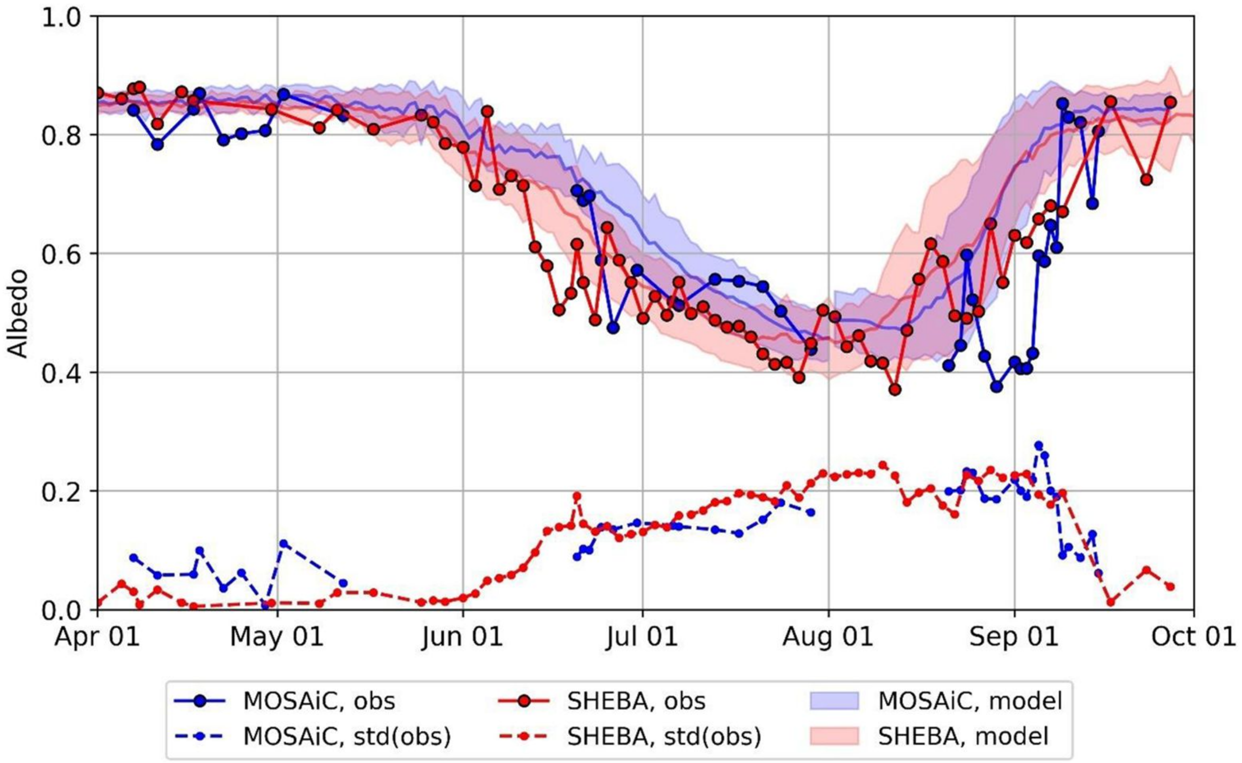
sealvl ponds:

an updated parameterization for melt ponds on sea ice in CICE

David Clemens-Sewall, Dave Bailey, Marika Holland, Bonnie Light, Don Perovich,
Chris Polashenski, Maddie Smith, Melinda Webster, Nicholas Wright

Motivation



Light et al. 2022

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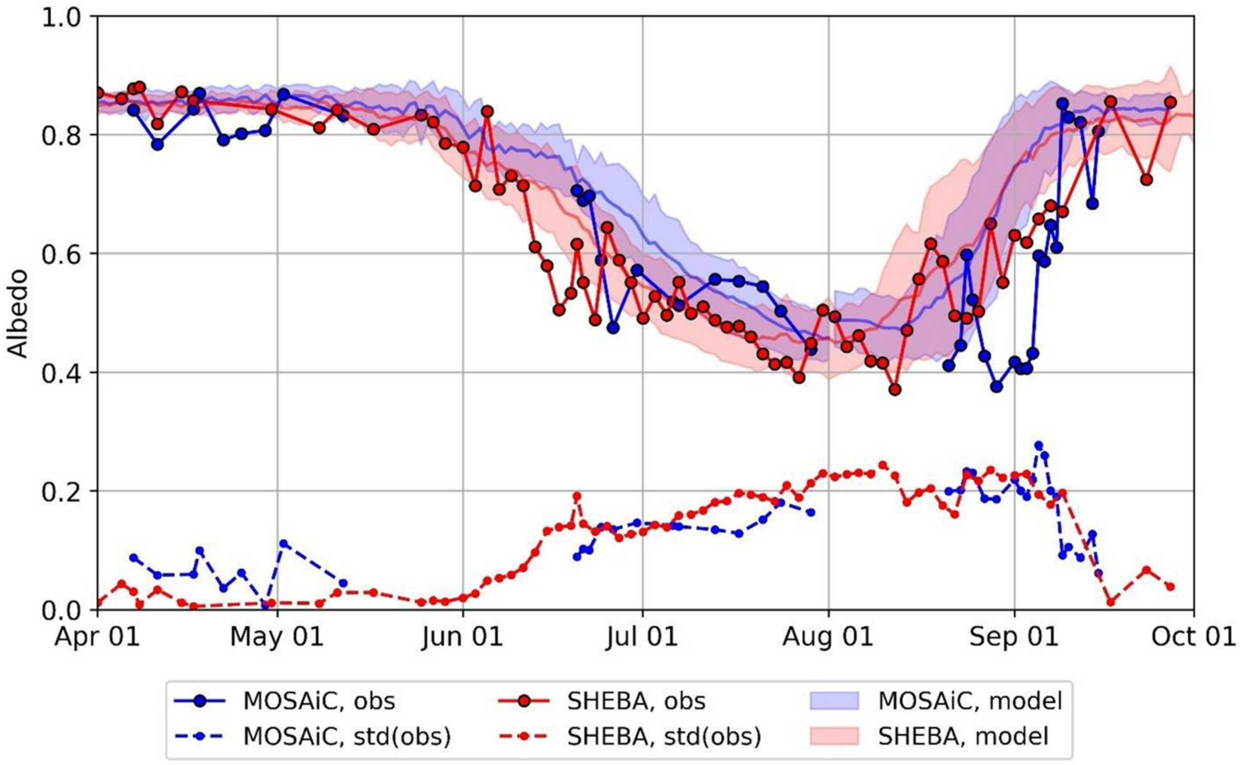

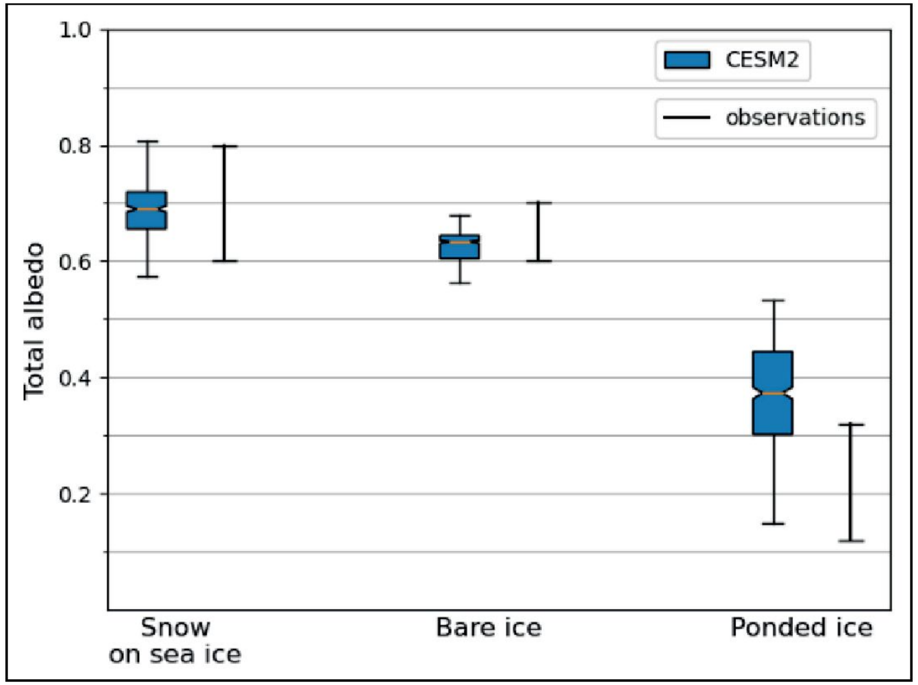

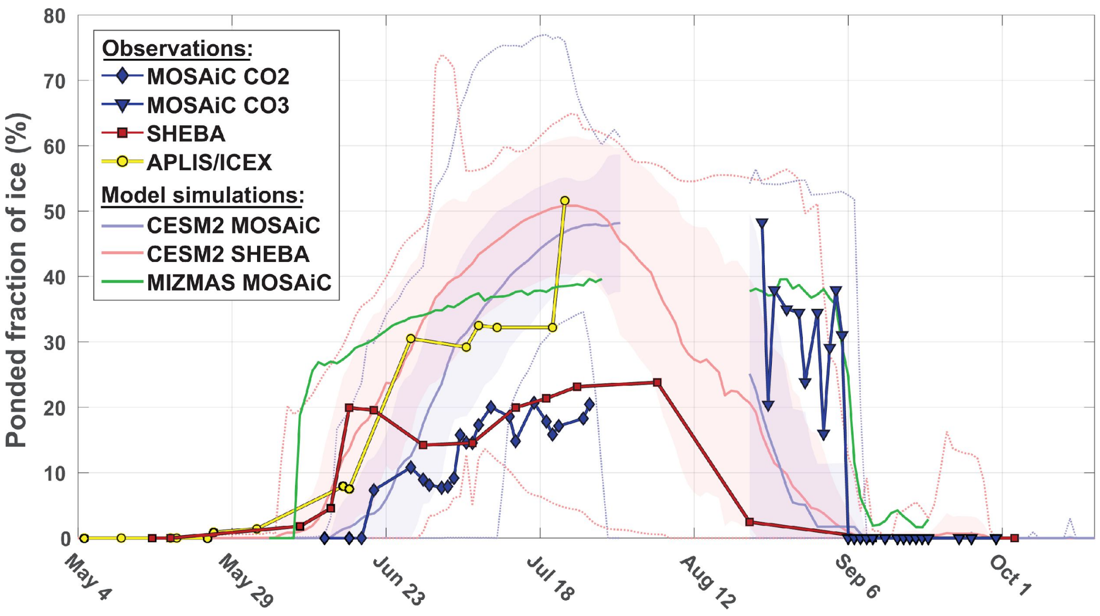

Light et al. 2022, Webster et al. 2022

Motivation

If the grid cell mean albedo is okay, why does it matter if pond area and albedo are inconsistent with observations?

1. No guarantee that errors will offset in different sea ice states.

1. Errors limit our ability to improve realism (e.g., cannot use DA for pond area if we need an incorrect pond area to offset albedo bias).

1. Albedo isn't the whole story (i.e., light transmission to the upper ocean).

Agenda

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- Lifecycle of a melt pond
- Updates to pond geometry
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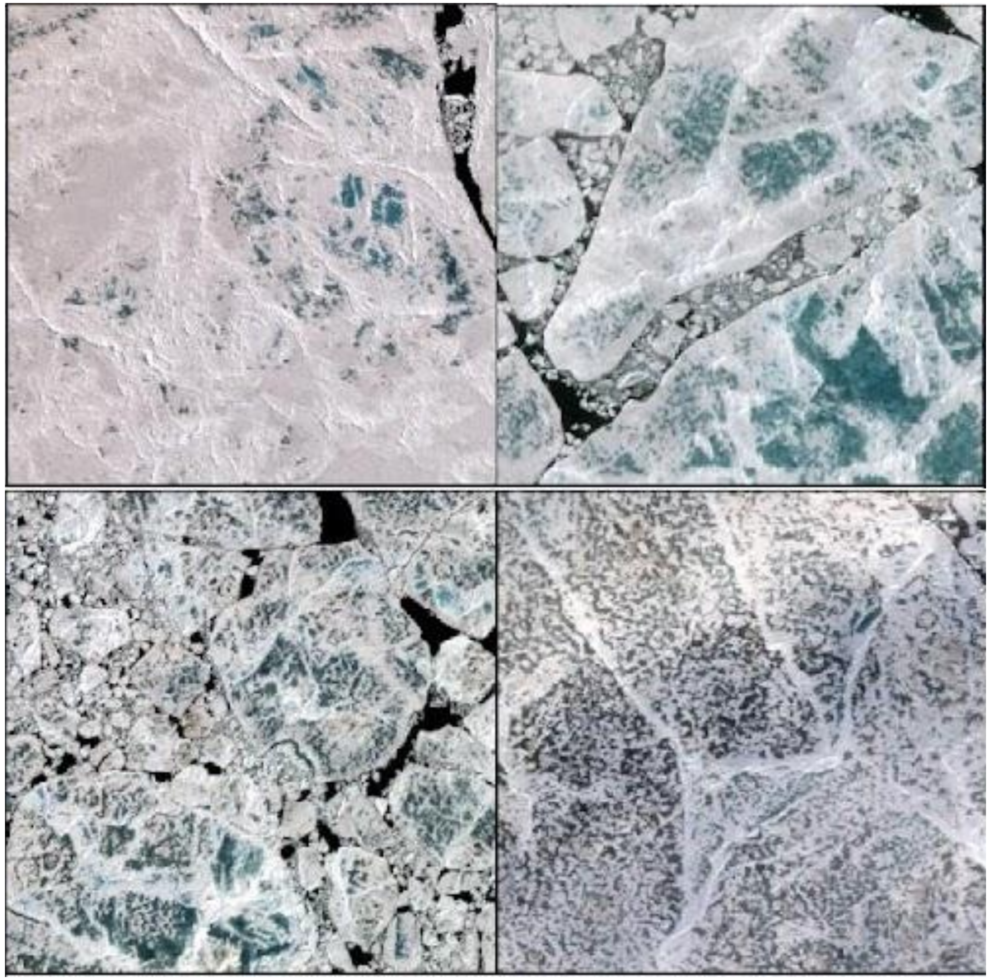
- Impacts in standalone and coupled models

Lifecycle of a melt pond

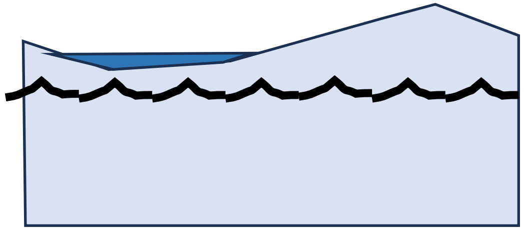


Photos: N. Wright (left), J. Delamere (right)

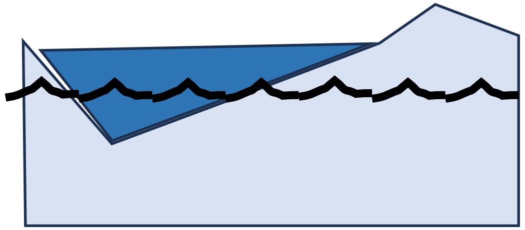
Lifecycle of a melt pond

Observations

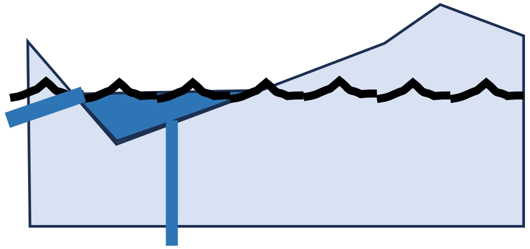
Meltwater fills depressions on impermeable ice creating above-freeboard ponds.



