Modelling Southern Ocean iceberg drift and decay with FESOM-IB

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Introduction

- Icebergs are commonly ignored in current general circulation models despite their connections to ocean stratification, phytoplankton growth through iron fertilization and the redistribution of freshwater in the Southern Ocean
- We developed an iceberg drift and decay module (**IB**) for the high resolution Finite-Element Sea Ice-Ocean Model **FESOM** augmented by ice cavities, see Fig. 3 (Timmermann et al., 2012).
- ***QUESTIONS***: *Is the model able to reproduce observed iceberg drift patterns? Quantitatively, what are typical meltrates?*

Iceberg momentum equations / Numerical discretization

- Icebergs are assumed to be cubical-shaped. They are treated as Lagrangian point masses having properties such as length L, height H and mass M
- Iceberg momentum balance: $M\frac{d\boldsymbol{u}}{dt} = \sum_k \boldsymbol{F}_k$, where $\boldsymbol{u} = (u, v)$ horizontal iceberg velocity
- Right hand side forces:
  - Coriolis: $F_c = -fM\,\boldsymbol{k} \times \boldsymbol{u}$, Surface slope: $F_p = -Mg\boldsymbol{\nabla}\eta$
    f Coriolisparameter, $\boldsymbol{k}$ vertical normal, η sea surface height
  - Ocean form and skin drag (coefficients c_o and $c_{do_{skin}}$)
  - Atmospheric form and skin drag (coefficients c_a and $c_{da_{skin}}$)
  - Sea ice capturing mechanism F_i: In case the ice concentration A and the ice strength P both exceed $A_s = 90\%$ or $P_s = 10000\ N/m^2$, respectively, icebergs are advected with the sea ice; for medium ice concentrations an ice form drag, coefficient c_i, is applied (mechanism similar to Lichey and Hellmer, 2001)
- **FESOM** ice/ocean velocity fields and sea surface height/temperature are evaluated at every timestep.
- CORE2 Forcing is used (Large and Yeager, 2009)
- Coriolis term is discretized implicitly (explicit: unstable)
- Ocean drags are discretized „partially implicit" in order to stabilize the method for smaller icebergs

Model setup / Configuration

- We start 308 artificial icebergs at circumantarctic positions (77 positions, 4 iceberg classes (see Table 1)) in January 1999.
- The simulation is run for 5 years until most icebergs have been melted (giant icebergs live longer).

Size class	Length L [m]	Height H [m]	Volume V [m³]	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}

Table 1: *Iceberg size classes used in this study. Mass is calculated from an assumed iceberg density of 850.0 kg/m³ (Silva et al., 2006).*

Model results

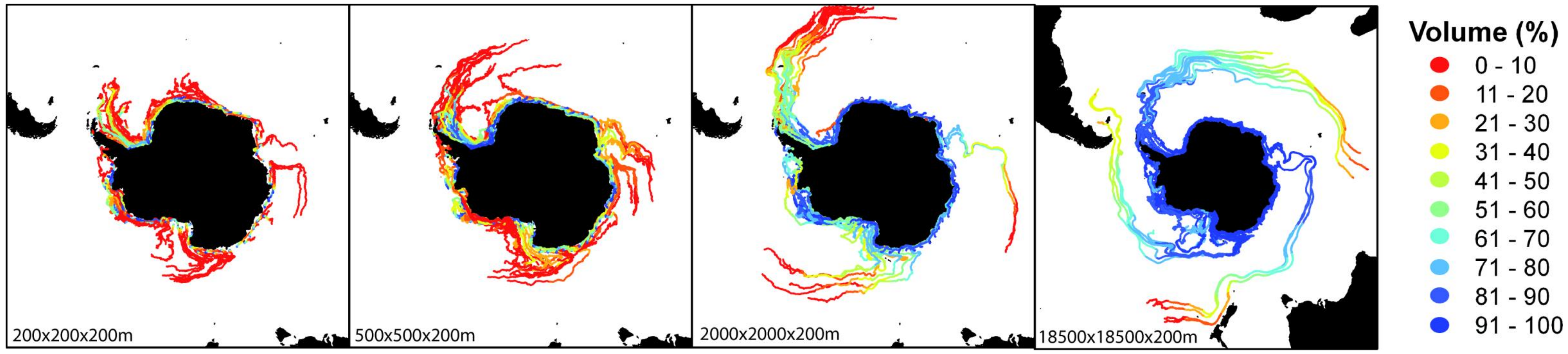
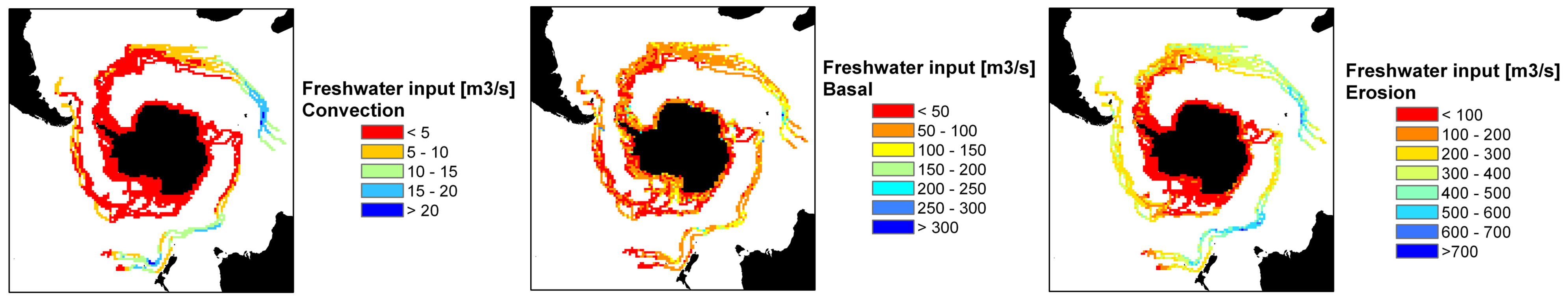


