Los Alamos NATIONAL LABORATORY

Climate, Ocean and Sea Ice Modeling Program

Sea Ice Thickness Sensitivities to Icebergs and More

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June 2010

Outline

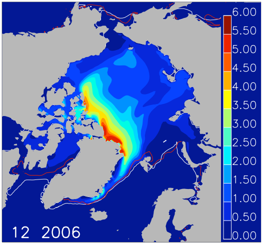
CICE Parameter Sensitivities

Objective

- Understand ice thickness sensitivity to ocean heat flux, sea ice conductivity, dynamic and radiative parameters

Approach

- Stand-alone CICE model forced with CORE atmo and CCSM3/POP ocean data, 1958-2006
- Set albedo parameters to measured values
- Vary other parameters chosen based on earlier DOE adjoint modeling study (Kim et al., 2006)



Sea ice thickness (m) with simulated (white) and satellite-derived (red) 15% concentration ice edge.

Impact

- Improved ice thickness and area simulation using more realistic physical description and parameters
- Will affect high-latitude sensitivity to climate change in global climate models

E. Hunke. "Thickness sensitivities in the CICE sea ice model," *Ocean Modelling*, in press, 2010.
J. Kim, E. C. Hunke and W. H. Lipscomb, 2006. "A sensitivity analysis and parameter tuning scheme for global sea-ice modeling. *Ocean Modelling* **14**, 61-80.

CICE Parameter Sensitivities

experiment	k_i	μ_{rdg}	α_{vis}	α_{nir}	u^*_{min}	1976–1988 Δh_{sub} (cm)
HB09	old	4	0.86	0.44	0.005	2
lowalb	old	4	0.78	0.36	0.005	-45
conduct	Pringle	4	0.78	0.36	0.005	-31
mu3	Pringle	3	0.78	0.36	0.005	-8
ocnheat	Pringle	3	0.78	0.36	0.0005	-5

Table: Sensitivity experiments run for 48 years, 1958–2006.

CICE Parameter Sensitivities

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albedo

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ice conductivity

Old: $k_i = 2.03 + 0.13\frac{S}{T}$

Pringle et al (2007): $k_i = \frac{\rho}{\rho_i}\left(2.11 - 0.011T + 0.09\frac{S}{T}\right)$

CICE Parameter Sensitivities

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an unnamed ridging parameter

Decreasing μ_{rdg}
reduces mean ridge height and
increases area covered by newly ridged ice

CICE Parameter Sensitivities

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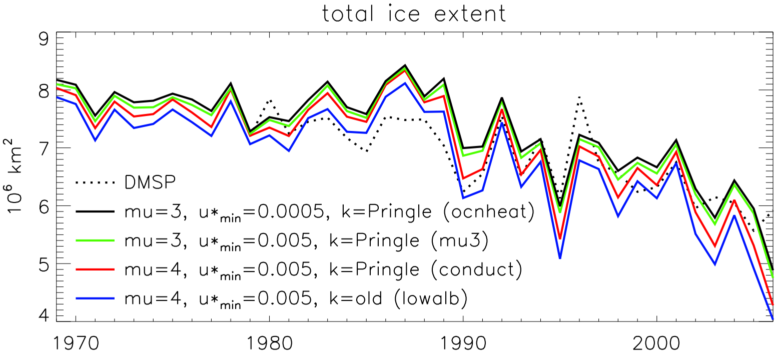
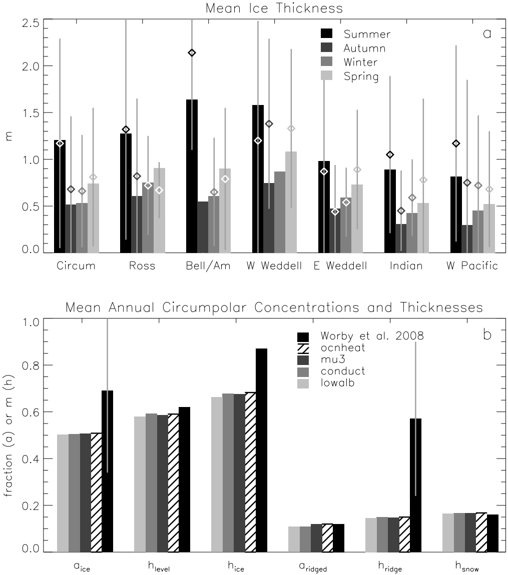
minimum friction velocity for ocean heat flux

September Arctic Ice Extent



Southern Hemisphere, 1981–2005



CICE Parameter Sensitivities

Summary:

- Albedo is a convenient and effective tuning parameter, but other parameters can be just as effective.
- There are more parameters available for tuning sea ice models than there are datasets to constrain them.
- We can match a given data set using multiple combinations of parameters.
- Sea ice conductivity, ridging and ocean heat flux parameters can be used to adjust thickness basin-wide.
- Critical parameters control the effect of external forcing.
- More work is needed to define model ridge diagnostics suitable for comparison with observations.

