Winter Arctic sea ice growth: Current variability and projections for the coming decades

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Modelling the snow depth on Arctic sea ice

Here we describe and showcase our recent efforts to improve our understanding of the snow depth on Arctic sea ice - with the primary aim of improving satellite altimetry derived estimates of sea ice thickness (e.g. from NASA's ICESat and the upcoming ICESat-2, and ESA's CryoSat-2).

We recently developed a new two-layer eulerian snow budget model - the NASA Eueleriаn Snow on Sea Ice Model (NESOSIM) . NESOSIM is forced by reanalysis derived snowfall/winds, and satellite derived ice drift/concentration. A model schematic is shown below.

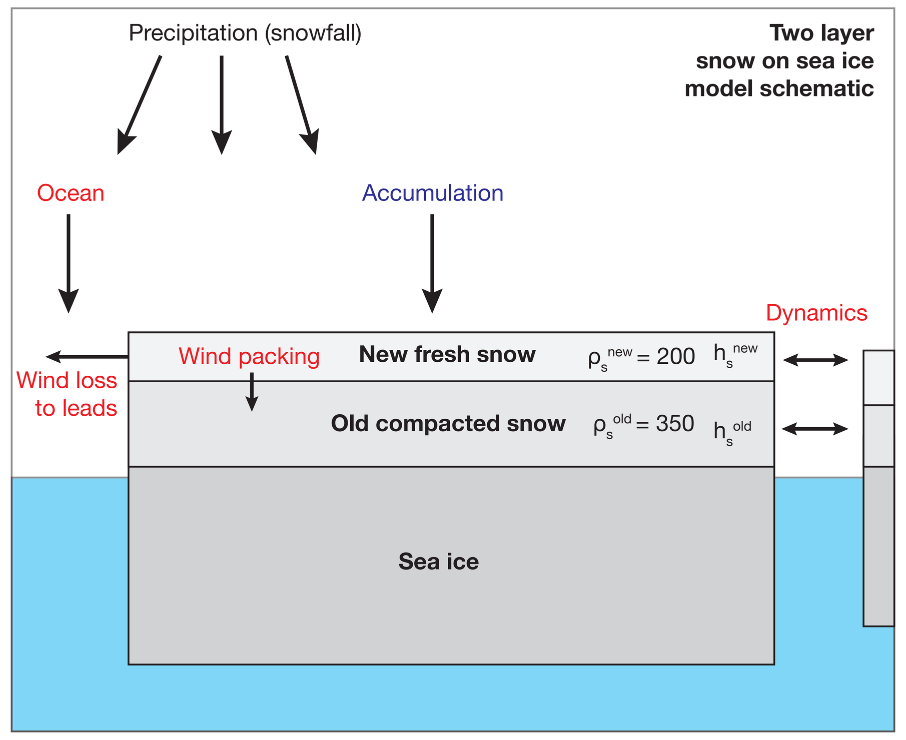


Figure 1: Schematic of the two-layer eulerian snow budget model. Dynamics indicates the combination of advection and convergence/divergence as discussed in the text. The red (blue) text indicates processes that result in a loss (gain) of snow depth (wind packing reduces snow depth through an increase

The model includes simple physical parameterizations representing snow accumulation, snow advection/divergence due to ice motion, snow compaction under wind forcing and snow loss to leads from blowing snow.

The use of two snow layers enables the snow to accumulate into a fresh snow layer (fixed density of 200 kg/m^3), with a small percentage of this fresh snow (default of 5%) 'compacted' into an old snow layer (fixed density of 350 kg/m^3) when the winds are above some threshold (default of 5 m/s). The seasonal evolution of the snow budget model, and the resultant snow depth in spring (May 1st) are shown on the right.

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.

