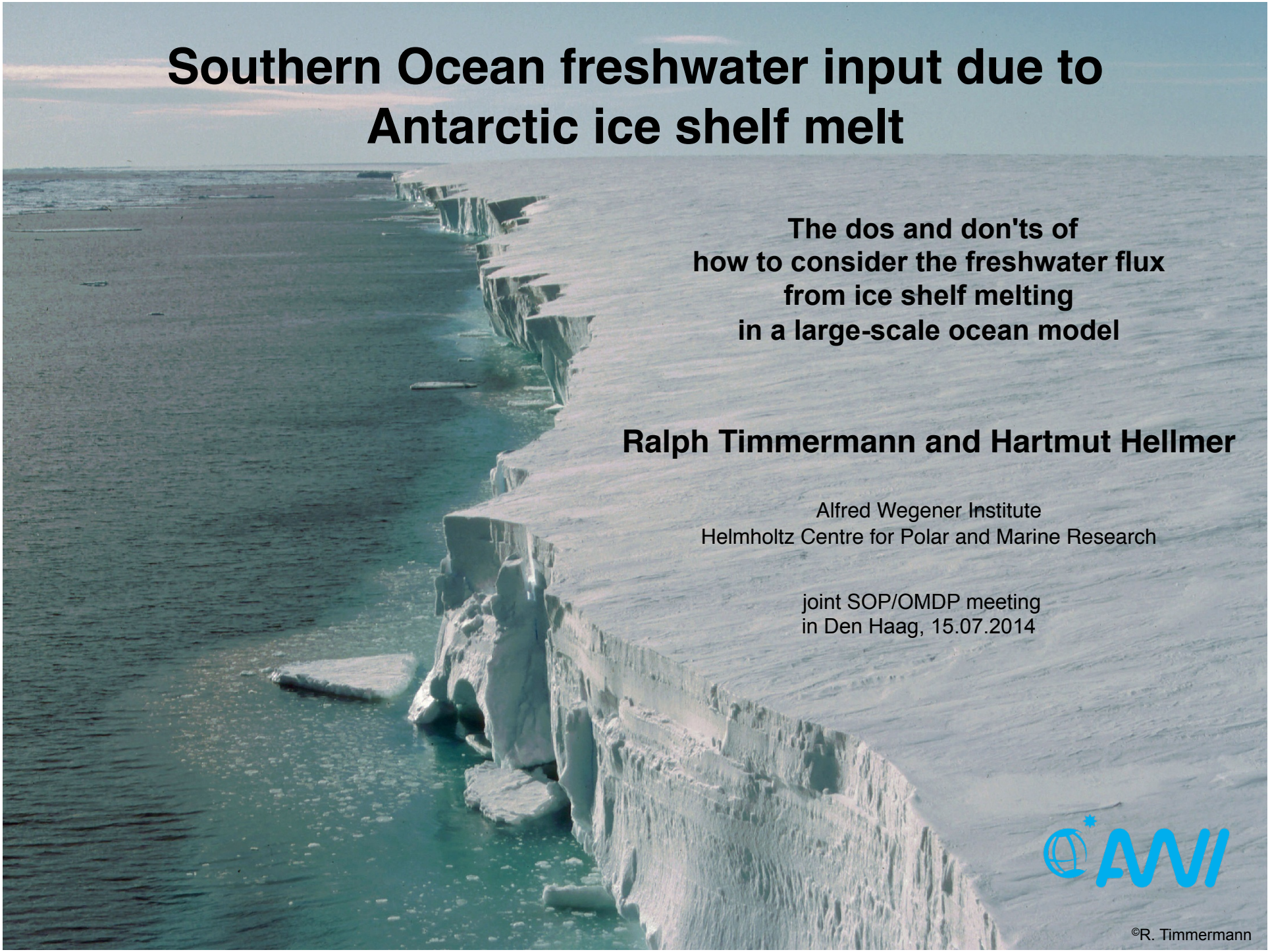
Southern Ocean freshwater input due to Antarctic ice shelf melt



The dos and don'ts of how to consider the freshwater flux from ice shelf melting in a large-scale ocean model

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Alfred Wegener Institute
Helmholtz Centre for Polar and Marine Research

joint SOP/OMDP meeting
in Den Haag, 15.07.2014

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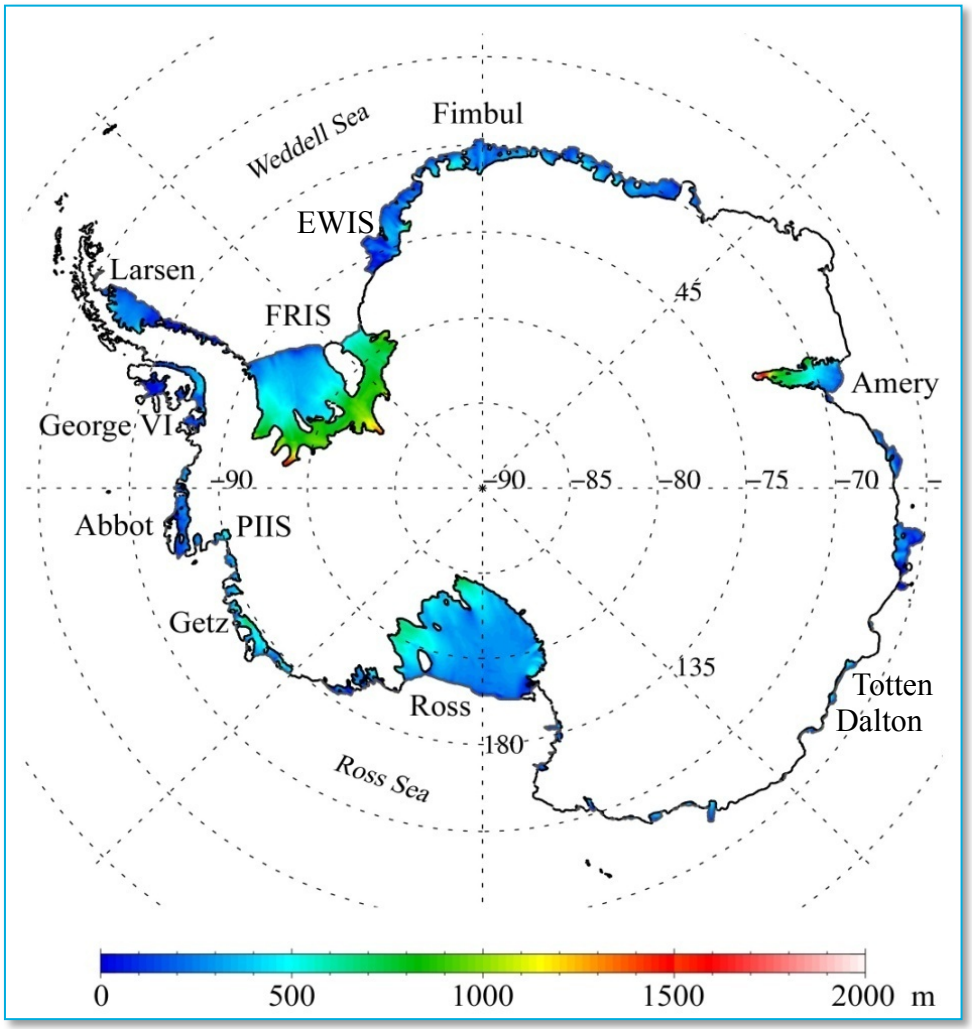
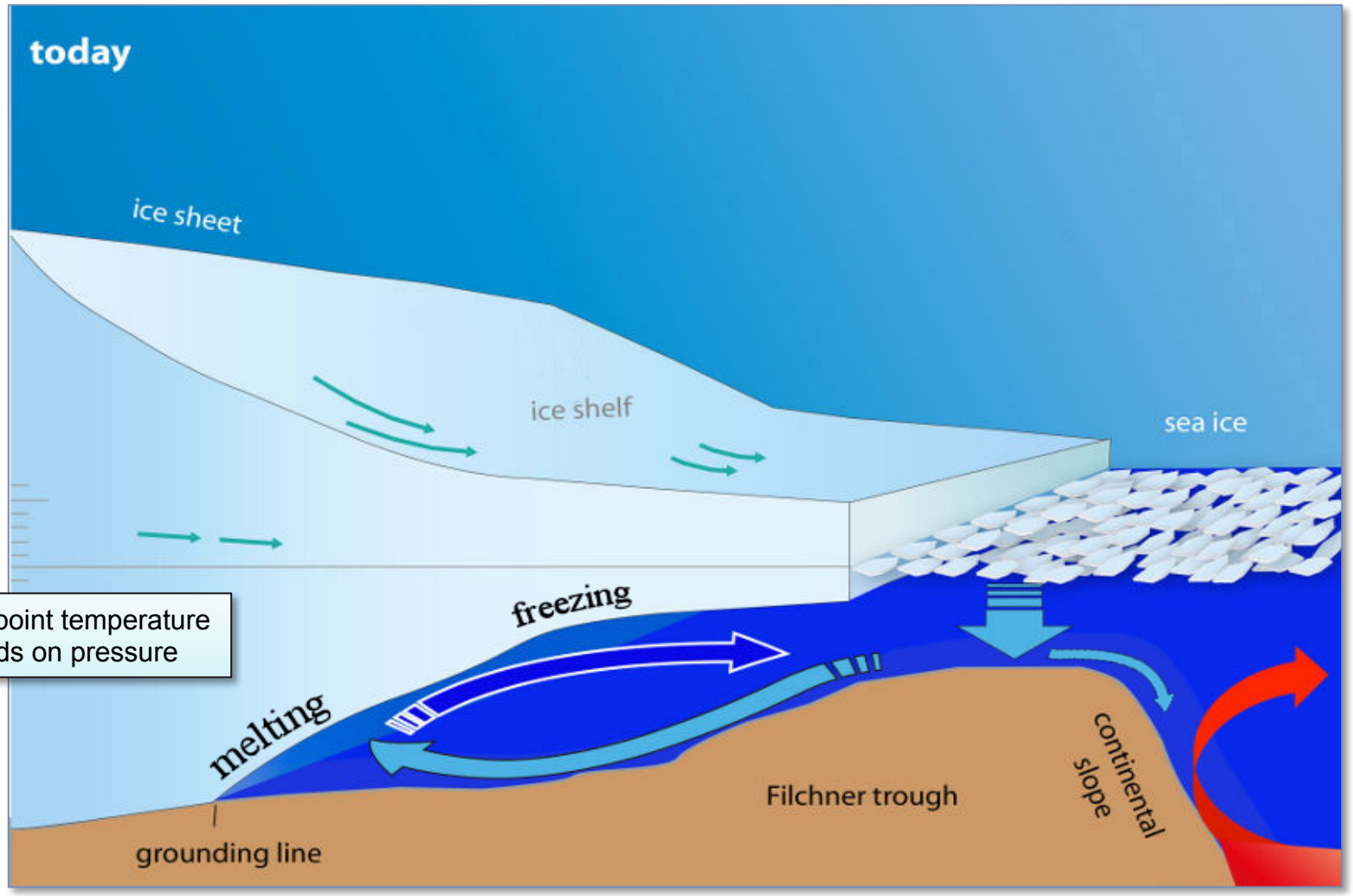
Antarctic Ice Shelves