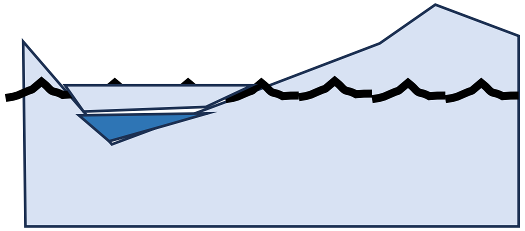
Low-albedo ponds accelerate melt, lowering pond base below freeboard.



Drainage through flaws and percolation lowers pond surfaces to freeboard.
~20-40% pond coverage



Pond surfaces remain at freeboard until refreezing or ice disintegrates.



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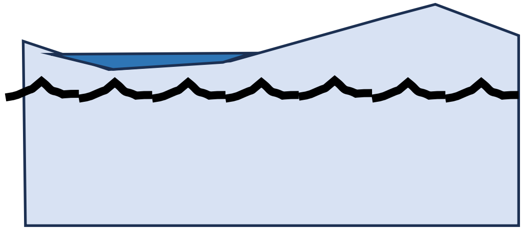

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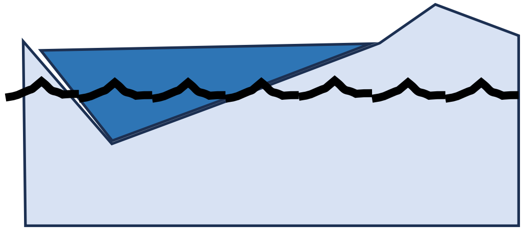

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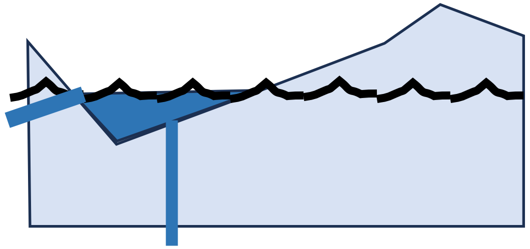

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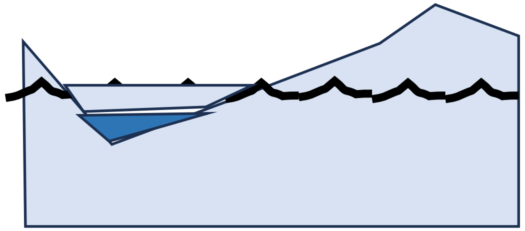

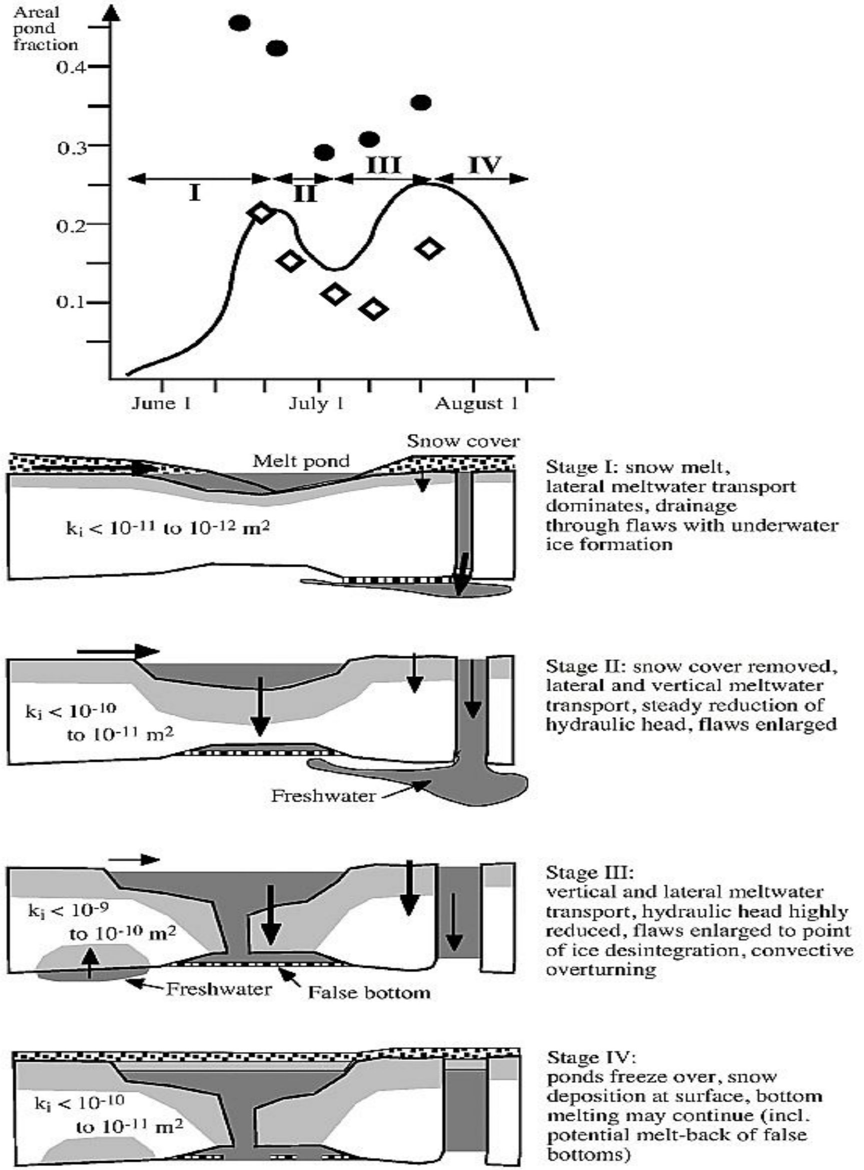

Stage I: snow melt, lateral meltwater transport dominates, drainage through flaws with underwater ice formation

Stage II: snow cover removed, lateral and vertical meltwater transport, steady reduction of hydraulic head, flaws enlarged

Stage III: vertical and lateral meltwater transport, hydraulic head highly reduced, flaws enlarged to point of ice desintegration, convective overturning

Stage IV: ponds freeze over, snow deposition at surface, bottom melting may continue (incl. potential melt-back of false bottoms)

Eicken et al. 2004

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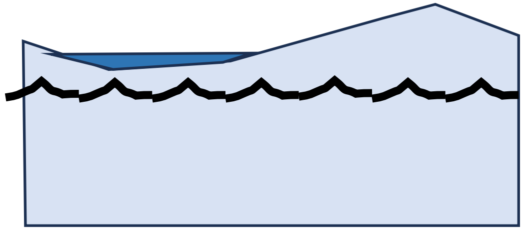

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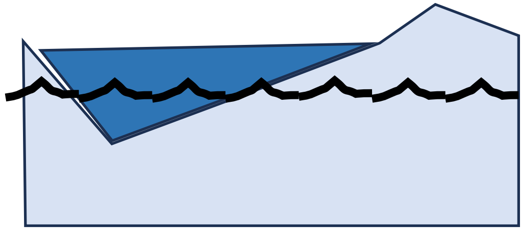

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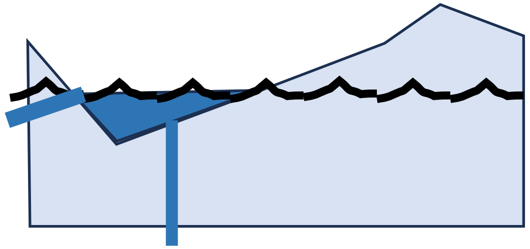

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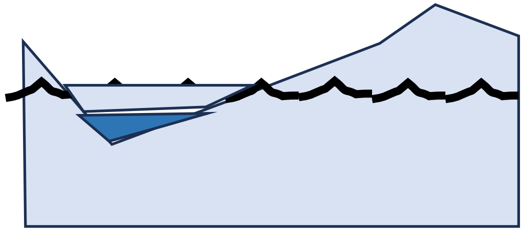
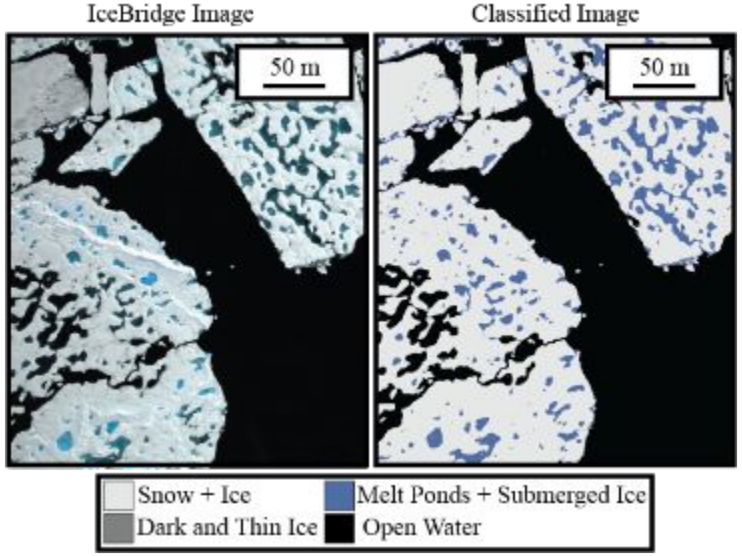
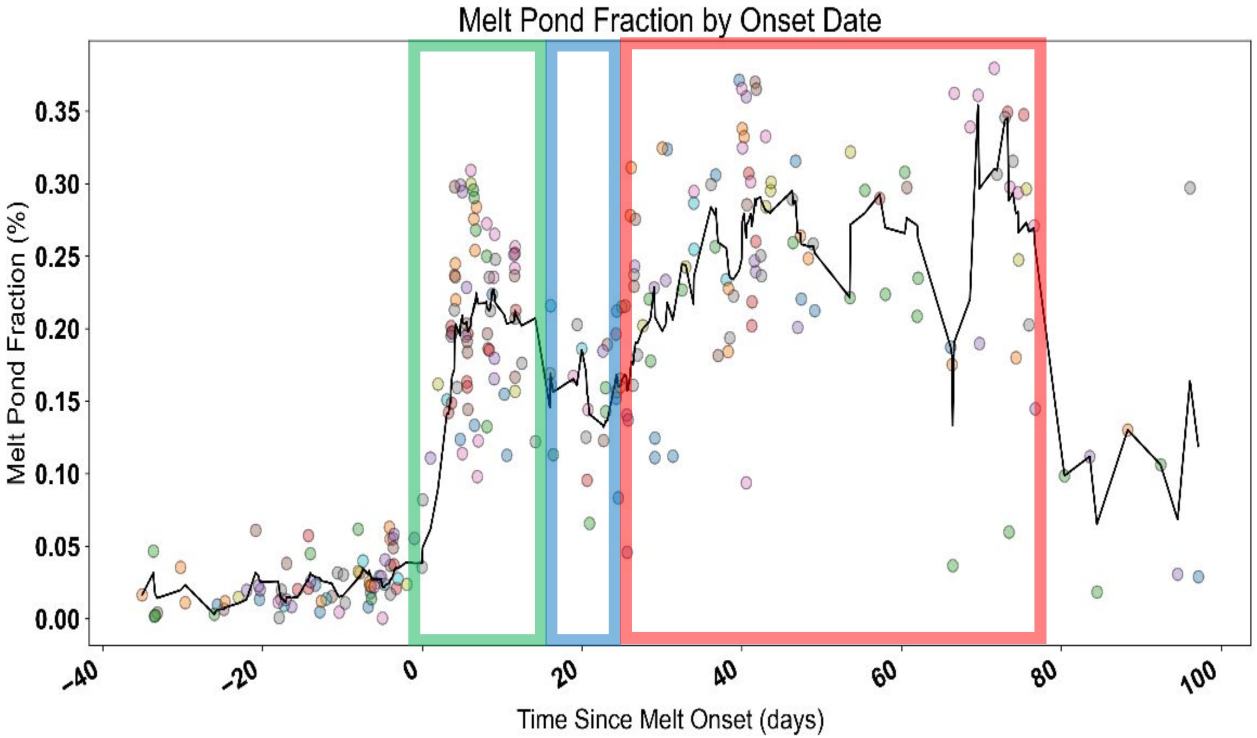
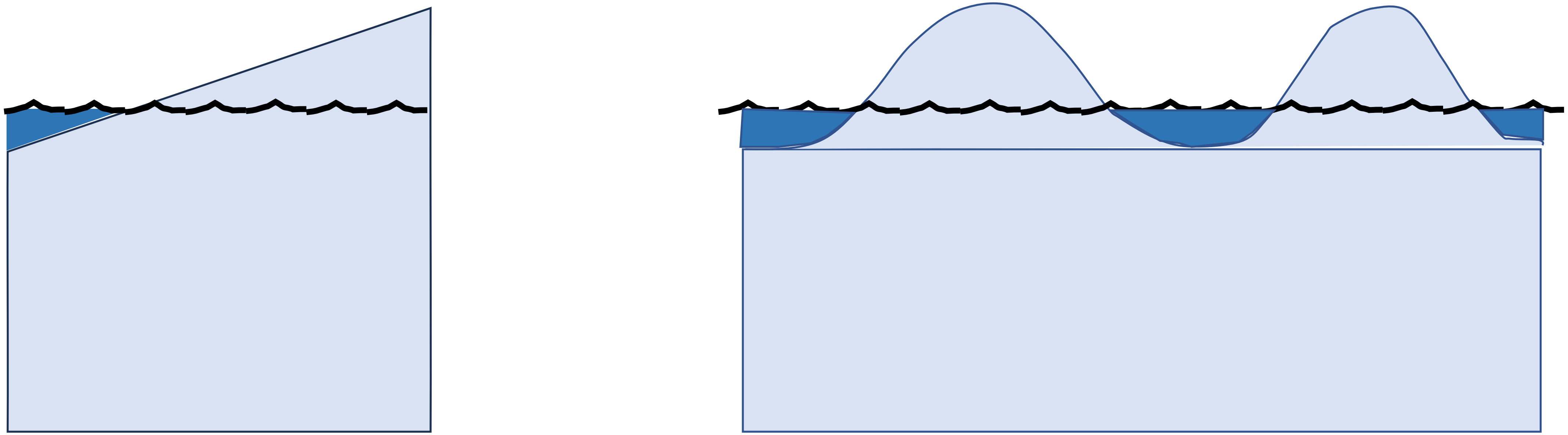






