Modeling Southern Ocean iceberg drift and decay

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AWI Climate Dynamics

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IUP – AWI block seminar on Ice – Ocean Interaction
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):

\[ M \frac{du}{dt} = \sum_k F_k, \text{ where } u = (u, v) \text{ horizontal iceberg velocity} \]

- Which forces enter the right hand side?

- Coriolis: \( F_c = -fM k \times u \), Surface slope: \( F_p = -Mg \nabla \eta \)
  - \( f \) Coriolis parameter, \( k \) vertical normal, \( \eta \) sea surface height

- Oceanic/Atmospheric skin and *form* drags

- **Sea ice capturing mechanism** \( F_i \): If the ice concentration \( A \) and the ice strength \( P \) both exceed \( \text{Conc}_{\text{sill}} = 90\% \) or \( P_s = 10000 \, N/m^2 \);
  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]:
    
    \[ M_b = 0.58 \times |u_o - u|^{0.8} \times \frac{T_o - T_{ib}}{L^{0.2}} \]

  • **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, \( u_o \) depth-integrated ocean velocity at position of iceberg, \( T_o \) sea surface temperature, \( T_{ib} = -4^\circ C \), \( S_s \) 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 ...

... with continuous linear basis functions

... triangles in the horizontal

... tetrahedra (or prisms) in the vertical
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 $d$:

\[
\frac{H}{d} = \frac{\rho_w}{\rho_{ib}}
\]

(density of water)  
(density of iceberg)

Buoyancy force

Gravitational force
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 /)
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 = (/ 0.352, 0.243 /)
real, dimension(ib_num):: lon_deg = (/ -54.752, -55.466 /)
real, dimension(ib_num):: lat_deg = (/ -54.752, -55.466 /)
!
Lichuy & 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.
logical :: l_melt = .false.
logical :: l_wave = .false.
```

use freezing?
use melting?
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

<table>
<thead>
<tr>
<th>Size class</th>
<th>Length L [m]</th>
<th>Height H [m]</th>
<th>Volume V [m$^3$]</th>
<th>Mass M [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>small</td>
<td>200</td>
<td>200</td>
<td>$8 \times 10^6$</td>
<td>$6.8 \times 10^9$</td>
</tr>
<tr>
<td>medium</td>
<td>500</td>
<td>200</td>
<td>$50 \times 10^6$</td>
<td>$42.5 \times 10^9$</td>
</tr>
<tr>
<td>big</td>
<td>2000</td>
<td>200</td>
<td>$800 \times 10^6$</td>
<td>$680 \times 10^9$</td>
</tr>
<tr>
<td>giant</td>
<td>18500</td>
<td>200</td>
<td>$68.45 \times 10^9$</td>
<td>$58.18 \times 10^{12}$</td>
</tr>
</tbody>
</table>

- Melting, grounding, „sea-ice capturing mechanism“ enabled
4. Results: Remaining volume

- ... for small, medium, and big icebergs:

Volume (%)
- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60
- 61 - 70
- 71 - 80
- 81 - 90
- 91 - 100

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)

Volume (%)
- 0 - 10
- 11 - 20
- 21 - 30
- 31 - 40
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- 51 - 60
- 61 - 70
- 71 - 80
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- 91 - 100

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

• 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)

Thank you!
7. Additional References


• 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:

\[ F_A = -V_v \rho_w g \]
\[ F_G = M g = V \rho_{ib} g \]

• 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:

\[
F_o = \left( \frac{1}{2} C_o \rho_w A_o + C_{do} \rho_w A_{skin,o} \right) ||u_o - u|| (u_o - u)
\]

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

Mean ocean velocity over the iceberg draft

- Atmospheric form and skin drag:

\[
F_a = \left( \frac{1}{2} C_a \rho_a A_a + C_{da} \rho_a A_{skin,a} \right) ||u_a - u|| (u_a - u)
\]

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

Wind velocity taken from the COREv2 data set by Large & Yeager (2009)
8. Appendix: Validation

adapted from Wesche et al. (2013)