Ice shelf draft
of the
ten larger ice shelves



RTopo-1
(*Timmermann et al., 2010*)

Sub-ice shelf processes



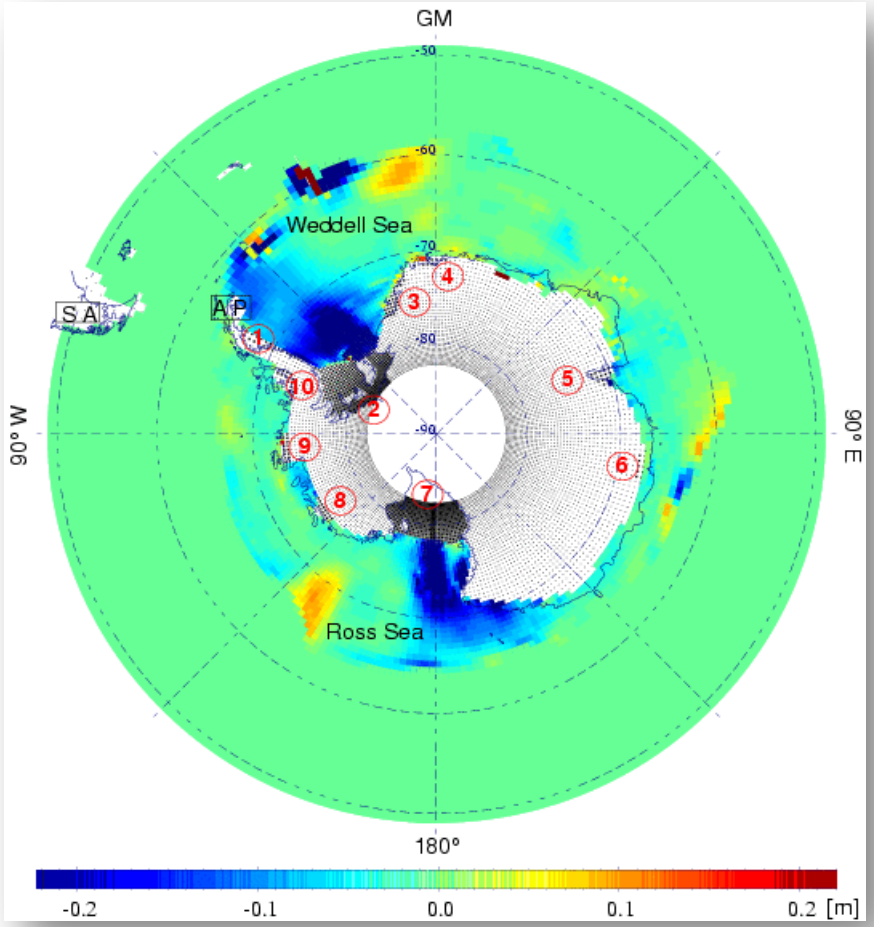
freezing-point temperature depends on pressure

Sina Löschke (modified)

