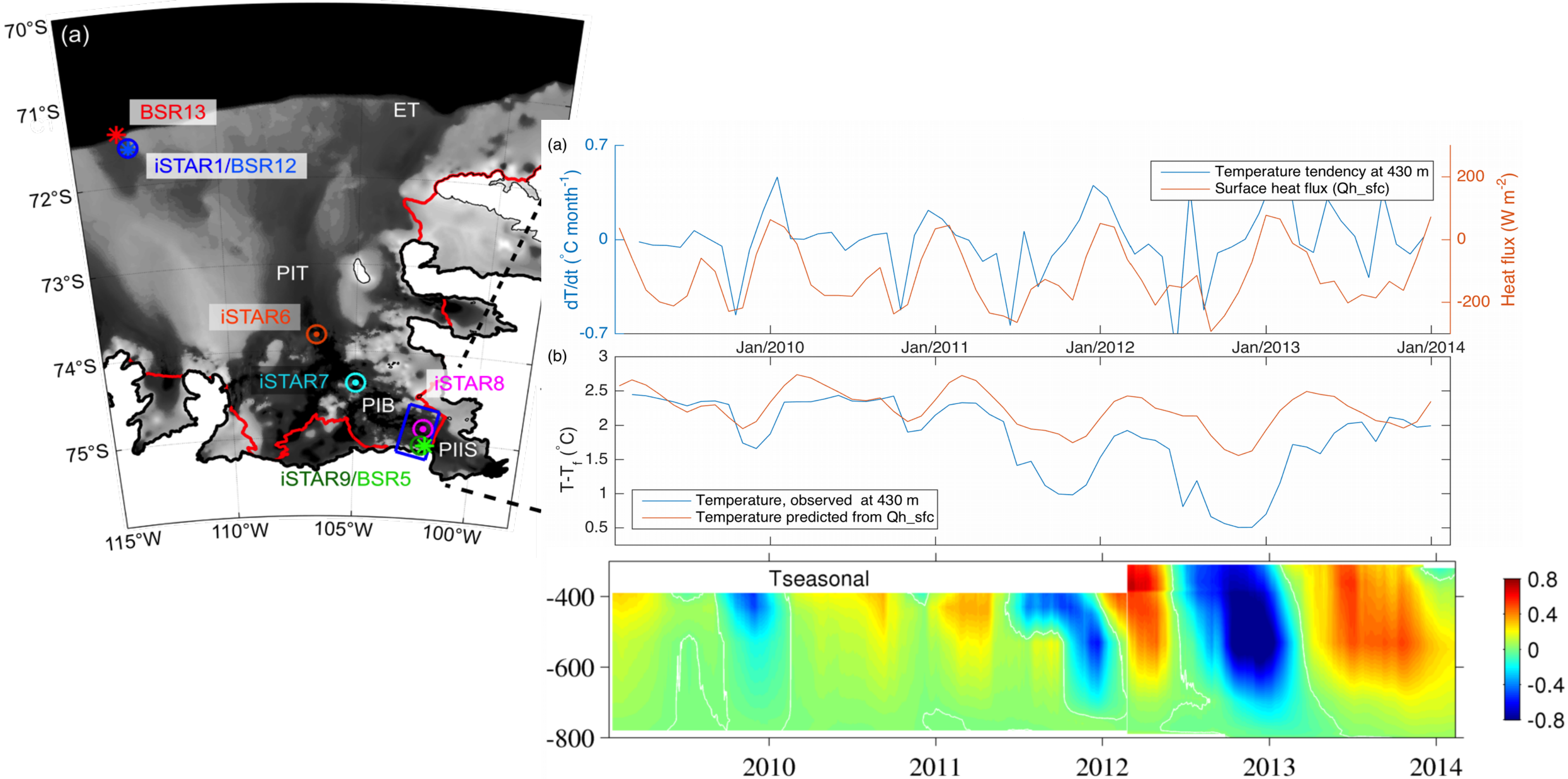


Variable ocean Heat content

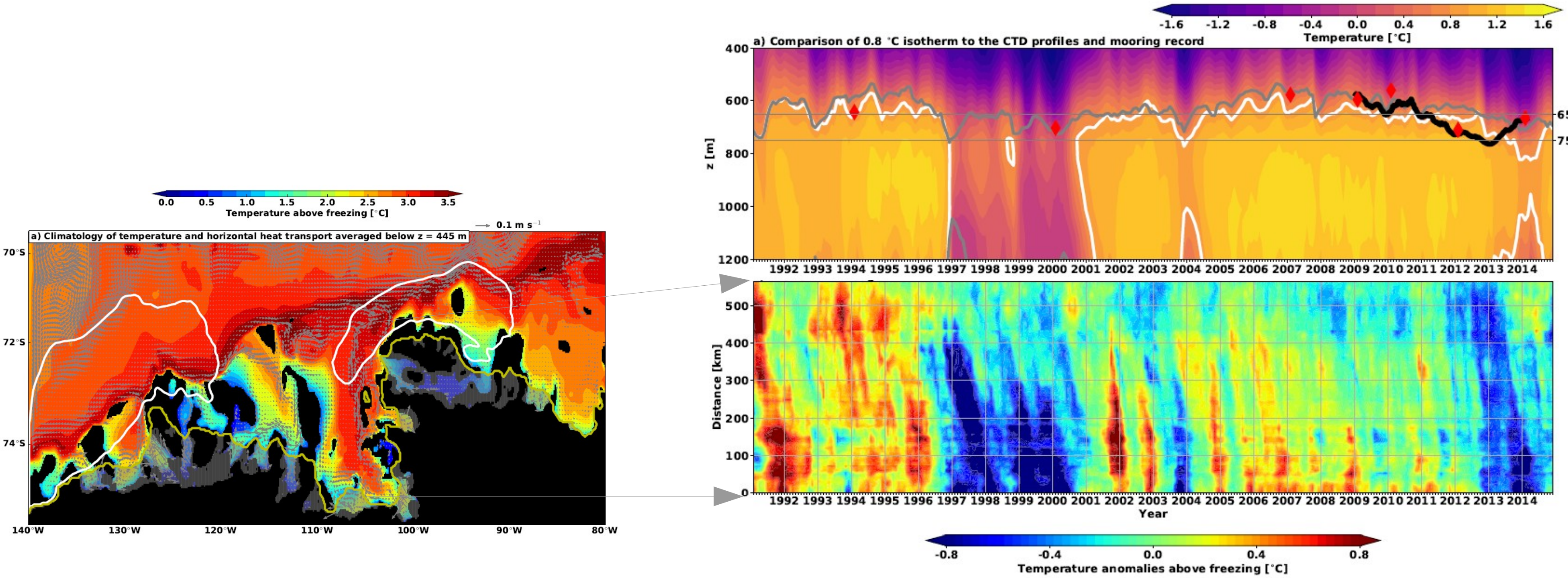
[Webber et al., 2017]


T
Tinterannual
Tseasonal
Tresidual
-400
-600
-800
2010
2011
2012
2013
2014
1.2
0.8
0.4
0
-0.4
-0.8
-1.2

Cause(s) of the variability?



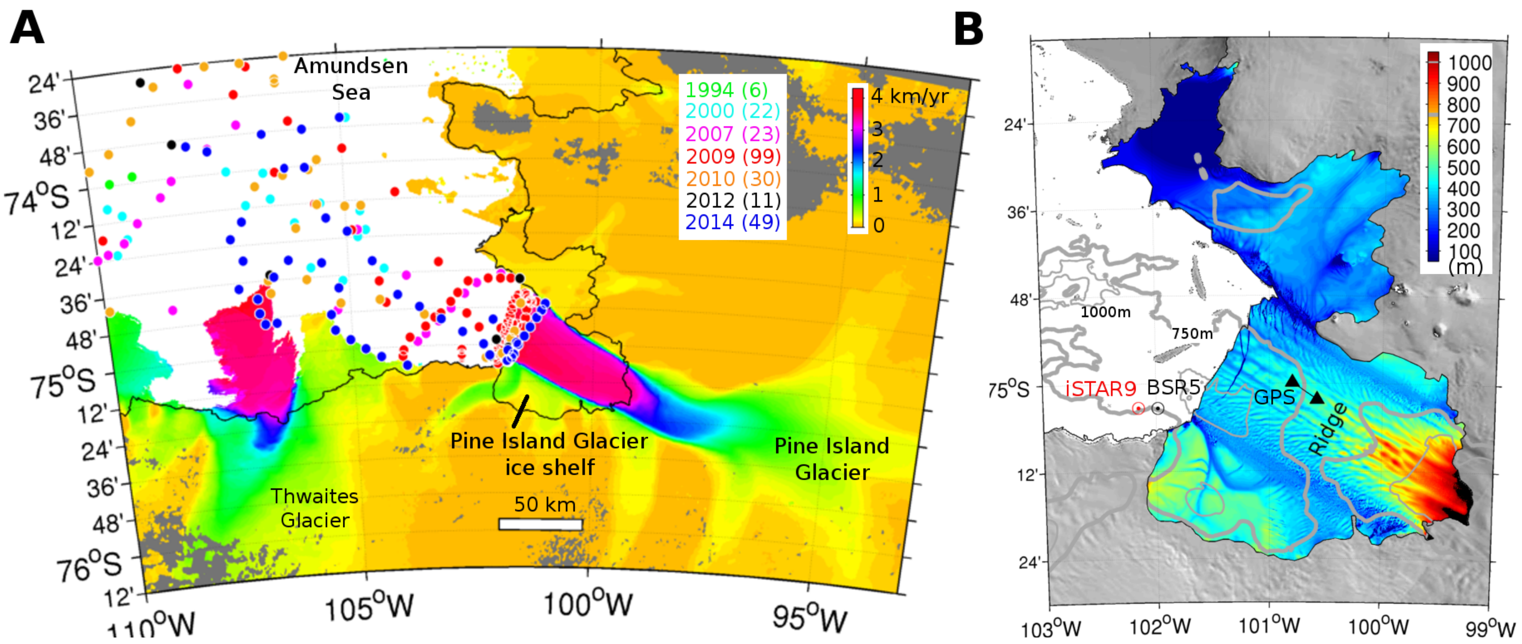
[Webber et al., 2017]



