Current variability and future projections of winter Arctic sea ice thickness

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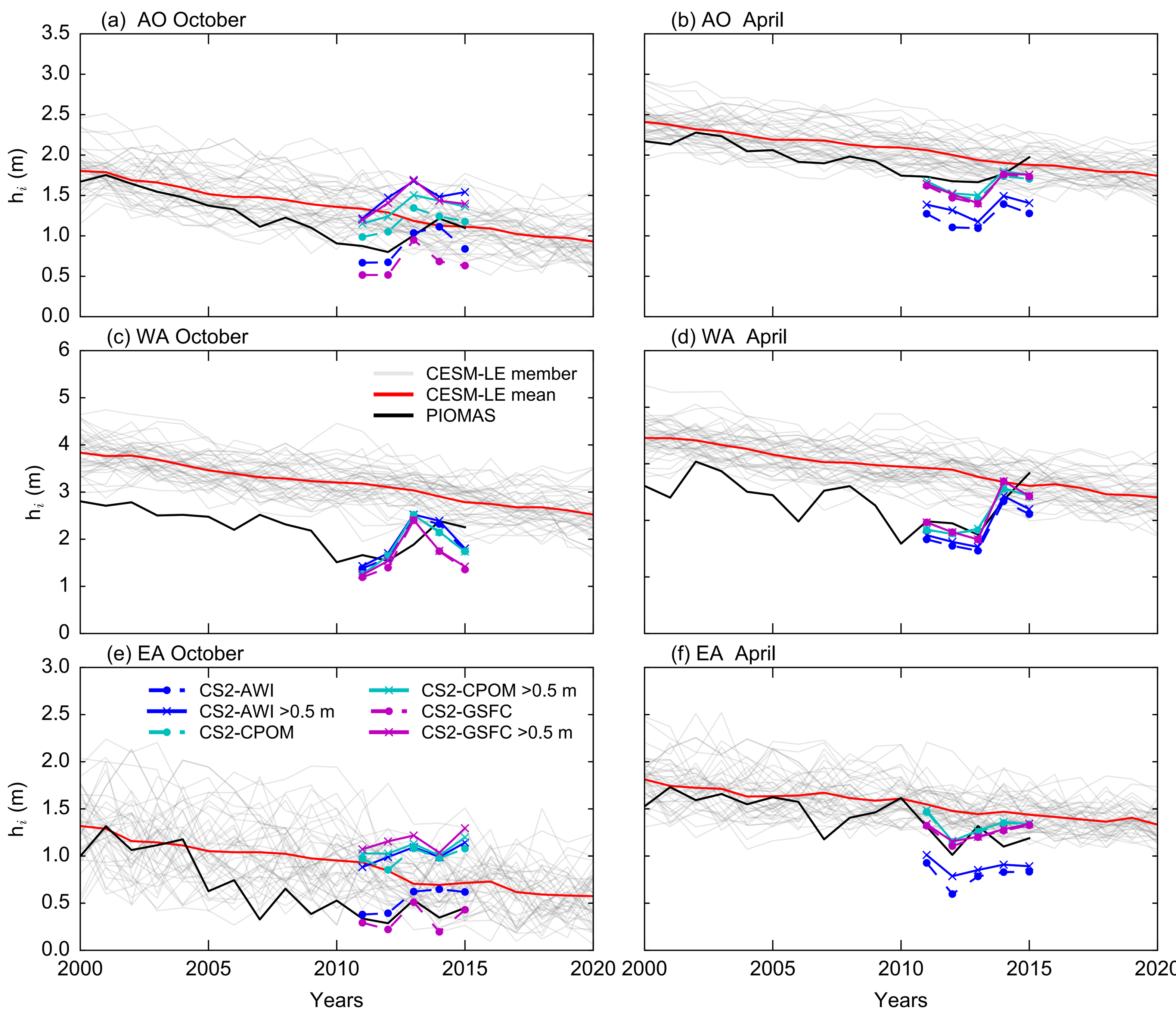
Variability in winter Arctic sea ice thickness growth

