Simulating wind redistribution of snow on sea ice

Elizabeth Hunke

June 2015

CLIMATE, OCEAN AND SEA ICE MODELING PROGRAM
Snow Influences

Sea Ice Dynamics
- mass
- form drag

Sea Ice Thermodynamics
- albedo
- thermal insulation
- melt pond water source
- radiative shield for ponds (infiltration, or on pond ice)
- meltwater flushing, ice salinity
- snow-ice formation
Snow Influences

Ocean

- fresh melt water
- energy content
- transmitted shortwave (if it survives through the ice)

Biogeochemistry

- vertical tracer transport
- tracer scavenging during meltwater flushing
- horizontal tracer transport (incl. fresh water)
Figure 2.1: Schematic of LIM1D's new snow module.

A Basic Snow Model

- thermodynamic model computes growth/melt rates
- vertical conductive, radiative and turbulent fluxes
- state variables: mass (volume), energy (temperature, enthalpy)
- assumed density profile, effective thermal conductivity
- salinity = 0 (unless sea water infiltrates)
- mass changes due to
  - snowfall
  - sublimation/deposition
  - melt
  - snow-ice formation
  - loss during ridging
- vertical discretization with multiple layers
- horizontal advection on top of sea ice
- Need synoptic weather data to capture discrete storms
- Evolve depth hoar using $\nabla T$, but ...
- Wind slab and depth hoar resist further densification
- Wind slab prevents further snow drifting
- Snow characteristics can be tied to ice type (thin, etc)
- Lateral variability is closely tied to melt pond features
- Snow depth can be treated as a normally distributed random variable with the mean and standard deviation set by ice type
ACME Snow-on-Sea-Ice Model Development

- Increase vertical resolution of the snow column
- Use daily precipitation data to capture discrete storms
- Model snow metamorphism (wet and dry)
  - effective snow grain radius
  - mass of liquid water in snow
  - mass of ice in snow
- Model wind effects on snow
  - wind slab
  - loss to leads
  - radiative effects of snow redistribution
ACME Snow-on-Sea-Ice Model Development

This talk:

- Increase vertical resolution of the snow column
- Use daily precipitation data to capture discrete storms
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  - radiative effects of snow redistribution
Resolution

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Snow Influences
Basics
Resolution
Simple Redistribution Tests
Wind Dependence

Where are we today?

$\text{net } F_L = F_e + F_s$

$\alpha F_r$

Ice Thickness Distribution Model Schematic

$A$
$h$
$T_1$
$S_1$
$T_2$
$S_2$
$T_3$
$S_3$
$T_4$
$S_4$
$h_s$

$p\text{onds}$

$\mathbf{v_{ice}}$

$\mathbf{u_{ice}}$

Slide courtesy C. Bitz, D. Bailey, M. Holland
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Vertical Resolution

![Graphs showing mean snow depth and mean ice thickness over the year with different vertical resolutions.](image-url)
Control Run

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Wind Dependence

CICE v5
1° global displaced pole grid
Modified CORE II forcing
Slab mixed-layer ocean
Control 1958 – 2009
Experiments 1980 – 2009

<table>
<thead>
<tr>
<th>h_{snow} (m)</th>
<th>control</th>
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<tbody>
<tr>
<td>h_{ice} (m)</td>
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Control Run

<table>
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<tr>
<th>hs (m)</th>
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<th>iage (yr)</th>
<th>30 percent: Increase snow lost in leads</th>
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12 2009
30% Rule: Loss to Leads / Redistribution

- control
- move snow from level ice to leads
- move snow from level ice to deformed ice (radiation)

$h_{\text{snow}}$

$h_{\text{ice}}$

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30% Rule: Loss to Leads / Redistribution

- control
- move snow from level ice to leads
- move snow from level ice to deformed ice (radiation)
- Density of new-fallen snow depends on surface wind speed.
- Some snow is blown into the ocean through leads.
- Transported snow mass flux is:
  - Proportional to wind speed.
  - Negatively proportional to snow density.
  - Inversely proportional to stddev(ITD).
- Conductivity depends on snow density, liquid water content.
- density of new-fallen snow depends on surface wind speed for wind redistribution
- some snow is blown into the ocean through leads
- transported snow mass flux is
  - proportional to wind speed
  - negatively proportional to snow density
  - inversely proportional to stddev(level+deformed ITD)
- conductivity depends on snow density, liquid water content
Wind Dependence: CICE

Wind redistribution

$\mathbf{h_{snow}}$

control

$\mathbf{h_{ice}}$

Wind redistribution w/ level+deformed ITD

$r30\text{percent}$

$r30\text{percentsw}$

$\text{ctl}$

$\text{ITDrdg}$

$\text{ITDsd}$

$\text{ITDrdg\_nocomp}$
Wind Dependence: CICE

Wind redistribution
--- w/ level+deformed ITD

$h_{\text{snow}}$

$h_{\text{ice}}$

Incremental Volume Difference

- Congelation growth
- Frazil growth
- Snow–ice growth
- Top melt
- Bottom melt
- Lateral melt

Simple Redistribution Tests

Resolution

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Basics

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Wind Dependence: CICE

- control
- Wind redistribution
  - w/ level+deformed ITD
  - w/ std ITD
  - w/ no compaction

\begin{itemize}
  \item $h_{\text{snow}}$
  \item $h_{\text{ice}}$
\end{itemize}
Experiments - Control

\[ \Delta h_{snow} \]

\[ \Delta h_{ice} \]

\[ \Delta h_s (m) \]

30 percent (snow loss)

\[ \Delta h_i (m) \]

ITDrdg - cntrl

12 2009

12 2009
Change in Deformed Ice Area

$\Delta a_{rdg}$

12 2009

12 2009

r30percent - cntrl $\Delta a_{rdg}$

ITDrdg - cntrl

$\Delta a_{rdg}$
Preliminary Results

- need at least 3 snow layers, preferably more
- snow loss to leads is critical
- feedback with deformed ice needs to be explored
- snow metamorphism likely to have bigger radiative impact
- new developments include varying snow density
- effects of synoptic precipitation need to be explored
Experiments - ITDrsg

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\[ \Delta h_{\text{snow}} \]

\[ \Delta h_{\text{ice}} \]