Figure 1: *Remaining volume in percent for the four iceberg classes in the 5-yr simulation starting 1999. From left to right: Small, medium, big and giant icebergs, see Table 1. The typical drift pattern for Antarctic icebergs (see Tchernia and Jeannin, 1984) can also be seen in the model.*

- Small icebergs are melting fast, giant icebergs may survive longer than 5 years .
- Giant bergs tend to stay near the coast and may just leave it at three well-defined bifurcation points in the Weddell Sea, the Ross Sea and over the Kerguelen Plateau.
- The freshwater input is mostly determined by wave erosion; regarding the smaller meltrates, basal melting is stronger than melting associated with bouyant convection.



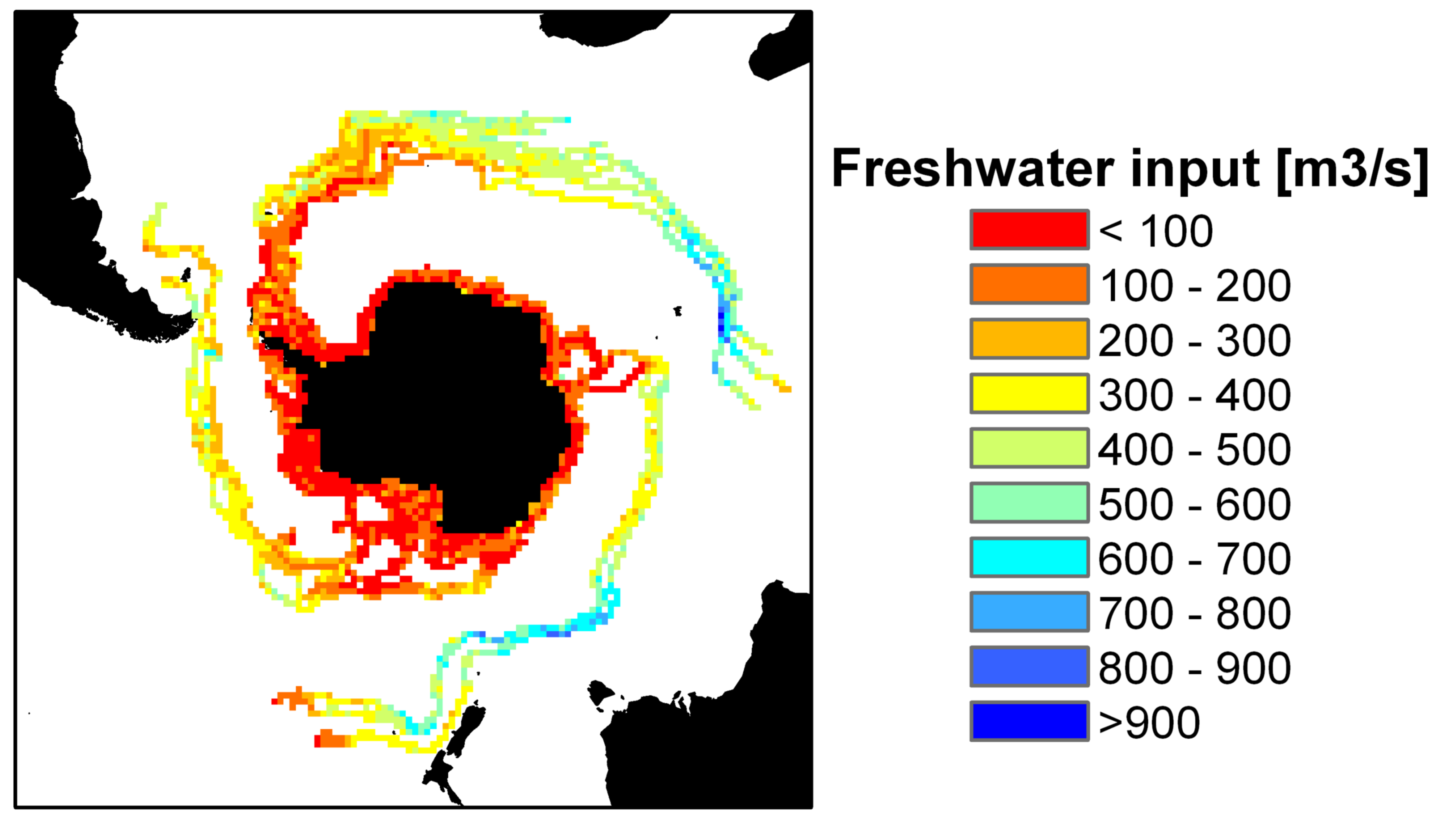


Figure 2: *Gridded average fresh-water input for the giant icebergs in the 5-yr simulation.*

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

Lower panel: *Combined freshwater input including convection, basal melting and wave erosion.*

Thermodynamics / Melting of icebergs

- 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]: $M_v = 7.62 \times 10^{-3} T_o + 1.29 \times 10^{-3}\, T_o$
  - Wave erosion [m/day]: $M_e = \frac{1}{12}[1 + \cos(A^3\pi)](T_o + 2)S_s$
- Melt rates are multiplied by the respective surface areas; the iceberg dimensions are adjusted accordingly.