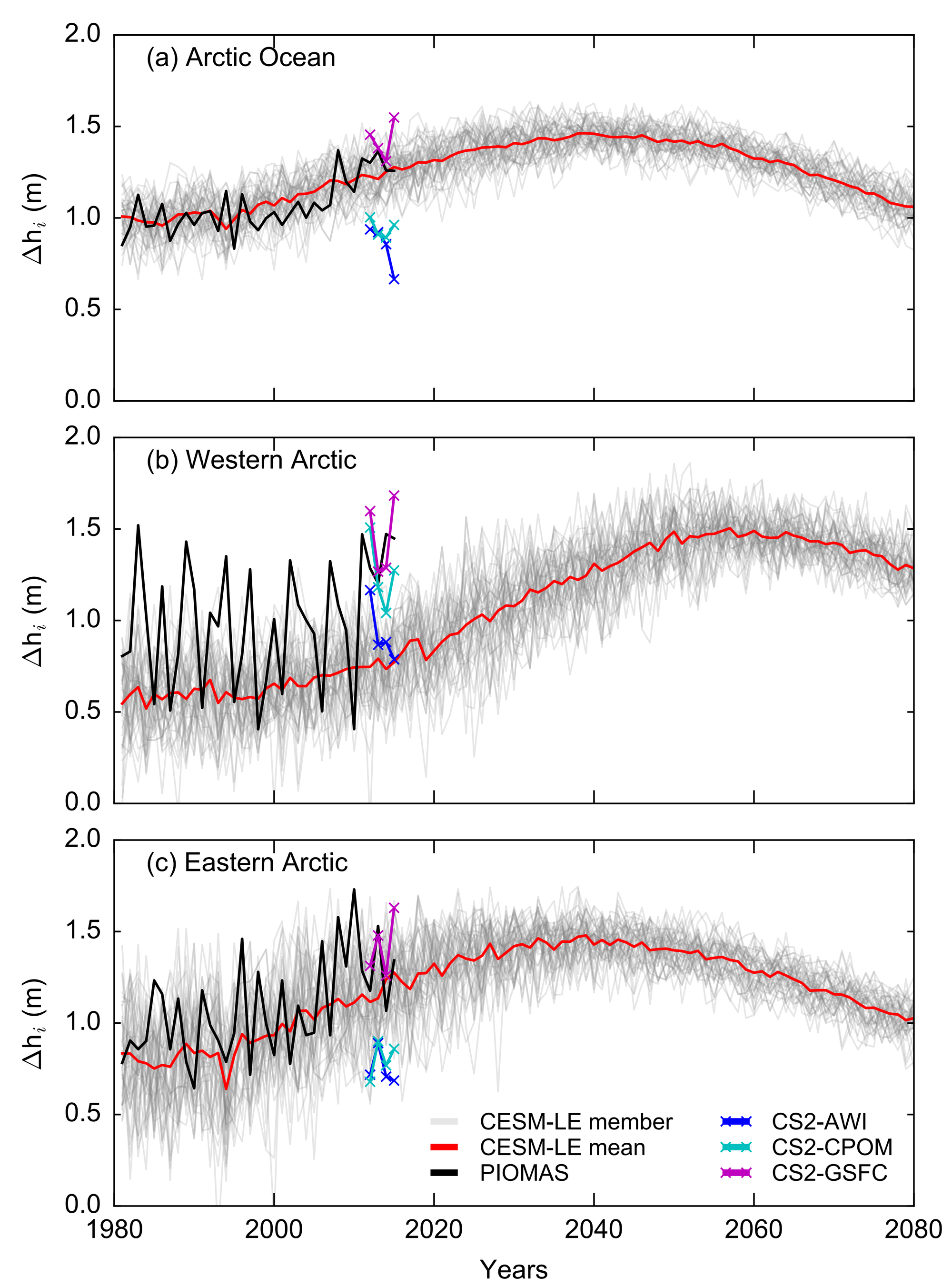
Here we explore the recentand future variability in Arctic sea ice growth using a combination of models and observations. While Arctic sea ice ice thickness is known to be in decline across all seasons and regions of the Arctic, less is known about the amount and variability of winter sea ice growth - due to challenges in seasonal observations and complex feedbacks associated with the freeze season. To explore these ideas in more detail we use data from the CESM Large Ensemble to explore winter Arctic sea ice growth, not just the total Arctic sea ice thickness. In contrast to the total winter thickness, winter Arctic sea ice growth shows an interesting temporal pattern in its evolution, with winter growth increasing over the coming decades, before decreasing towards the end of the century (Figure 2). A comparison of the CESM-LE sea ice winter growth with PIOMAS (an ice-ocean model) and CryoSat-2 (CS2) thickness estimates are shown in Figure 1 and 2, highligting the general consistency between the products, but the surprsingly large spread across the avaiable CS2 products, making more robust validations challenging. The models and observations show similar levels of interannual variability, providing some extra confidence in our use of the CESM-LE.



