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Modeling Southern Ocean iceberg drift and decay

Thomas Rackow, C. Wesche, R. Timmermann
AWI Climate Dynamics

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IUP – AWI block seminar on *Ice – Ocean Interaction*

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Overview

1. Role of icebergs in the climate system

2. Physics of iceberg drift and decay / (Thermo-)Dynamics

3. FESOM-IB / The model

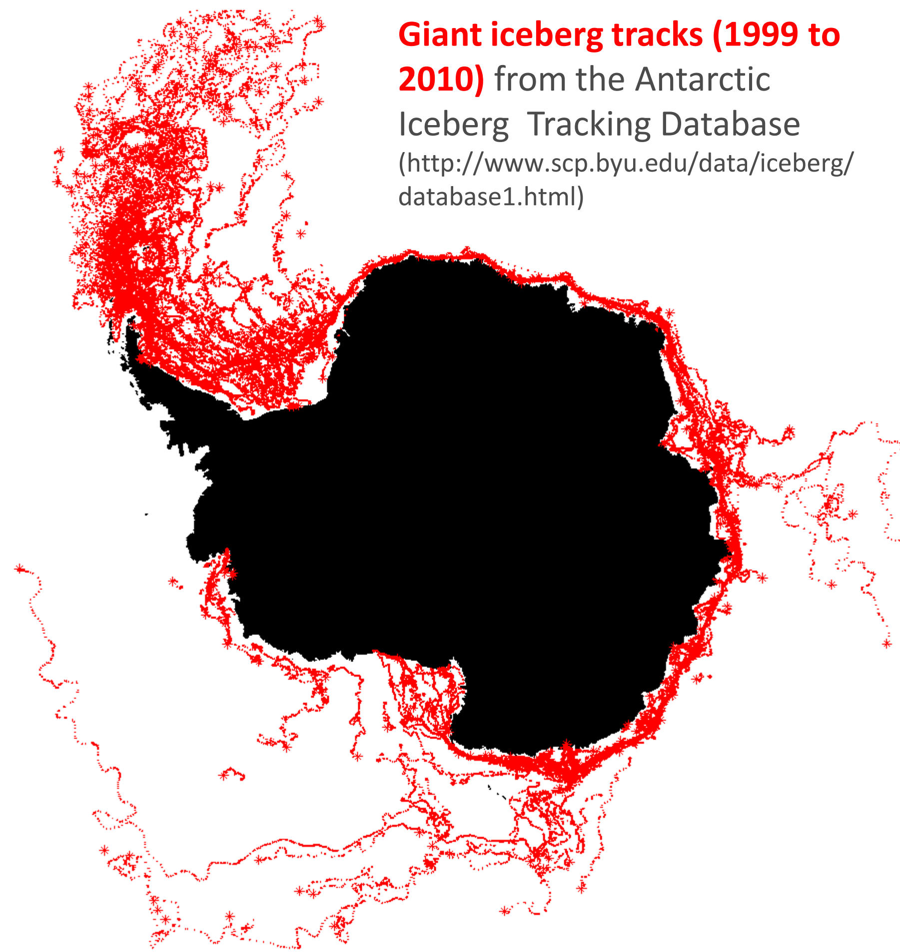
4. Results / Drift patterns, freshwater input

5. Outlook

6. Summary

1. Role of icebergs in the climate system

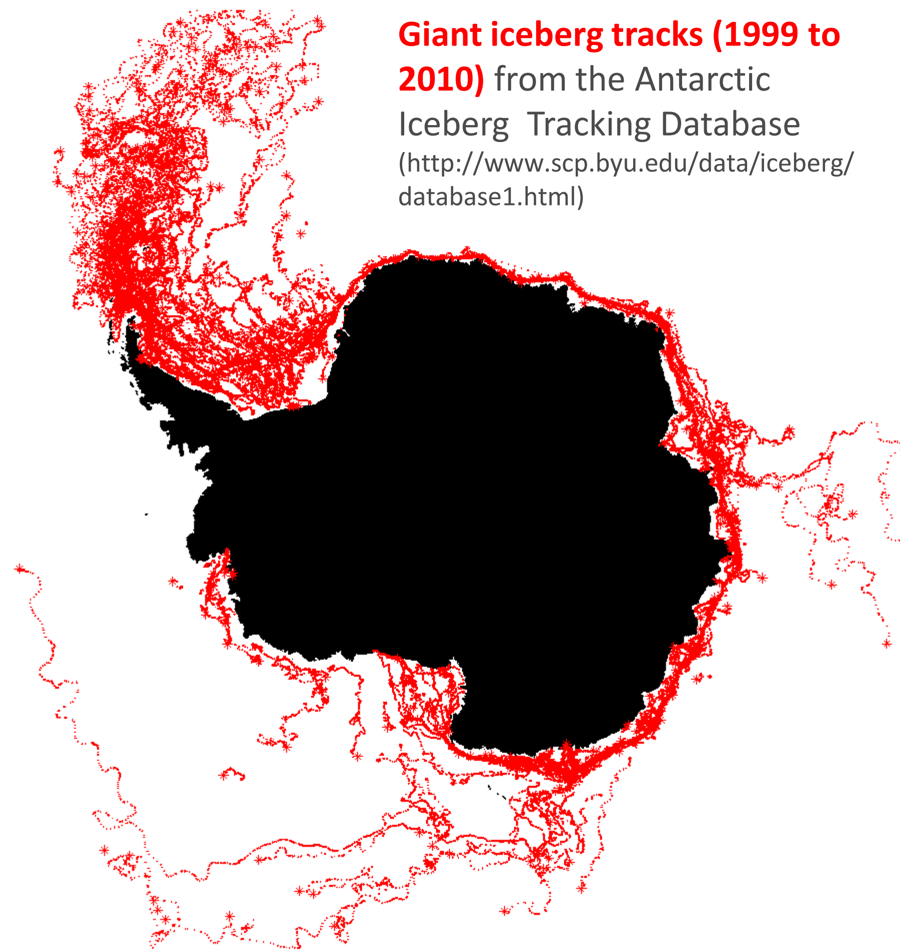
- Icebergs may drift under the influence of winds, currents, and sea ice
- Despite their potential importance, icebergs are still widely neglected in current GCMs
- **ocean**:
  Icebergs distribute fresh water over the ocean while melting => influence on the stability of the water column; cooling effect due to latent heat fluxes