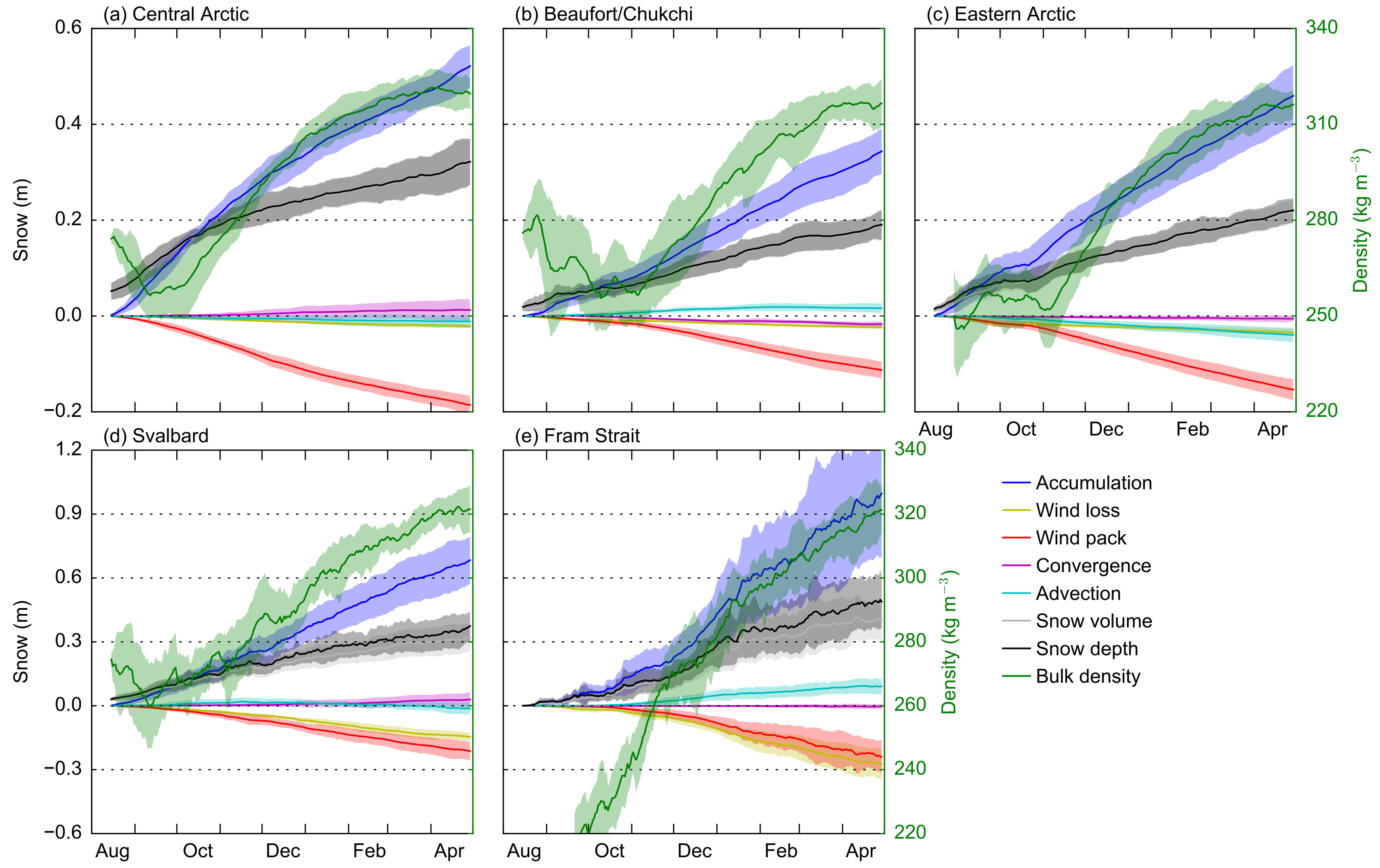


Figure 2: Seasonal snow budget evolution across the five study regions (shown by the black boxes in Figure 3), from August 15th 2004-2014 to May 1st 2005-2015. The thick lines show the interannual mean values over this time period, while the shaded areas represent the interannual variability (one standard deviation). All model runs are forced with ERA-I snowfall and winds, NSIDCv3 ice drift and Bootstrap sea ice concentration.