We believe the increase in winter sea ice growth in the initial decades is due to the negative feedback associated with sea ice loss (thinner sea ice promotes more ice growth than thicker ice due to its lower insulative properties), with atmospheric processes associated with lower sea ice (warmer air/ocean temperatures etc) eventually dominating over this negative feedback in later de-

Figure 1 (left): Winter Artic sea ice thickness in October and April across three study regions (Arctic Ocean, Western Arctic and Eastern Arctic) from the CESM-LE (ensemble members in grey, ensemble mean in red), the PIOMAS ice-ocean model (black lines) and CryoSat-2 data (provided by AWI, CPOM, & GSFC). We also show CryoSat-2 regional means where ice regions < 0.5 m have been masked as these estimates are highly uncertain.

Figure 2 (right): As in Figure 1 but showing the winter Artic sea ice thickness change (October to April). Further analysis not shown indicates this is primarily thermodynamically driven.

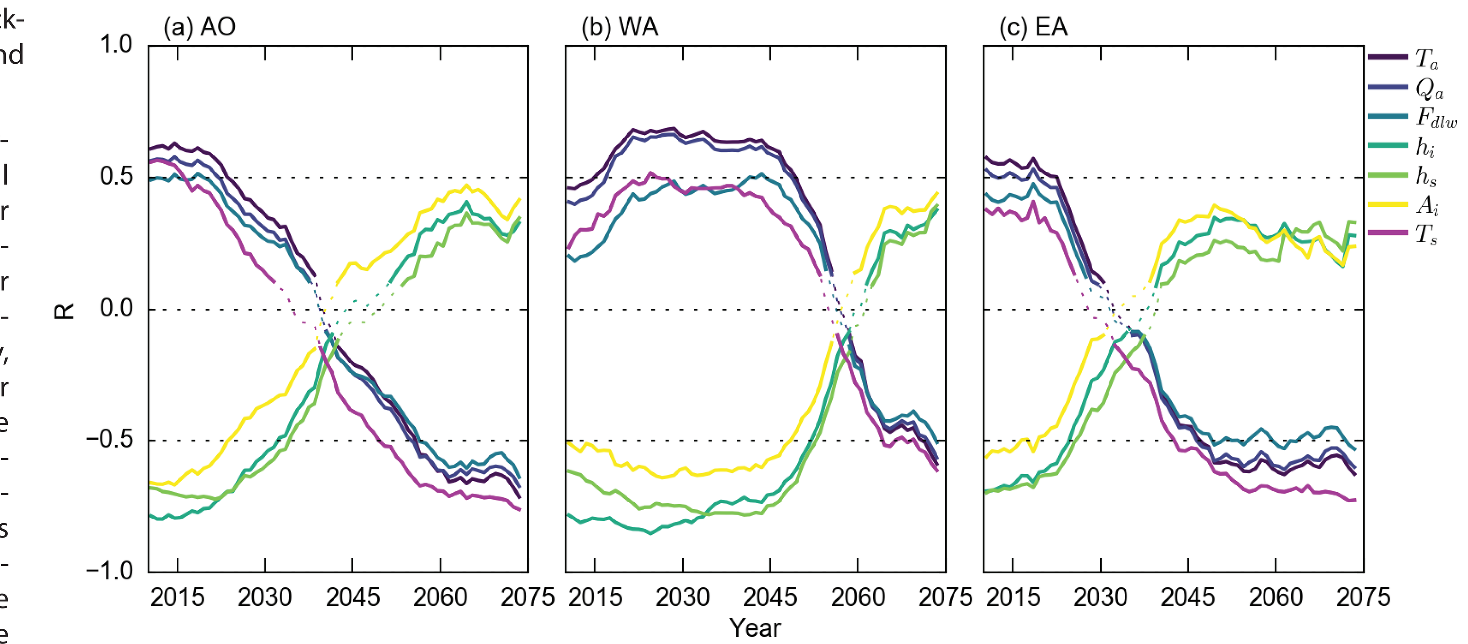