[Kimura et al., submitted]

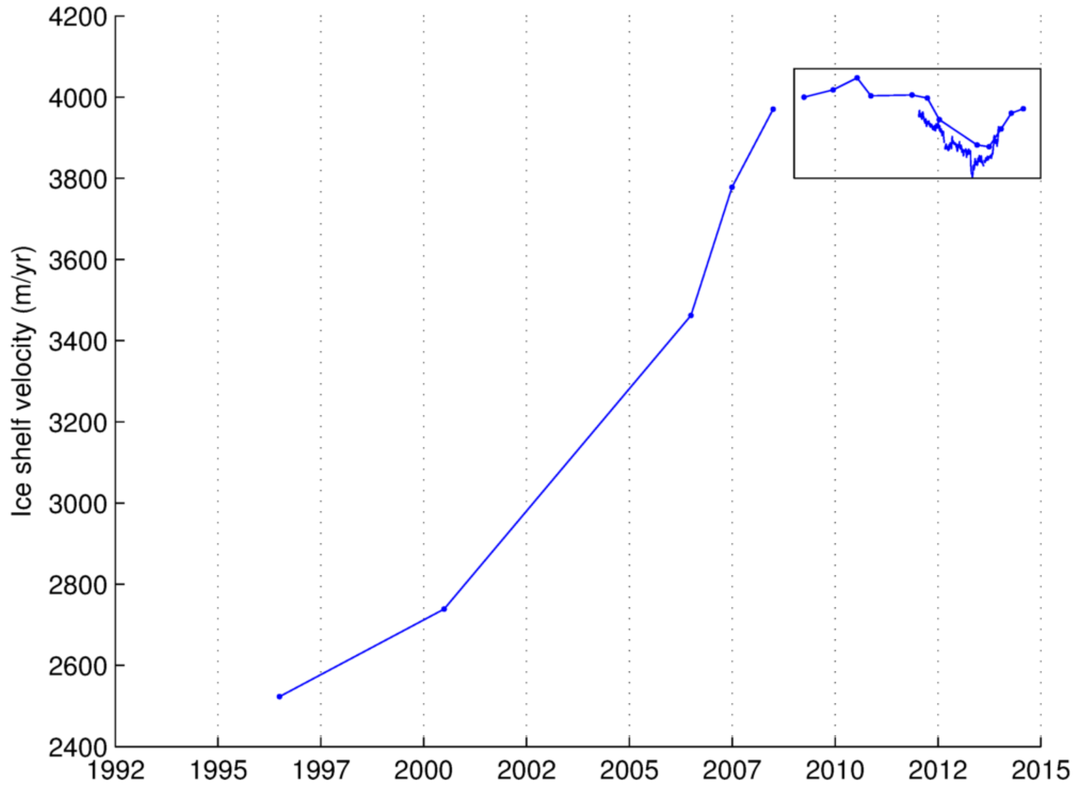
- Amundsen Sea heat content varies at seasonal to interannual time-scales;
- At seasonal time scales, local air/sea-ice buoyancy forcing plays a large role;
- At interannual time scales, continental shelf edge exchanges play a large role;
- All remains to be quantified by observations...

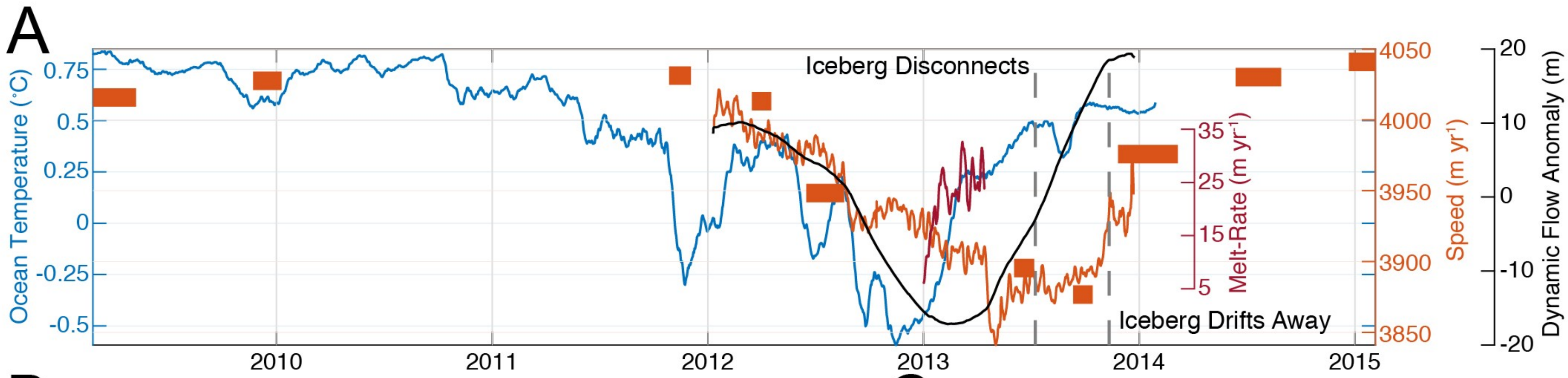
Impact on the glacier?



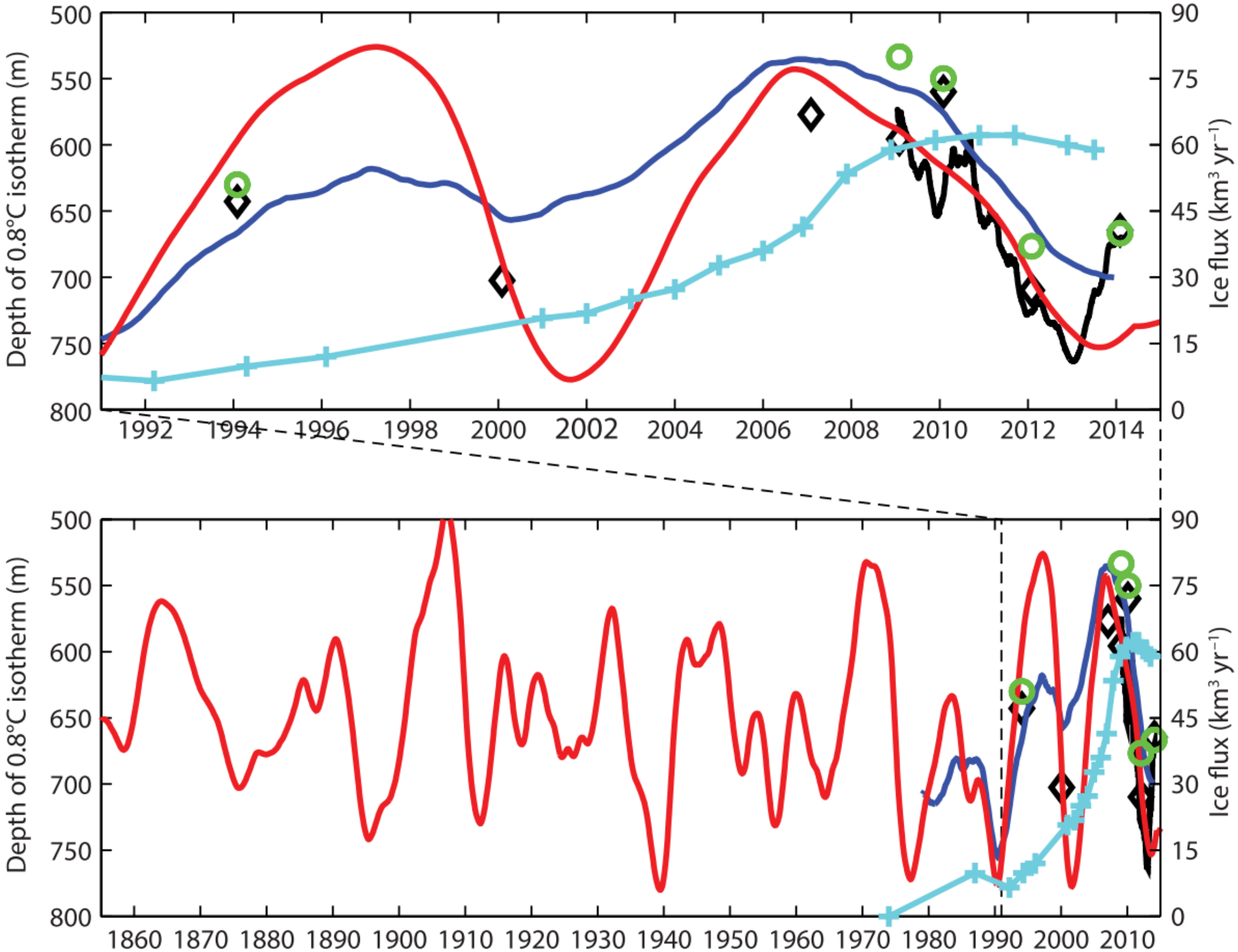
Geometrical constraints on dynamics

Impact on the ice? Maybe recently...