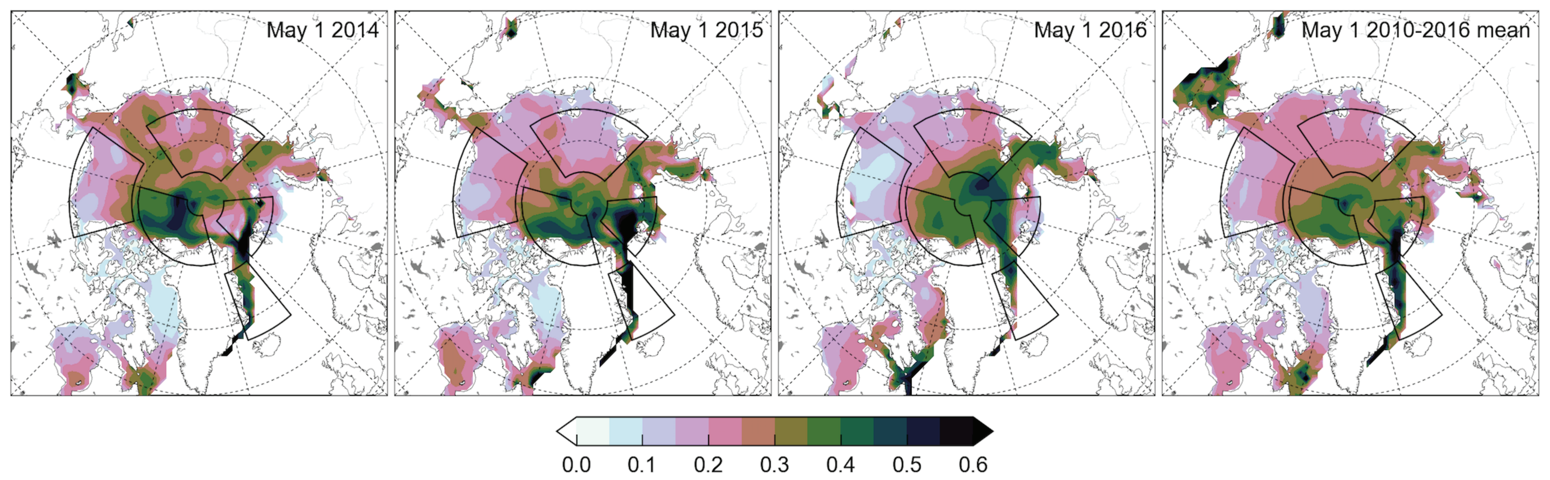


Figure 3: Modelled snow depths for May 1st for various years (all initialized on August 15th of the previous year). The model uses the default parameter settings and is forced with ERA-I snowfall and winds, NSIDCv3 ice drift and Bootstrap sea ice concentration.

Improved Arctic sea ice thickness estimates

Here we demonstrate the impact of this new snow depth data on estimtes of Arctic sea ice thickness. The thickness data are based on the updated (version 2) NASA GSFC sea cie thickness dataset, which features an improved waveform retracker 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, version 1, thickness data (we refer to this as version 2.1). A preliminary comparison of the new v2.1 thickness data with ice draft data collected by upward looking sonars in the Beaufort Sea (Figure 5) and EM-bird data (not shown) indicate an improvement in the thickness data, mainly in-terms of lower root mean squared errors (the correlations were similar).

Our plan is to use the new snow model in a near real-time framework to produce updated, near real-time CryoSat-2 thickness data to the sea ice community.

A similar effort is expected for the freeboard data collected by ICESat-2 after its launch in September 2018.