Consequences of neglect

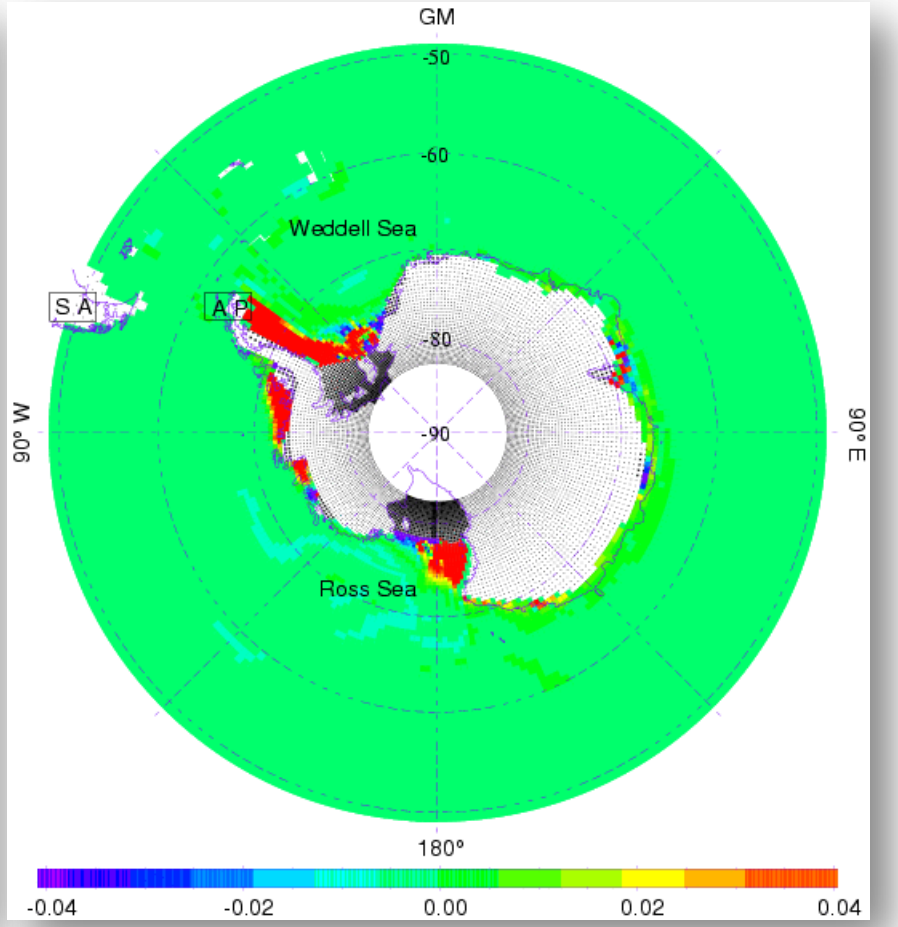
Sea Ice Thinning

Without IS - Ctrl for September year 20



Bottom salinity difference

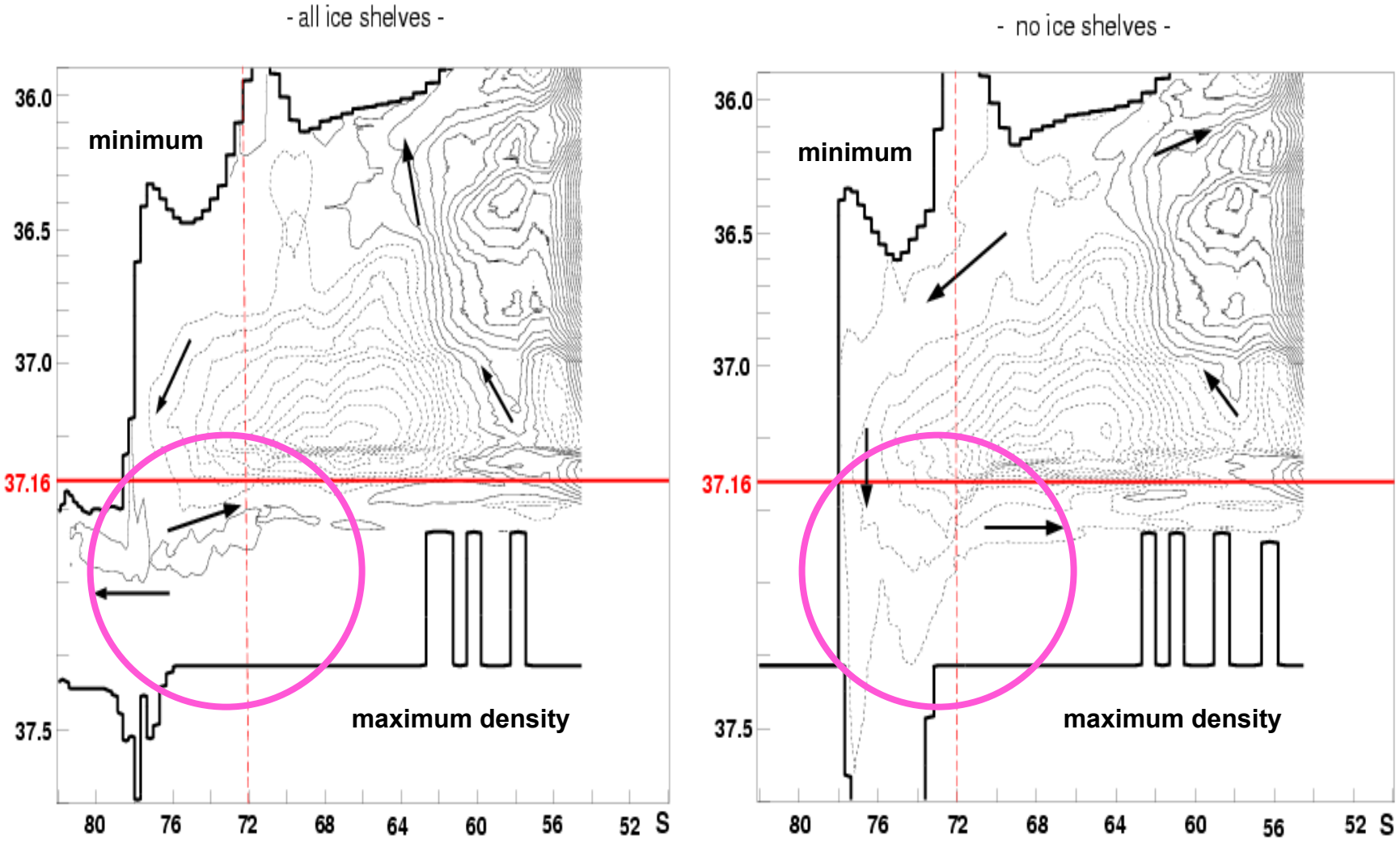
Without IS - Ctrl for September year 20



Hellmer (2004)