To explore this idea more we correlated (in ten year windows all enesmble members) the October ice conditions (thickness, concentration, snow depth) and October atmospheric conditions (Surface/air temperature, humidity, longwave) against the total winter Arctic sea ice growth (top right). We see that in the middle of this century, the CESM-LE simulations demonstarte a transition in the correlations between the October ice/atmospheric conditons and winter sea ice growth - i.e. at the start (end) of the simulations, less ice (more ice) in October results in more ice growth (less ice growth) through winter.

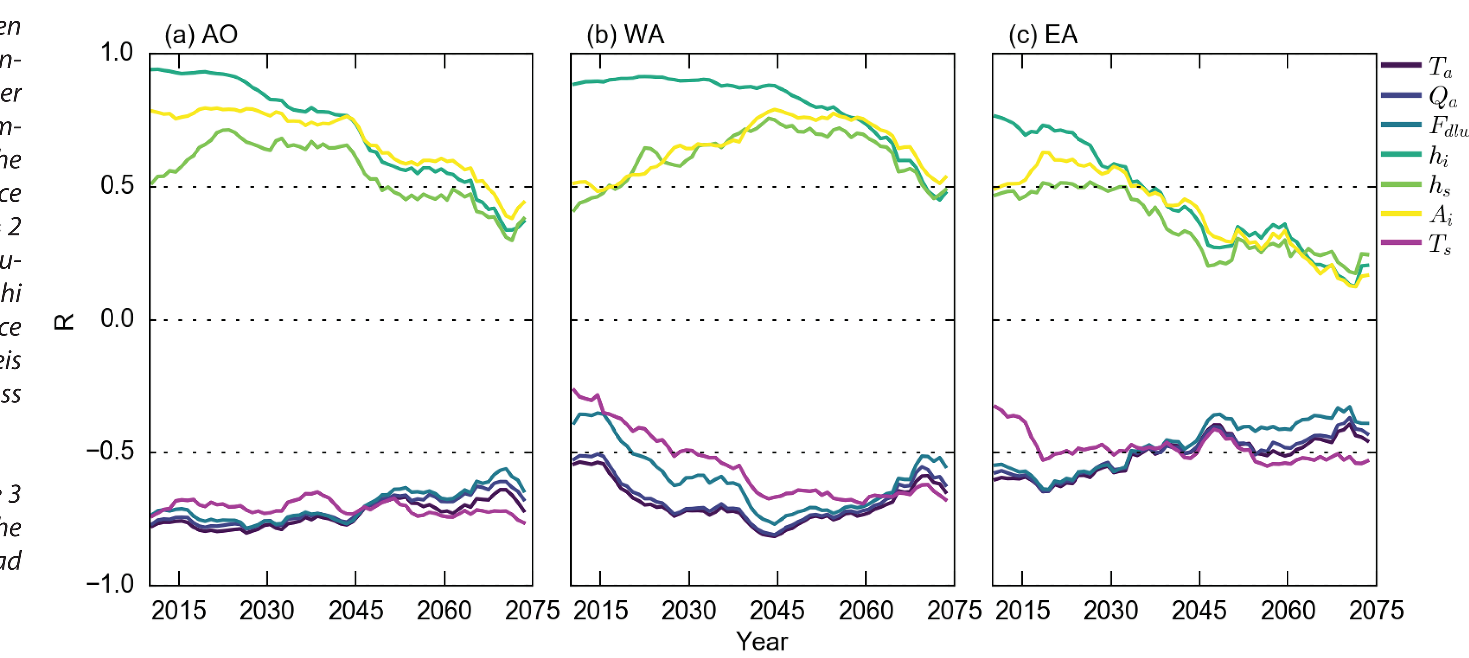
Figure 3 (top right): Correlations between October ice conditions (thickness, concentration, snow depth) or October atmospheric conditions (surface/air temperature, humidity, longwave) with the total winter (October-April) Arctic sea ice growth. Ts = surface temperature, Ta = 2 m air temperature, Qa= 2 m specific humidity, Fdlw=longwave downwelling, hi = ice thickness, hs=snow depth, aice = ice concentration. Each correlation valueis calculated using 10 years of data across all 40 ensemble members.