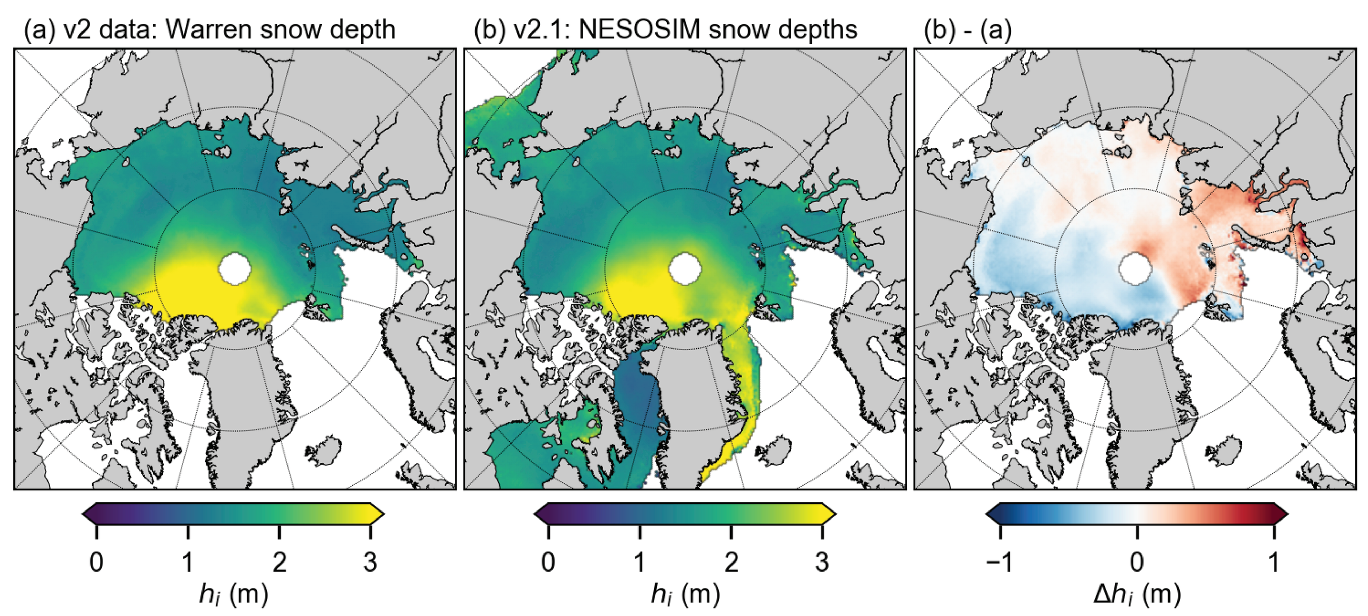


Figure 4: Comparison of the winter (October-April) 2010-2016 Arctic sea ice thickness from (left) the preliminary version 2 NASA GSFC thickness data including new waveform tracker but using the Warren snow depth climatology and (middle) our preliminary version 2.1 NASA GSFC thickness data as in version 2, but using the updated NESOSIM (daily) snow depth data. Data are winter averages calculated from the daily thickness data.

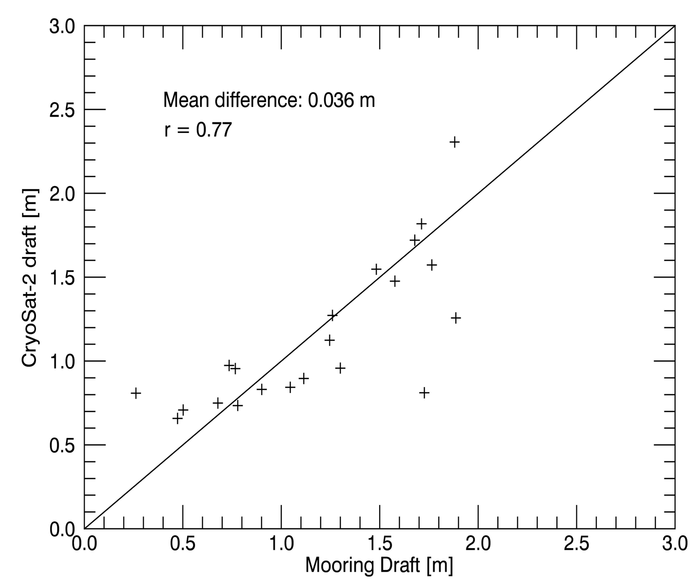


Figure 5: Correlations between the version 2.1 NASA GSFC CryoSat-2 derived ice draft estimates, and the ice drafts measured by moorings in the Beaufort Sea.