Giant iceberg tracks (1999 to 2010) from the Antarctic Iceberg Tracking Database (http://www.scp.byu.edu/data/iceberg/database1.html)

1. Role of icebergs in the climate system

- **sea ice**:
  Sea ice coverage is also influenced; in addition, direct dynamic influence through ridging at the iceberg's sides.
- **biosphere**:
  Icebergs (large draft) can influence ecosystems close to the bottom
  Iron Fertilization: Phytoplankton growth
- **ice sheets**:
  One component in mass balance



Giant iceberg tracks (1999 to 2010) from the Antarctic Iceberg Tracking Database (http://www.scp.byu.edu/data/iceberg/database1.html)

2. Physics of iceberg drift and decay

- **Dynamics**: Iceberg momentum balance (similar to sea ice):

$$M\frac{d\boldsymbol{u}}{dt} = \sum_k \boldsymbol{F}_k$$, where $\boldsymbol{u} = (u, v)$ horizontal iceberg velocity

- Which forces enter the right hand side?

- Coriolis: $\boldsymbol{F}_c = -fM\,\boldsymbol{k} \times \boldsymbol{u}$, Surface slope: $\boldsymbol{F}_p = -Mg\boldsymbol{\nabla}\eta$
  - f Coriolisparameter, $\boldsymbol{k}$ vertical normal, η sea surface height

- Oceanic/Atmospheric skin and ***form*** drags

- ***Sea ice capturing mechanism*** $\boldsymbol{F}_i$: If the ice concentration A and the ice strength P both exceed $\mathrm{Conc_{sill}} = 90\%$ or $\mathrm{P_s} = 10000\ N/m^2$;
  for medium ice concentrations an ice form drag is applied (mechanism similar to *Lichey and Hellmer, 2001*)

2. Physics of iceberg drift and decay

- **Thermodynamics**: Simple (diagnostic) equations (*Bigg et al., 1997, Gladstone et al., 2001)*:

- (Basal) **Turbulent melting** [m/day]:

$$M_b = 0.58 \times |\boldsymbol{u}_o - \boldsymbol{u}|^{0.8} \times \frac{T_o - T_{ib}}{L^{0.2}}$$

- **Bouyant convection** [m/day]:

$$M_v = 7.62 \times 10^{-3} T_o + 1.29 \times 10^{-3} {T_o}^2$$

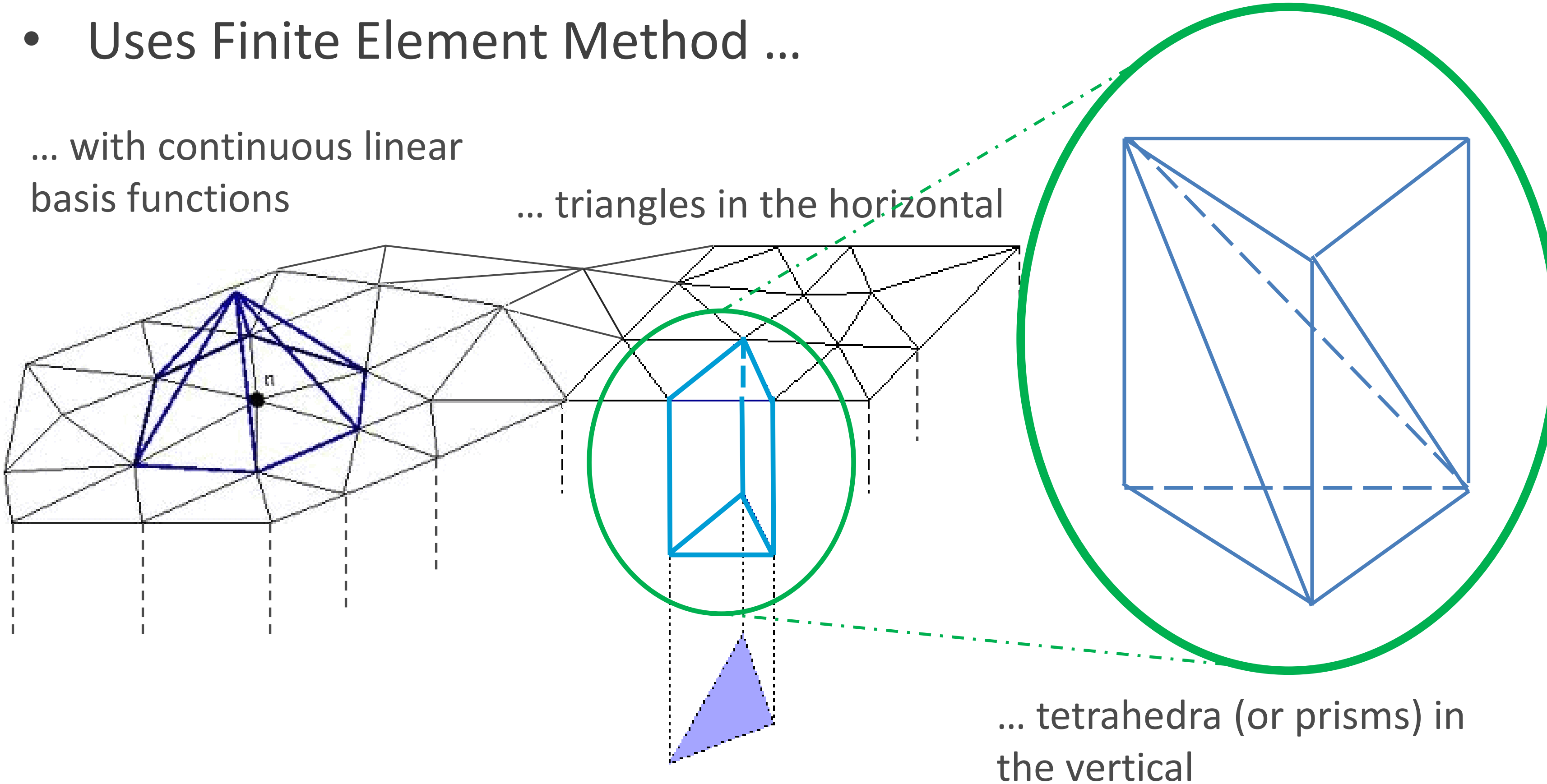
- **Wave erosion** [m/day]:

$$M_e = \frac{1}{12}[1 + \cos(A^3 \pi)](T_o + 2)S_s$$

L iceberg length, $\boldsymbol{u}_o$ depth-integrated ocean velocity at position of iceberg, T_o sea surface temperature, $T_{ib} = -4°\text{C}$, S_s sea state, A sea ice concentration

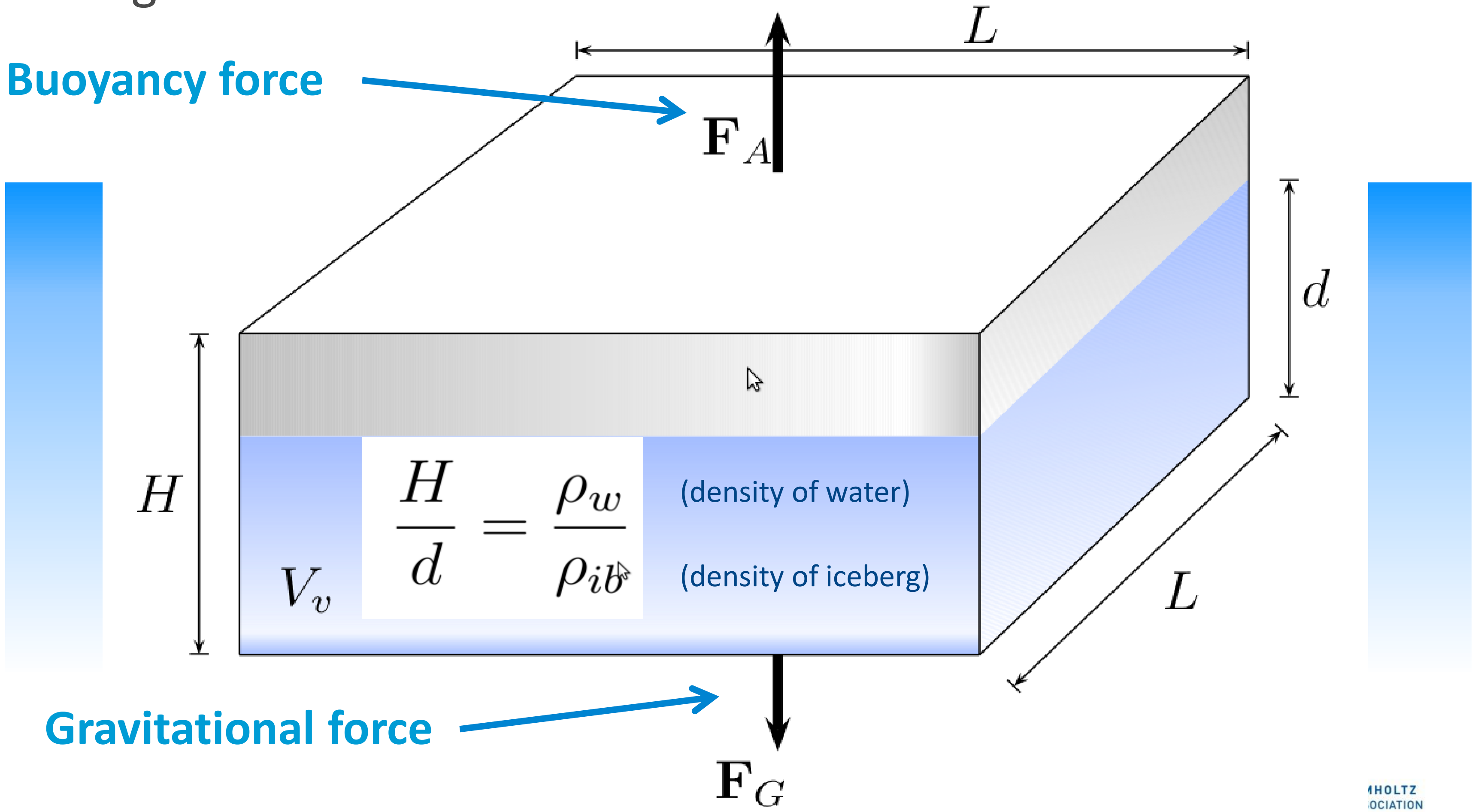
3. **FESOM-IB:** Sea ice—ocean model

- FESOM solves the hydrostatic primitive equations as well as the sea ice momentum and thermodynamic equations *(Danilov et al., 2004, Wang et al., 2008, Timmermann et al., 2009)*
- Uses Finite Element Method …



3. **FESOM-IB:** The IceBerg module (IB)

- Icebergs are assumed to be cubical-shaped. They are treated as Lagrangian point masses having properties such as length ***L***, height ***H*** and draft ***d***:



3. FESOM-IB: The IceBerg module (IB)

- **Numerics**

- **Discretisation**
  - Coriolis term: (semi-)implicit; ocean drag terms: partly implicit; all other terms: explicit
  - Time derivative of momentum eq. is approximated with Euler-Forward differences

- FESOM ice/ocean velocity fields and sea surface height/temperature are evaluated at every timestep (**3 min.**)

- IB model is written in FORTRAN; settings are controlled in the iceberg FORTRAN module