Figure 4 (bottom right): same as Figure 3 but showing the correlations against the end of winter (April) ice thickness instead of ice growth.

Correlations between October ice/atmos/ocean variables and winter ice growth in CESM-LE



Correlations between October ice/atmos/ocean variables and April ice thickness in CESM-LE



Improving snow & ice thickness estimates with NESOSIM (v1.0 out now!)

As snow is the key cource of uncertainity in satellite estimates of sea ice thickness, we recently developed a new two-layer eulerian snow budget model - the NASA Euelerian Snow on Sea Ice Model (NESOSIM) - with the primary aim of improving satellite altimetry derived estimates of sea ice thickness from NASA's ICESat and the upcoming ICESat-2, and ESA's CryoSat-2. NESOSIM is forced by reanalysis derived snowfall & winds, and satellite derived ice drift & concentration. A model schematic is shown in FIgure 5. The model has been calibrated with in-situ data of Arctic snow depth and density collected by drifiting Soviet stations (various data through the 1980s). The model shows good agreement with the regional Arctic snow depths derived from NASA's Operation IceBridge snow depth data, giving RMSE values of ~10 cm, implying the expected level of accuracy of our product. Unfortunately not much better than the commonly used Warren climatology. The seasonal evolution of the snow depth and density estimtaes are shown below (Figure 5). Improvements to NESOSIM are planned and expected to lower these RMSEs and increase their utility, especially into the melt season. Community engagement in these efforts is desired!

