Assimilating Cyrosat2 freeboard into a coupled ice-ocean model

- work in progress -

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Background

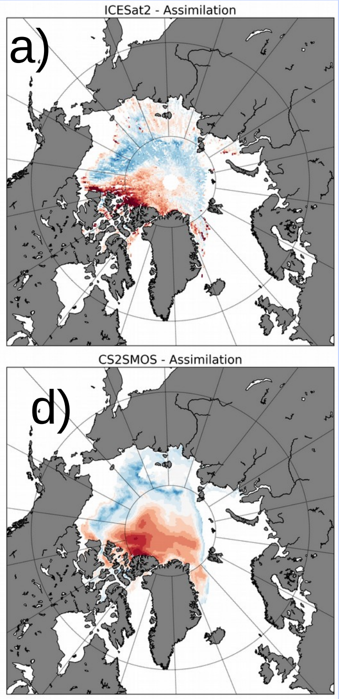
Many studies have shown that the skill and memory of sea ice models using sea ice thickness as initial condition improve, compared to model runs only initializing sea ice concentration. The only Arctic wide sea ice thickness (SIT) data which could be used for initialization is coming from satellite observations. Since sea ice can’t directly be measured from space freeboard data is used to derive sea ice thickness. Freeboard is converted under assumption of hydrostatic equilibrium to sea ice thickness. For this conversion snow thickness is needed. Due to a lack of Arctic wide snow cover observations most products use a snow climatology or a modification of one. This has proofed to introduce errors. To avoid the errors introduced by this method the presented work aims to assimilate freeboard directly.
This presentation will introduce the method and show first results. The assimilation period overlaps with ICESat2 mission, to which we compare our results of a first winter season of assimilation.

Methods

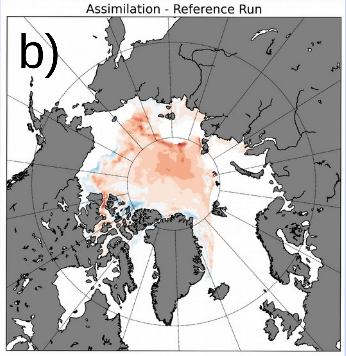
- Arctic regional ocean-ice model
- CICE6-NEMO4 set up on a 10x10 km grid
- Ensemble Karmanfilter (PDAF)
- Assimilating sea ice concentration and freeboard
- Radar freeboard is assimilated
- From freeboard to ice volume:
    - ➔ Assuming snow model is correct
    - ➔ Assuming hydrostatic balance
    - ➔ Calculating SIT from radar freeboard

First results Sea ice thickness

Satellite vs. Assimilation SIT

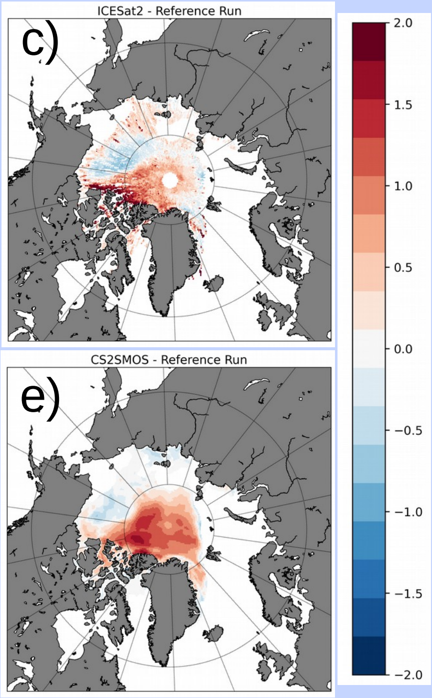


Assimilation vs. Reference SIT



Figures: Assimilation model out put and Reference run out put compared to IceSat2 data from Petty et. al 2022 (a) and c)) And CS2SMOS data product (Ricker et. al. 2016) (d) and e)) for Nov 2020 after one season and 2 month of assimilation. Figure b) comparing assimilation to reference run SIT.

Satellite vs. Reference SIT



What’s next?