Stage: 1 2 3

Stage 3 melt pond fraction



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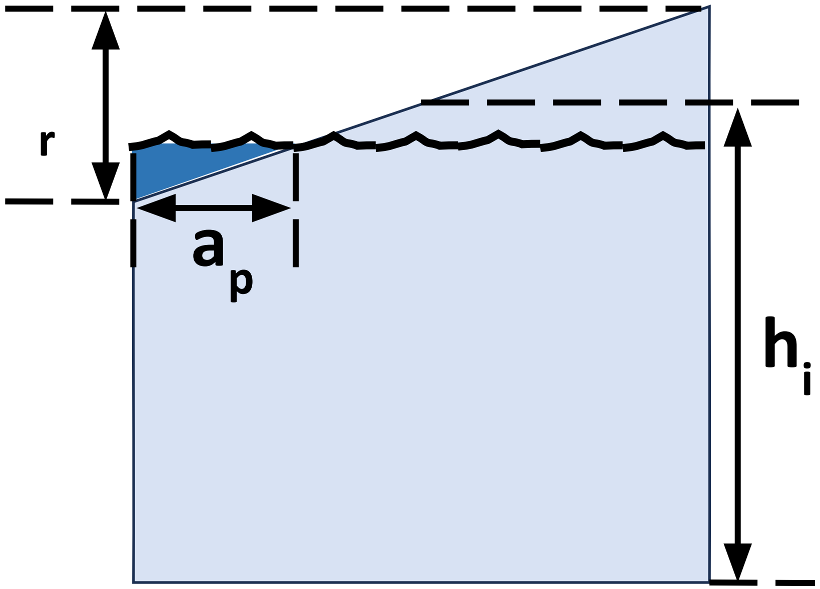
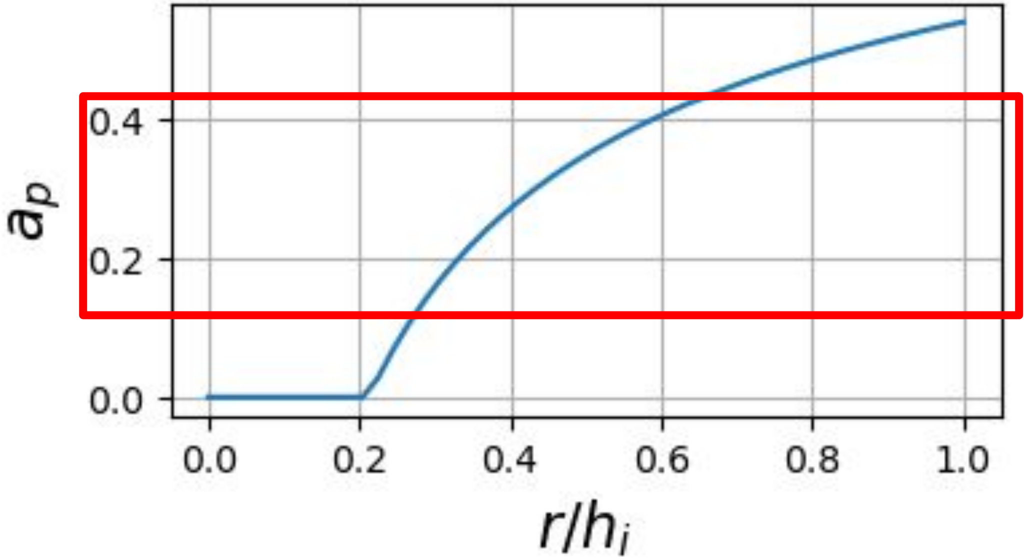


figure **is** to scale

$$a_p = 1 - \sqrt{2\frac{h_i}{r}\left(1 - \frac{\rho_i}{\rho_o}\right)}$$



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Melt ponds in Icepack

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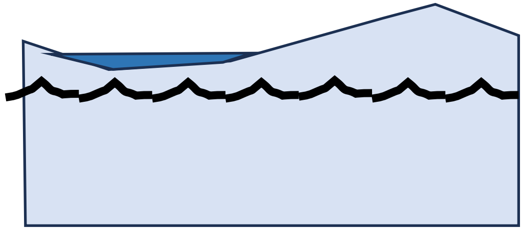

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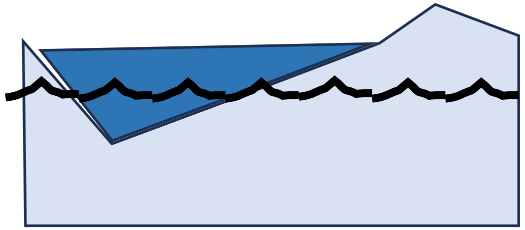

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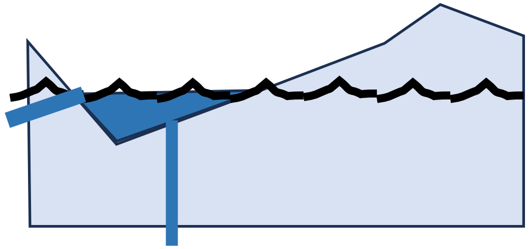

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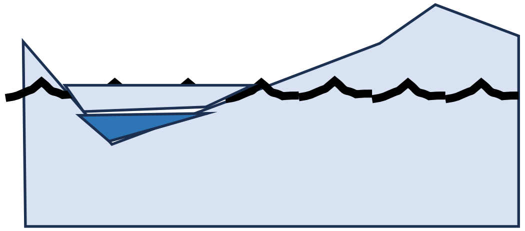
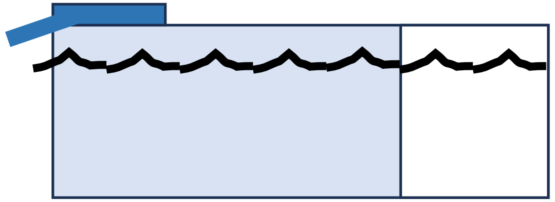
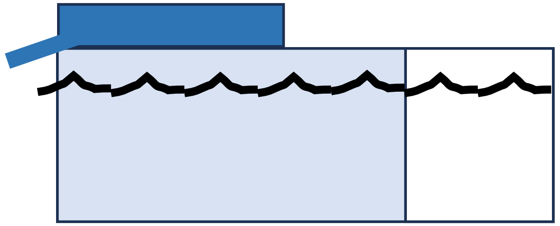


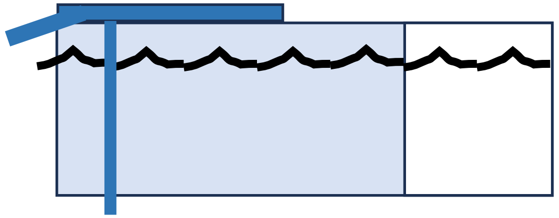
Icepack currently



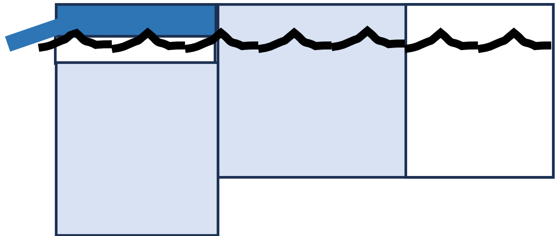
Ponds are perched above the ice surface and exponentially decay.



Pond area and depth grow by fixed ratio. Drainage only reduces depth.



The pressure head for percolation drainage assumes perched ponds.



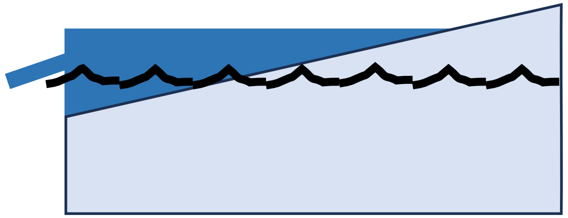
If pond mass would depress ice locally below freeboard, instantaneous drainage.

Proposed changes

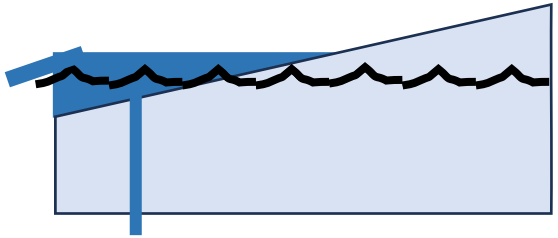
Icepack proposed

1. Explicitly represent hypsometry -> controls depth-area changes and enables sea level ponds.
    1. based on target sea level area fraction and isostatic balance.
2. Exponential drainage driven by pressure head.
3. Pressure head computed from hypsometry.
4. Freeboard constraint applied to entire category.

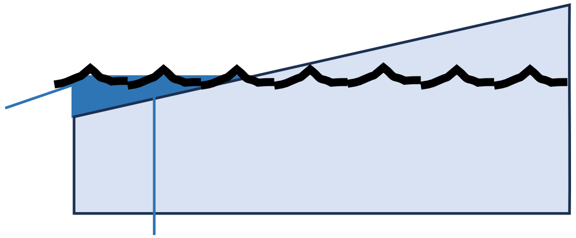
Icepack proposed



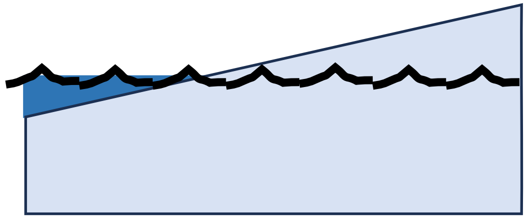
Pond area, depth, and pressure head depend on linear hypsometry.



Drainage reduces both depth and area based on hypsometry



Percolation and macroscopic drainage depend on pressure head.



Category has nonnegative buoyancy. Ponds can be locally below freeboard.

Proposed changes

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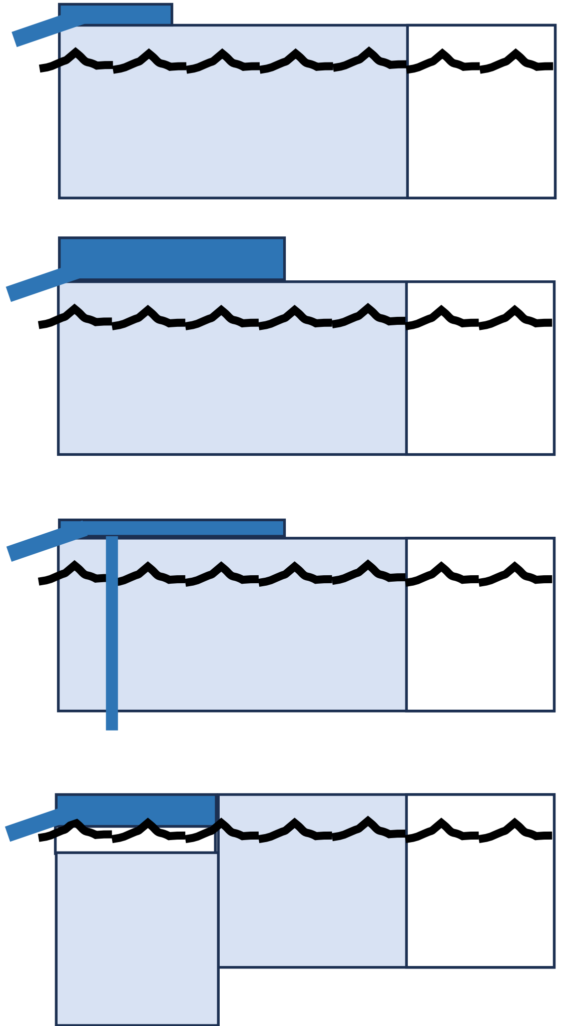