But no clear apparent co-variability on long term

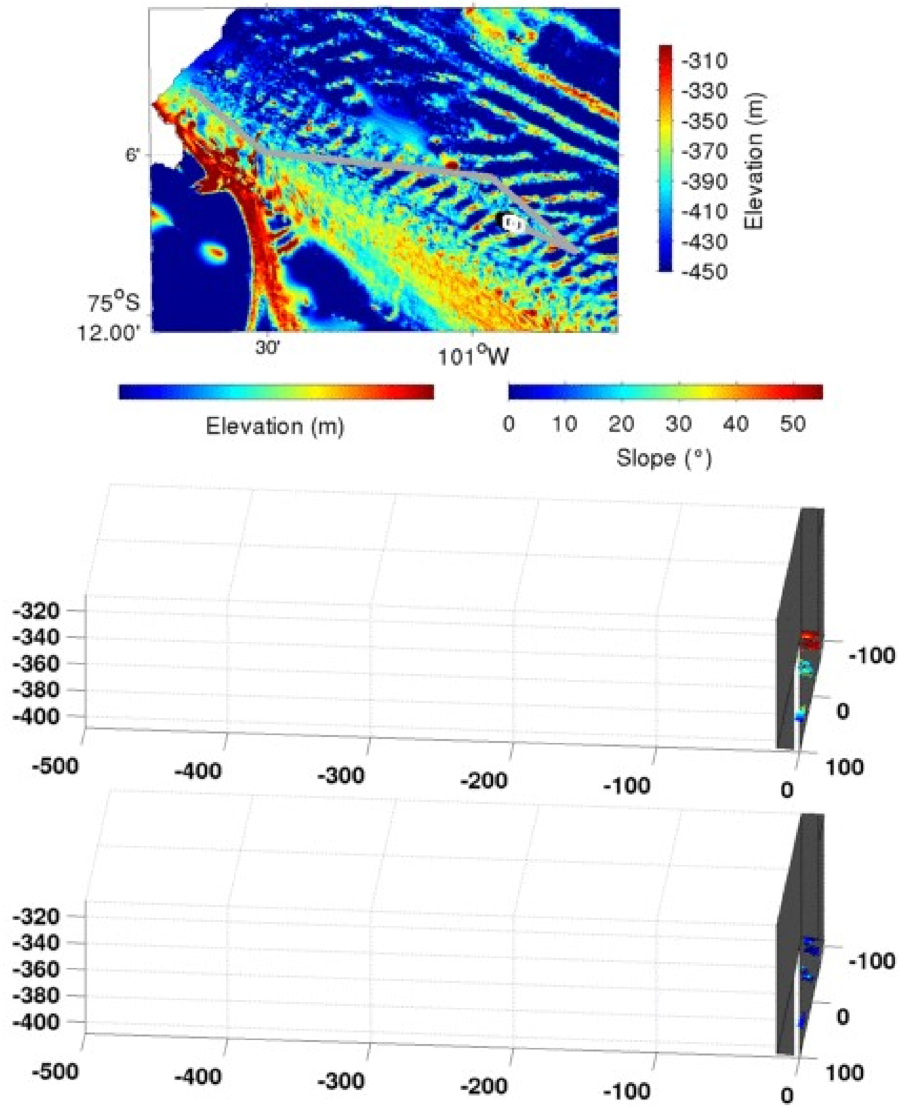


[Jenkins *et al,* 2016]

- Short term covariability of ocean and ice shelf observed once, but...
- No clear link between the expected oceanic variability and the ice shelf response!

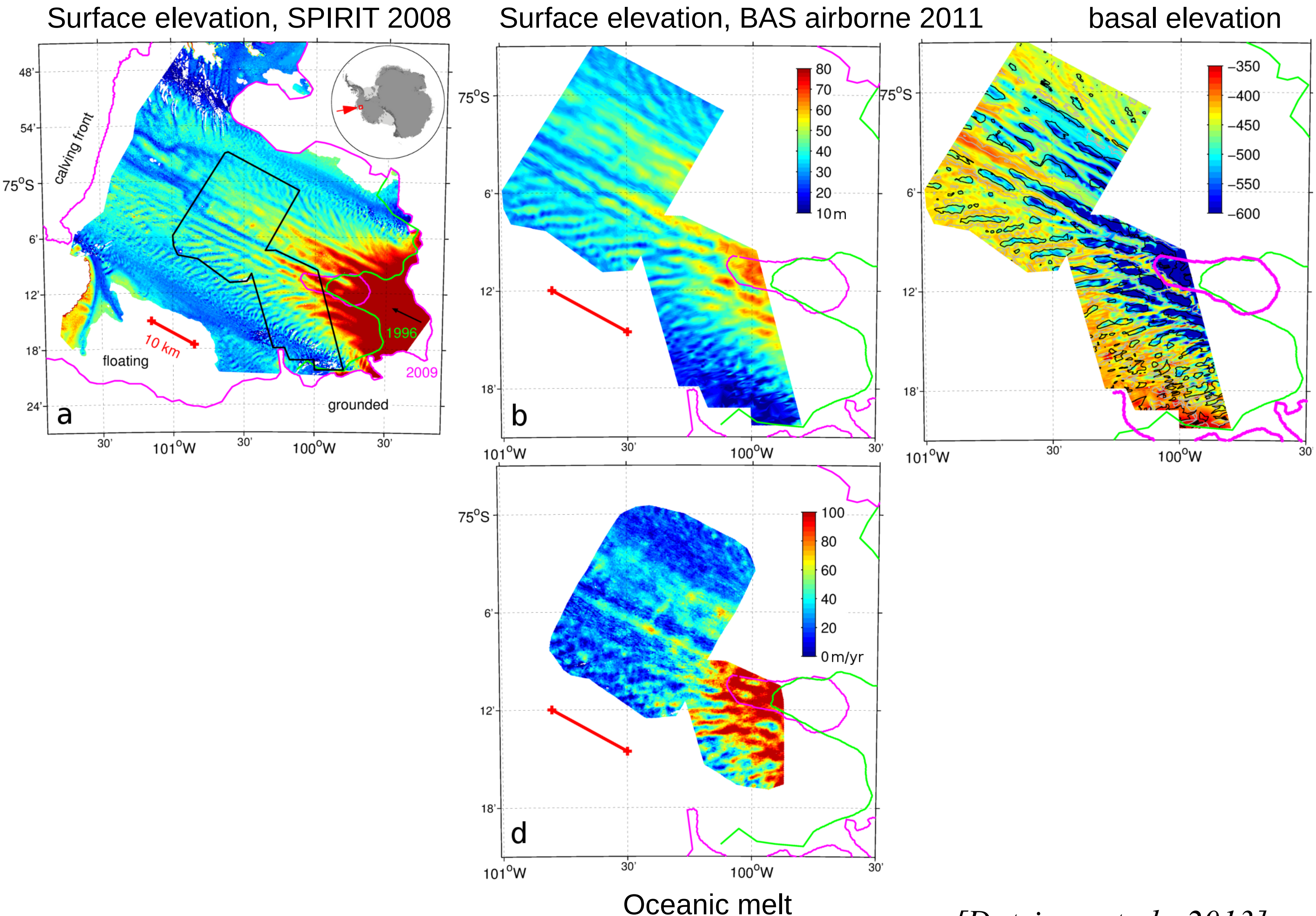
  > coupled dynamics is the next frontier

Ice base geometry



[Dutrieux *et al.,* 2014, 2016]

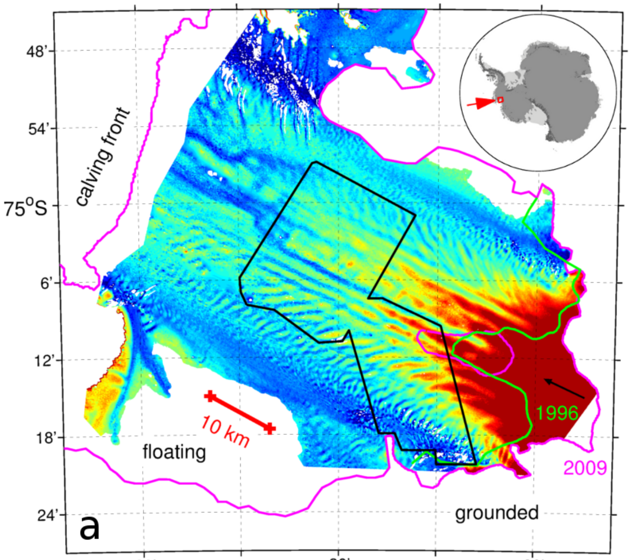
A detailed pattern of melt



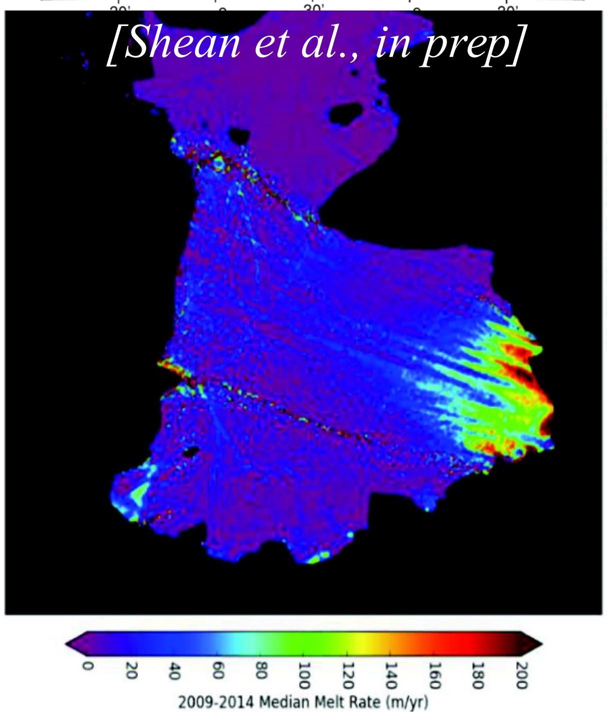
[Dutrieux et al., 2013]