Icebergs

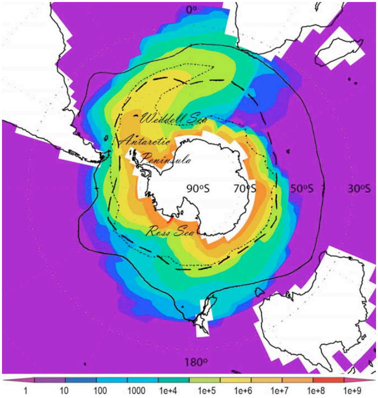


Fig. 2. Distribution of simulated iceberg melt in the Southern Ocean. The average volume flux of fresh melt water per day (m^3/day) provides a combined insight in the distribution of the dynamic icebergs and their melting speed. Note logarithmic scale. Dotted line is the iceberg limit in the Southern Ocean as simulated by Gladstone et al. (2001). Dashed line is an estimate from Russian exploration in 1964 (adapted from Gladstone et al., 2001). The solid line is an estimate of maximum iceberg extent based on a large collection of observational data (adapted from Robe, 1980).

Jongma et al., *Ocean Modelling* (2009)
(ECBilt-CLIO model)

Simulated iceberg meltwater flux (color)
Observed iceberg extent (lines)

Fresh meltwater
1) stabilizes ocean column
2) increases sea ice area
3) further cools ocean surface

Thermodynamic influence on sea ice

Icebergs in CICE: *Dynamic interaction*

Work with Darin Comeau, Univ. of Arizona

- Lagrangian particles with finite size
- Cylindrical, height 225 m and area 686 km^2
- Archimedes' Principle $\Rightarrow$ vertical contact area with water, sea ice, and air
- May overlap into neighboring grid cells
- May become temporarily grounded
- Can be blocked by coastlines or grid cells already filled with other bergs
- No iceberg thermodynamics

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Icebergs in CICE: *Dynamic interaction*

- Iceberg momentum:

$$M\frac{du_b}{dt} = F_a + F_w + F_c + F_{ss} + F_{si}$$

- When the sea ice is highly concentrated and strong, bergs are captured and drift with sea ice velocity, $u_b = u_i$. Otherwise,

$$F_{si} = \begin{cases} 0, & a_i < 15\% \\ \frac{1}{2}\rho_i c_i A \left| u_i - u_b \right| \left(u_i - u_b \right), & 15\% < a_i < 90\% \text{ or} \\ & P \leq 10^4 N/m \end{cases}$$

where A is the area of the sea ice/iceberg contact interface, a_i is sea ice concentration and P is strength.

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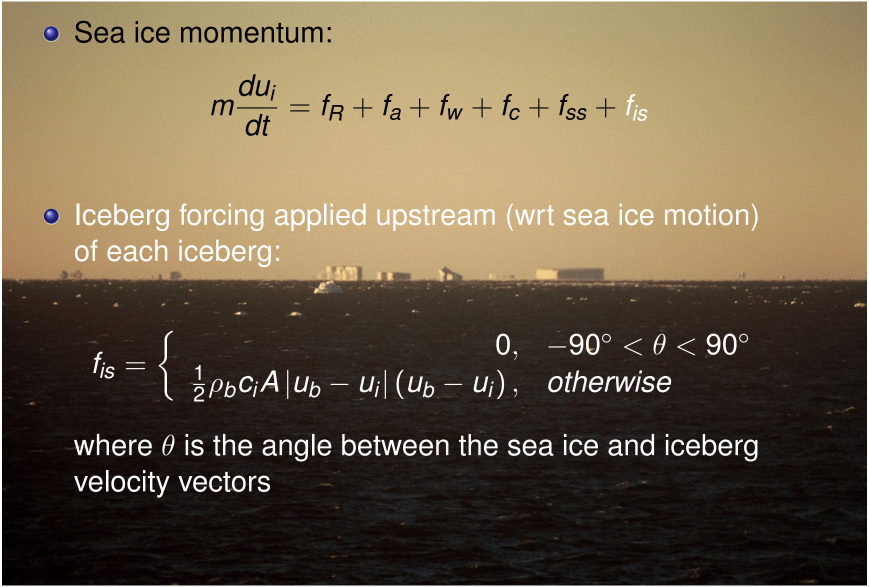
Icebergs in CICE: *Dynamic interaction*