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

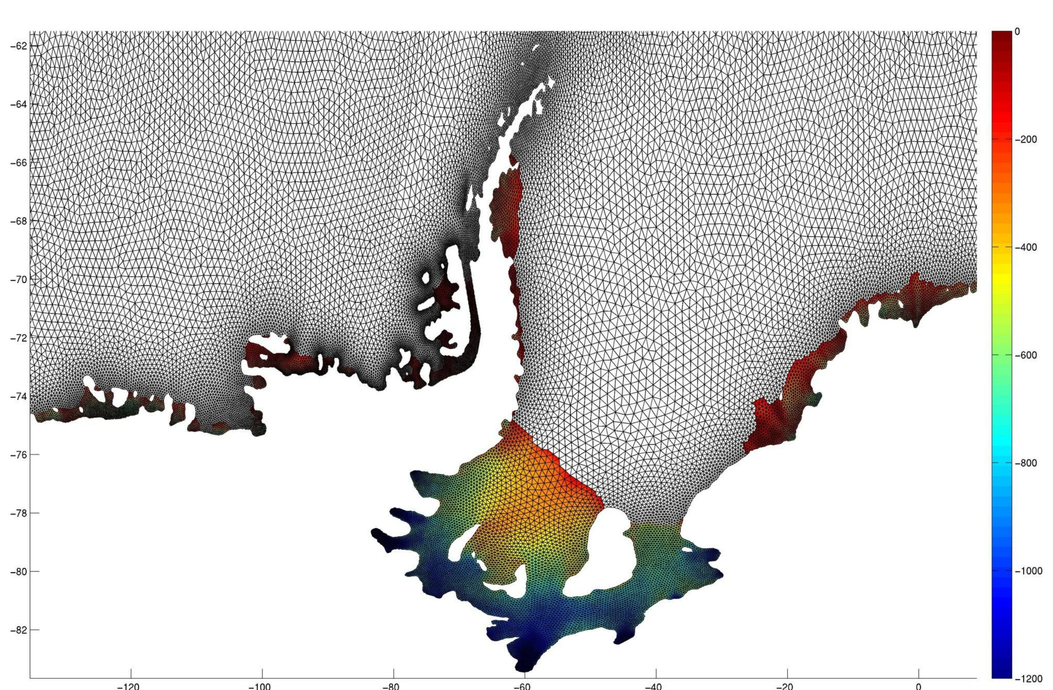


Figure 3: *Weddell Sea sector of the mesh used in this study. Resolution ranges from 50 km to 10 km along the Antarctic coast (7 km under the large ice shelves). Colors give the ice shelf thickness (cf. Timmermann et al., 2012).*

Table 2: *Parameter settings for the 5-year simulation analyzed here.*

Parameter	Numerical value
C_o	0.85
C_a	0.4
C_o	1.0
$C_{do_{skin}}$	5×10^{-3}
$C_{da_{skin}}$	2.5×10^{-3}
A_s	0.9
P_s	10000

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Summary and outlook

- The iceberg model captures the main observed iceberg drift patterns (cf. Tchernia and Jeannin, 1984)
- Giant icebergs tend to stay close to the Antarctic coast showing westward drift in the coastal current
- Smaller icebergs show an off-shore drift component early after calving
- Erosional loss has by far the largest influence on volume loss
- Additional results :
  - First tests performing extensive sensitivity studies revealed the relative influence of the different driving forces
  - The iceberg model has been fed with satellite-observed iceberg positions and dimensions for further validation and insights

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