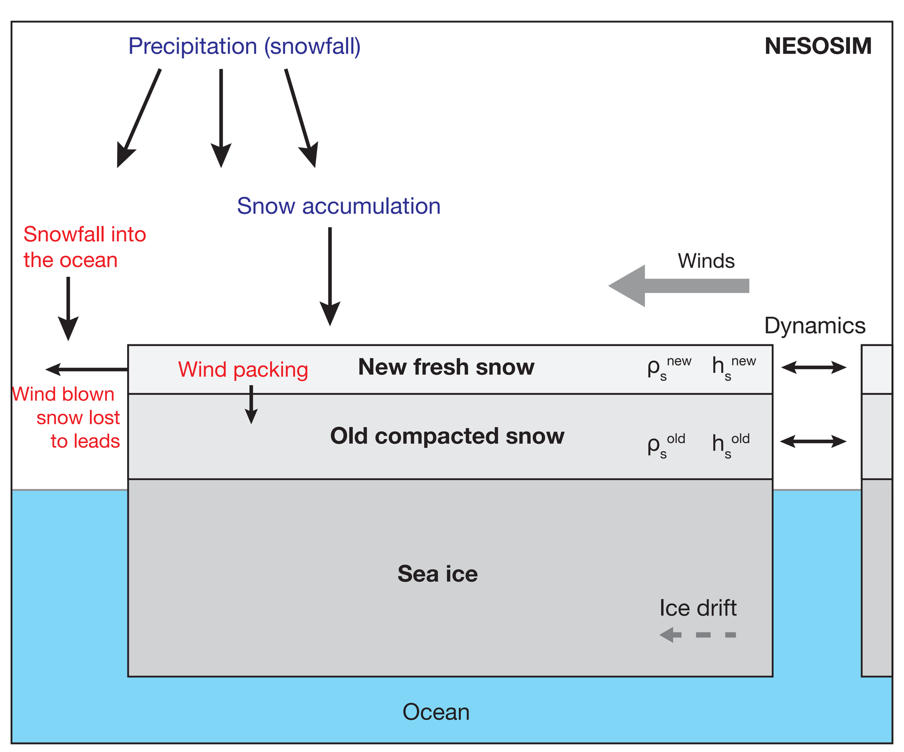


Figure 5: Schematic of the two-layer eulerian snow budget model. The red (blue) text indicates processes that result in a loss (gain) of snow depth.

On the right we demonstrate the impact of this new snow depth data on estimtes of Arctic sea ice thickness. The thickness data are based on updated NASA GSFC CS-2 and IS2 freeboard datasets, which feature improved input data and waveform retrackers for more reliable freeboard retrievals. We apply the daily NESOSIM snow depth data to these new freeboard data to produce a further enhancement to the original thickness datasets. A preliminary comparison of the new CS-2 v2.1 thickness data with ice draft data collected by upward looking sonars in the Beaufort Sea shows promising improvements.