→ A discussion of ideas how to improve the results

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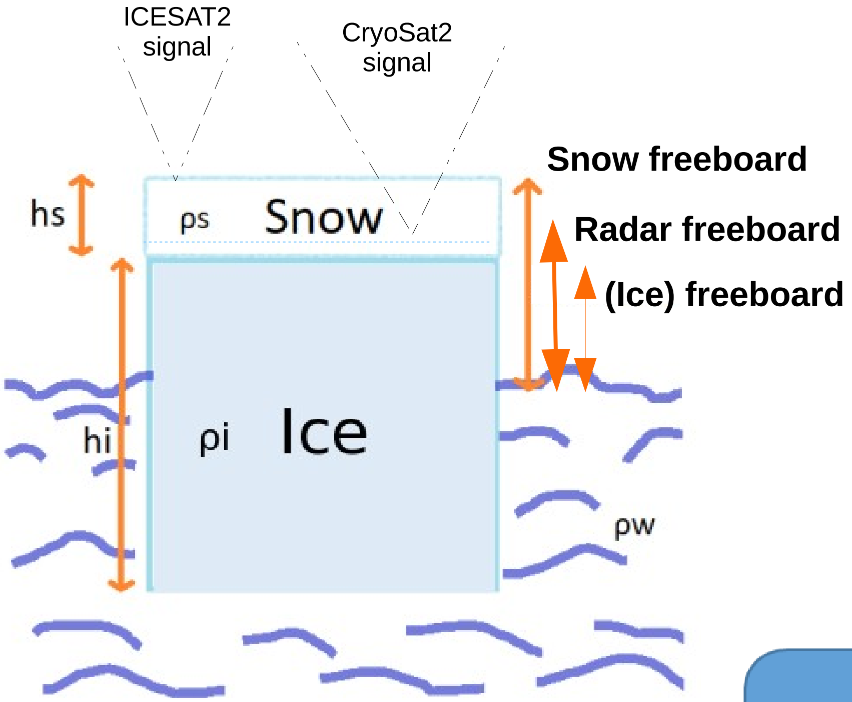
Background



Having an exact estimate of the sea ice thickness in the Arcitc is crucial to monitor climate change, but also handy to plan Arcitc shipping routes. Unfortunately is is very hard to measure and current estimates are biased. Since sea ice can't directly be measured from space altemitry freeboard data is used to derive sea ice thickness. Freeboard is converted under assumption of hydrostatic equilibrium to sea ice thickness. For this conversion snow thickness is needed. Due to a lack of Arctic wide snow cover observations most products use a snow climatology or a modification of one. This has proofed to introduce errors. To avoid the errors introduced by this method the presented work aims to assimilate freeboard directly. We calculate radar freeboard from model data and use an ensemble Kalmanfilter to get the best estimate from modeled freeboard and observed freeboard. The results are compared to ICESAT2 data. ICESAT2 uses laser altemetry to obtain snow freeboard.

Sea ice thickness from freeboard under assumption of hydro-static balance:

$$hi = \frac{\rho w}{\rho w - \rho i}(fb) + \frac{\rho s}{\rho w - \rho i} hs$$

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Method

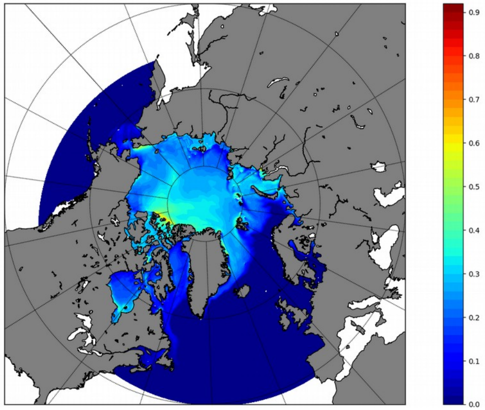
- the components used -

Observations

- OSISAF:
  - Daily sea ice concentration (SIC)
  - Interpolated onto Arctic model grid (10km gird)
- CryoSat2:
  - L2 radar Freeboard
  - L2 along track to model grid interpolation: Mean mode of all measurements within one grid cell
  - Only positive freeboard considered

Model

- NEMO4-CICE6
- 10km resolution
- Atmospheric forcing: ERA-5
- Lateral boundaries: Glorys12



Assimilation algorithm

- PDAF
- Static ensemble
- Localized ensemble Kalman filter
  - Offline
  - Time step 1 day
  - Localization radius 60km
  - multi variate: freeboard, sea ice concentration

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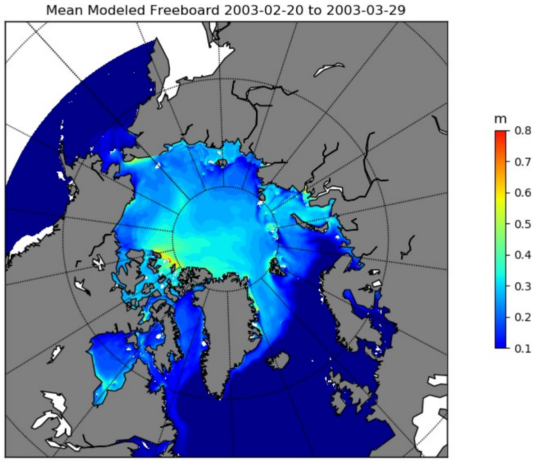
Method

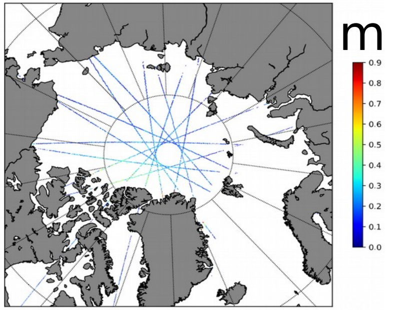
- the assimilation set up -

Forcing
(Atmosphere and boundary)

Ensemble (20 years free run)

Model





Observations

Daily cycle

PDAF

Conversion of freeboard increment back into sea ice thickness under the assumption that modeled snow thickness, density and ice density, is correct.

$$hi = \frac{\rho w}{\rho w - \rho i}(fb) + \frac{\rho s}{\rho w - \rho i} hs$$

$\rightarrow$ hi

INFO BOX
This slide shows the general freeboard assimilation work flow of the assimilation as it was run for the presented results for the period 01.10.2019 – 31.12.2020.