A detailed pattern of melt

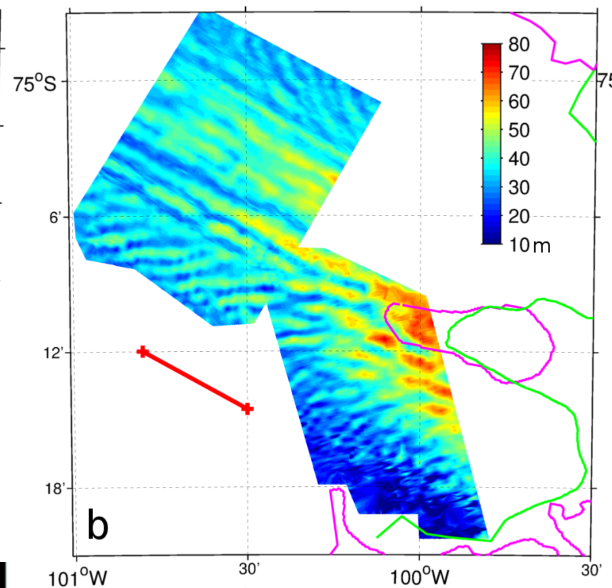
Surface elevation, SPIRIT 2008



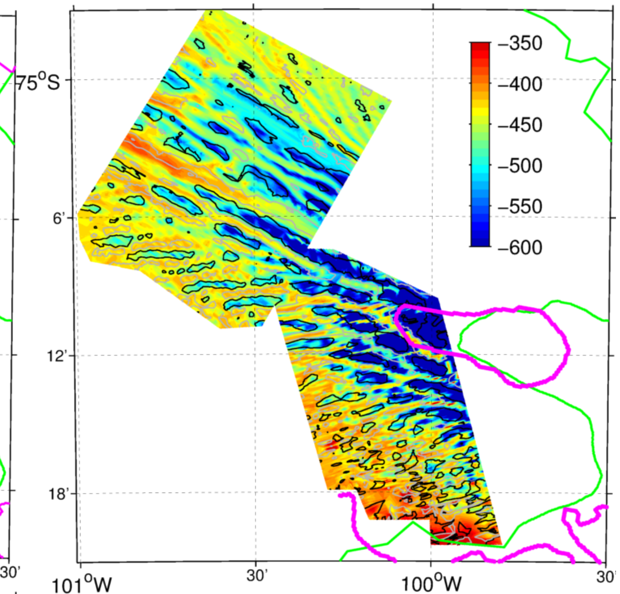
[Shean et al., in prep]

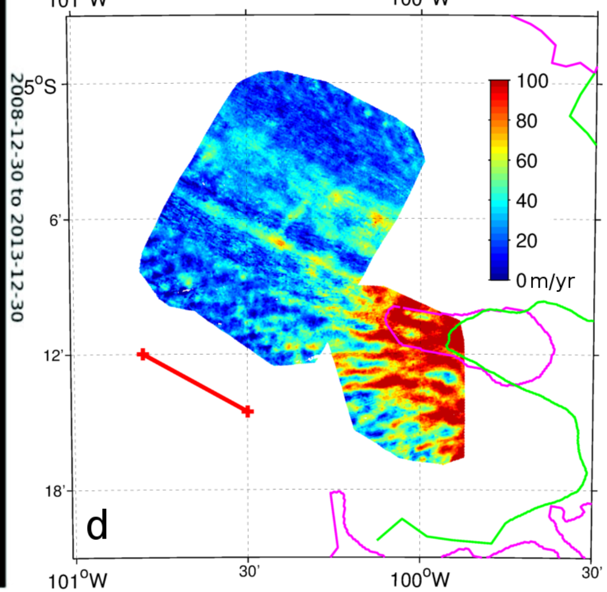


Surface elevation, BAS airborne 2011



basal elevation

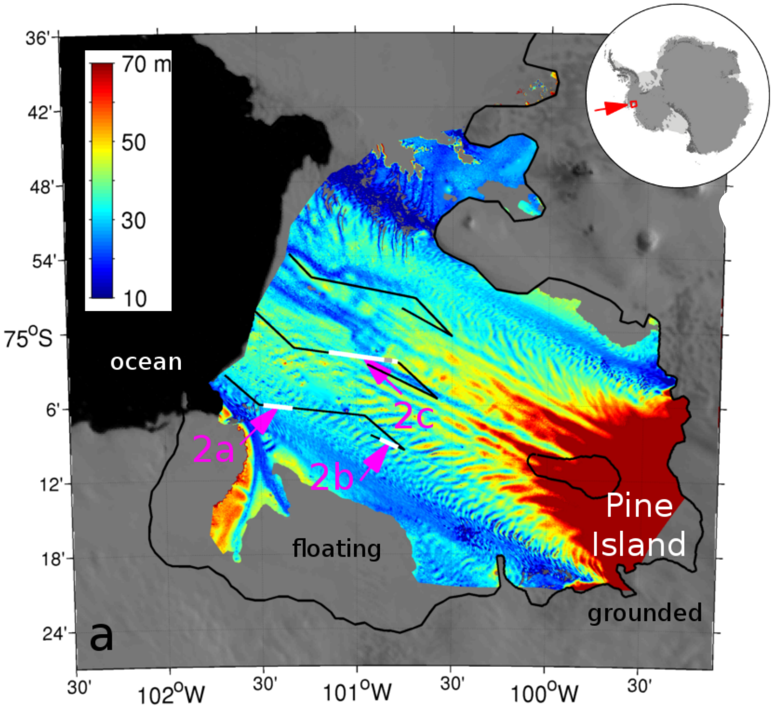


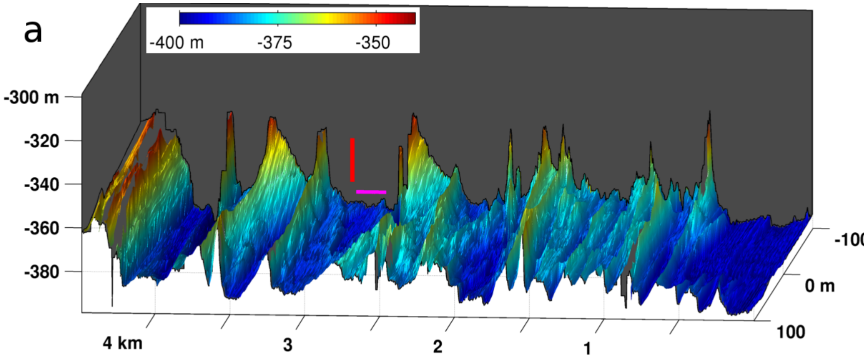


Oceanic melt

[Dutrieux et al., 2013]