3. FESOM-IB: The IceBerg module (IB)

- **FORTRAN module**:

```fortran
module iceberg_params
implicit none
save

  integer,parameter                  :: ib_num=2
  real,dimension(ib_num)             :: calving_day=(/ 14.5, 15.5 /)      !
! ======= Jan99 icebergs (Schodlok/Hellmer paper) =======                 !
                                                                          !
  real,dimension(ib_num)  :: height_ib  = (/  231.5,   289.4  /)          !
  real,dimension(ib_num)  :: length_ib  = (/  250.0,  1180.0  /)          !
  real,dimension(ib_num)  :: width_ib   = (/  250.0,  1180.0  /)          !
  real,dimension(ib_num)  :: lon_deg    = (/  0.352,   0.243  /)          !
  real,dimension(ib_num)  :: lat_deg    = (/ -54.752, -55.466 /)          !
! ========================================================================!
! ======= Lichey & Hellmer values =======                                 !
                                                                          !
  real,dimension(ib_num)  :: Co= 0.85                                     !
  real,dimension(ib_num)  :: Ca= 0.4                                      !
  real,dimension(ib_num)  :: Ci= 1.0                                      !
  real, dimension(ib_num) :: Cdo_skin= 0.0005                             !
  real, dimension(ib_num) :: Cda_skin= 0.0025                             !
! ========================================================================!
  real,dimension(ib_num)  :: conc_sill=0.90                               !
  real,dimension(ib_num)  :: P_sill=13000.                                !
  logical                 :: l_freeze = .false.                           ! use freezing?
! ========================================================================!
  logical                 :: l_melt = .false.                             ! use melting?
! ========================================================================!
  logical                 :: l_wave = .false.                             ! use wave rad.?
                                                                          ! use tides?
```

4. Results: 5-yr simulation of Antarctic icebergs

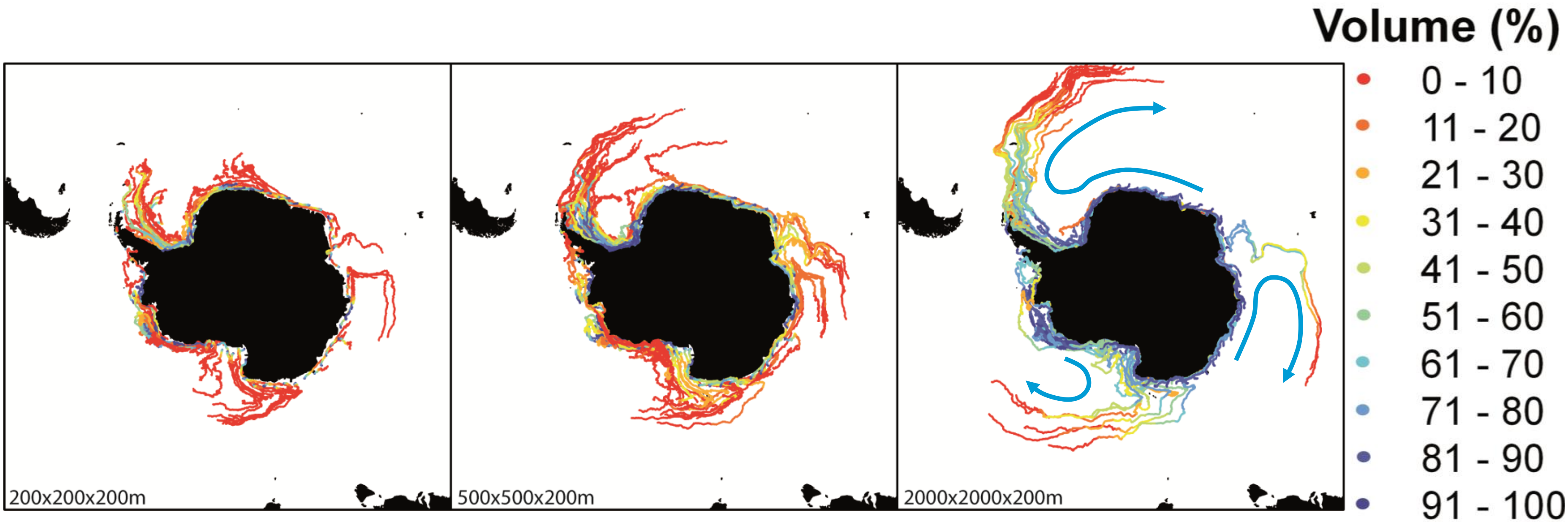
- simulation is started in Jan 1999
- 308 icebergs in total (4 size classes started from 77 circum-Antarctic locations / calving sites)
  => total volume of all icebergs is not necessarily realistic

Size class	Length L [m]	Height H [m]	Volume V [m^3]	Mass M [kg]
small	200	200	8×10^6	6.8×10^9
medium	500	200	50×10^6	42.5×10^9
big	2000	200	800×10^6	680×10^9
giant	18500	200	68.45×10^9	58.18×10^{12}

- Melting, grounding, „sea-ice capturing mechanism“ enabled

4. Results: Remaining volume

- … for small, medium, and big icebergs:

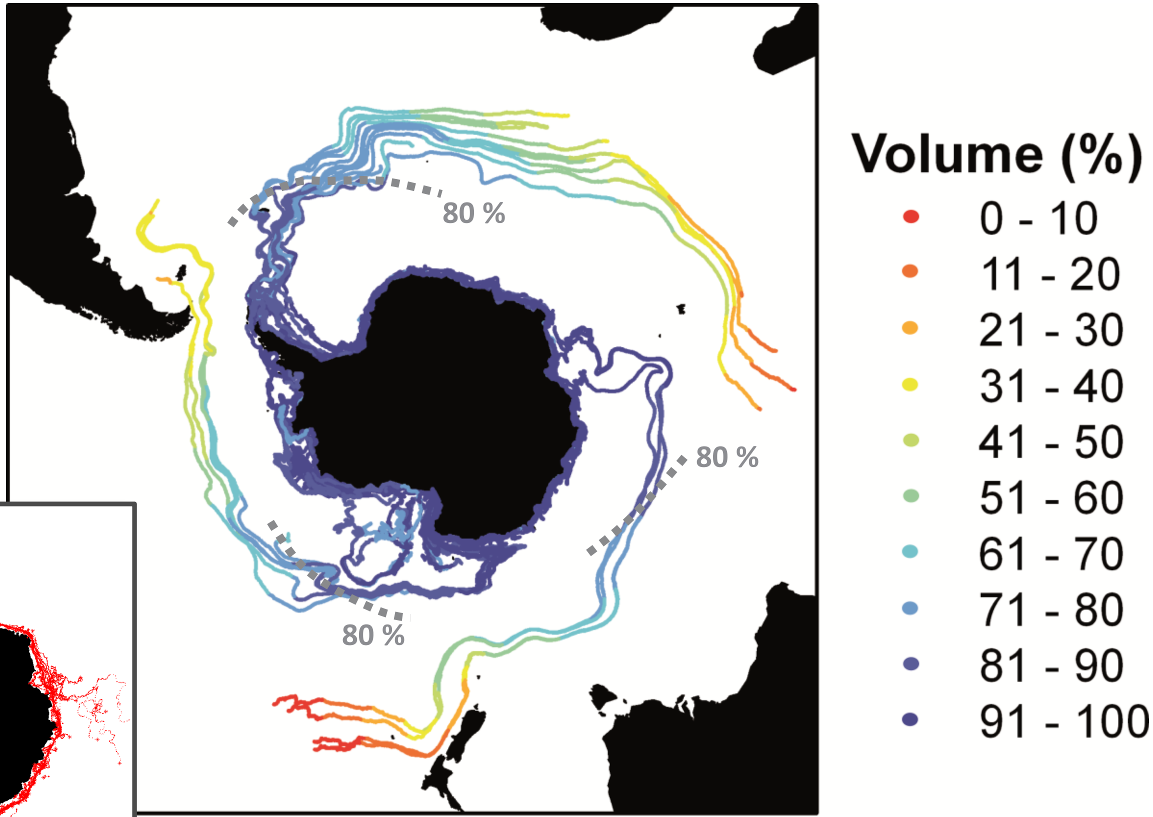


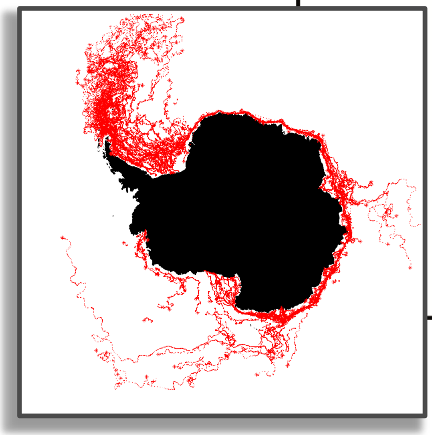
adapted from Rackow et al. (2013)

4. Results: Remaining volume

- … for giant icebergs:

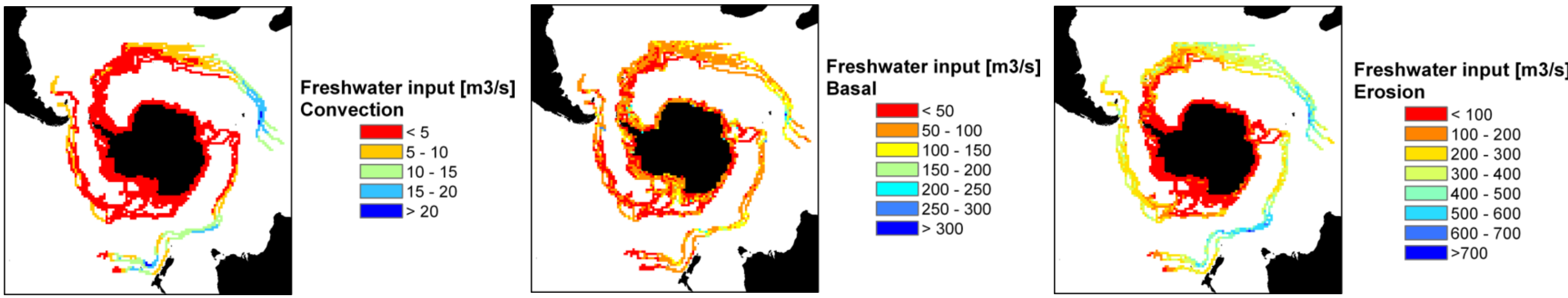
Giant iceberg tracks (1999 to 2010) from the Antarctic Iceberg Tracking Database (http://www.scp.byu.edu/data/iceberg/database1.html)

