Snow on Sea Ice

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Snow in the Changing Sea Ice System

Webster et al, 2018. Nature Climate Change
- **AUTUMN-WINTER**: Snow fall, wind redistribution + ice deformation, snow-ice formation and flooding of the ice surface, metamorphic snow grain/density layers ➞ enhanced heterogeneity

- **WINTER-SUMMER**: Snow heterogeneity is keyed to ice deformation state, depth hoar (good insulator, large grain size) and wind slab (dense, hard, poor insulator), meltwater percolation coarsens grains, flushes sea ice, refreezes, melt-pond forms adjacent to dunes ➞ dynamic surface albedo

MPAS-seaice v1

- **1 snow layer** for thermodynamics
- **2 radiation layers**
  - Includes snow, bare ice and pond fraction
- Snow may fall in leads but **no wind redistribution**
- **Fixed snow density**
- Optical properties depend on effective **snow grain radius**, locally parameterized (no memory) as
  - If $T_{sfc} \leq -1.5^\circ C$, $R_{snw} = 125$ um
  - If $T_{sfc} \geq 0^\circ C$, $R_{snw} = 1500$ um
  - For $-1.5 < T_{sfc} < 0$, linear increase (tunable parameter $R_{snw} = 1.5$).
MPAS-seaice v2

• **Increased number of snow layers** in thermo and radiative calculations (5 and 6, respectively)
• **Dynamic effective snow grain radius** (snow pack has memory). Adds 3 snow tracers
  – Temperature gradient metamorphism (**depth hoar** formation, same as land model snow)
  – Snow ages (grain size increases) with **liquid content** from rain and melt.
• **Wind redistribution**: 30%, 30%sw, ITDsd, ITDrdg
• **Evolve snow density** but do not feed back into physics (no wind slab or density heterogeneity). Based on wind slab production and liquid/ice content *
Changing the number of Snow Layers
Default is nSnow = 1

Sea Ice Volume (years 1-15 of JRA-55)
1. Increase Ice volume with increasing number of snow layers (nslyr).

2. Evaluation of the snow surface layer (SSL) in the radiation calculation is dependent on nslyr.

Dashed lines show SSL scaled by nslyr.
How do changes from snow layer number (black line) compare with changes from improved physics (blue lines)?

Diff in Arctic Sea Ice Extent

Diff in SO Sea Ice Extent

O(5000 km$^3$)

O(500 km$^3$)
Sea Ice Extent

Arctic Sea Ice Extent

Southern Ocean Sea Ice Extent

Julian Day

E3SM All-hands 19-21 Nov 2019
Computational Expense

Model speed with number of snow layers

Model Year per Comp-Day

Number of Snow Layers

E3SM All-hands 19-21 Nov 2019
Adding snow tracers does not significantly degrade performance for 5 snow layers.
Simulation Experiments for Snow Redistribution and Aging (G-CASE)

- **JRA-55 with original snow model (nsnowlayers = 1).** v1
- **JRA-55 with all snow mods (nsnowlayers = 5, rsnw_fall = 125 um) + 30% rule.** 30%. (Sturm and Holmgren 2001)
- **Branched from year 25 of CNTL-30%.**
  - all snow mods + 30% rule with shortwave Feedback. **30%sw**
  - All snow mods + snow redistributed among ice categories based on wind speed, density, and standard deviation of ice thickness distribution **ITDsd.** (Lecomte et al. 2015; LIM)
  - all snow mods + snow redistribution among level/ridged. **ITDrdg**
  - all snow mods but no snow redistribution. **NONE**
  - all snow mods but rsnw_fall = 54.526 um and ITDrdg. **rsnw54ITDrdg**
Russian Drift Data (1983-1990s)

30% + rsnw_fall = 125 um

rsnw_fall = 125 um
Snow Depth vs Month

- OBS (Russian Drift - RW)
- OBS (Russian Drift - LA)
- v1
- 30%
- 30%sw
- ITDsd
- ITDrdg
- none
- rsnw=54.526, ITDrdg

$h_s$ (cm)

Month
Sea Ice Thickness, Model – Obs (FM; yrs 1983-2002 of JRA-55)

E3SM.v1

v2 SnowMods

Overall thicker NH Sea ice and generally more extensive, though not in early spring.

Less extensive SH sea ice, though thicker during maximum extent and thinner during minimum.

Preliminary results indicate GCASE SnowMods produce...