How about even finer scale?
Shear margin crevasses

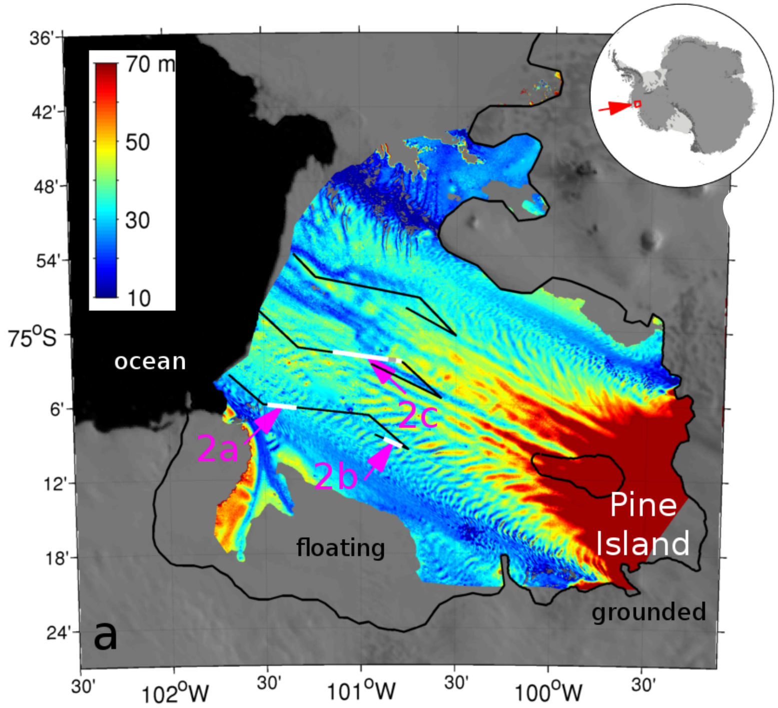


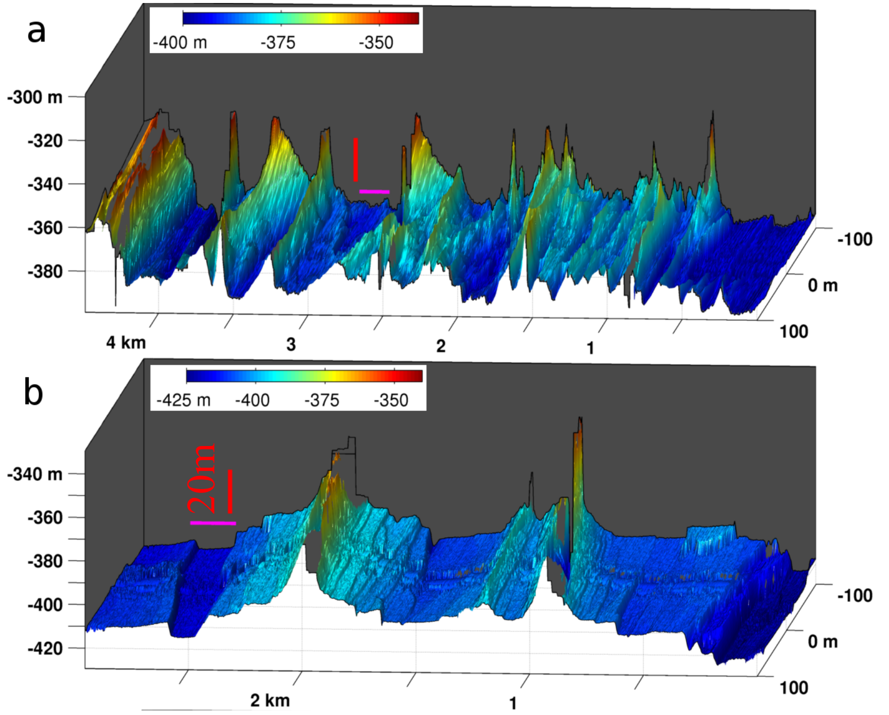


[Dutrieux et al., 2014]

How about even finer scale?

Transverse channels

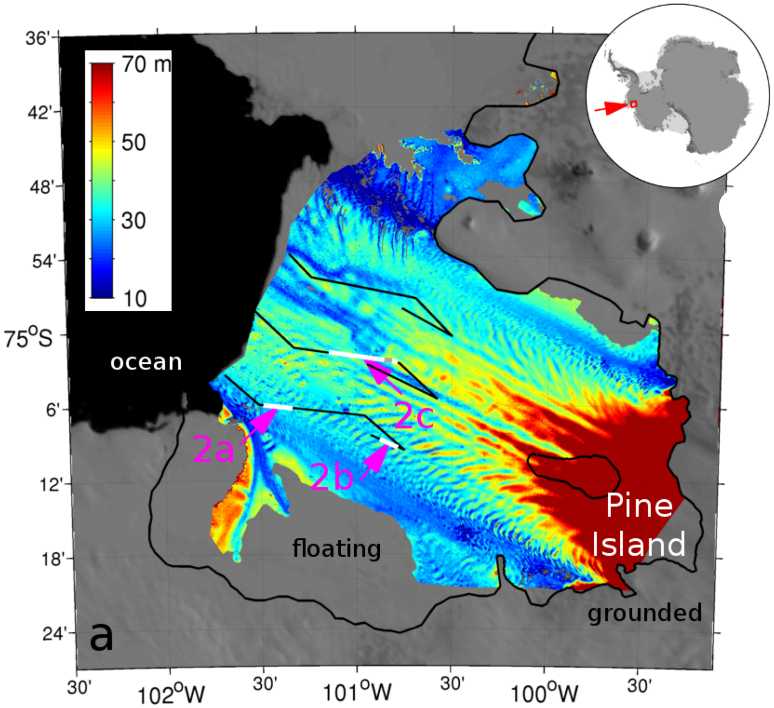


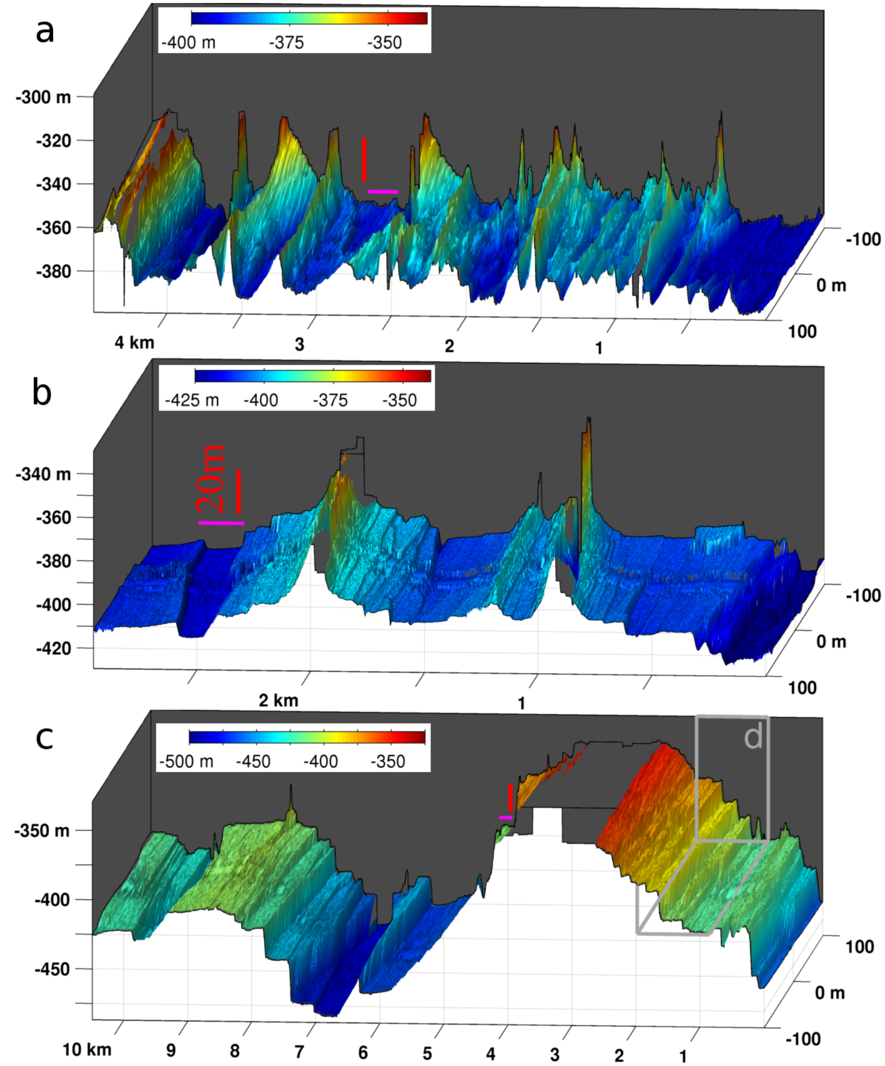


[Dutrieux et al., 2014]

How about even finer scale?