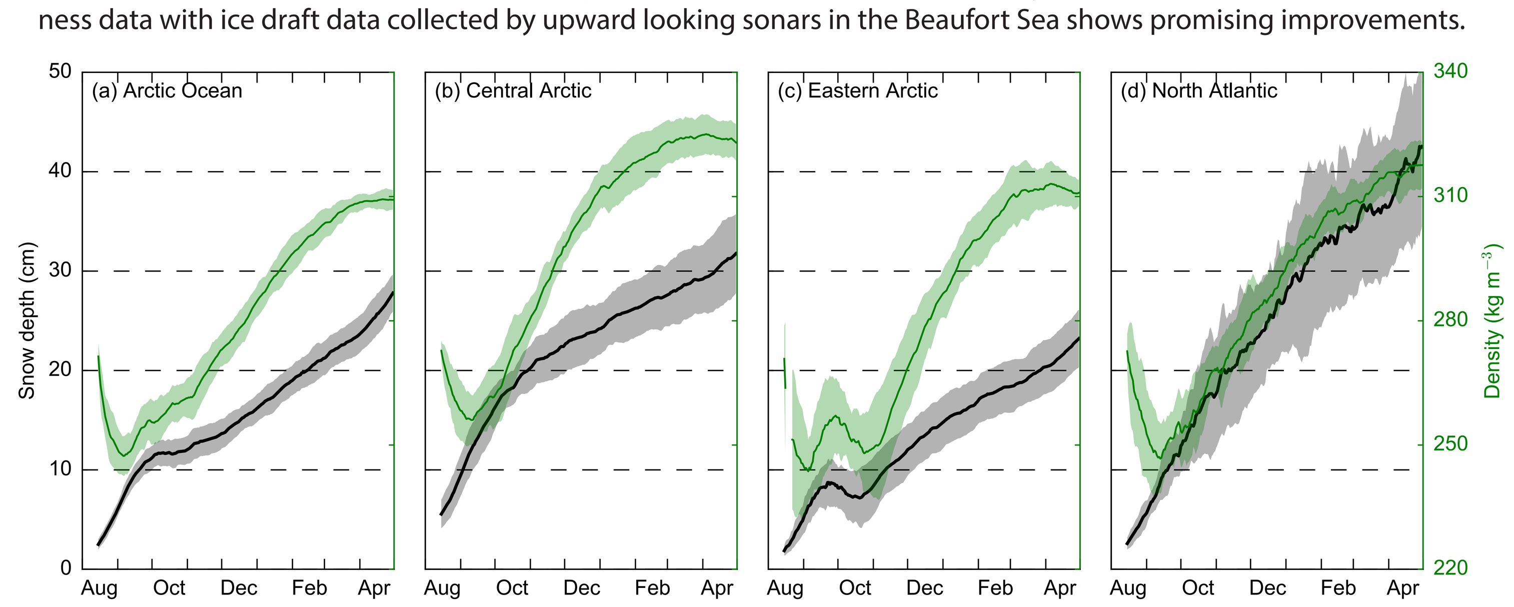


Figure 6: Seaonsal snow depth and density evolution across four study regions averaged over the period 2000 to 2015. The shading represents the interannual variability (one standard deviation).

Look, we can use NESOSIM snow depth/density to derive new ice thickness estimates!

ICESat-1 (Feb/Mar, 2003-2008)

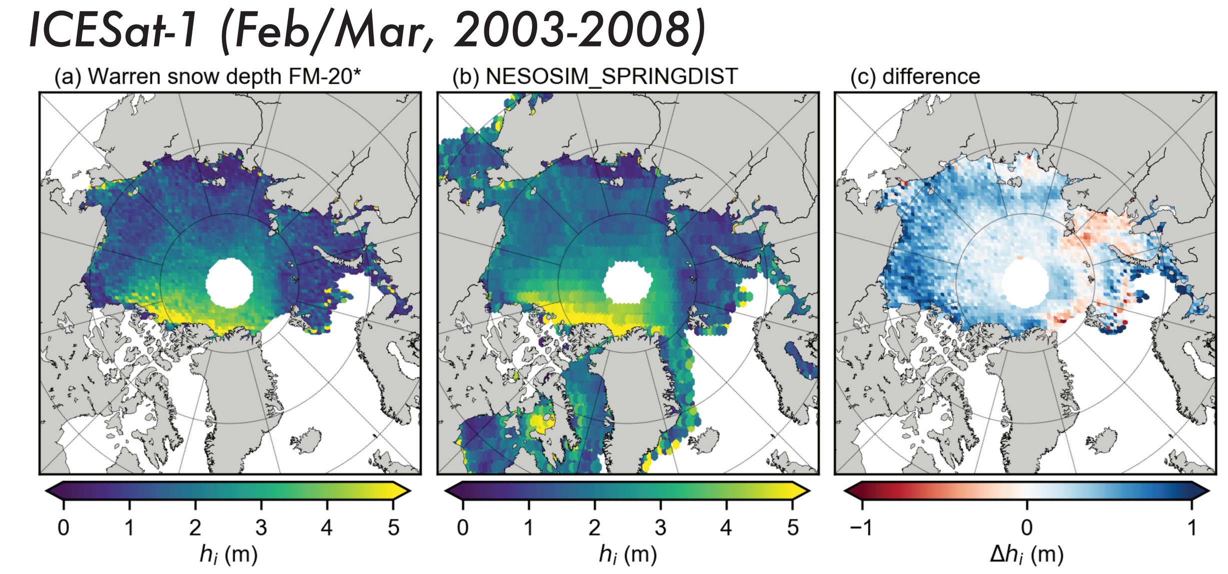


Figure 7: Comparison of the late winter (February-March) 2003-2008 Arctic ICESat-1 sea ice thickness based on (left) the Warren snow depth climatology and (middle) using the updated NESOSIM (daily) snow depth/density data. Warren snow depth data constrained to the Central Arctic domain.

