Sea Ice Modeling: An Overview

Elizabeth Hunke

November 2016
Fig. 1. Schematic illustration of the sea ice model.
Fig. 1. Schematic illustration of the sea ice model.
Fig. 1. Schematic illustration of the sea ice model.
Fig. 1. Schematic illustration of the sea ice model.
Fig. 1. Schematic illustration of the sea ice model.
Fig. 1. Schematic illustration of the sea ice model.
\[
\frac{\partial q}{\partial t} = \frac{\partial}{\partial z} k \frac{\partial T}{\partial z} + Q(z)
\]
Sea Ice Modeling: An Overview

Elizabeth Hunke

Surface character
Optics
Ice thickness
Ridging
Thermo
Ongoing work
Model calibration
Summary

Ice Thickness Distribution

\[
\frac{\partial q}{\partial t} = \frac{\partial}{\partial z} k \frac{\partial T}{\partial z} + Q(z)
\]
Schematic of model representation of $g(H)$ in five ice “categories”

$$A = \text{fractional coverage of a category}$$
Ice Thickness Distribution $g$

$g(x, h, t) \, dh =$ the fractional area covered by ice in the thickness range $(h, h + dh)$ at a given time $t$ and location $x$

$$\frac{\partial g}{\partial t} = -\nabla \cdot (gu) + \psi - \frac{\partial}{\partial h}(fg) + L,$$

$\nabla = (\frac{\partial}{\partial x}, \frac{\partial}{\partial y})$

$u =$ horizontal ice velocity

$\psi =$ mechanical redistribution function

$f =$ rate of thermodynamic ice growth

$L =$ lateral melting
What’s important?
What’s important? **ALBEDO**

- **Sea Ice Modeling: An Overview**
- Elizabeth Hunke
- Surface character
- Optics
- Ice thickness
- Ridging
- Thermo
- Ongoing work
- Model calibration
- Summary

E. Hunke
What's important? **ALBEDO**

What else?

---

**Sea Ice Modeling: An Overview**

Elizabeth Hunke

Surface character

Optics

Ice thickness

Ridging

Thermo

Ongoing work

Model calibration

Summary

---

E. Hunke
What’s important? ALBEDO
What else? ICE VOLUME

Sea Ice Modeling: An Overview
Elizabeth Hunke

Surface character
Optics
Ice thickness
Ridging
Thermo
Ongoing work
Model calibration
Summary

E. Hunke

What’s important? ALBEDO
What else? ICE VOLUME
Surface characteristics

lateral growth and melt
ice motion
rheology
elastic-viscous-plastic
elastic-anisotropic-plastic
momentum
wind, currents, Coriolis, tilt, internal stress
Monin-Obukhov similarity for turbulent fluxes
form drag (ridges, keels, floe and pond edges)
transport equations
Sea Ice Modeling: An Overview

Elizabeth Hunke

Surface characteristics

vertical conductive, radiative, turbulent fluxes
assumed density profile (constant!)
effective thermal conductivity
salinity = 0
mass changes due to
snow-ice formation
snowfall
sublimation/deposition
melt
loss during ridging
transported on top of sea ice
interacts with melt ponds

E. Hunke
Surface characteristics

- fed by meltwater, rain
- pool on thinner ice or level ice
- hidden in snow until saturation
- drain through permeable ice
- refreeze at the top
- snow collects on refrozen ponds
- transported on sea ice
Delta Eddington
Multiple Scattering Parameterization for Solar Radiation

Sea Ice Modeling: An Overview
Elizabeth Hunke
Surface character
Optics
Ice thickness
Ridging
Thermo
Ongoing work
Model calibration
Summary
Sea Ice Modeling: An Overview

Elizabeth Hunke

Surface character

Optics

Ice thickness

Ridding

Thermo

Ongoing work

Model calibration

Summary

Inherent optical properties:
- extinction coefficient
- single scattering albedo
- scattering asymmetry

Apparent optical properties:
- albedo
- internal absorption
- transmission to ocean

Tuning parameters:
- snow grain radii
  - fresh, melting, nonmelting
  - standard deviation

Delta Eddington

Multiple Scattering Parameterization for Solar Radiation

Thin snow is patchy

Air

Snow scattering layer

Snow interior

Pond

Ice scattering layer

Ice interior
Ice thickness

- mechanical redistribution (ridging)
- thermodynamic growth/melt
- top and bottom ablation
- bottom accretion (congelation)
- frazil growth
- snow-ice formation
- “mushy layer” with prognostic salinity
A Variational Formulation for Sea Ice Ridging

Andrew Roberts et al.

- $\phi = 0.2$
- $\alpha_1 = 22^\circ$, $\alpha_2 = 35^\circ$
- $h_{f_1} = 2.0 \text{ m}$, $h_{f_2} = 0.5 \text{ m}$
- $h_{r_1} = 0.3 \text{ m}$, $h_{r_2} = 0.0 \text{ m}$
- $H_k = 5.1 \text{ m}$, $H_r = 1.6 \text{ m}$

- Isostatic quanta
- Sea level
- Asymmetric
- Rubble
- Centroid
- Thick floe
- Thin floe

- Observed (Davis and Wadhams, 1995)
- Euclidean morphology with bulk ridge porosity $\phi_R$
- Expected path $\langle \xi \rangle$
- Expected path $\langle \xi \rangle$
“Mushy Layer” Thermodynamics

**Equations**
- Conservation of energy
- Conservation of salt
- Ice-brine liquidus relation
- Darcy flow through a porous medium

**Variables**
- Enthalpy
- Bulk salinity
- Liquid fraction
- Vertical velocity

brine channels
Many sea ice models / exciting new work

- frazil ice formation
- under-ice freshwater lenses
- floe size distribution
- discrete-element models
- new rheologies
- ice deformation/ridging/keel formation
- ridge consolidation
- fast ice
- detailed snow modeling
- detailed melt pond modeling
- biogeochemistry
- data assimilation ...
39 parameters were tested simultaneously for primary and secondary (interacting) sensitivities

- 400 CICE model runs were used to develop a fast statistical emulator for sea ice volume, area and extent

- CICE is mainly sensitive to snow conductivity, melt pond drainage, snow grain size, ice radiative scattering layer and snow and ice densities

- Primary effects are nonlinear in parameter space and interactions can produce the opposite sign

Jorge Urrego-Blanco et al., JGR Oceans, 2016
Probabilistic Validation of Sea Ice Models

- Use a distance metric $D_n$ to compare observations ($O$) and model ($M$) data:
  - uncertainties in $O$ and $M$
  - multiple variables and observational data sets
  - skill on probabilistic scale

$D_n \sim \text{Gamma}(a, b) \Rightarrow$ calculate $D_n$, $a$, and $b$ from $O$, $M$, and uncertainties $\Rightarrow$ Low $D_n$ percentiles are good

- Evaluate CICE from 2003-2009 over parametric uncertainty (398 model configurations, 40 parameters)

- Best configuration for sea ice concentration is (A), for thickness it is (B), but optimal is (C)

---

1 Jorge R. Urrego-Blanco, Elizabeth C. Hunke, Nathan M. Urban, Nicole Jeffery, Adrian K. Turner, James R. Langenbrunner, and Jane M. Booker, Validation of Sea Ice Models Using an Uncertainty-Based Distance Metric for Multiple Model Variables, submitted to JGR-Oceans.
Sea ice models have advanced remarkably since the 1970s

Basic processes (dynamics, thermo) are represented

Modelers are busy refining the details

Snow is critical

Is it time to move sea ice modeling beyond deterministic simulations and small ensembles, into probability space?