Variability in winter Arctic sea ice thickness growth (October to April)

Here we explore the current and potential 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 re-growth - due to challenges in seasonal observations and complex feedbacks associated with the freeze season.

To explore these ideas we primarily use data from the CESM Large Ensemble Project (mean winter Arctic sea ice thickness and thermodynamic ice growth are shown in Figure 6) 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 the re-growth increasing over time, then decreasing towards the end of the century across our four study regions. A comparison of the CESM-LEP sea ice winter growth with PIOMAS (an ice-ocean model) and CryoSat-2 thickness estimates are shown in Figure 7. We believe the increase in winter sea ice growth in the initial decades is due to a 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 temperatures etc) eventually driving a reversal of this pattern in later decades. In other words, the atmospheric forcing driving low sea ice in October is sufficient to drive less sea ice growth through the winter season, despite the thinner sea ice and negative feedback associated with these ice conditions.

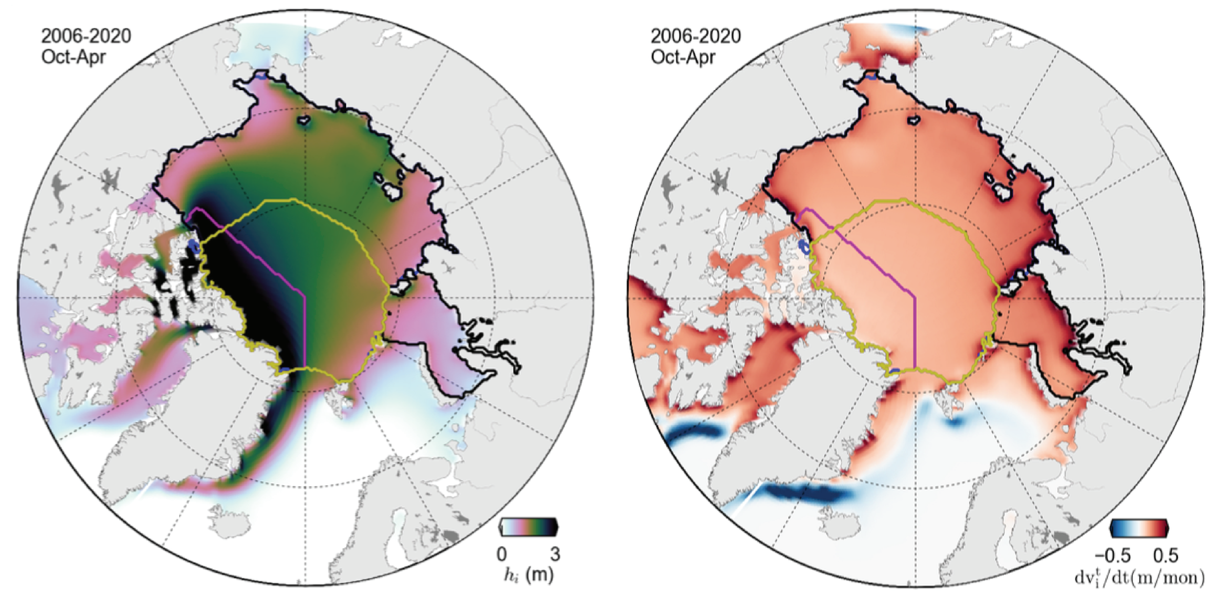
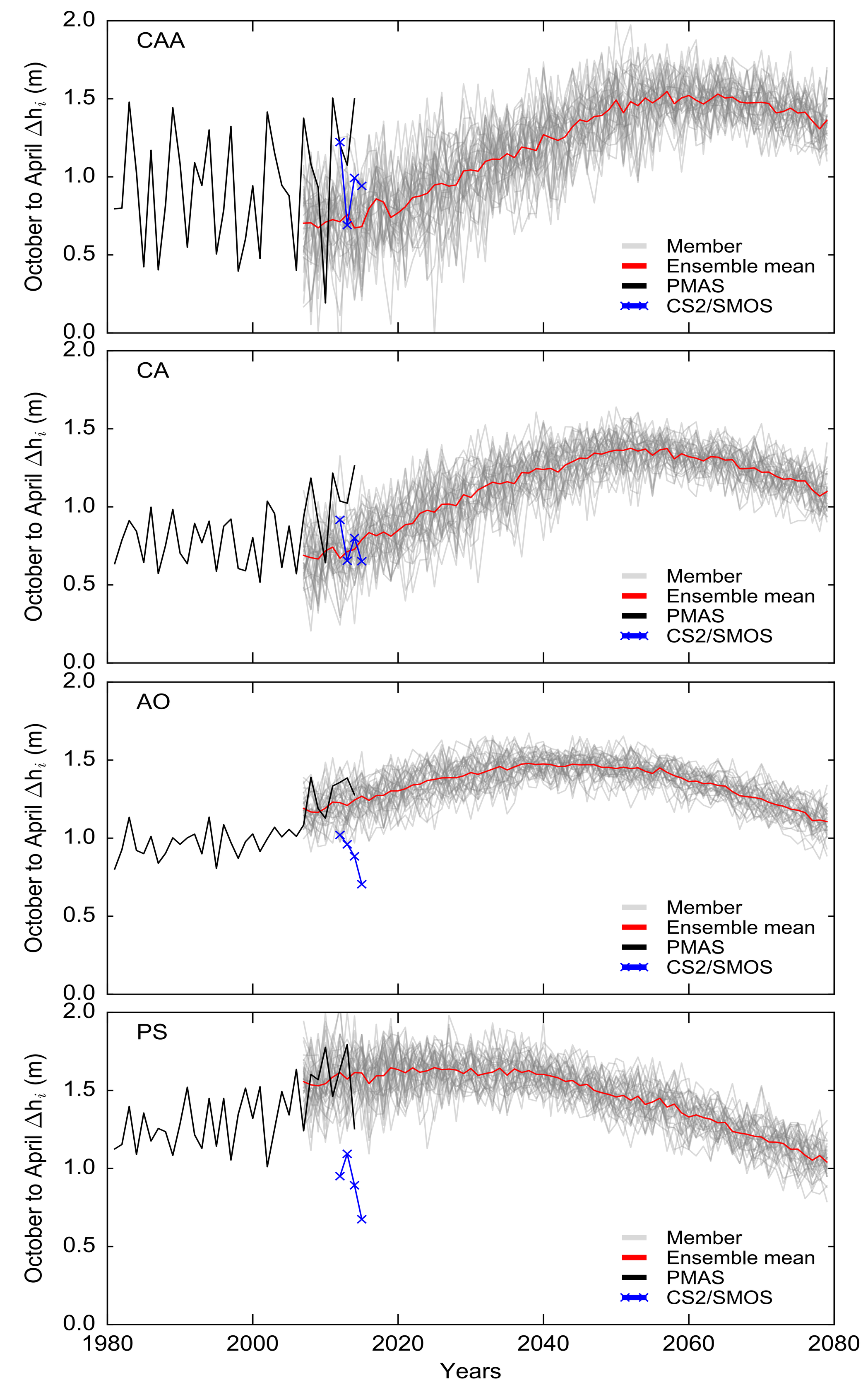


Figure 6: (left) Mean winter (2006-2020, October-April) Arctic sea ice thickness from all 33 members of the CESM Large Ensemble project, (right) winter Arctic sea ice thickness volume tendency from

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 (Figure 8). We see that in the middle of this century, the CESM-LEP 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.