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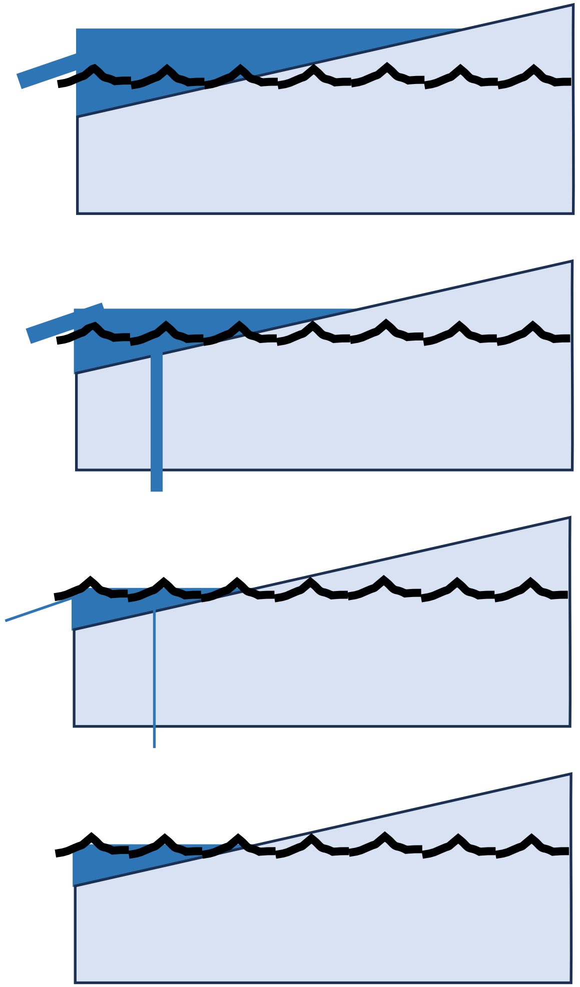

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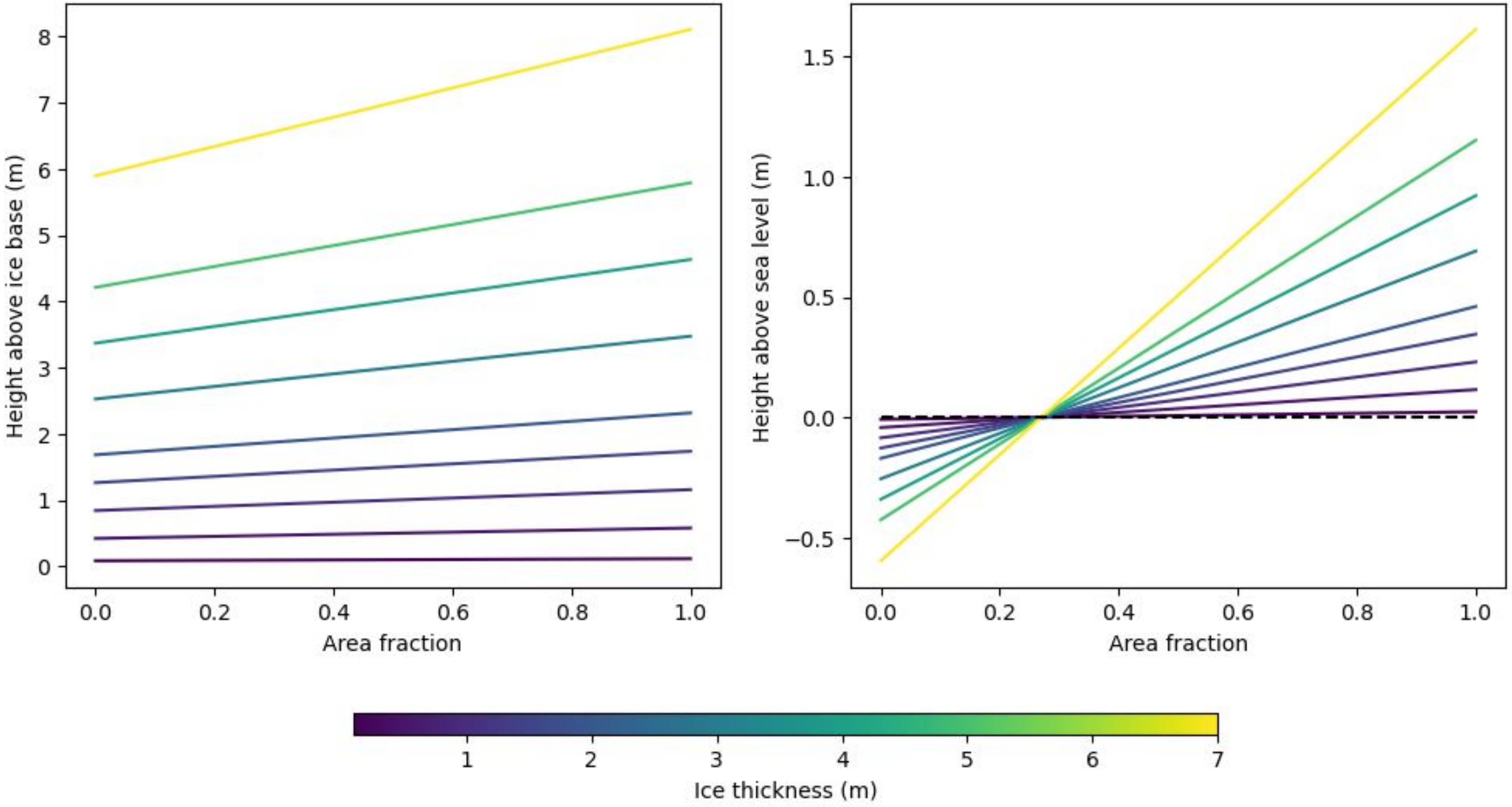
Drainage reduces both depth and area based on hypsometry

Percolation and macroscopic drainage depend on pressure head.

Category has nonnegative buoyancy. Ponds can be locally below freeboard.

Proposed Changes

Assume linear hypsometric curve which is a function of ice thickness, such that when **pond surface is at sea level, pond area is constant**.



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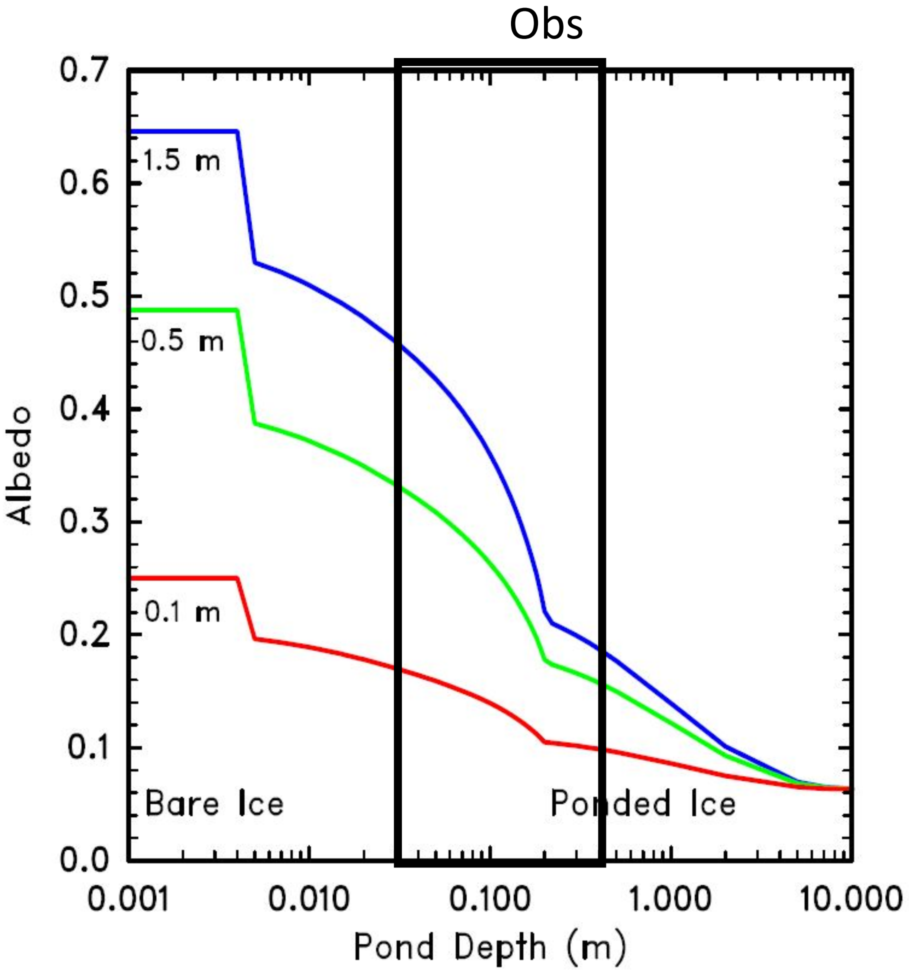
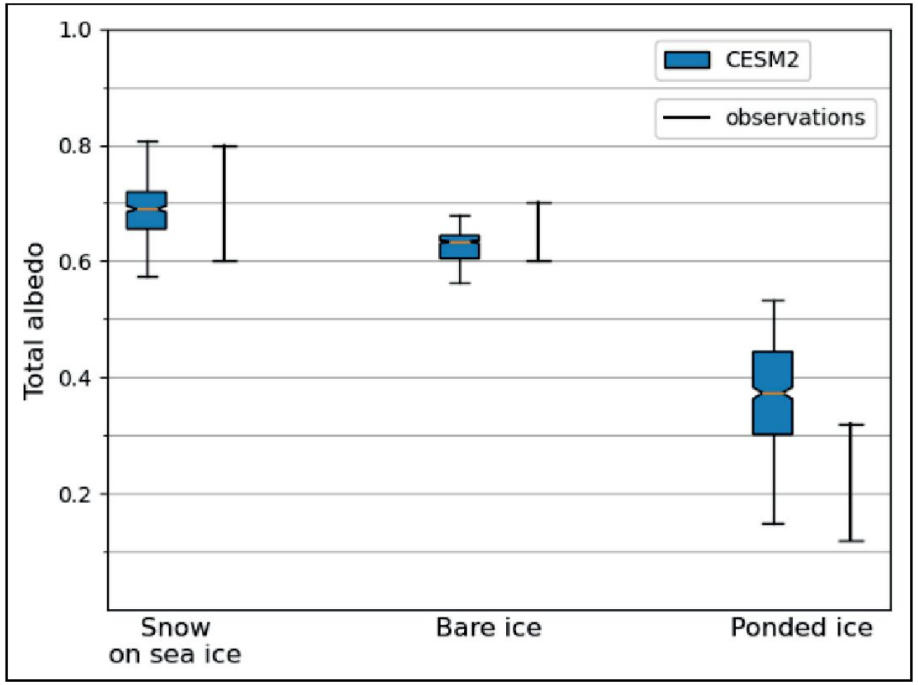
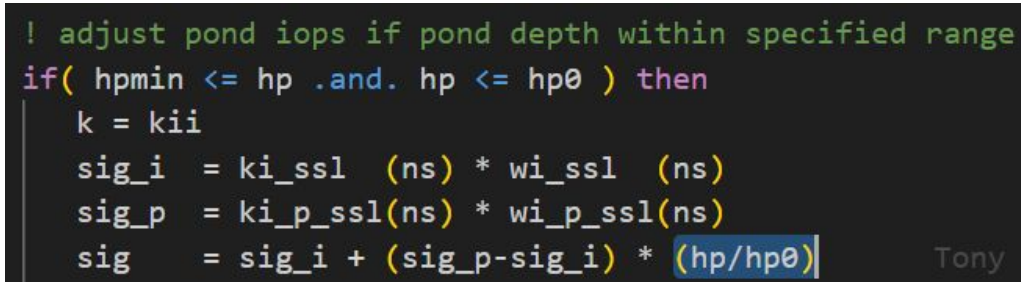
Pond optical properties