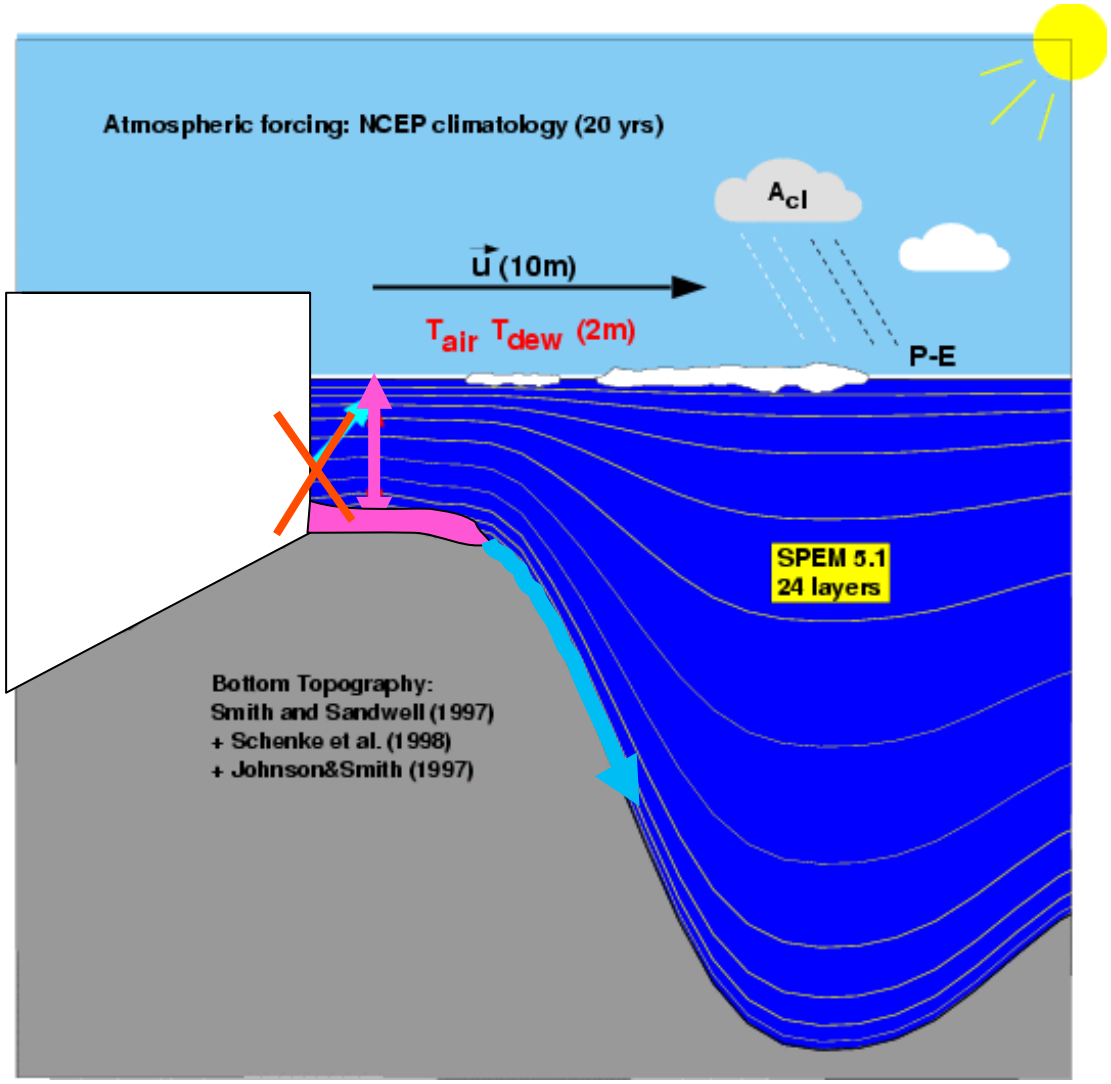
Consequences of neglect

Meridional Overturning (sigma-2 vs. latitude)



Consequences of neglect

How does it work?



Techniques (1/4)

If freshwater flux from ice shelf basal melting is to be considered in a large-scale ocean model that does not explicitely represent the sub-ice cavities, it is essential to get the main properties right.

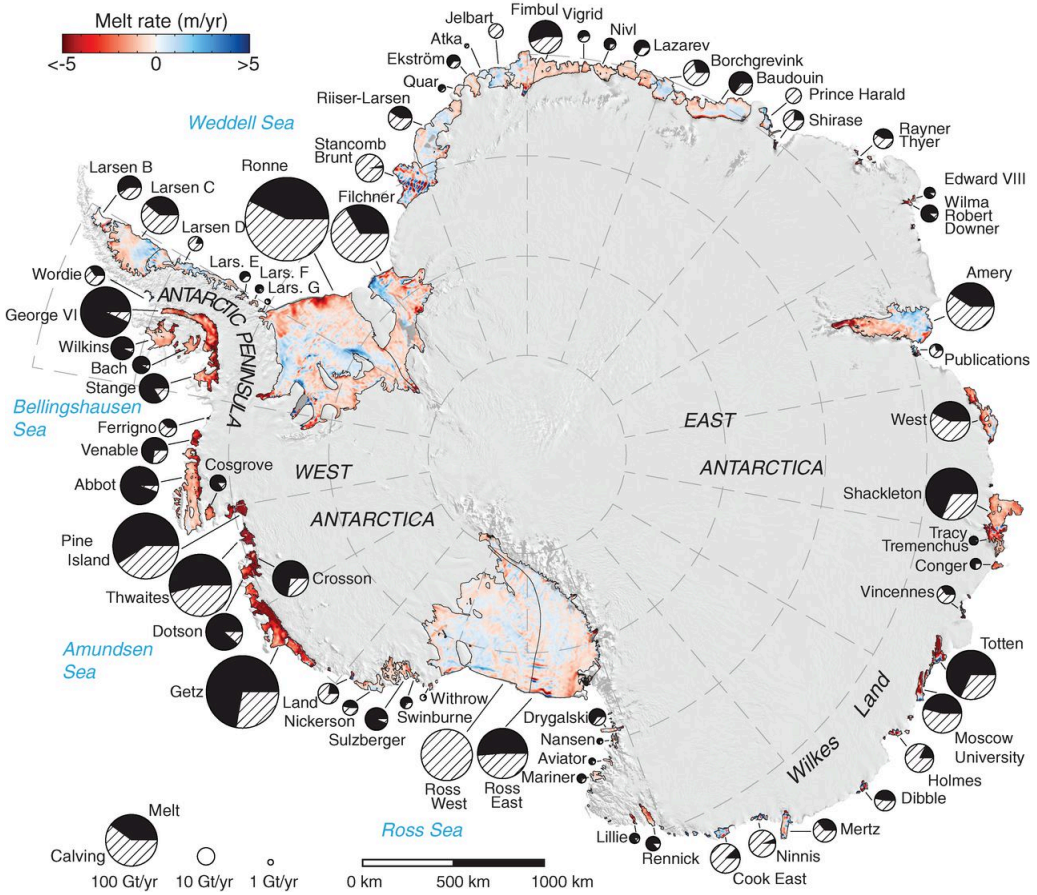
1. the volume flux
2. the location:
    - horizontal distribution
    - vertical distribution

For the volume flux and the horizontal distribution, the observation-based studies of Rignot et al. (2013) provide a perfect guideline. They comprise estimates for total mass loss, divided into iceberg calving and ice shelf basal melting for each and every ice shelf in Antarctica:

next slide please ☺

Ice sheet mass loss / Freshwater sources

Basal melt rates of Antarctic ice shelves. Color coded from <–5 m/year (freezing) to >+5 m/year (melting) and overlaid on a 2009 Moderate Resolution Imaging Spectroradiometer mosaic of Antarctica.



Rignot et al., Science 2013

Table with numbers in the appendix!

Techniques (2/4)

If freshwater flux from ice shelf basal melting is to be considered in a large-scale ocean model that does not explicitely represent the sub-ice cavities, it is essential to get the main properties right.

1. the volume flux
2. the location:
    - horizontal distribution
    - vertical distribution

For vertical distribution, things are a bit more tricky, especially when it comes to sensitivity studies with increased meltwater flux. Putting all the (additional) freshwater flux the into the surface, Bintanja et al. (Nature Geoscience 2013) suggested that the freshwater flux stabilizes the water column, thus reducing the heat transfer into the mixed layer from the deeper ocean, thus increasing ice extent and volume. If only it were that simple.

Next slide please ☺

Techniques (3/4)

Vertical distribution of melt water (cont'd)

In contrast to Bintanja's results, Pierre Mathiot reported (at the 2014 EGU general assembly) that increased meltwater flux actually reduces sea ice volume in a regional Amundsen Sea model – if (and that is the point here) meltwater is injected not at the surface but at depth, where it meets modified warm deep water, reduces its density (freshening effect dominates over cooling here) and brings it up (probably by convection rather than by upwelling), reducing sea ice formation by an increased supply of heat at the mixed layer base. Sea ice thickness reduction in his experiments can be as big as 50 cm.

Obviously this process only works if deep water temperature is above the surface freezing point.

Mathiot suggests to approximate ice shelves by a vertical wall at the location of the ice front and distribute the melt water flux over the depth interval between the ice shelf base and the ocean bottom.

Techniques (4/4)

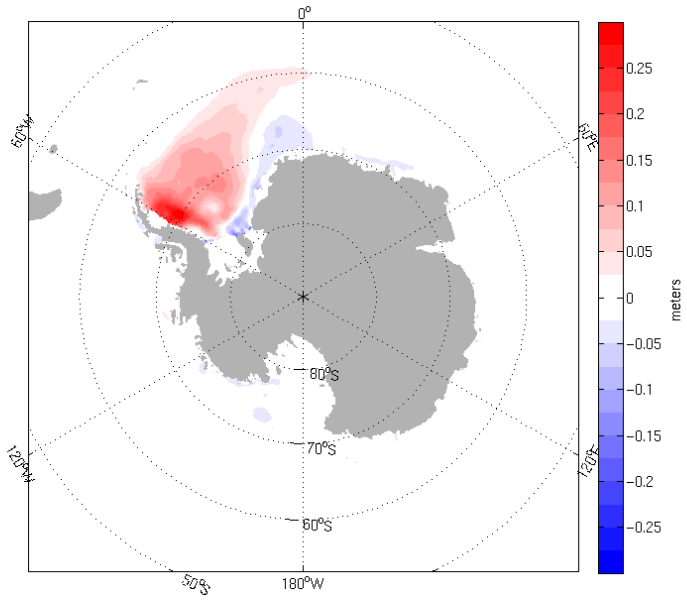
Vertical distribtion of melt water (cont'd)

Water hosing experiments with the Finite Element Sea ice – ice shelf - Ocean Model (FESOM) seem to show both processes in one model:

We prescribed projections of future melt rates of Weddell Sea ice shelves (i.e. an increased meltwater flux) in a simulation with present-day atmosphere.