- Sea ice momentum:

$$m\frac{du_i}{dt} = f_R + f_a + f_w + f_c + f_{ss} + f_{is}$$

- Iceberg forcing applied upstream (wrt sea ice motion) of each iceberg:

$$f_{is} = \begin{cases} 0, & -90^\circ < \theta < 90^\circ \\ \frac{1}{2}\rho_b c_i A \left| u_b - u_i \right| \left(u_b - u_i \right), & \textit{otherwise} \end{cases}$$

where θ is the angle between the sea ice and iceberg velocity vectors

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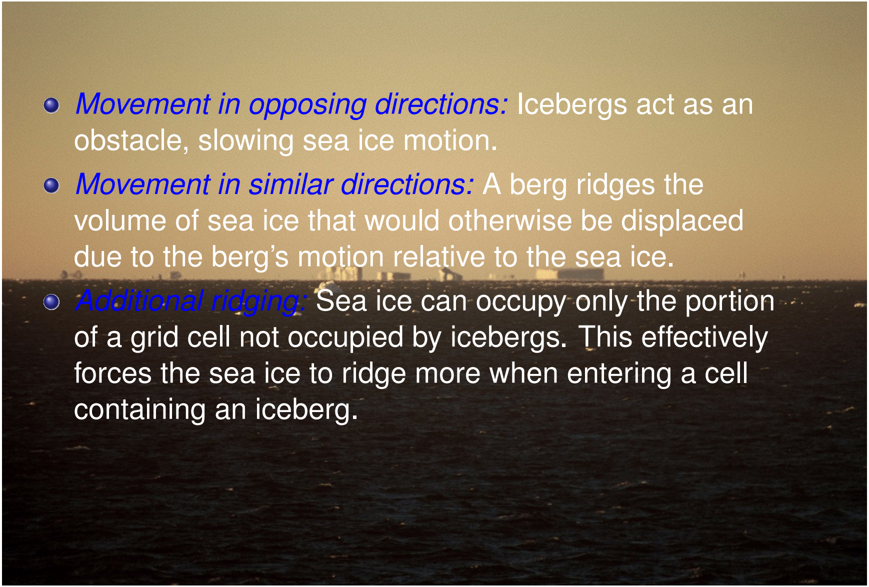
Icebergs in CICE: *Dynamic interaction*



- *Movement in opposing directions:* Icebergs act as an obstacle, slowing sea ice motion.
- *Movement in similar directions:* A berg ridges the volume of sea ice that would otherwise be displaced due to the berg's motion relative to the sea ice.
- *Additional ridging:* Sea ice can occupy only the portion of a grid cell not occupied by icebergs. This effectively forces the sea ice to ridge more when entering a cell containing an iceberg.

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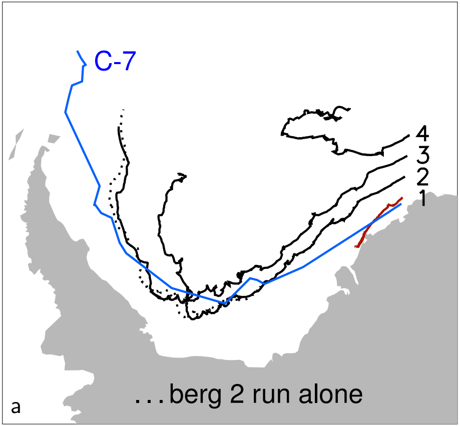
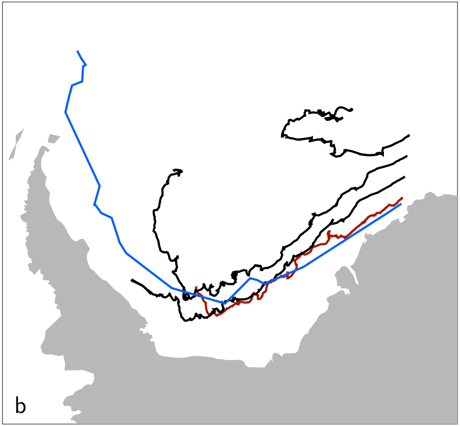
Icebergs in CICE: *Dynamic interaction*