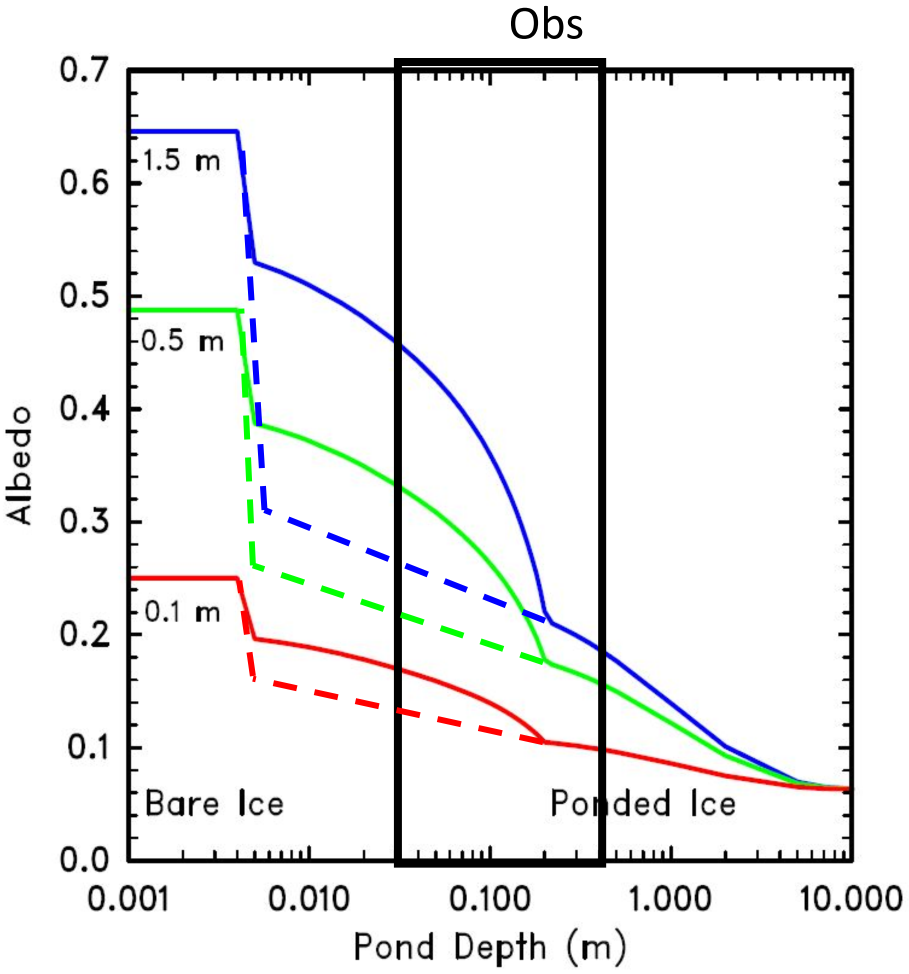


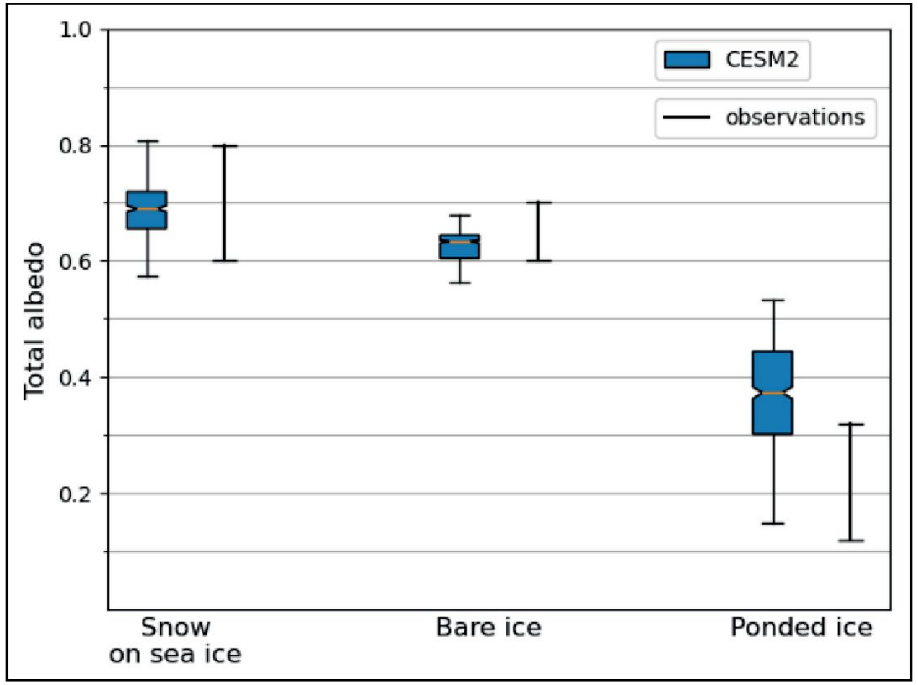


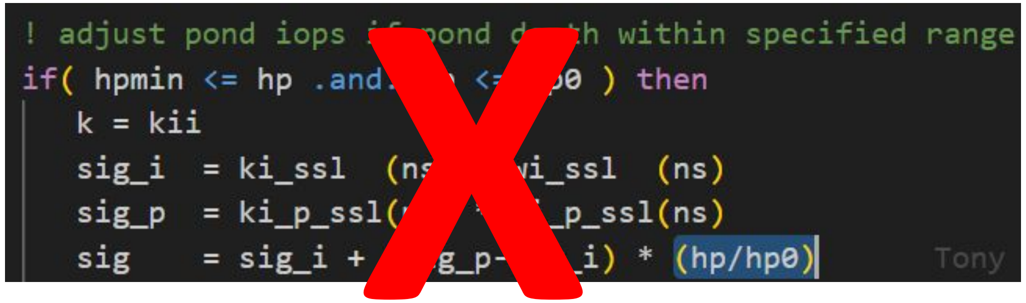
```
! adjust pond iops if pond depth within specified range
if( hpmin <= hp .and. hp <= hp0 ) then
   k = kii
   sig_i  = ki_ssl  (ns) * wi_ssl  (ns)
   sig_p  = ki_p_ssl(ns) * wi_p_ssl(ns)
   sig    = sig_i + (sig_p-sig_i) * (hp/hp0)        Tony
```

Light et al. 2022, Briegleb and Light 2007

Pond optical properties







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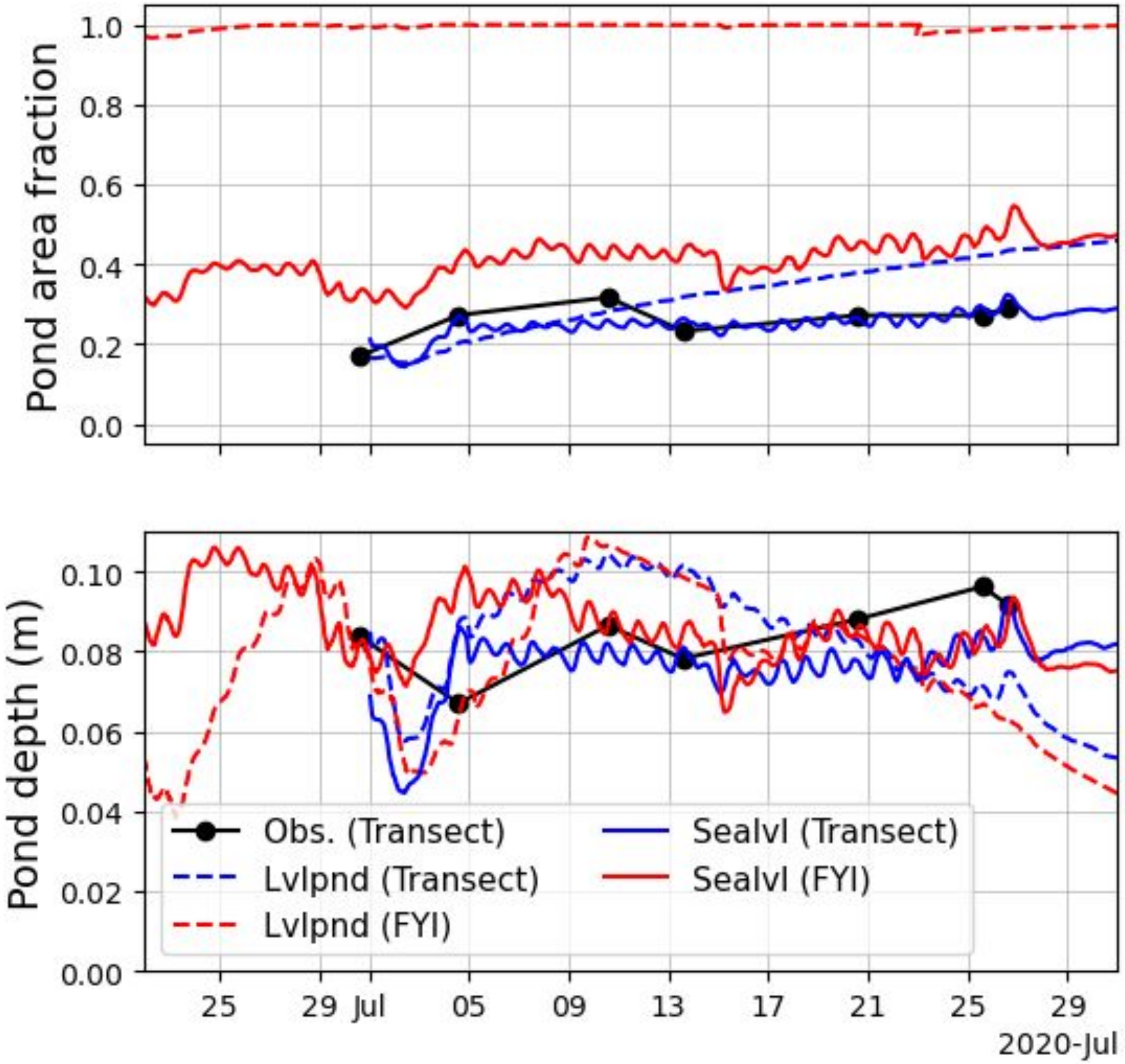
Sealvl ponds in Icepack simulations



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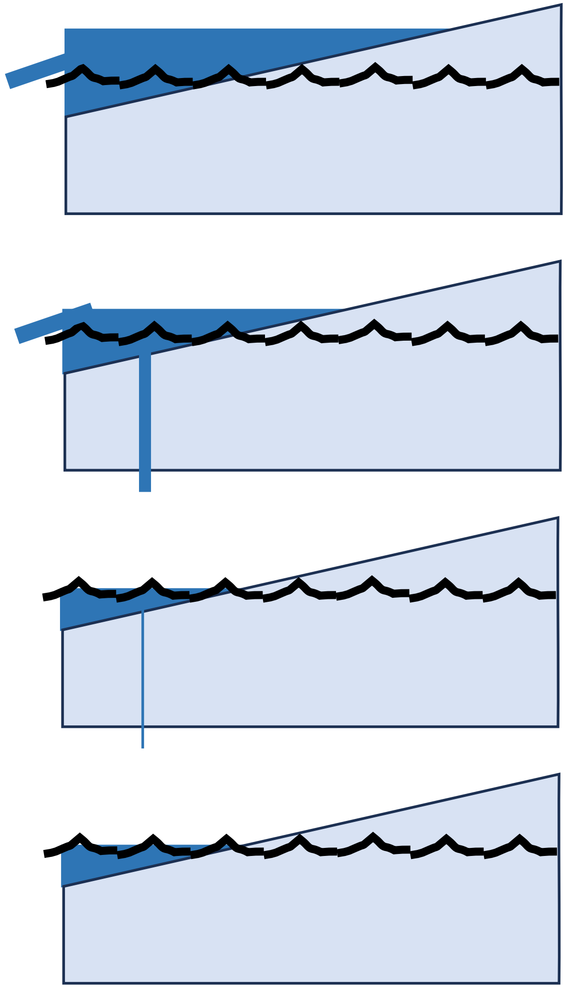

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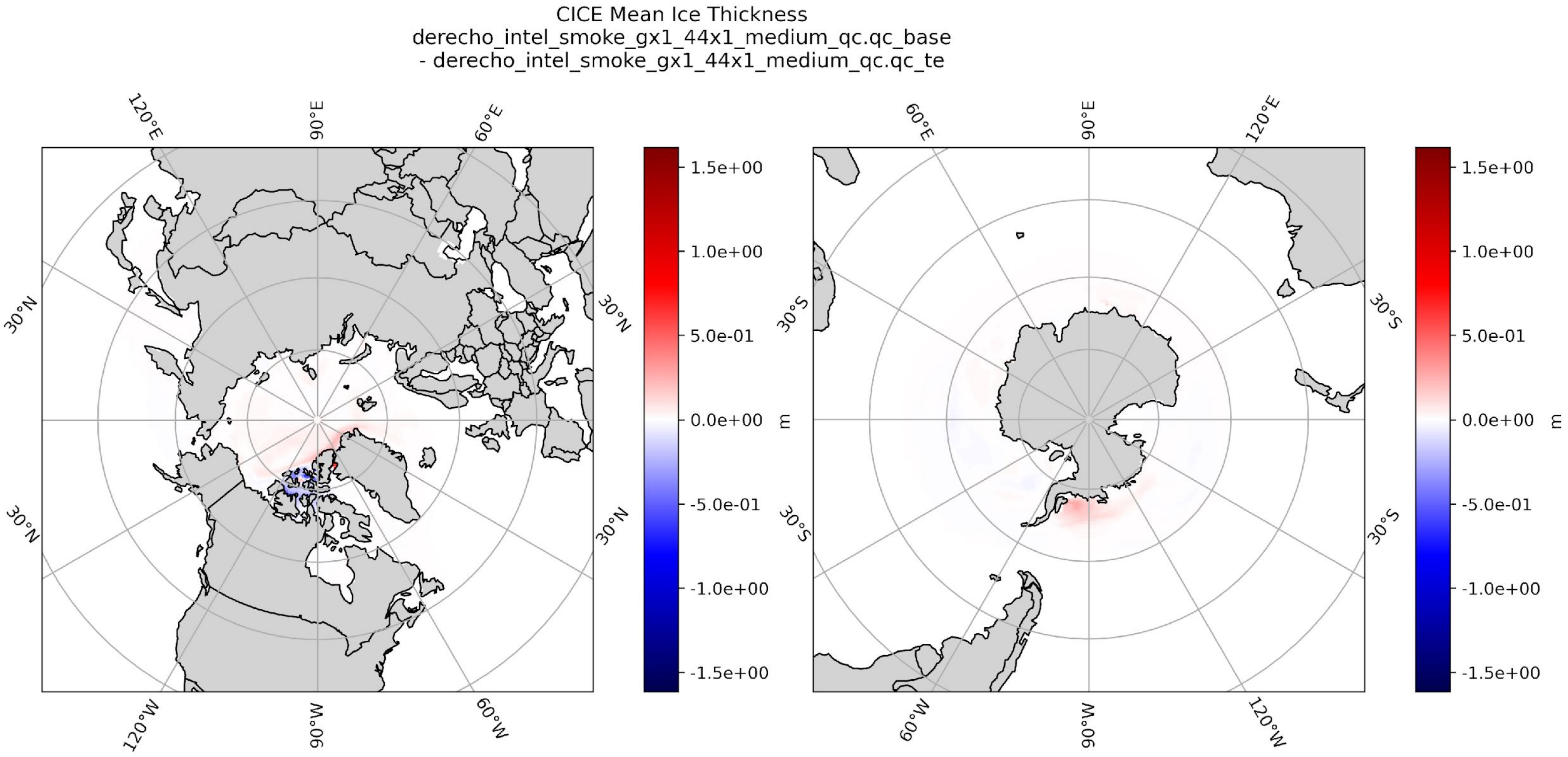
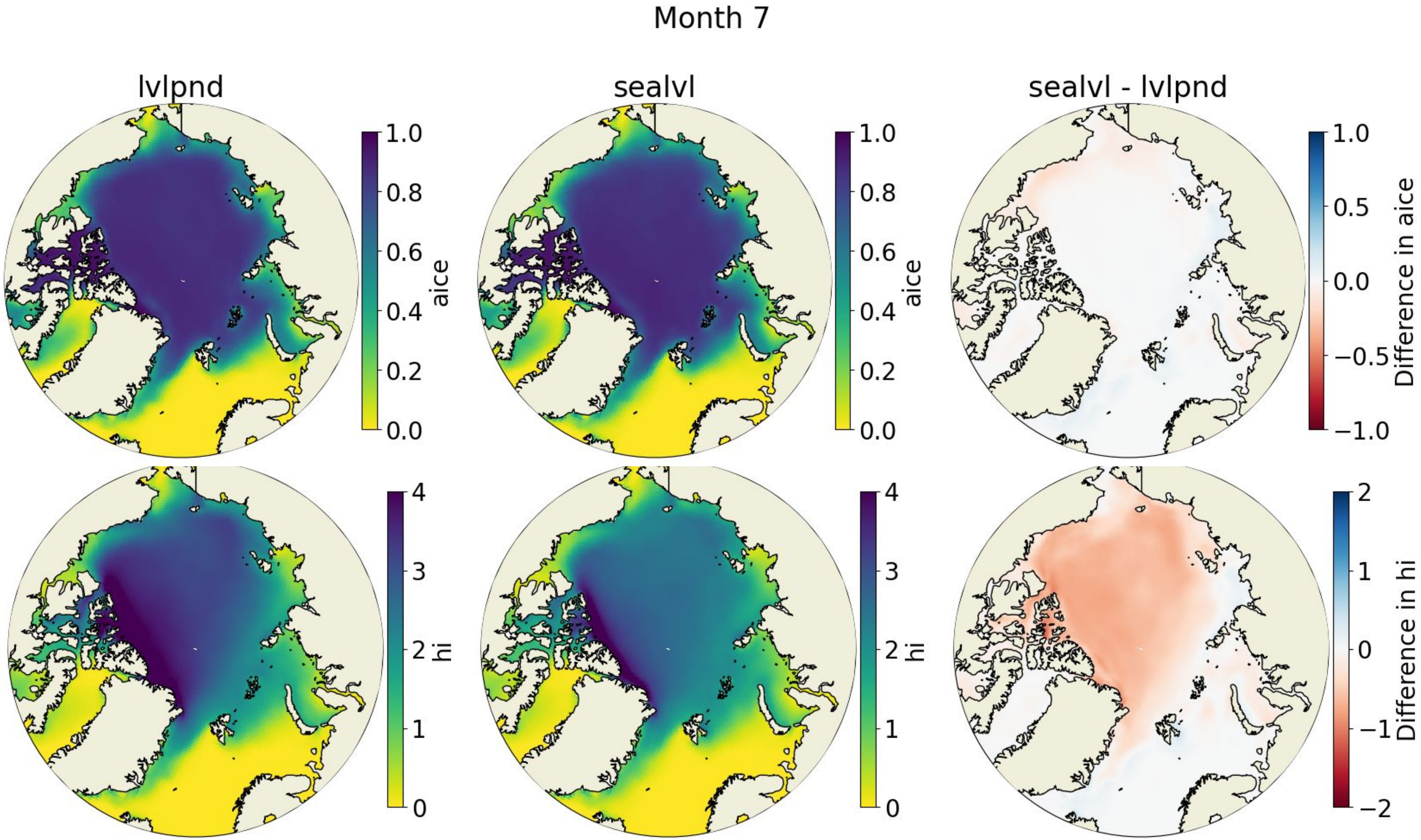
Category has nonnegative buoyancy. Ponds can be locally below freeboard.