Result: Increased ice thickness in the west, where most of the melt water remains near the surface. Reduced ice thickness in the eastern Weddell Sea, where meltwater leaves the cavity at depth and meets relatively warm water.

note: this is work in progress; analysis has not been completed yet.

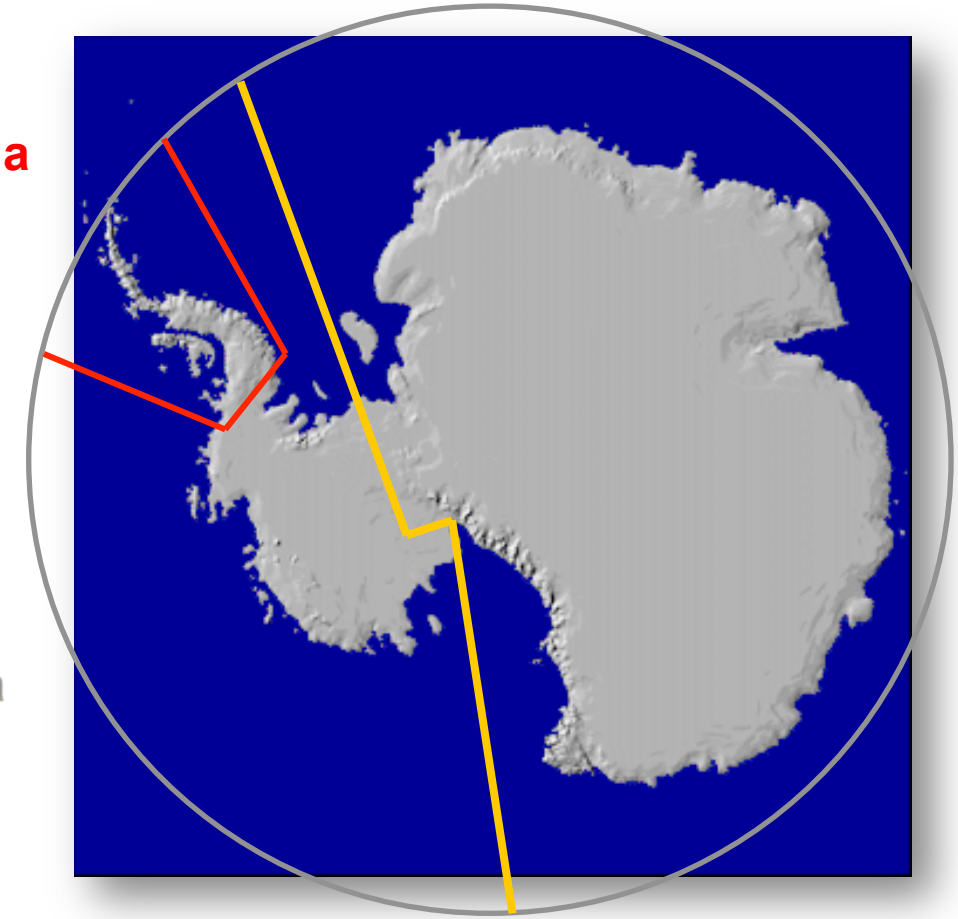


Ice thickness difference:
„fresh" minus CTRL

Icebergs

Basal melting vs. *iceberg calving*

Antarctic Peninsula
191 ± 80 Gt/a
69 ± 13 Gt/a



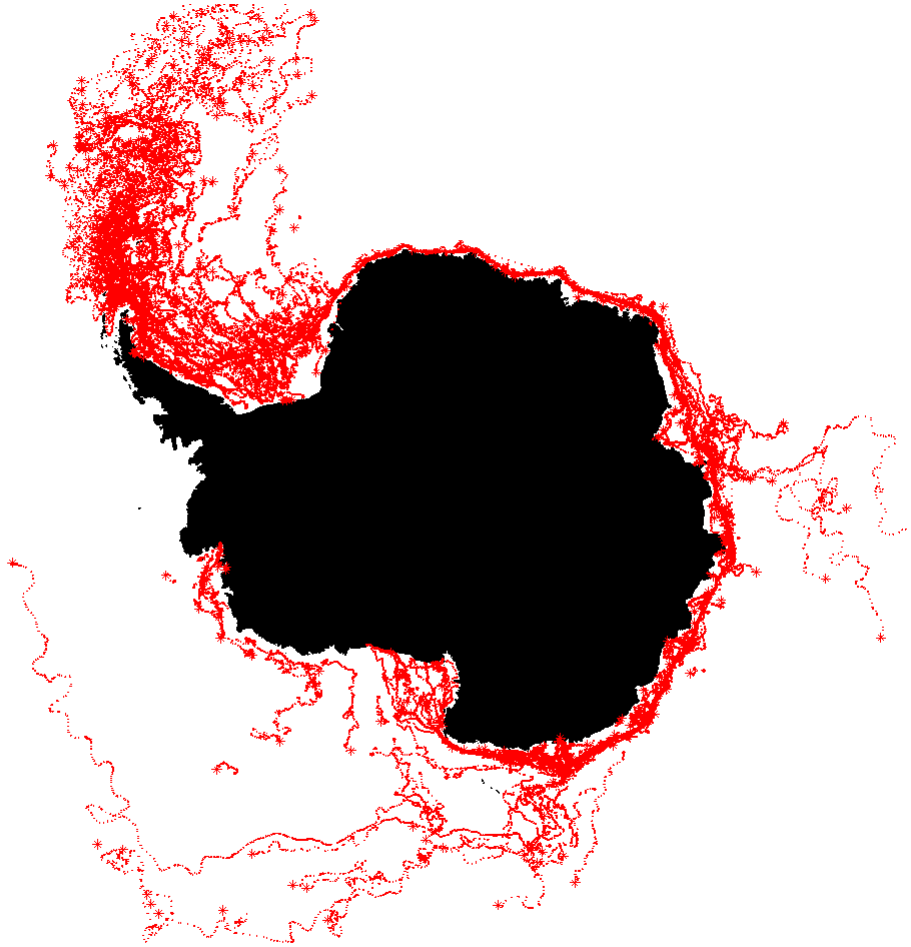
East Antarctica
480 ± 116 Gt/a
546 ± 70 Gt/a

West Antarctica
654 ± 89 Gt/a
494 ± 57 Gt/a

Rignot et al., 2013

Distribution of icebergs

The Antarctic Iceberg Tracking Database
1978 & 1992-2013 (Brigham Young University)



Iceberg tracks from 1999-2010

Madsen et al.

Despite the existence of an iceberg track database, estimates of the freshwater distribution from iceberg melting are still hard to obtain.

An embedded iceberg model in FESOM forced with a mean size class distribution and observed calving rates is currently work in progress at AWI.