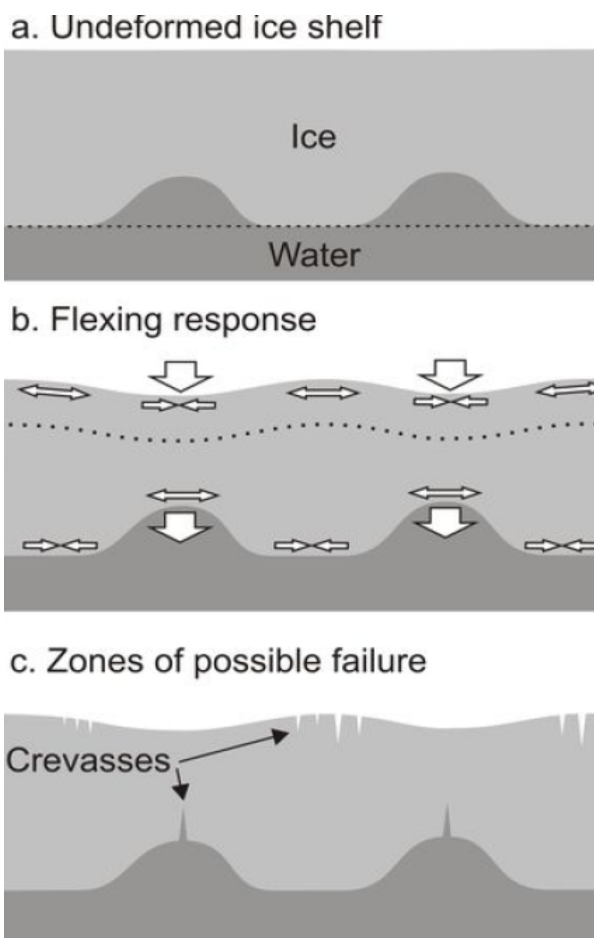
Longitudinal channels

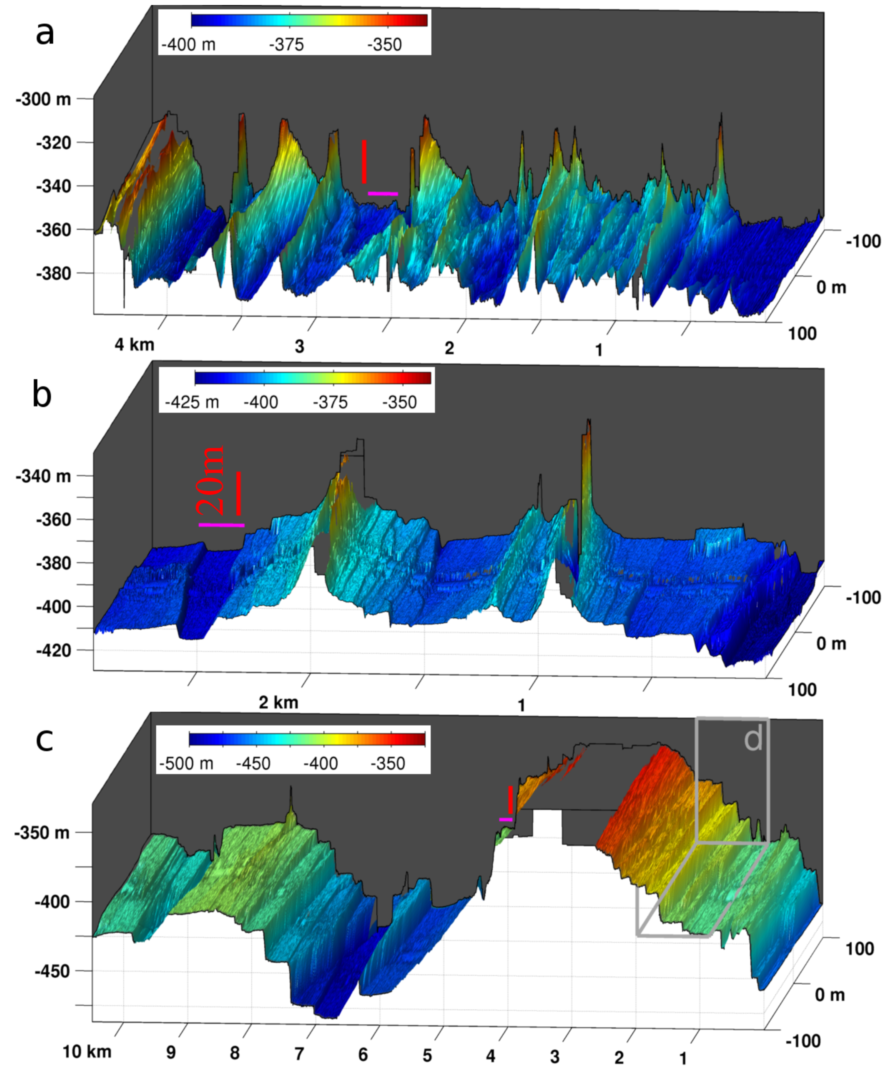




[Dutrieux et al., 2014]

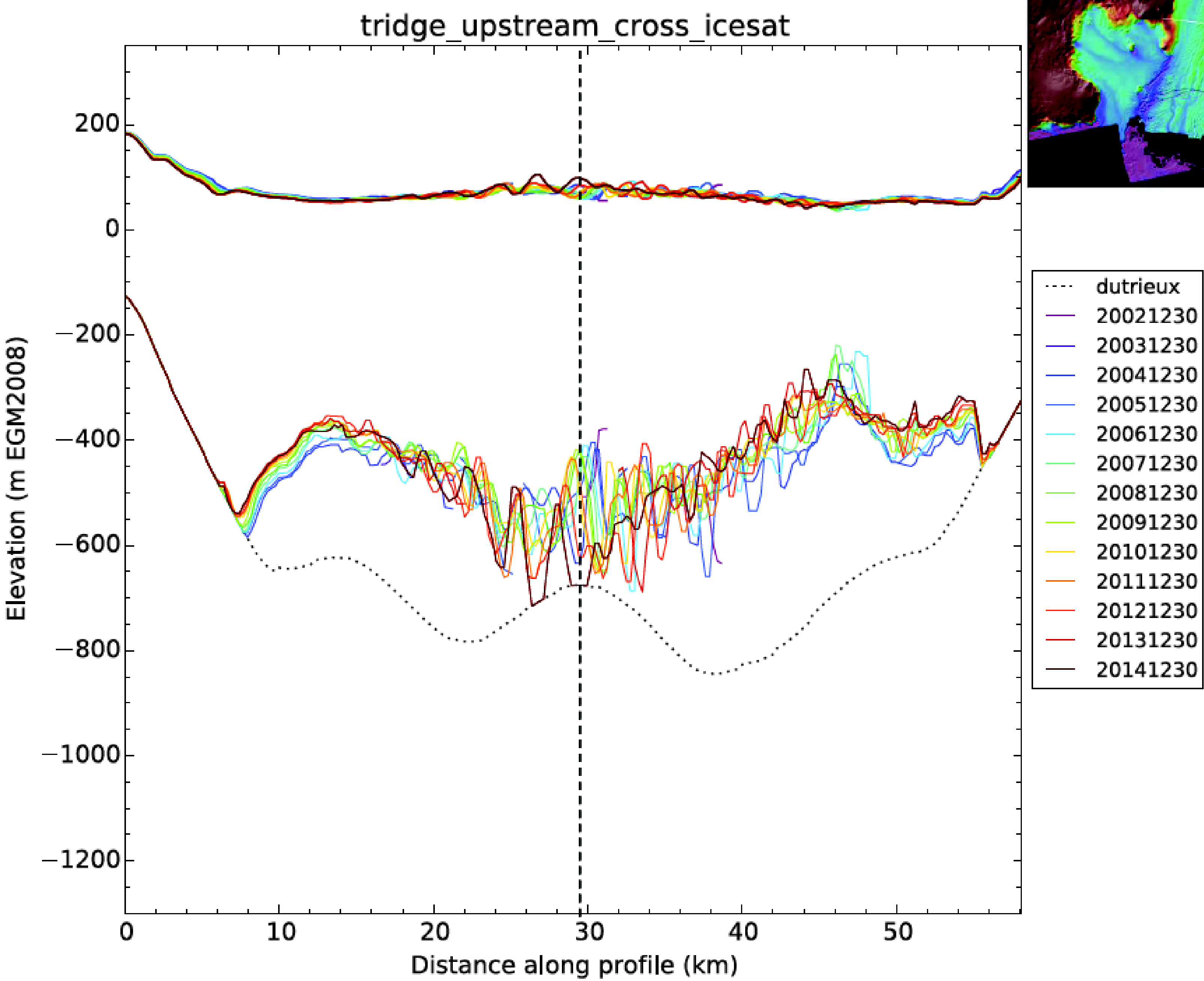
Impact on the ice?

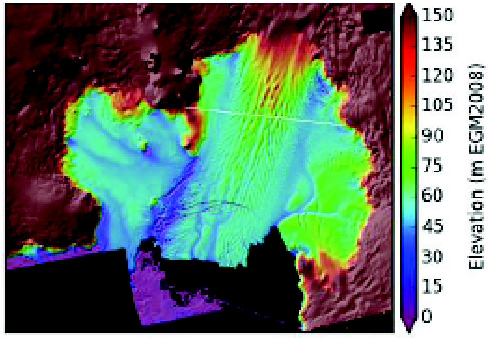




from Vaughan et al, JGR 2012

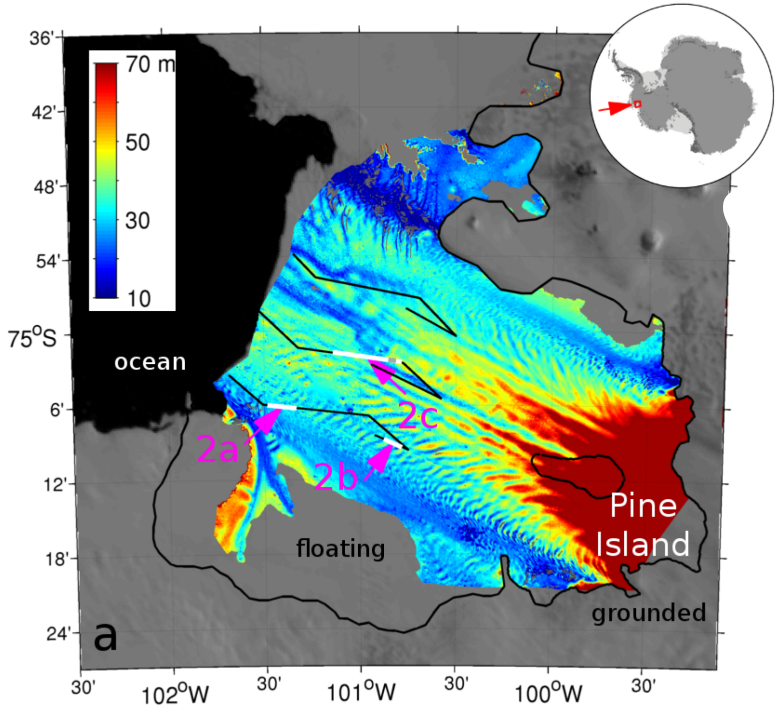
[Shean et al., in prep]