Not climate-changing in standalone test



CESM3 Impacts



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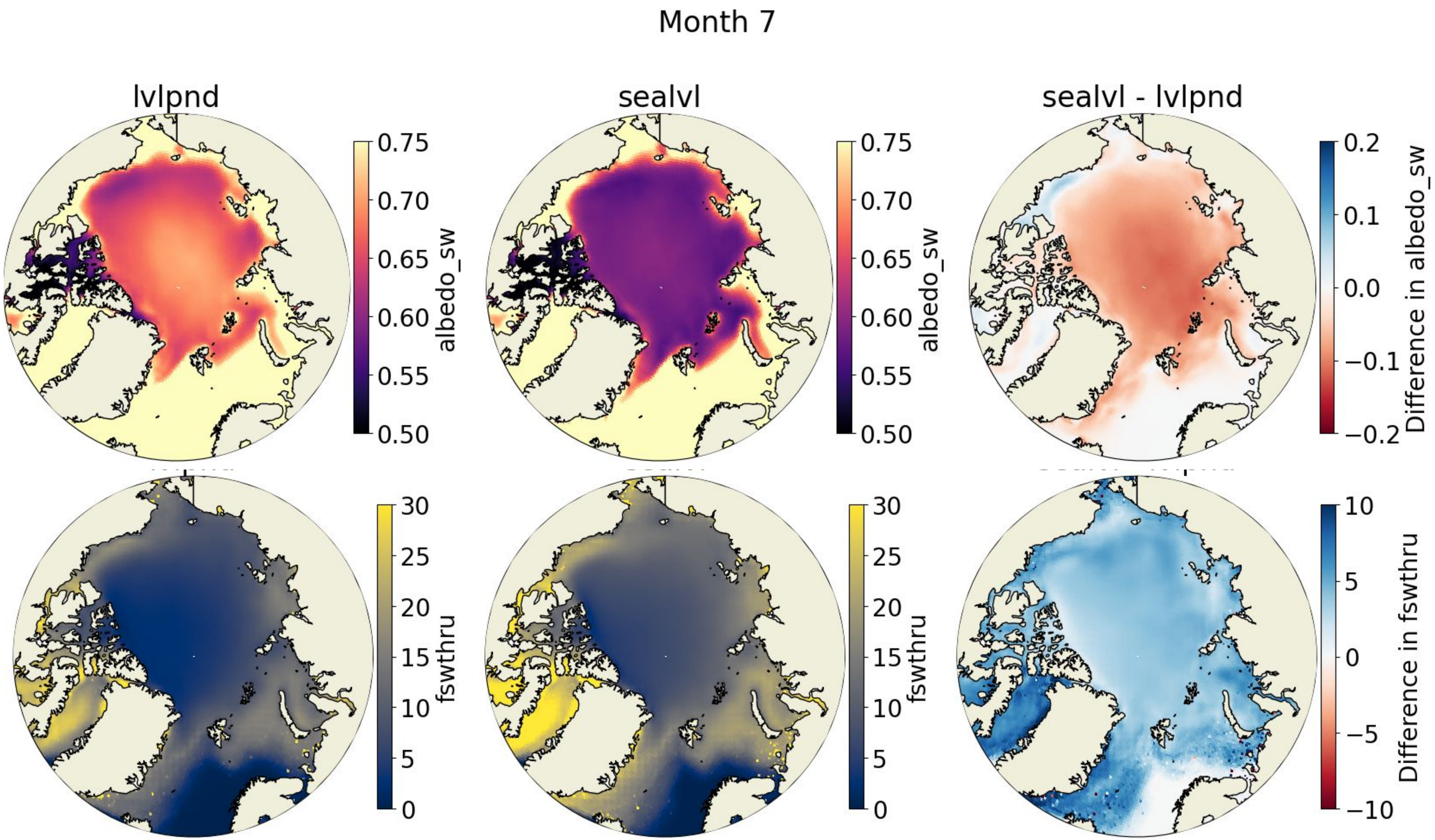


Conclusions

Sealvl ponds improves physical realism of pond processes without degrading the albedo evolution in standalone simulations.

Preliminary results suggest larger impacts in coupled simulations.

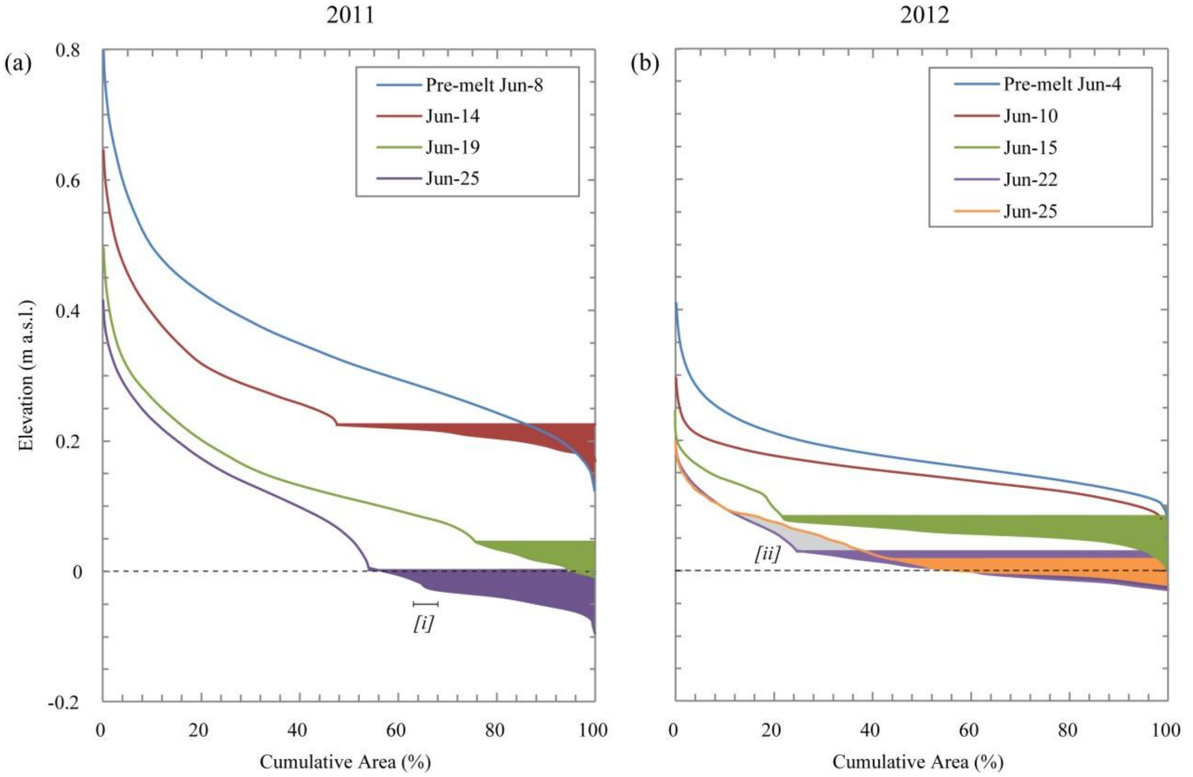
There are many future opportunities for enhancements (notably drainage and phases 1&2 of pond evolution).

Contact: davidclemenssewall@gmail.com

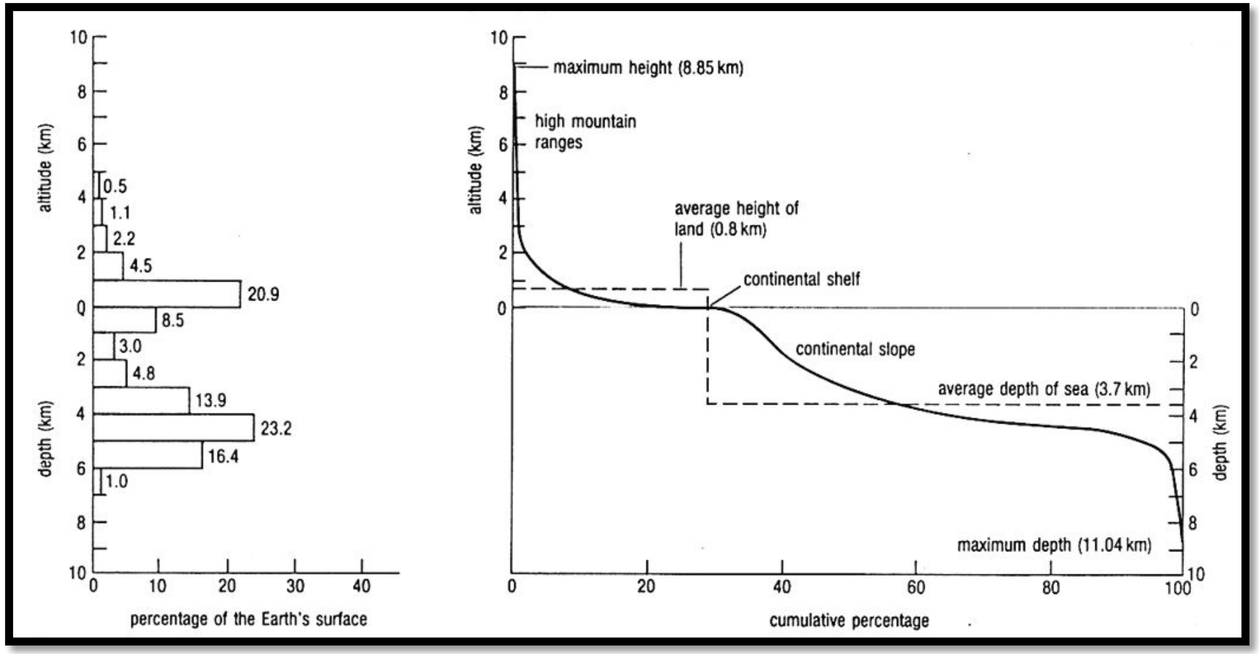
Addendum

Hypsometry

“the measurement of the elevation and depth of features of Earth's surface relative to mean sea level”