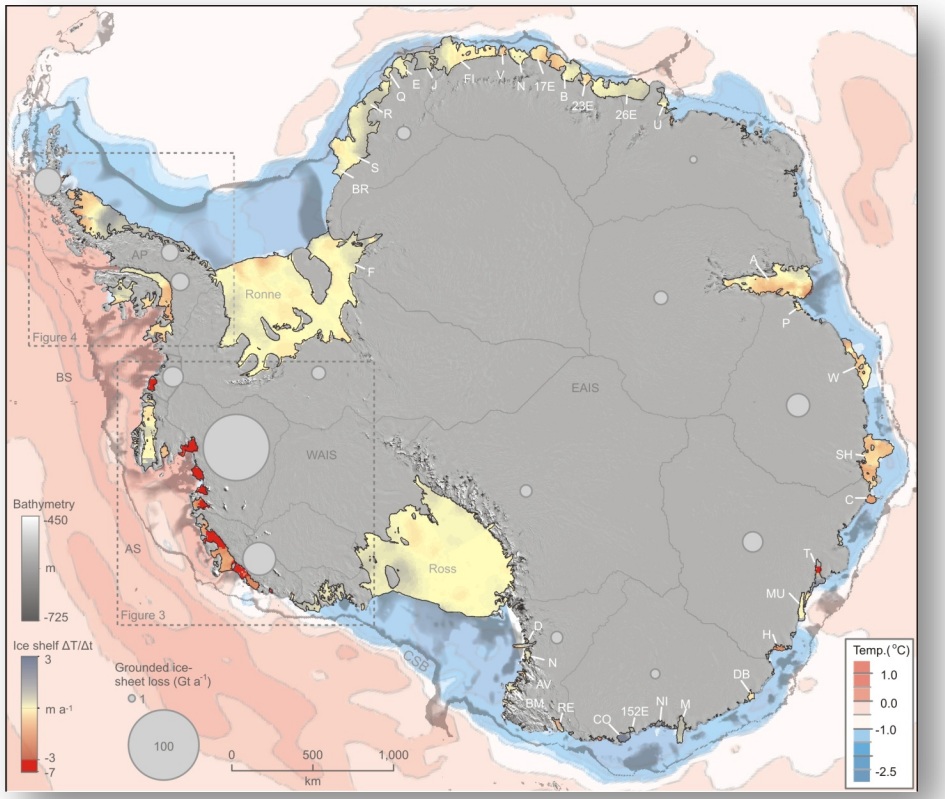
Validation

Model validation is essential not only for Southern Ocean models. Here are a few examples of things that a model should get right:

Southern Ocean bottom temperature features a characteristic dipole with cold water on the continental shelf in the Weddell and Ross Seas and along the East Antarctic, and warm water near the coast in the Amundsen and Bellingshausen Seas.

The cold water is not a problem for models, but the warm water is. Horizontal resolution O(km) is required to enable the warm deep water to enter the continental shelf through narrow troughs.

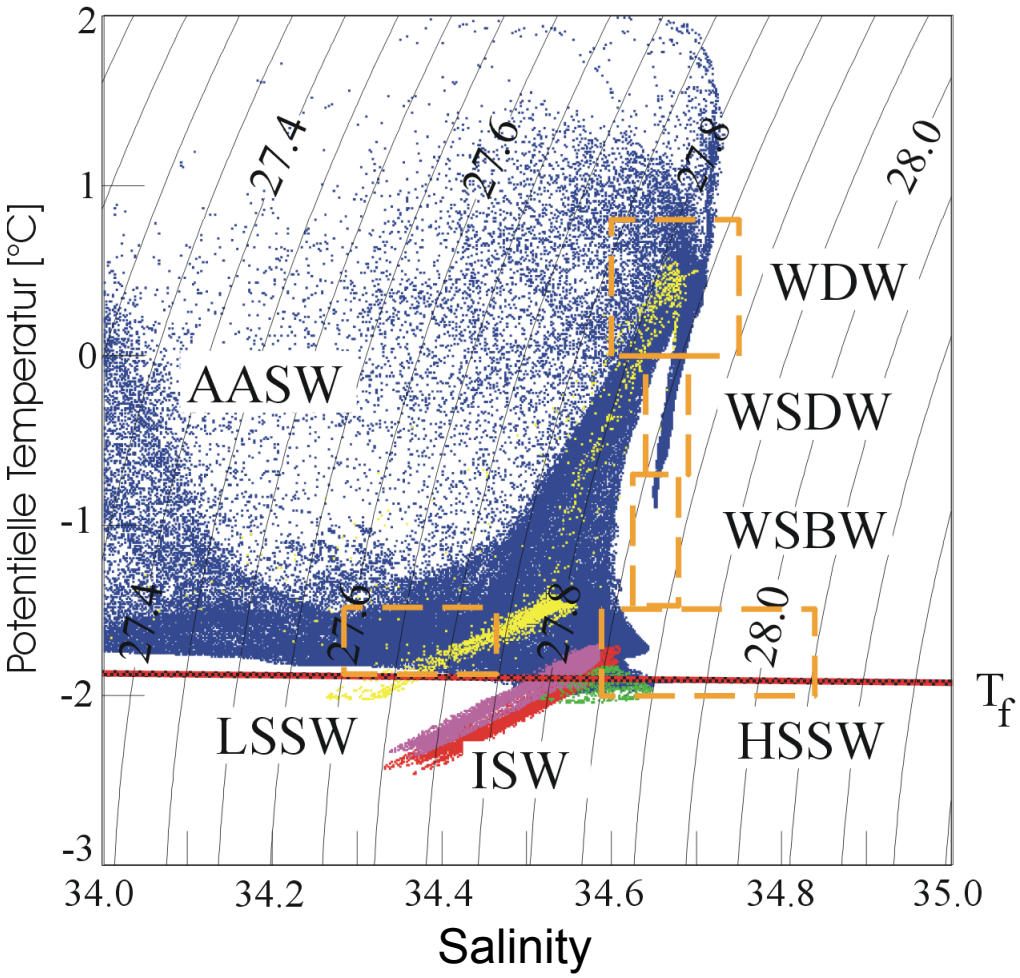
Ocean bottom temperature



Pritchard et al. (2012)

Validation (cont'd)

Weddell Sea water mass characteristics (from BRIOS-2)