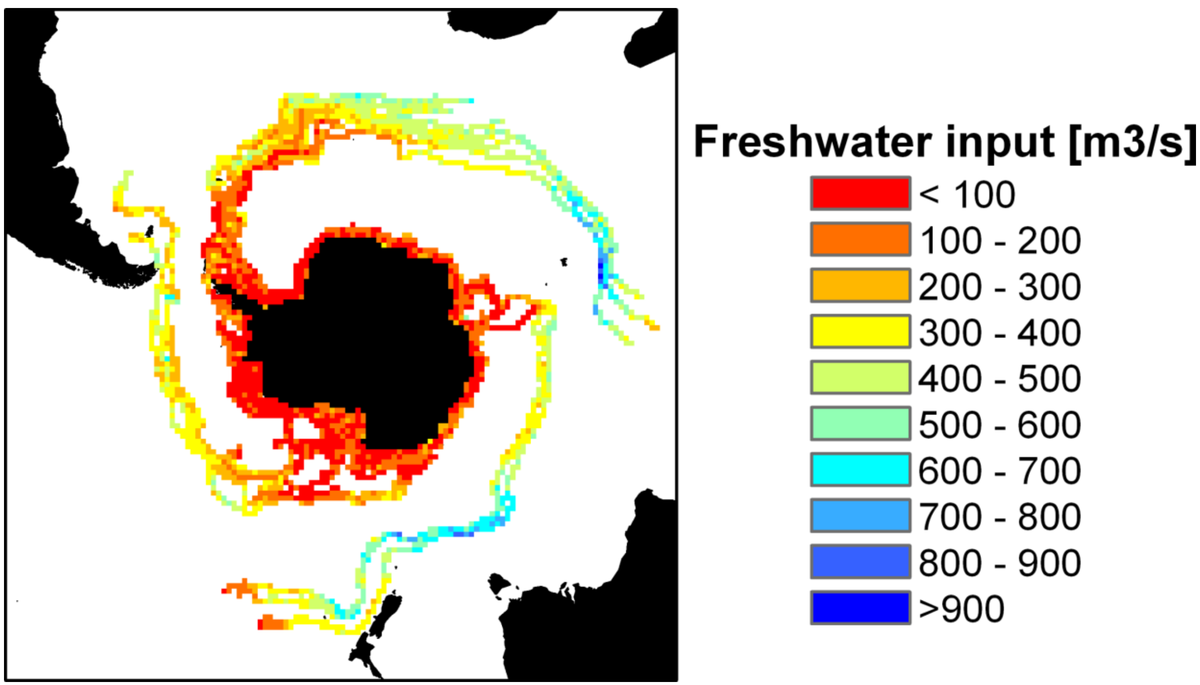




adapted from Rackow et al. (2013)

4. Results: Freshwater input from giant icebergs





Gridded freshwater input for the giant icebergs in the 5-yr simulation.

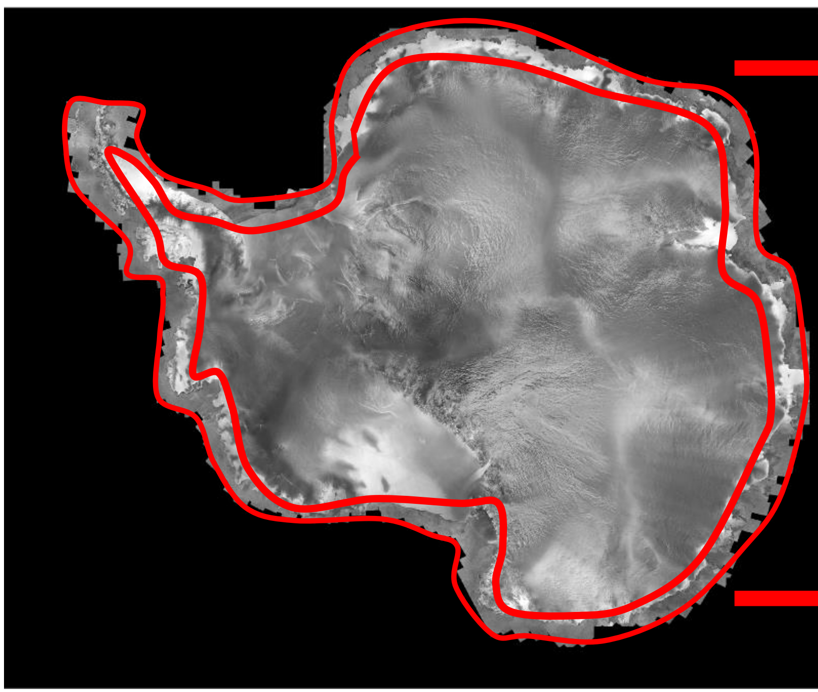
Top panels: Meltrates due to ***(left)*** convection terms, ***(middle)*** basal melting and ***(right)*** wave erosion.

Lower panel: Combined freshwater input

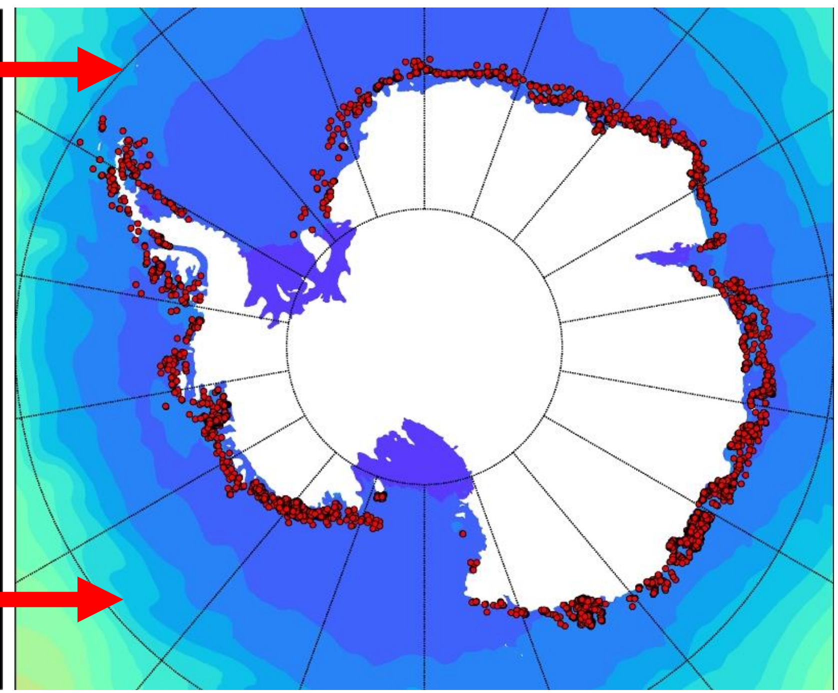
adapted from Rackow et al. (2013)

5. Outlook: Next (realistic) setup

- Realistic initial distribution of icebergs needed
- Use snapshot of most icebergs from SEP 1997 (ca. 7000) in coastal strip around Antarctica *(C. Wesche, manuscript in preparation)*



SAR Image Mosaic (125m resolution) from
http://repository.agic.umn.edu/imagery/satellite/radarsat/
RADARSAT-1 **(Antarctic Mapping Mission)**



Initial iceberg distribution in FESOM-IB (ca. 7000 icebergs, red dots)