Landy et al., 2014



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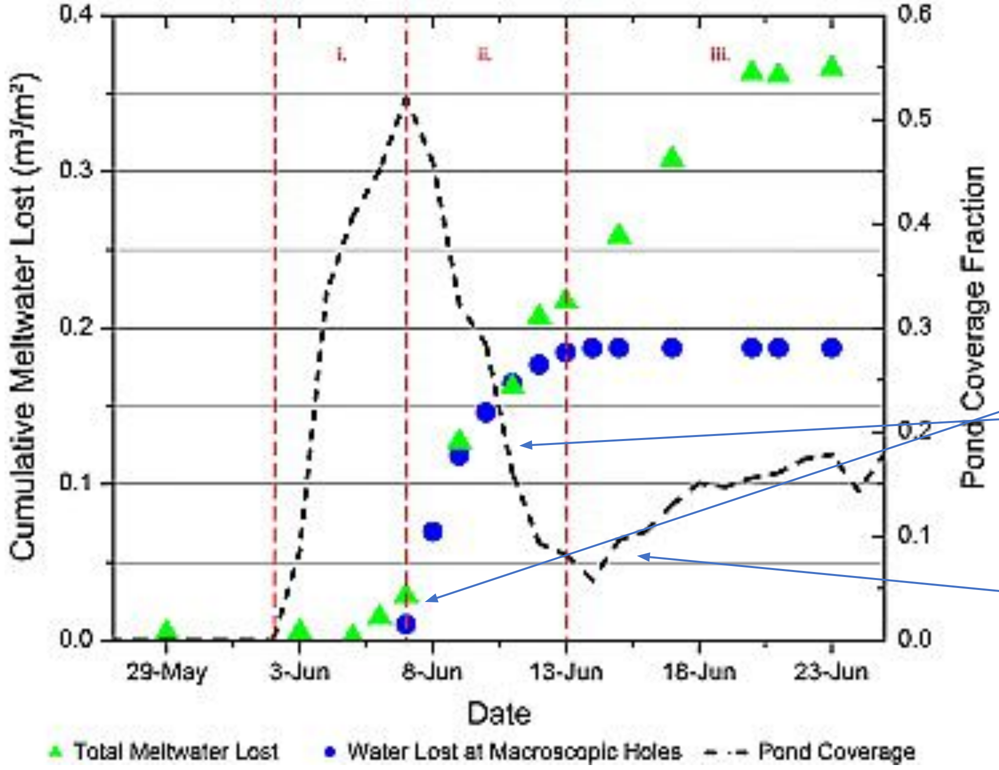
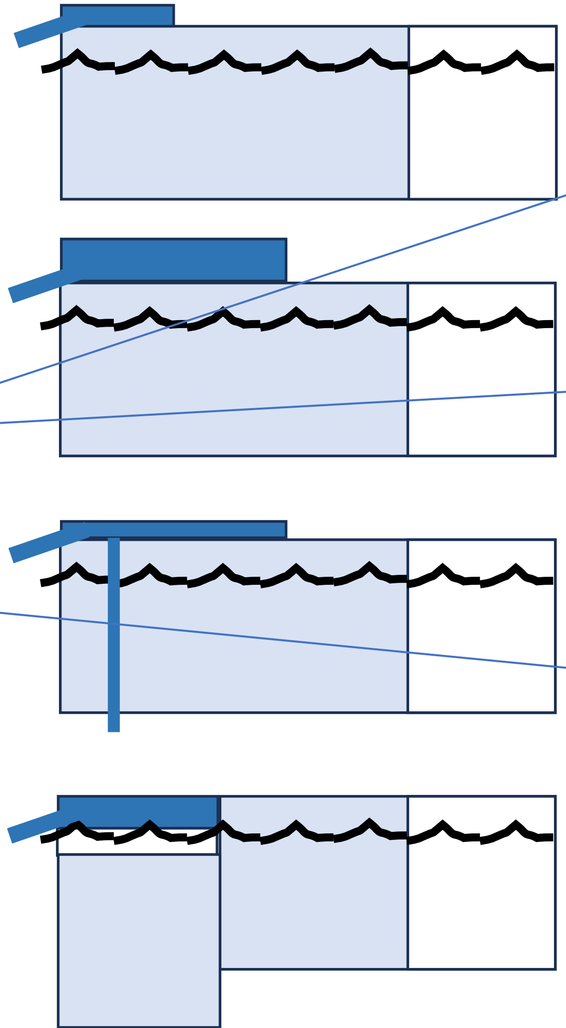
Lifecycle of a melt pond

Observations



Polashenski et al., 2012

Icepack currently



Ponds are perched above the ice surface and **exponentially decay.**

Pond area and depth grow by fixed ratio. **Drainage only reduces depth.**

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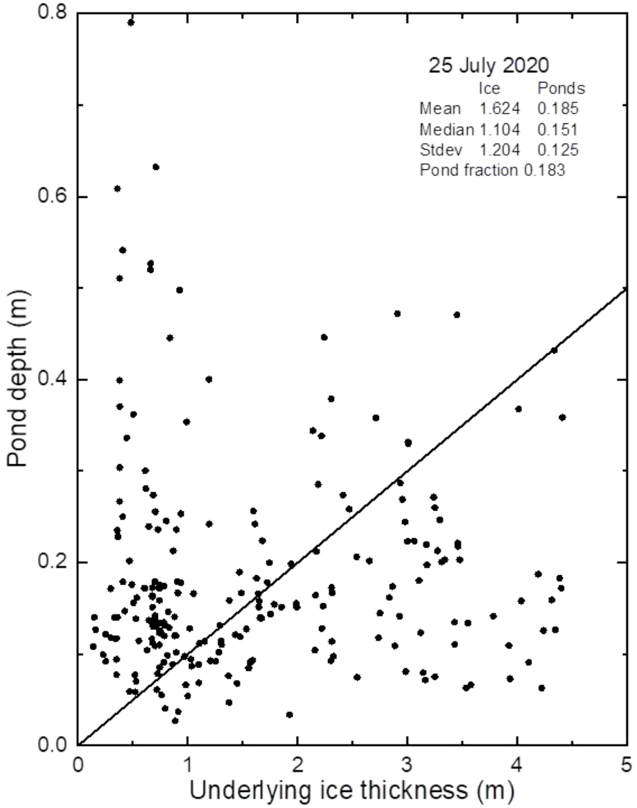
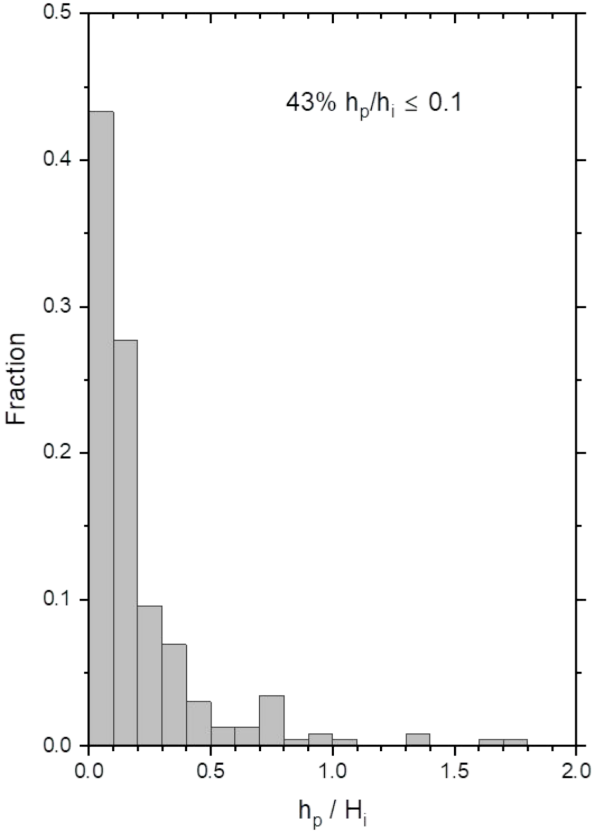


	Ice	Ponds
Mean	1.624	0.185
Median	1.104	0.151
Stdev	1.204	0.125
Pond fraction	0.183	



MOSAiC transect obs.

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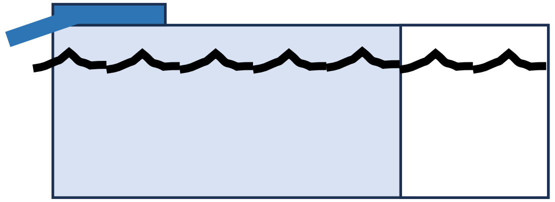

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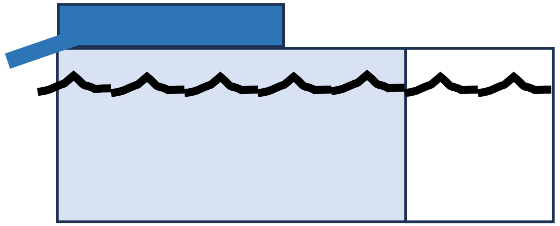
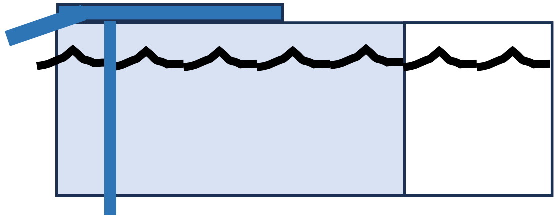
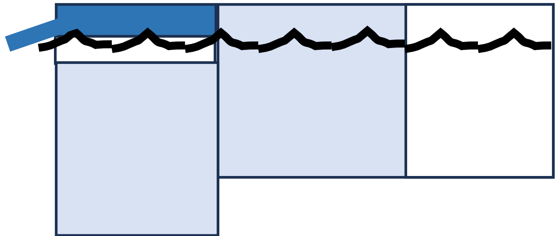


Pond area and depth grow by fixed ratio. Drainage only reduces depth.



The pressure head for percolation drainage assumes perched ponds.



If pond mass would depress ice locally below freeboard, instantaneous drainage.

Freeboard Constraint

Existing parameterization

Lines 217-218 in icepack_meltpond_lvl.F90:

! limit pond depth to maintain nonnegative freeboard

hpondn = min(hpondn, ((rhow-rhoi)*hi - rhos*hs)/rhofresh)

Where hi and hs are category mean ice and snow thickness respectively, but hpondn is the meltwater thickness **just over the ponded area, not average melt pond thickness over the entire category.**

Algebraically rearrange line 218:

rhofresh*hpondn <= rhow*hi - rhoi*hi - rhos*hs

rhofresh*hpondn + rhoi*hi + rhos*hs <= rhow*hi

The left hand side of this equation is the mass of a column of ice, snow, and pond, per m^2 of **ponded area**. Right hand side is the mass of a column of displaced sea water if the ice surface were at freeboard.

Proposed parameterization

dhpondn = min(c0, ((rhow-rhoi)*hi - rhos*hs)/(rhofresh*apondn) - hpondn)

Where apondn is the category pond area fraction (aka. apndn*alvln). We've switched to computing a pond depth change, instead of directly modifying hpondn. Assuming in the next step that we will update hpondn by adding dhpondn, this is equivalent to:

hpondn = min(hpondn, ((rhow-rhoi)*hi - rhos*hs)/(rhofresh*apondn))

Same algebraic rearrangement as before yields:

rhofresh*hpondn***apondn** + rhoi*hi + rhos*hs <= rhow*hi

The left hand side of this equation is the mass of a column of ice, snow, and pond, per m^2 of **category area**. Note that multiplying the pond mass per unit ponded area by the category pond fraction is equivalent to the pond mass per unit category area (i.e., averaging together the ponded and unponded areas of the category). Because the mean ice and snow thicknesses are assumed to be identical on the ponded and unponded areas of the category, changing the pond mass to be per unit category area is the only change we need to make the freeboard constraint over the entire category.

Rfrac parameterization

Existing parameterization

Lines 144-151 in icepack_meltpond_lvl.F90:

```
if (use_smliq_pnd) then
   dvn = rfrac/rhofresh*(meltt*rhoi + meltsliqn)*aicen
else
   dvn = rfrac/rhofresh*(meltt*rhoi + melts*rhos + frain*  dt)*aicen
endif
```

Where `rfrac` comes from line 2759 in icepack_therm_vertical.F90:

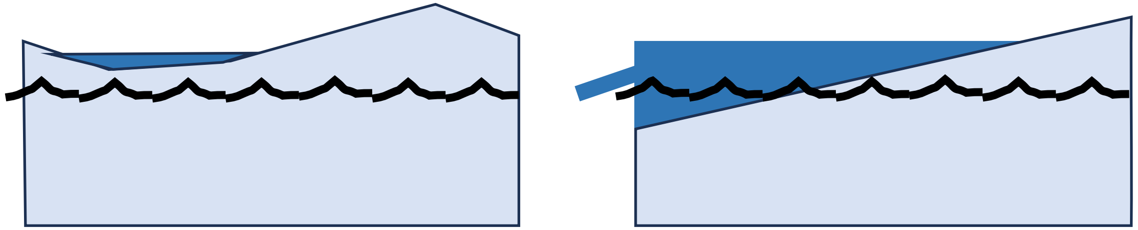
```
rfrac = rfracmin + (rfracmax-rfracmin) * aicen(n)
```

Lifecycle of a melt pond

Observations

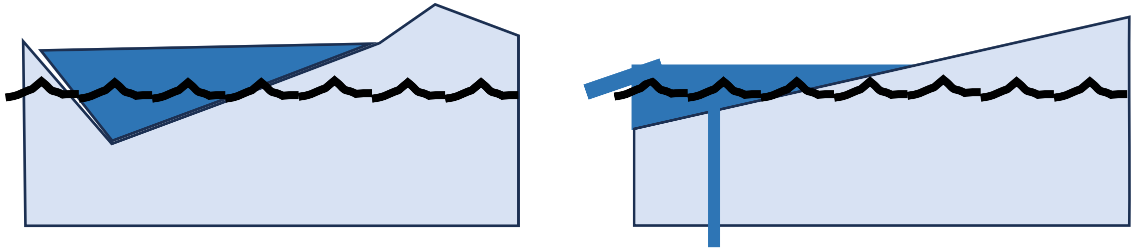
Icepack proposed

Meltwater fills depressions on impermeable ice creating above-freeboard ponds.



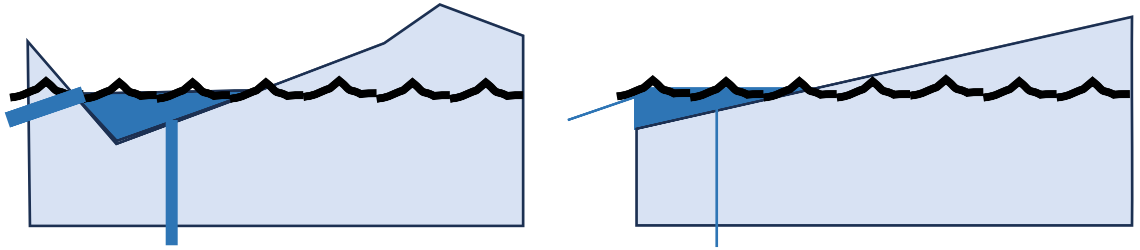
Pond area, depth, and pressure head depend on linear hypsometry.