1990–1992



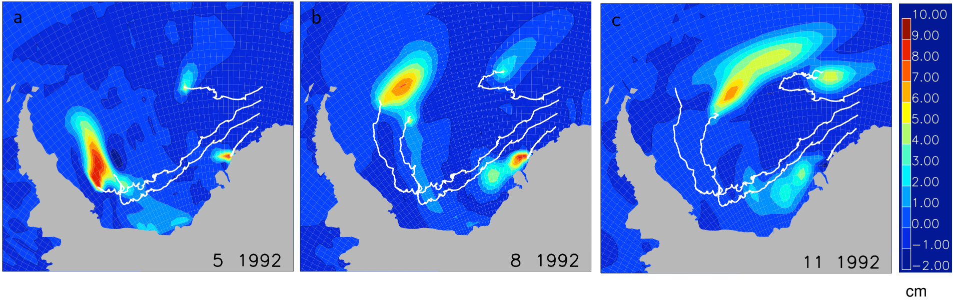
full model



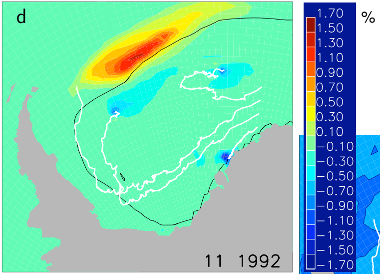
all terms except $f_{is} = 0$

Icebergs in CICE: *Dynamic interaction*

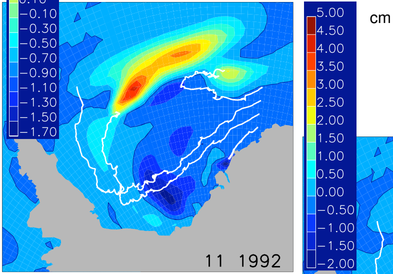
Δ sea ice thickness, with bergs - without bergs



Icebergs in CICE: *Dynamic interaction*

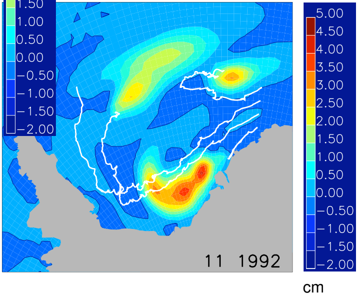


Δ concentration



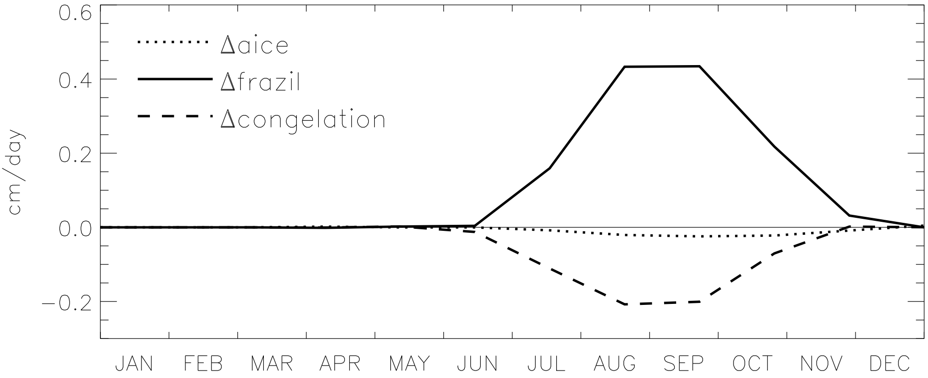
Δ ridged ice *h*

Δ level ice *h*



Icebergs in CICE: *Dynamic interaction*

In a polynya downstream of a grounded iceberg:



Icebergs in CICE: *Dynamic interaction*

Summary:

- Dynamical effects of icebergs on surrounding sea ice are observed.
- Icebergs act as obstacles, causing sea ice ridging (upstream) and open water formation (downstream).
- Open water near icebergs increases level ice downstream of the bergs.
- Anomalies in sea ice area and thickness are transported with the sea ice flow, expanding over time.
- Iceberg tracks are highly sensitive to minor model changes.
- Statistical approach is needed for climate applications.

CICE development

The Multi-Phase Physics of Sea Ice:
Growth, Desalination and Transport Processes

September 8-10, 2010
Santa Fe, New Mexico