On the improvement of the snow component in large-scale sea ice models

Olivier Lecomte*, Martin Vancoppenolle, Thierry Fichefet, François Massonnet

*Université Catholique de Louvain (UCL), Earth and Life Institute (ELI), Georges Lemaître Center for Earth and Climate Research (TECLIM), Louvain-la-Neuve, Belgium.
Importance of snow on sea ice

- Greater albedo than ice
- Efficient insulator
- Response to wind forcing
- Presence of melt ponds when snow melts away
- Contributes to ice production (surface)
- Snow – sea ice feedbacks
Outline

- Model description
- Experimental Setup (Forcing & experiments)
- Results: Sensitivity of sea ice to snow related processes
- Summary & conclusions & Future Work
Model description & experimental setup

**NEMO-3**

- LIM3: 5-category sea-ice thickness, enthalpy, salinity and age distribution model
- NEMO: State-of-the-art OGCM (from IPSL, Paris)

**SNOW SCHEME**

- Snowfall: \( \rho_{\text{snowfall}} = f(\text{wind speed}) \)
- Surface melt if: \( F_0 > 0, T_{su} = 0°C \)
  - \( F_{sw} \)
  - \( \alpha F_{sw} \)
  - \( (1-\alpha)(1-i_0)F_{sw} \)
  - \( I_0 = (1-\alpha)i_0F_{sw} \)
- Internal melt if: \( T_s(z) \geq 0°C \)
- Radiation absorbed and transmitted through the snow (surface and deep snow extinction coefficients from observations)
- Uniform or linear snow density profile based on observations
- Evaporation if surface humidity > air humidity
- Sea level

AGU Fall Metting 2011, San Francisco, USA
Experimental Setup

Forcing
NCEP/NCAR daily surface air temperatures and wind speeds (1951-2007) + monthly climatological surface relative humidities, cloud fractions and precipitation rates + monthly climatological river runoffs

Tripolar global grid, 2° resolution

LIM3 (sea ice model) ↔ NEMO (ocean model)

5 EXPERIMENTS: (Analysed from 1982 to 2007)
• CTL: Control run with every snow processes enabled
• SN1: CTL, Yen (1981) snow thermal conductivity -> Sturm and others (1997)
• SN2: CTL, snow evaporation disabled
• SN3: CTL, INOT -> EXTC radiation in snow
• SN4: CTL, INOT -> EXTC radiation, snow internal melt disabled
Sensitivity of sea ice to snow processes -I-

Results

SN1: Sturm and others (1997) snow thermal conductivity \( \Rightarrow \) lower \( k_s \) values

What happens in the South?

\( \downarrow k_s \Rightarrow \downarrow \) conductive heat flux through snow \( \Rightarrow \downarrow \) bottom ice growth \( \Rightarrow \) thinner ice

\( \ast \) More FYI, less MYI \( \Rightarrow \) smaller extent in summer (Arctic), Lindsay et al. (2008).

One explanation (?) :

\( \ast \) Negative feedback: \( \downarrow \) ice growth \( \Rightarrow \downarrow \) brine rejection \( \Rightarrow \) stronger ocean stratification \( \Rightarrow \downarrow \) oceanic heat flux to the ice \( \Rightarrow \uparrow \) ice growth in some places, Fichefet et al. (2000).

Oceanic heat flux to the ice \([W.m^{-2}]\)

mean difference “SN1 – CTL” throughout growing period

Sea-ice Extent
\( [10^6 \text{ km}^2] \)
1982 - 2007

Sea-ice Extent

Control Run
SN1 experiment

Sea-ice Extent

Sea-ice Extent

Sea-ice Extent
Results

Control Run

SN2 experiment

Sea-ice Extent
[10^6 km^2]
1982 - 2007

Arctic

Antarctic

SN2 : Evaporation turned off.

- Surface energy overbalance used for melting instead of evaporation => intense snow thinning by surface melt
- Less significant in Antarctic due to scarcer melt conditions, Andreas and Ackley (1981), Nicolaus et al. (2006).

↗ snow mass loss by surface melt => ↗ sea-ice surface melts too => thinner ice (noticeable on volume plots).

Sea-ice surface melt [cm.day^{-1}] mean difference “SN2 – CTL” throughout melting period
**Results**

**Control Run**
SN3 experiment

**SN3 : EXTC Radiation.**

**In the Arctic:**
- More absorption of solar radiation inside the snow:
  - Colder surface
  - Warmer internal snow layers
- Strong internal melt of snow
  (Arctic)

**In the Antarctic:**
- More penetration of solar radiation into the sea ice => warming of the ice
- Stronger bottom ablation, lateral melt, dynamical process.

**Cautions:**
- Extinction coefficients to be calibrated
- Too strong melting rate
- No refreezing scheme, Willmes et al. (2006).
**Results**

**Control Run**

**SN4 experiment**

SN4: EXTC Radiation – Snow internal melt turned off.

**Arctic:**
- Although the inner snow is warmer than in control run, it is not melted:
  - Sea ice is preserved from surface melt
  - Warmer snow => warmer sea ice => bottom ablation ↗ (smaller ice volume compared to CTL run)

**Antarctic:**
- No volume difference with SN3 EXTC experiment! => internal melt is not the reason for the difference with CTL run
- => Bottom or lateral melt, feedback with dynamical process might be responsible for smaller southern sea ice extent in summer
Summary

- A multi-layer snow representation with specifically related processes was included in a large-scale sea ice – ocean coupled model.

- Model experiments exhibit a fairly large sensitivity of the modelled sea ice to snow properties and related processes. This highlights the importance of the snow component in sea-ice models.

- Snow thermal conductivity, evaporation and shortwave radiation transmission through the snow all have a significant impact on the sea-ice extent and volume of both hemispheres, and underline the differences between Arctic and Antarctic sea-ice growth and melt regimes.

Then, what’s next?

- Comparison & calibration with respect to observations is required.
- New processes need to be investigated:
  - Refreezing of meltwater inside the snow
  - Blowing snow
  - Melt ponds
Thank you!
Comparison with NSIDC monthly values of sea-ice extent from 1978 to 2011

+ 

Use of specific metrics to evaluate the new snow processes in the model: *Massonnet et. Al. 2011*

- On the whole, the new model version behaves well (without any calibration)
- Sensitivity experiments sometimes improve the results in the Northern or Southern hemisphere, but not necessarily in both