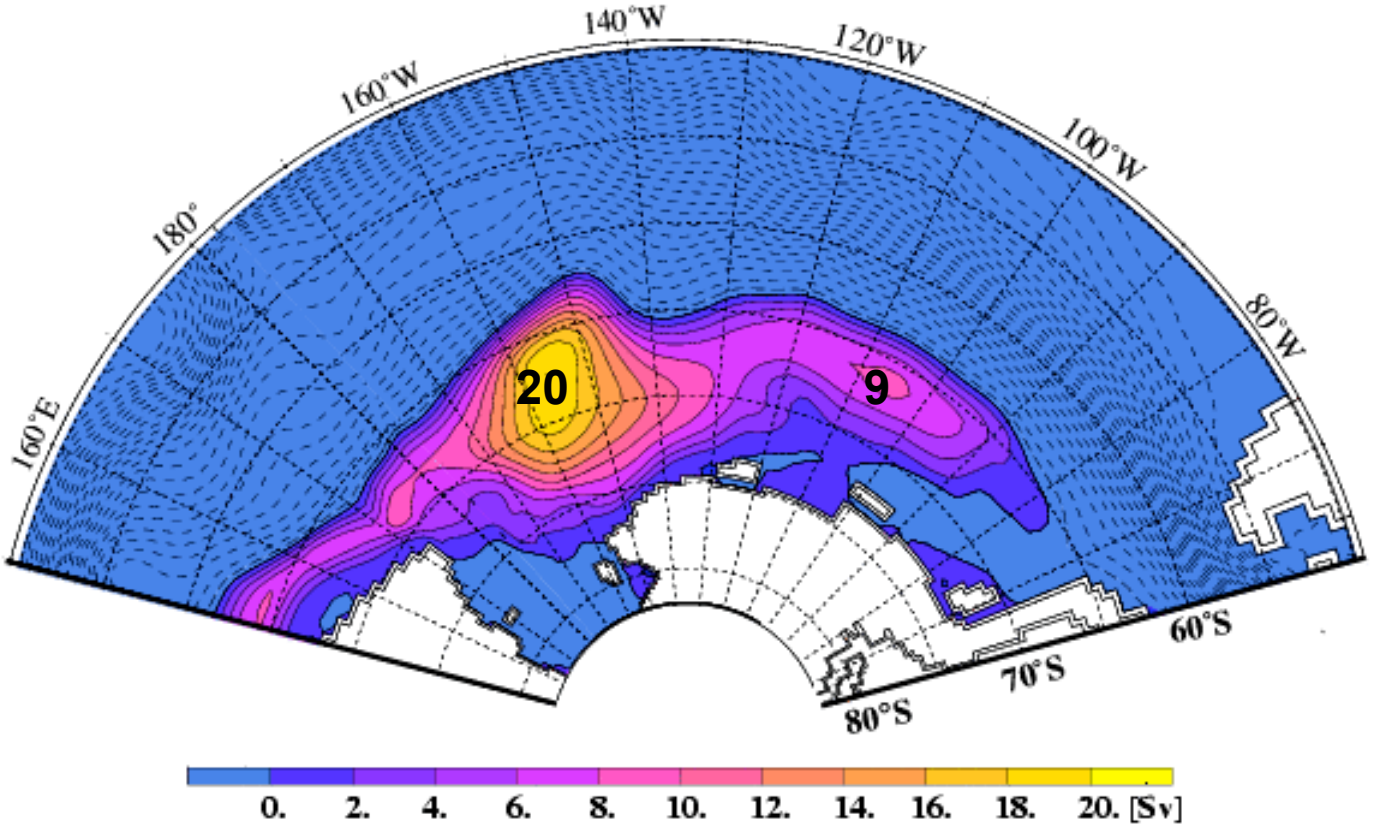


Ice shelf cavities

- eastern Weddell Sea
- Larsen Ice Shelf
- Filchner Ice Shelf
- Ronne Ice Shelf

Validation (cont'd)

Sub-polar gyre strength
e.g. Pacific Sector 24-year mean (1978-2001)
from BRIOS-2



Summary

- **An appropriate representation of the freshwater flux from ice shelf basal melting is an important step towards a realistic respresentation of water mass modification in the Southern Ocean.**

- **Next to the horizontal distribution of volume flux, the vertical distribution is of paramount importance, especially where warm deep water approaches the ice shelf front.**
  Don't just put everything into the surface layer!

- **For the horizontal distribution, studies of, e.g., Rignot et al. (2013) provide the necessary information.**

- **For the vertical distribution, wait for Mathiot et al. paper. Or talk to him.**

Appendix

- Tables with numbers for mass fluxes at the grounding line, ice base, and ice front (=calving), and the surface mass balance for all the ice shelves (from Rignot et al., 2013)

Ice sheet mass loss (1/5)

Name	Area km2	GL Gt/year	SMB Gt/year	Ice front Gt/year	$\partial H/\partial t$ Gt/year	Basal melt Gt/year (m/year)
Larsen G	412	0.9 ± 0.2	0.1 ± 0	0.7 ± 1	0.0 ± 0	0.3 ± 0.2 (0.71 ± 0.6)
Larsen F	828	1.5 ± 0.3	0.3 ± 0.1	0.6 ± 1	-0.7 ± 0.5	1.2 ± 0.4 (1.4 ± 0.5)
Larsen E	1,184	3.6 ± 0.7	0.4 ± 0.1	1.5 ± 1	1.1 ± 0.7	1.4 ± 1 (1.2 ± 0.9)
Larsen D	22,548	18.5 ± 4	9.8 ± 2	6.3 ± 1	20.5 ± 14	1.4 ± 14 (0.1 ± 0.6)
Larsen C	46,465	29.6 ± 3	23.8 ± 4	31.3 ± 3	1.4 ± 67	20.7 ± 67 (0.4 ± 1)
Larsen B*	6,755	13.6 ± 3	3.0 ± 0.6	8.9 ± 1	-4.5 ± 13	12.2 ± 14 (1.8 ± 2)
Wordie	277	13.8 ± 1	0.3 ± 0	7.6 ± 3	-0.1 ± 0	6.5 ± 3 (23.6 ± 10)
Wilkins	12,866	7.8 ± 2	8.3 ± 2	0.7 ± 0.4	-3.4 ± 16	18.4 ± 17 (1.5 ± 1)
Bach	4,579	5.4 ± 1	1.8 ± 0.3	0.8 ± 0.2	-4.0 ± 0.3	10.4 ± 1 (2.3 ± 0.3)
George VI	23,434	68.2 ± 5	12.7 ± 2	5.7 ± 1.2	-13.8 ± 16	89.0 ± 17 (3.8 ± 0.7)
Stange	8,027	21.0 ± 3	6.0 ± 1	4.6 ± 0.8	-5.6 ± 5	28.0 ± 6 (3.5 ± 0.7)
Antarctic Peninsula	127,375	184 ± 26	66 ±13	69 ± 13	-9 ± 74	191 ± 80 (1.5 ± 0.6)

Riognot et al. (2013)

Ice sheet mass loss (2/5)

Name	Area km2	GL Gt/year	SMB Gt/year	Ice front Gt/year	$\partial H/\partial t$ Gt/year	Basal melt Gt/year (m/year)
Ronne	338,887	156.1 ± 10	59.3 ± 11	149.2 ± 22	-47.4 ± 22	113.5 ± 35 (0.3 ± 0.1)
Ferrigno	117	11.2 ± 1	0.16 ± 0	6.6 ± 2	-0.3 ± 0	5.1 ± 2 (43.4 ± 17)
Venable	3,194	14.6 ± 2	3.5 ± 1	6.5 ± 1	-7.7 ± 1	19.4 ± 2 (6.1 ± 0.7)
Abbot	29,688	34.0 ± 4	25.0 ± 5	2.4 ± 0.5	4.7 ± 18	51.8 ± 19 (1.7 ± 0.6)
Cosgrove	3,033	5.2 ± 1	1.5 ± 0.3	1.3 ± 1.2	-3.1 ± 2	8.5 ± 2 (2.8 ± 0.7)
Pine Island	6,249	126.4 ± 6	4.6 ± 0.9	62.3 ± 5	-33.2 ± 2	101.2 ± 8 (16.2 ± 1)
Thwaites	5,499	113.5 ± 4	4.8 ± 0.9	54.5 ± 5	-33.7 ± 3	97.5 ± 7 (17.7 ± 1)
Crosson	3,229	27.4 ± 2	3.7 ± 0.7	11.7 ± 2	-19.2 ± 1	38.5 ± 4 (11.9 ± 1)
Dotson	5,803	28.4 ± 3	5.7 ± 1	5.5 ± 0.7	-16.6 ± 2	45.2 ± 4 (7.8 ± 0.6)
Getz	34,018	96.7 ± 5	34.2 ± 7	53.5 ± 2	-67.6 ± 12	144.9 ± 14 (4.3 ± 0.4)
Land	640	14.5 ± 1	0.8 ± 0.1	12.2 ± 1	-0.7 ± 0.3	3.8 ± 1 (5.9 ± 2)
Nickerson	6,495	7.8 ± 1	4.6 ± 0.9	4.3 ± 0.6	3.9 ± 1	4.2 ± 2 (0.6 ± 0.3)
Sulzberger	12,333	15.1 ± 2	8.2 ± 2	1.0 ± 0.2	4.1 ± 2	18.2 ± 3 (1.5 ± 0.3)
Swinburne	900	4.9 ± 0.4	0.9 ± 0.2	1.5 ± 0.3	0.6 ± 0.2	3.8 ± 0.5 (4.2 ± 0.6)
Withrow	632	1.3 ±0.2	0.3 ± 0.0	1.2 ± 0.3	0.1 ± 0.1	0.3 ± 0.4 (0.5 ± 0.6)
Ross West	306,105	73.0 ± 4	33.5 ± 6	100.4 ± 8	7.6 ± 17	-1.4 ± 20 (0.0 ± 0.1)
West Antarctica	756,822	730 ± 47	191 ± 36	494 ± 57	-208 ± 36	654 ± 89 (0.9 ± 0.1)

Riognot et al. (2013)

Ice sheet mass loss (3/5)