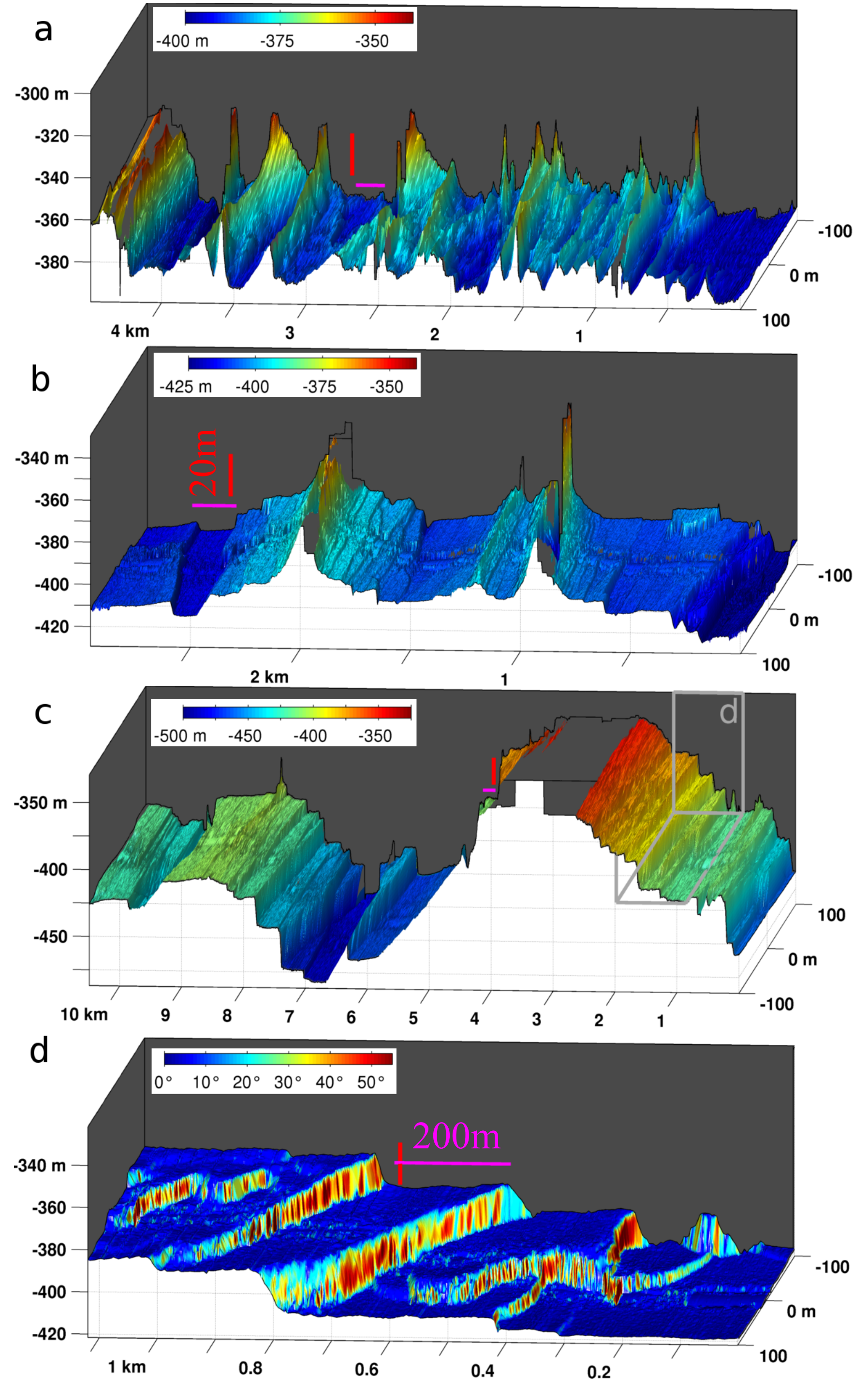


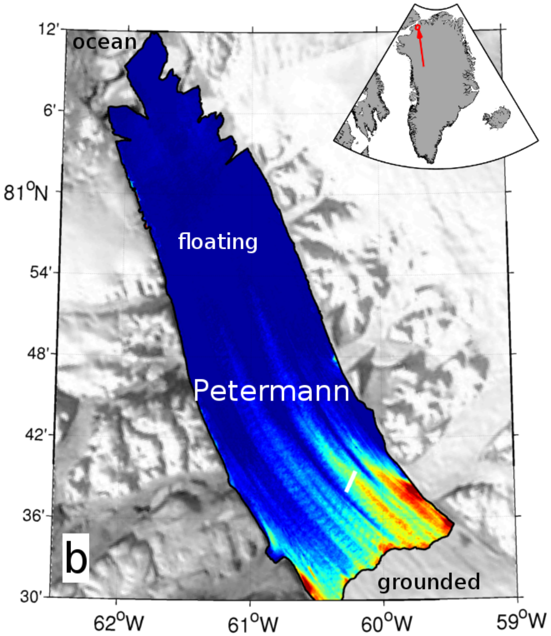


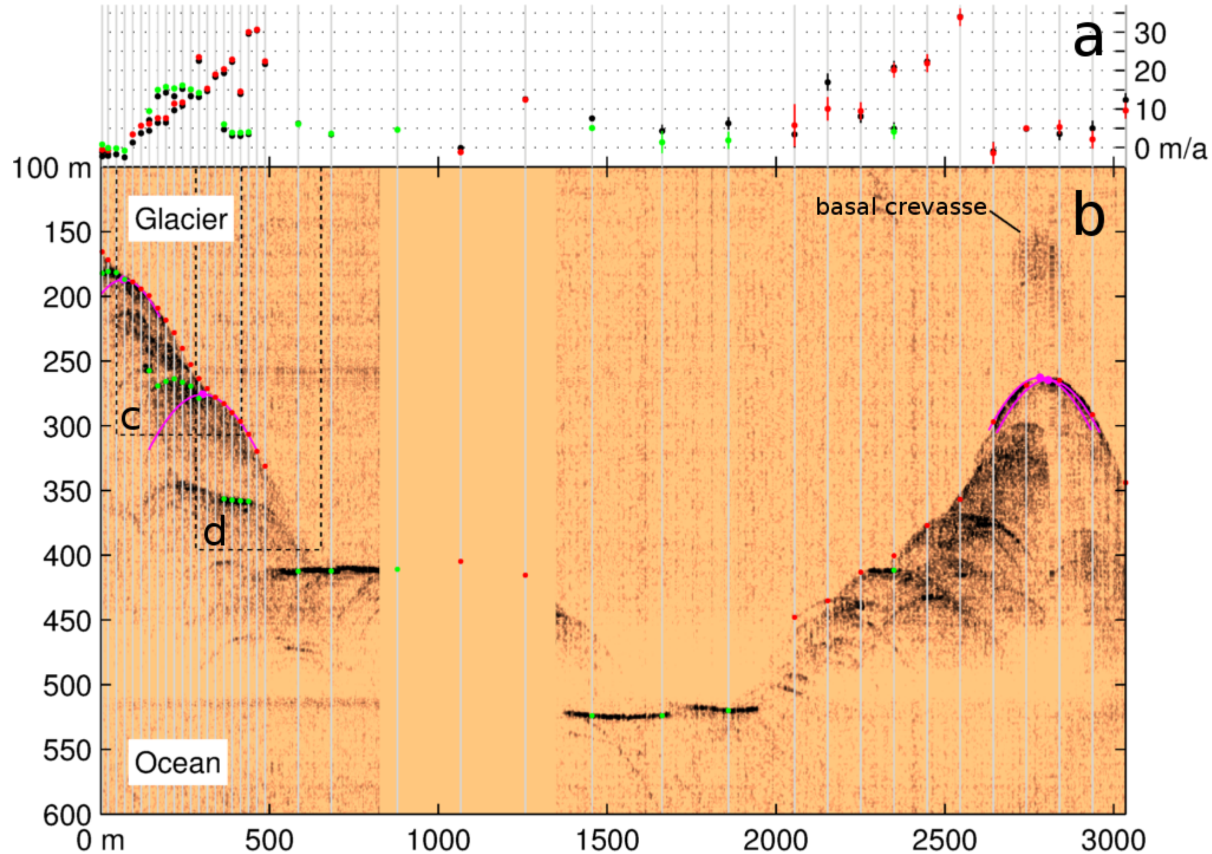
How about even finer scale?