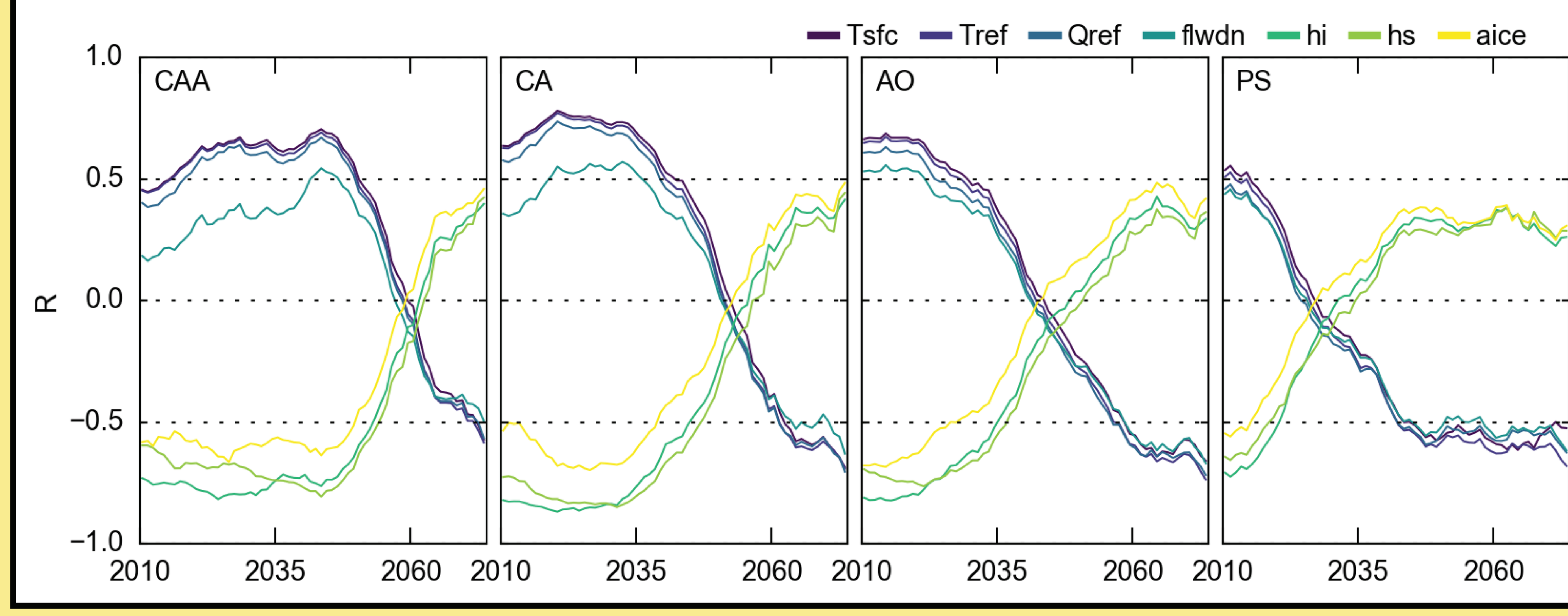


Figure 7 (shown above): Winter Artic sea ice thickness growth variablity from the CESM-LEP (grey and red), the PIOMAS ice-ocean model (black lines, 1980-2015) and CryoSat-2 data (provided by AWI).

Figure 8 (shown on the left): 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. Tsfc = surface temperature, Tref = 2 m air temperature, Qref = 2 m specific humidity, flwdn=longwave downwelling, hi = ice thickness, hs=snow depth, aice = ice concentration. Each correlation varlue is calculated using 10 years of data across all 33 ensemble members .

Summary

We are improving both direct observations of winter Arctic sea ice thickness, primarily thorough improved representation of snow on sea ice, and our understanding of winter Arctic sea ice thickness variability using both models and observations. Our new NESOSIM snow on sea ice model produces reliable seasonal Arctic snow depth estimates, with the snow depth and density showing good agreement with in-situ data collected by soviet station drifting data. The data are now being used to improve sea ice thickness estimates from CryoSat-2 (updated near real-time thickness data forthcoming) and will be used to derive sea ice thickness from the upcoming ICESat-2 mission. An analysis of Arctic sea ice thickness growth variability in the CESM-LEP demonstrates the potential for a transition in the importance of initial (October) Arctic sea ice thickness in controlling the total winter Arctic sea ice growth, due to the changing importance of feedbacks associated with sea ice thickness/growth.