Name	Area km2	GL Gt/year	SMB Gt/year	Ice front Gt/year	$\partial H/\partial t$ Gt/year	Basal melt Gt/year (m/year)
Ross East	194,704	56.1 ± 4	31.0 ± 6	45.9 ± 4	-7.8 ± 11	49.1 ± 14 (0.3 ± 0.1)
Drygalski	2,338	9.6 ± 0.6	0.3 ± 0.1	3.0 ± 1	-0.8 ± 0.4	7.6 ± 1 (3.3 ± 0.5)
Nansen	1,985	1.3 ± 0.5	0.3 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	1.1 ± 0.6 (0.6 ± 0.3)
Aviator	785	1.1 ± 0.2	0.2 ± 0.	0.2 ± 0.1	-0.3 ± 0.1	1.4 ± 0.2 (1.7 ± 0.3)
Mariner	2,705	2.5 ± 0.4	1.1 ± 0.2	0.6 ± 0.2	0.6 ± 0.3	2.4 ± 0.6 (0.9 ± 0.2)
Lillie	770	3.6 ± 0.3	0.2 ± 0.	0.5 ± 0.1	0.0 ± 0.	3.4 ± 0.3 (4.4 ± 0.4)
Rennick	3,273	4.8 ± 1	0.7 ± 0.1	0.8 ± 0.2	-2.3 ± 0.9	7.0 ± 1 (2.2 ± 0.3)
Cook	3,462	36.0 ± 3	1.7 ± 0.3	27.6 ± 3	5.5 ± 1	4.6 ± 5 (1.3 ± 1)
Ninnis	1,899	27.6 ±2	1.3 ± 0.2	24.6 ± 3	2.0 ± 0.9	2.2 ± 3 (1.2 ± 2)
Mertz	5,522	20.0 ± 1	3.6 ± 0.7	12.0 ± 2	3.6 ± 1	7.9 ± 3 (1.4 ± 0.6)
Dibble	1,482	12.5 ± 1	1.5 ± 0.3	8.2 ± 0.9	-2.3 ± 0.7	8.1 ± 1 (5.5 ± 0.9)
Holmes	1,921	26.0 ± 2	2.8 ± 0.5	24.7 ± 4	-2.5 ± 1	6.7 ± 4 (3.5 ± 2)
Moscow Univ.	5,798	52.3 ± 1	4.7 ± 0.9	29.6 ± 3	-0.1 ± 3	27.4 ± 4 (4.7 ± 0.8)
Totten	6,032	71.0 ± 3	6.2 ± 1	28.0 ± 2	-14.0 ± 2	63.2 ± 4 (10.5 ± 0.7)

Rignot et al. (2013)

Ice sheet mass loss (4/5)

Name	Area km2	GL Gt/year	SMB Gt/year	Ice front Gt/year	$\partial H/\partial t$ Gt/year	Basal melt Gt/year (m/year)
Vincennes	935	12.7 ± 1	0.5 ± 0.1	6.8 ± 1	1.3 ± 0.6	5.0 ± 2 (5.3 ± 2)
Conger/Glenzer	1,547	1.7 ± 0.4	0.9 ± 0.2	1.1 ± 0.8	-2.1 ± 1	3.6 ± 1 (2.3 ± 0.9)
Tracy/Tremenchus	2,845	0.6 ±0.4	1.0 ± 0.2	0.2 ± 0.1	-1.7 ± 2	3.0 ± 2 (1.5 ± 0.7)
Shackleton	26,080	55.0 ± 4	16.2 ± 3	30.3 ± 3	-31.7 ± 14	72.6 ± 15 (2.8 ± 0.6)
West	15,666	41.9 ± 4	6.9 ± 1	32.6 ± 7	-11.1 ± 7	27.2 ± 10 (1.7 ± 0.7)
Publications	1,551	5.8 ± 0.8	0.4 ± 0.1	5.2 ± 1	-0.5 ± 0.8	1.5 ± 2 (1.0 ± 1)
Amery	60,654	56.0 ± 0.5	8.5 ± 2	50.4 ± 8	-21.4 ± 21	35.5 ± 23 (0.6 ± 0.4)
Wilma/Robert/ Downer	858	10.3 ±0.5	0.6 ± 0.1	0.8 ± 0.4	0.0 ± 0	10.0 ± 0.6 (11.7 ± 0.7)
Edward VIII	411	4.1 ± 0.8	0.4 ± 0.1	0.3 ± 0.1	0.0 ± 0	4.2 ± 0.8 (10.2 ± 2)
Rayner/Thyer	641	14.2 ± 1	0.3 ± 0.1	7.8 ± 0.6	0.0 ± 0	6.7 ± 1 (10.5 ± 2)
Shirase	821	15.0 ± 1	0.4 ± 0.1	9.6 ± 1	0.0 ± 0	5.7 ± 1 (7.0 ± 2)
Prince Harald	5,392	8.3 ± 1	4.1 ± 0.8	10.3 ± 2	4.0 ± 2	-2.0 ± 3 (-0.4 ± 0.6)
Baudouin	32,952	22.0 ± 3	8.4 ± 2	6.5 ± 1	9.8 ± 11	14.1 ± 12 (0.4 ± 0.4)
Borchgrevink	21,580	19.6 ± 3	6.1 ± 1	17.5 ± 3	0.7 ± 4	7.5 ± 6 (0.3 ± 0.3)

Riognot et al. (2013)

Ice sheet mass loss (5/5)

Name	Area km2	GL Gt/year	SMB Gt/year	Ice front Gt/year	$\partial H/\partial t$ Gt/year	Basal melt Gt/year (m/year)
Lazarev	8,519	3.7 ± 0.6	2.0 ± 0.4	3.1 ± 1	-3.6 ± 2	6.3 ± 2 (0.7 ± 0.2)
Nivl	7,285	3.9 ± 0.8	1.8 ± 0.3	1.3 ± 0.4	0.6 ± 1	3.9 ± 2 (0.5 ± 0.2)
Vigrid	2.089	2.7 ± 0.4	0.4 ± 0.1	2.0 ± 0.4	-2.0 ± 0.4	3.2 ± 0.7 (1.5 ± 0.3)
Fimbul	40,843	24.9 ± 4	12.7 ± 2	18.2 ± 2	-4.0 ± 7	23.5 ± 9 (0.6 ± 0.2)
Jelbart	10,844	9.9 ± 1	4.9 ± 0.9	8.8 ± 2	6.9 ± 2	-1.0 ± 3 (-0.1 ± 0.3)
Atka	1,969	0.9 ± 0.2	0.8 ± 0.1	1.0 ± 0.2	1.1 ± 0.2	-0.5 ± 0.4 (-0.2 ± 0.2)
Ekstrom	6,872	4.1 ± 0.8	2.6 ± 0.5	2.3 ± 0.6	0.0 ± 0	4.3 ± 2 (0.6 ± 0.2)
Quar	2,156	1.0 ±0.2	0.5 ± 0.1	0.6 ± 0.1	-0.5 ± 0.4	1.4 ± 0.5 (0.7 ± 0.2)
Riiser-Larsen	43,450	21.5 ± 3	12.7 ± 2	12.1 ± 2	13.4 ± 8	8.7 ± 9 (0.2 ± 0.2)
Brunt/Stancomb	36,894	20.3 ± 3	11.4 ± 2	28.1 ± 4	2.6 ± 4	1.0 ± 7 (0.03 ± 0.2)
Filchner	104,253	97.7 ± 6	13.4 ± 2	82.8 ± 4	-13.6 ± 7	41.9 ± 10 (0.4 ± 0.1)
East Antarctica	669,781	782 ± 80	174 ± 33	546 ± 70	-70 ± 34	480 ± 116 (0.7 ± 0.2)
Total surveyed	**1,553,978**	**1,696 ± 146**	**430 ± 81**	**1,089 ± 139**	**-287 ± 89**	**1,325 ± 235 (0.85 ± 0.1)**
Total Antarctica	1,561,402	2,048 ± 149		1,265 ± 141		1,500 ± 237

Rignot et al. (2013)