5. Outlook

- Same thermodynamics for the iceberg thermodynamics as in the ice shelf module (3-eq. formulation of ice shelf-ocean interaction after *Hellmer et al. (1997)*);
  3D ocean information used instead of only 2D fields

- Currently, the meltwater and associated latent heat fluxes are **not** coupled, so the ocean model does not see them
  => We expect influences on the coastal currents around Antarctica due to the *combined meltwater input from ice shelves and icebergs*

- Icebergs have to be prescribed **manually;** for some applications it might be preferable to allow some kind of calving distribution

6. Summary

- Iceberg model reproduces reasonable large scale drift patterns in the Southern Ocean for various size classes
- Meltrates as well as working forces (not shown) may be quantified
- Outlook: Iceberg meltwater estimate will be produced
- Other potential applications: biogeochemical FESOM module

- **Wesche, C., Rackow, T., and Dierking, W. (2013):** Iceberg drift in the eastern Weddell Sea: Observed and modeled *(**Proc. 'ESA Living Planet Symposium 2013'**, Edinburgh, UK, held 9-13 September 2013 (ESA SP-722, December 2013))*
- **Rackow, T., Wesche, C., Timmermann, R., Juricke, S. (2013):** Modelling Southern Ocean iceberg drift and decay with FESOM-IB (***poster at EGU 2013**, held 7-12 April, 2013 in Vienna, Austria, p. 13911*)
- **Rackow, T. (2011):** Iceberg drift modeling in the framework of a finite element sea ice—ocean model (*Modellierung der Eisbergdrift als Erweiterung eines Finite-Elemente-Meereis-Ozean Modells, **diploma thesis**, in German)*

Thank you!

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7. Additional References

- **Bigg, G. et al. (1997):** Modelling dynamics and thermodynamics of icebergs *(**Cold Reg. Sci. Technol.** 26, 113-135)*
- **Gladstone, R. et al. (2001):** Iceberg trajectory modeling and meltwater injection in the Southern Ocean *(**J. Geophys. Res.** 106 (C9), 19903-19915)*
- **Hellmer, H. H. et al. (2012):** Twenty-first-century warming of a large Antarctic ice-shelf cavity by a redirected coastal current (***Nature*** 485, 225–228)
- **Lichey, C. and Hellmer, H. H. (2001):** Modeling giant iceberg drift under the influence of sea ice in the Weddell Sea *(**J. Glaciol.** 47, 452-460)*
- **Silva, T. A. M. et al. (1997):** Contribution of giant icebergs to the Southern Ocean freshwater flux *(**J. Geophys. Res.** 111)*
- **Danilov et al., 2004**, **Wang et al., 2008**, **Timmermann et al., 2009:** FESOM literature

8. Appendix: FESOM mesh + cavities

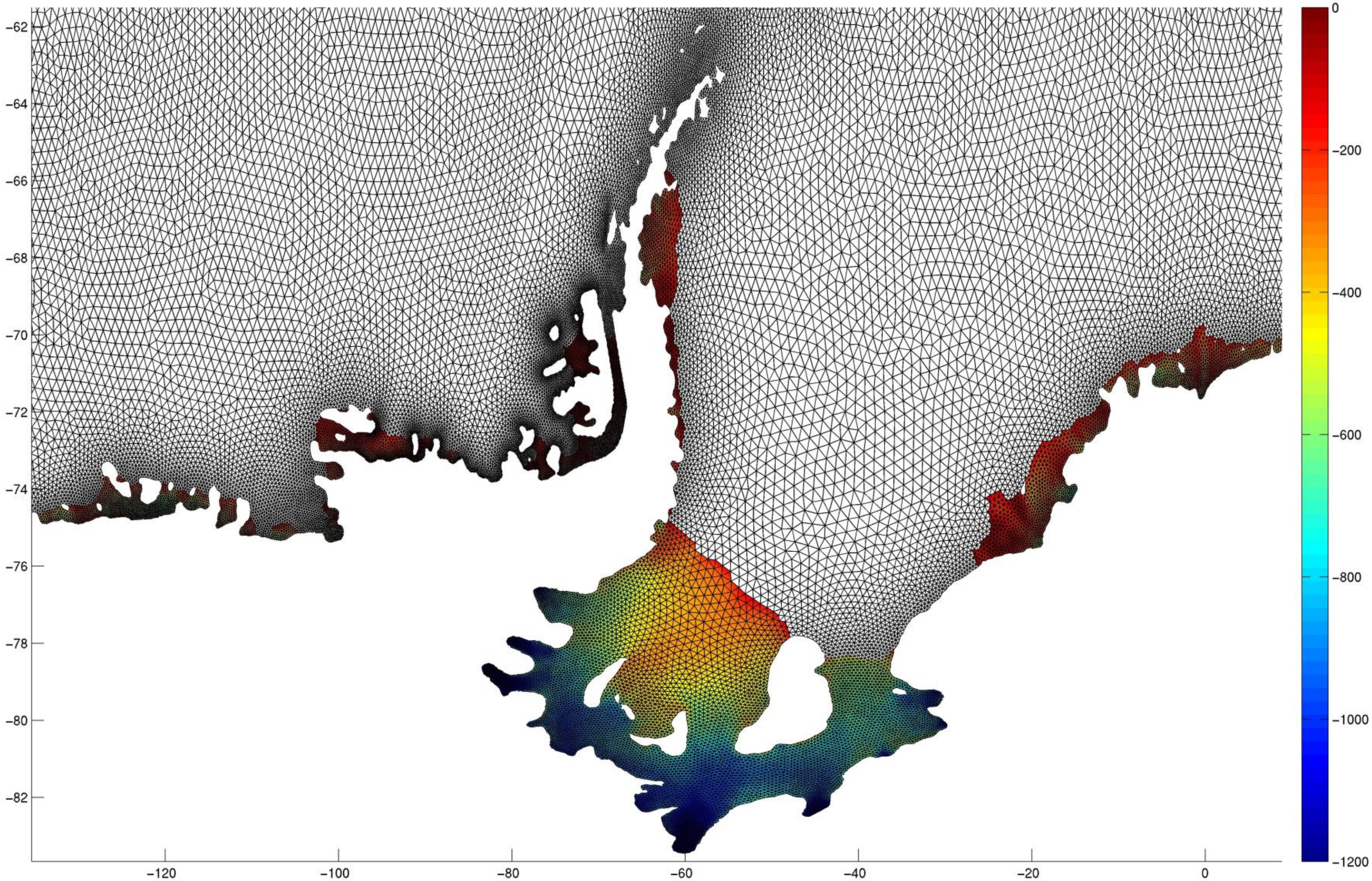


Illustration by R. Timmermann

8. Appendix

- Bouyancy force and gravitational force:

$$\mathbf{F}_A = -V_v \rho_w \mathbf{g}$$

$$\mathbf{F}_G = M\mathbf{g} = V \rho_{ib} \mathbf{g}$$

- If the height ***H*** is known, the draft ***d*** may be calculated via

$$\frac{H}{d} = \frac{\rho_w}{\rho_{ib}}$$

8. Appendix

- Ocean form and skin drag according to the general drag equation:

$$\mathbf{F}_o = (\frac{1}{2}\, C_o \rho_w A_o + C_{do} \rho_w A_{skin,o})\ ||\mathbf{u}_o - \mathbf{u}||(\mathbf{u}_o - \mathbf{u})$$

$C_o = 0.85 \quad C_{do} = 0.0005 \quad A_o = dL \quad A_{skin,o} = L^2$

Mean ocean velocity over the iceberg draft

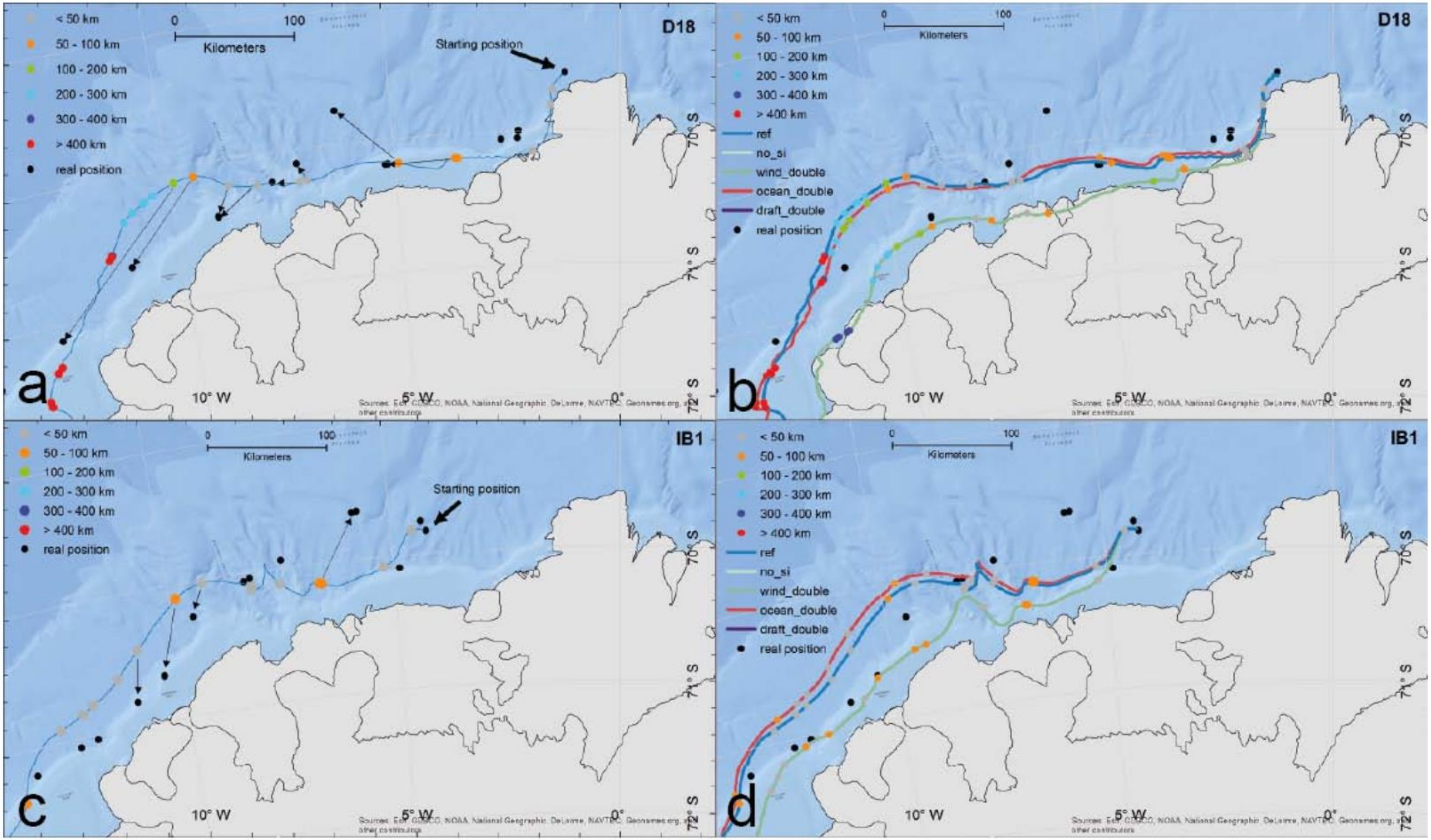
- Atmospheric form and skin drag:

$$\mathbf{F}_a = (\frac{1}{2}\, C_a \rho_a A_a + C_{da} \rho_a A_{skin,a})\ ||\mathbf{u}_a - \mathbf{u}||(\mathbf{u}_a - \mathbf{u})$$

$C_a = 0.4 \quad C_{da} = 0.00025 \quad A_a = (H-d)L \quad A_{skin,a} = L^2$

Wind velocity taken from the COREv2 data set by Large & Yeager (2009)

8. Appendix: Validation



adapted from Wesche et al. (2013)