CryoSat-2 (Oct-Apr, 2010-2016)

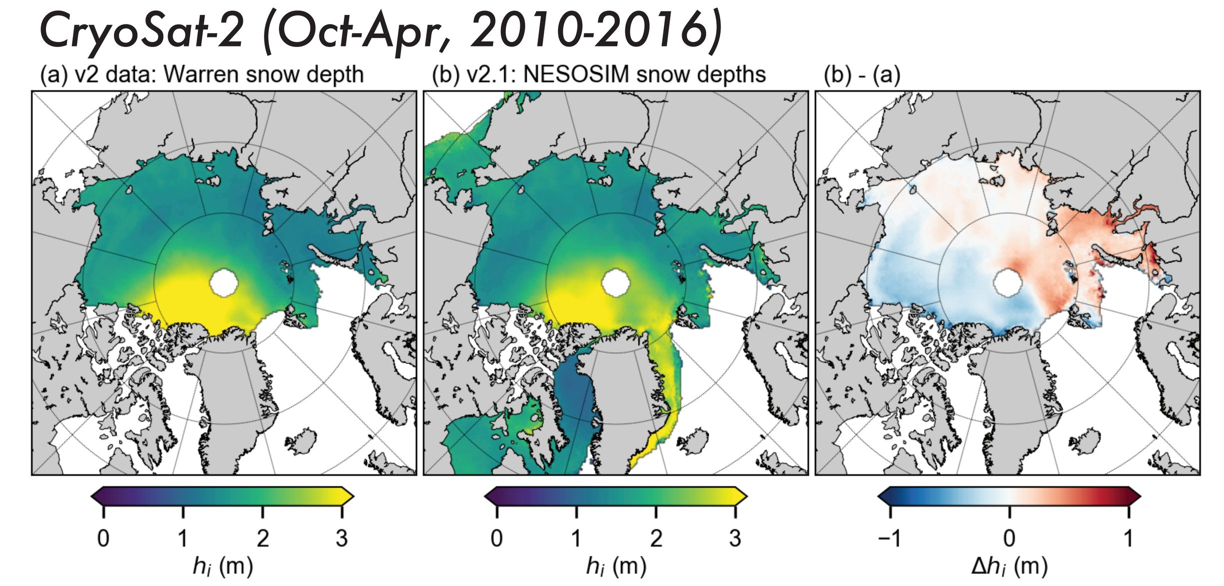


Figure 8: Comparison of the winter (October-April) 2010-2016 Arctic CryoSat-2 sea ice thickness including (left) new waveform tracker and the Warren snow depth climatology and (middle) using the updated NESOSIM daily snow depth/density data.

Summary & references

We are improving both direct observations of winter Arctic sea ice thickness, primarily thorough improved representation of snow on sea ice, and our understading of winter Arctic sea ice thickness variability using both models and observations. Our new snow on sea ice model NESOSIM (v1.0) produces reliable seasonal Arctic snow depth estimates and is now being used to improve sea ice thickness estimates from ICESat-1 and CryoSat-2 (updated near real-time thickness data forthcoming). Plans are in place to derive sea ice thickness from the upcoming ICESat-2 mission, with a product release expected sometime midway through 2019.

Petty, A. A., M. M. Holland, D. A. Bailey, N. T. Kurtz, (2018), Warm Arctic, increased winter sea-ice growth?, Geophysical Research Letters, 45, doi:10.1029/2018GL079223.

Petty, A. A., M. Webster, L. N. Boisvert, T. Markus (2018), The NASA Eulerian Snow on Sea Ice Model (NESOSIM) v1.0: Initial model development and analysis, Geosci. Model Dev., doi: 10.5194/gmd-11-4577-2018. Code available at: www.github.com/akpetty/NESOSIM