Terraces

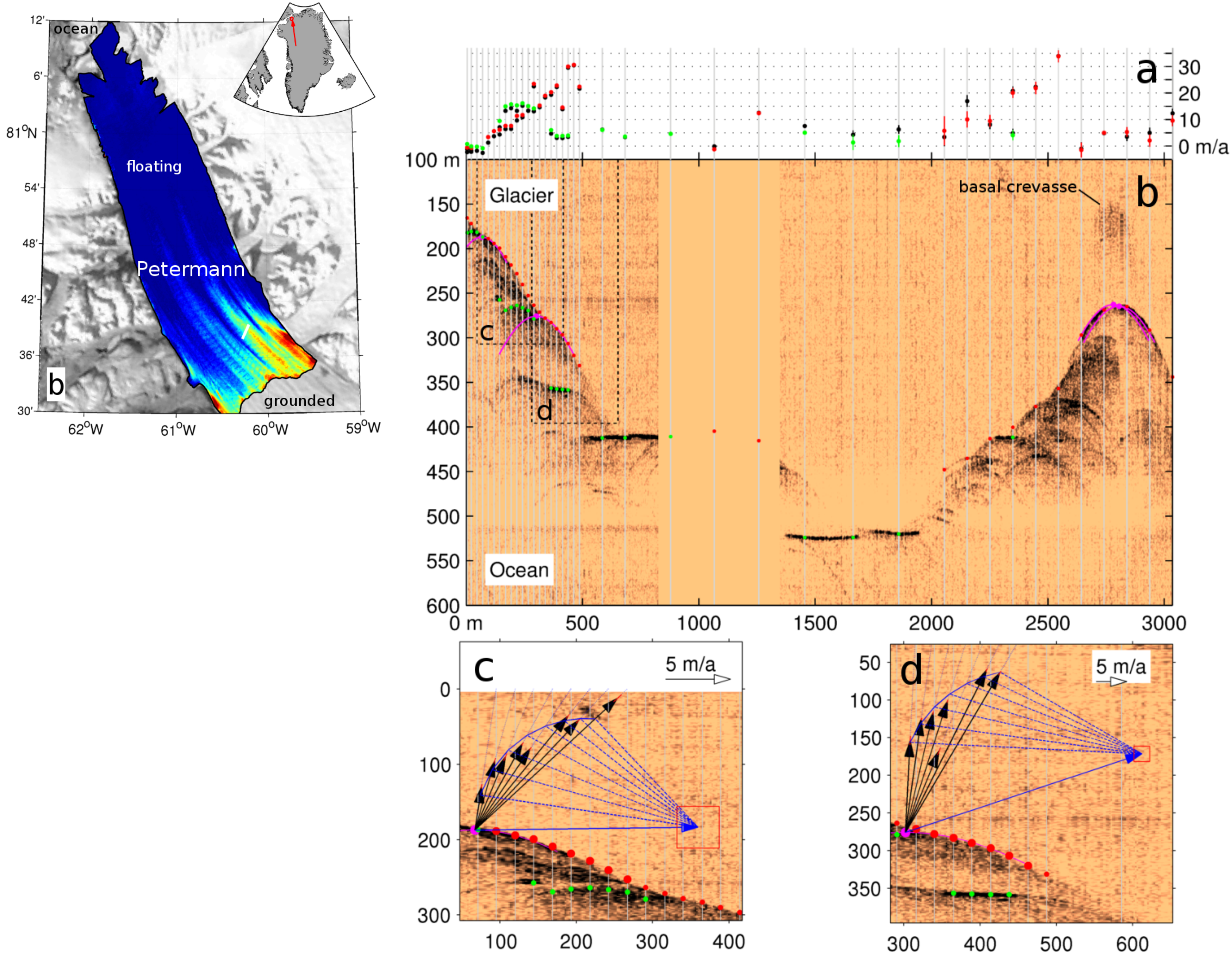




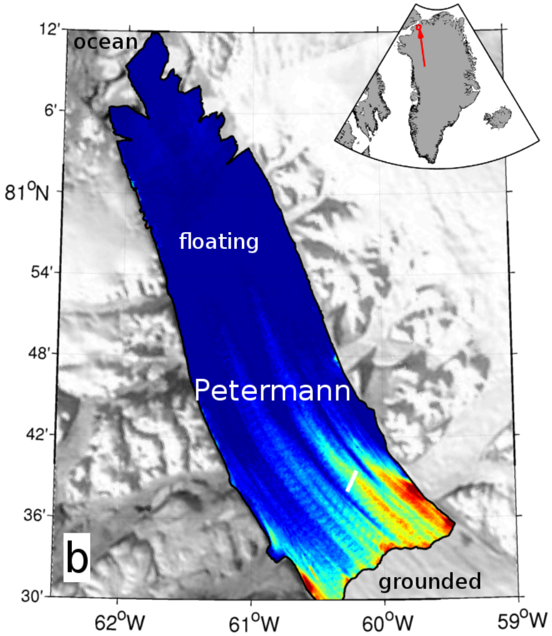


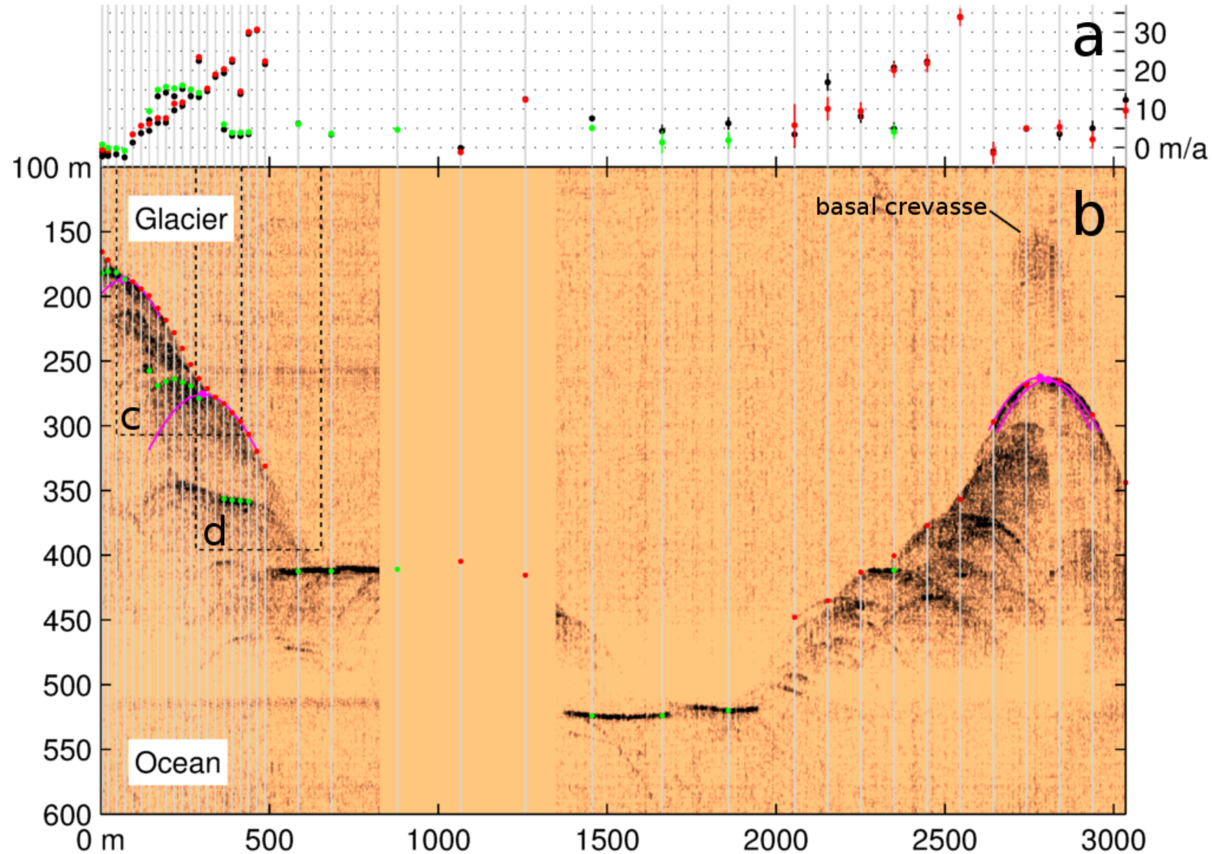


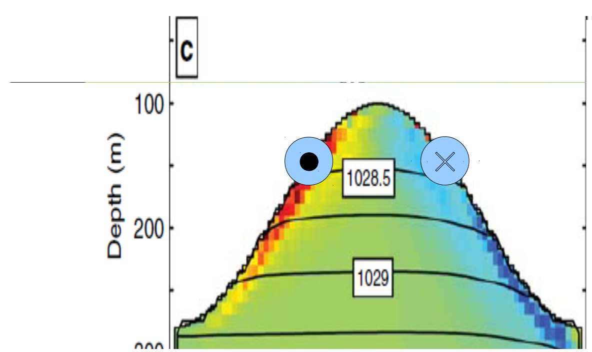
[Dutrieux et al., 2014]

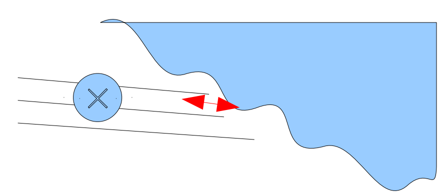


ocean
floating
Petermann
grounded
b
81°N
62°W
61°W
60°W
59°W
a
30
20
10
0 m/a
100 m
Glacier
basal crevasse
b
c
d
Ocean
150
200
250
300
350
400
450
500
550
600
0 m
500
1000
1500
2000
2500
3000
c
5 m/a
d
5 m/a









Adapted from Millgate et al, 2013

• Interesting geometries at the ice/ocean interface
• Melt tightly associated to this geometry
• Ocean-ice coupling is operating over a broad range of scales!
Thanks for your undivided attention!