Low-albedo ponds accelerate melt, lowering pond base below freeboard.



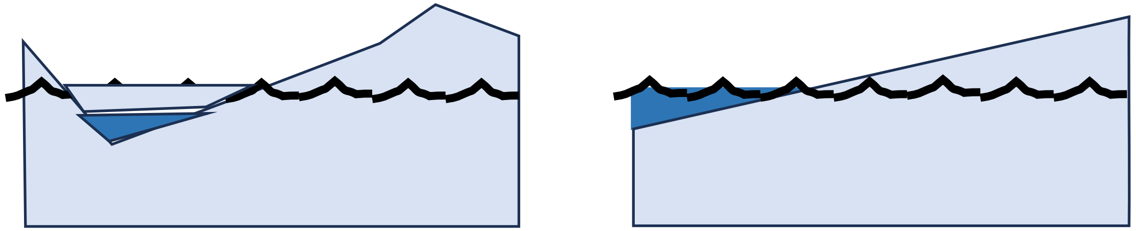
Drainage reduces both depth and area based on hypsometry

Drainage through flaws and percolation lowers pond surfaces to freeboard.
~20-40% pond coverage

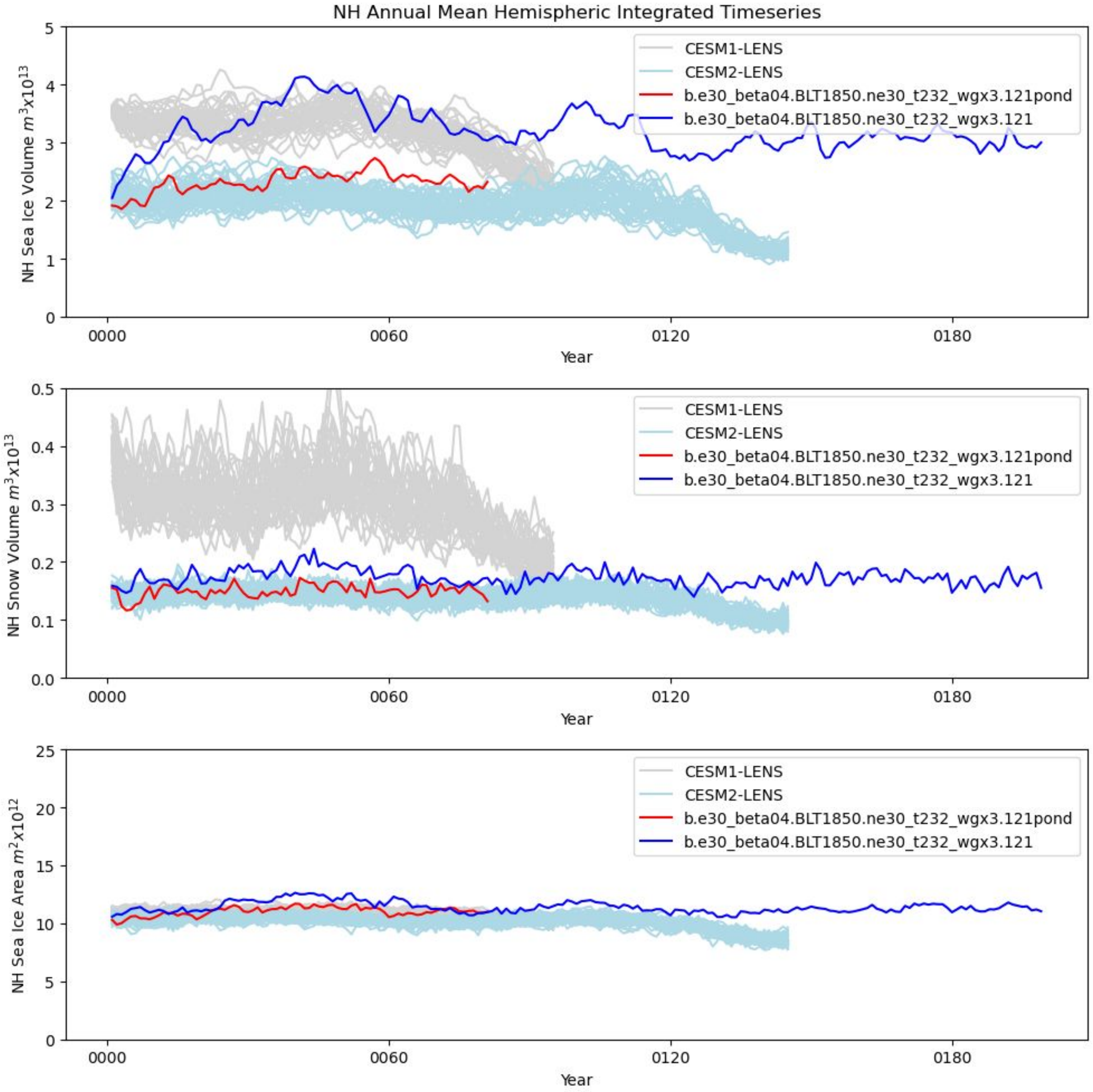


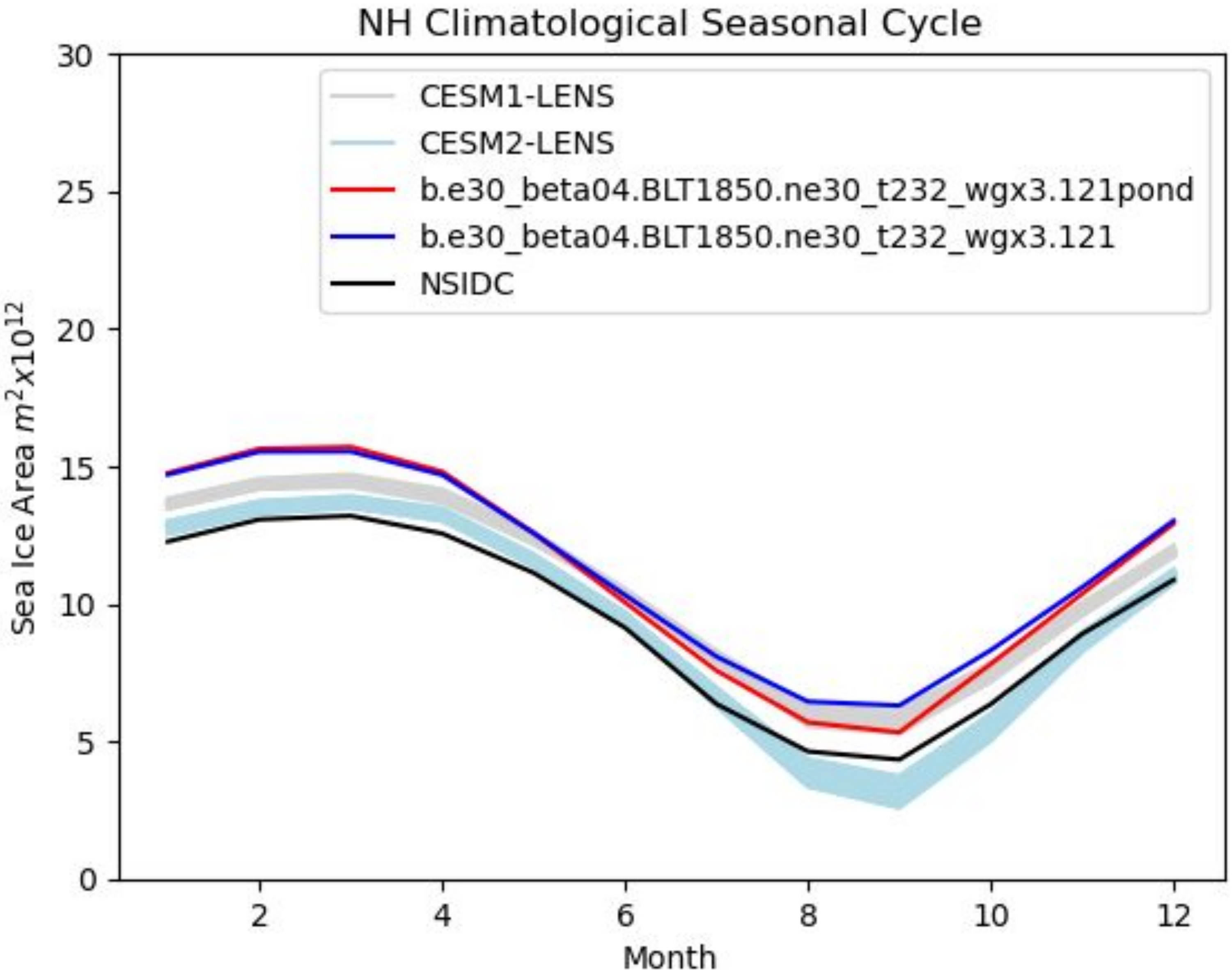
Percolation and macroscopic drainage depend on pressure head.

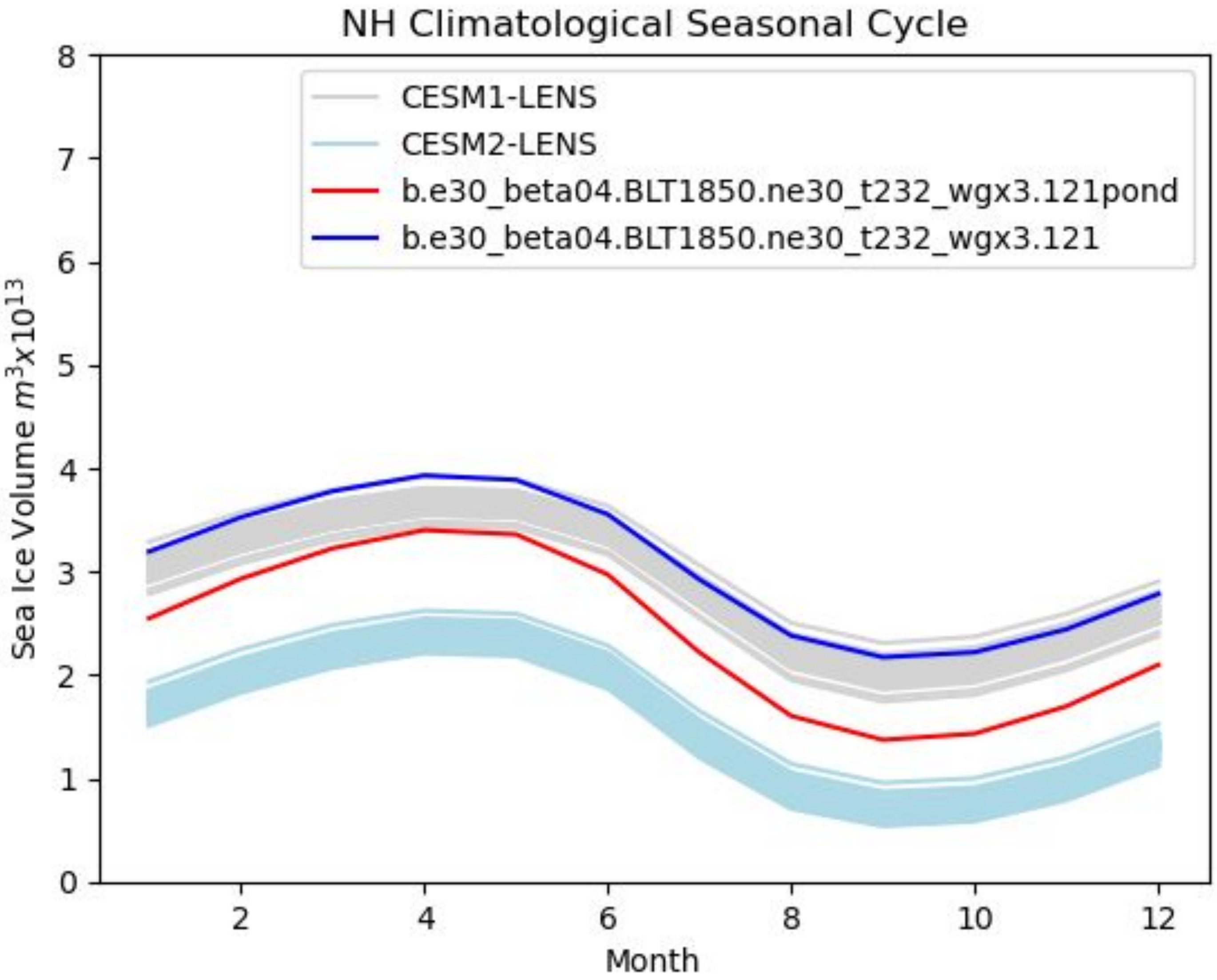
Pond surfaces remain at freeboard until refreezing or ice disintegrates.



Category has nonnegative buoyancy. Ponds can be locally below freeboard.


NH Annual Mean Hemispheric Integrated Timeseries
NH Sea Ice Volume $m^3 x10^{13}$
0
1
2
3
4
5
NH Snow Volume $m^3 x10^{13}$
0.0
0.1
0.2
0.3
0.4
0.5
NH Sea Ice Area $m^2 x10^{12}$
0
5
10
15
20
25
0000
0060
0120
0180
Year
CESM1-LENS
CESM2-LENS
b.e30_beta04.BLT1850.ne30_t232_wgx3.121pond
b.e30_beta04.BLT1850.ne30_t232_wgx3.121


NH Climatological Seasonal Cycle
CESM1-LENS
CESM2-LENS
b.e30_beta04.BLT1850.ne30_t232_wgx3.121pond
b.e30_beta04.BLT1850.ne30_t232_wgx3.121
NSIDC
Sea Ice Area $m^2 x 10^{12}$
0
5
10
15
20
25
30
2
4
6
8
10
12
Month


NH Climatological Seasonal Cycle
CESM1-LENS
CESM2-LENS
b.e30_beta04.BLT1850.ne30_t232_wgx3.121pond
b.e30_beta04.BLT1850.ne30_t232_wgx3.121
Sea Ice Volume $m^3 x 10^{13}$
0
1
2
3
4
5
6
7
8
2
4
6
8
10
12
Month