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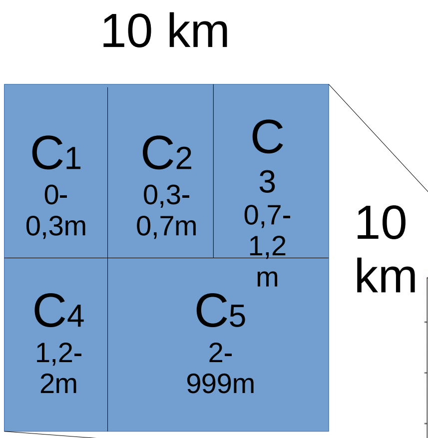
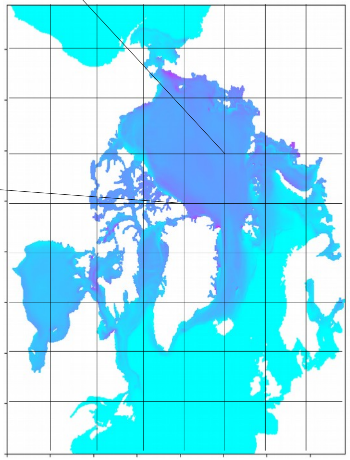
Method

- translate the increment into model state variable -





Schematic graph showing one grid cell of sea ice made up out of 5 thickness categories.

- The problem: The increment (difference between model state and PDAF state) is calculated per grid cell and needs to be added to one of (in our case) 5 categories (C_1-C_5). Only adding the ice to one categories can introduce biases.
- The solution: We calculate a ratio of change and multiply all categories with this ratio of change. Like this all categories are changed equally This method is applies both to sea ice concentration and sea ice thickness

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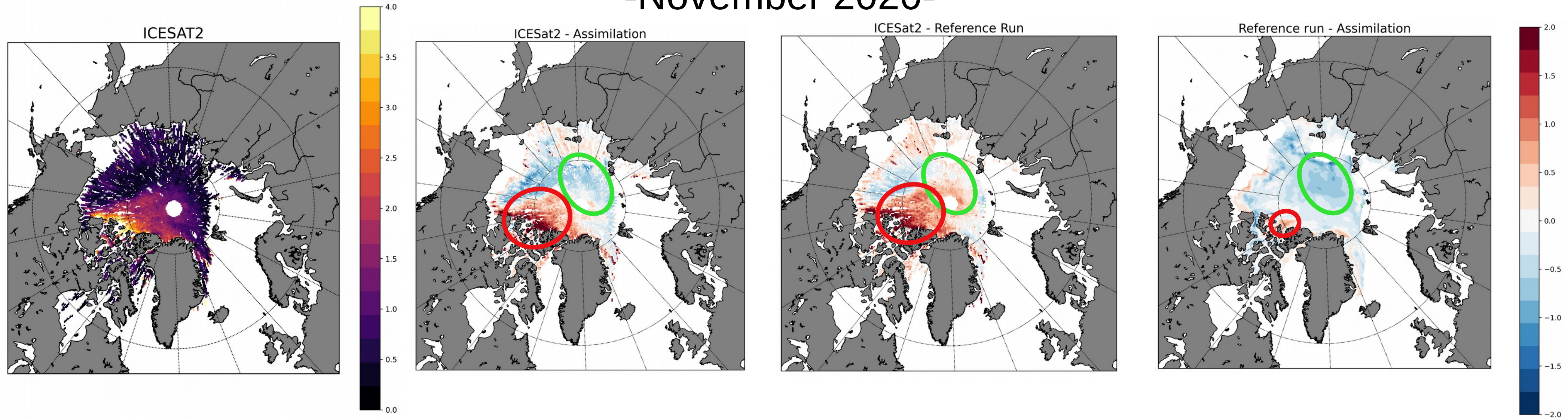
Results

-November 2020-



- After 1 year and 2 month the assimilated run shows significant differences to the reference run. Comparing the runs to satellite sea ice thickness products (middle left and right) shows that both runs differ, but no one is significantly closer to observations.
- In general the reference run performed better than the assimilation north of the Canadian Archipelago. The areas where the largest differences between reference run and assimilation occur are the same in which October sea ice concentrations assimilation lead to a reduced sea ice concentration.
- Following the evolution of sea ice thickness and snow thickness at the ice edge where new ice is formed during the freeze-up (no figures included) shows that the changes made by the assimilation lead to the overestimation of ice thanks to an underestimation of snow.
- IceSat2 has thicker ice north of Greenland and Canadian Archipelago. This is also the case if the data is compared to the CS2SMOS data set (first slide).
- The Assimilation has thicker ice in the Beaufort sea and Russian Shelf region compared to observations

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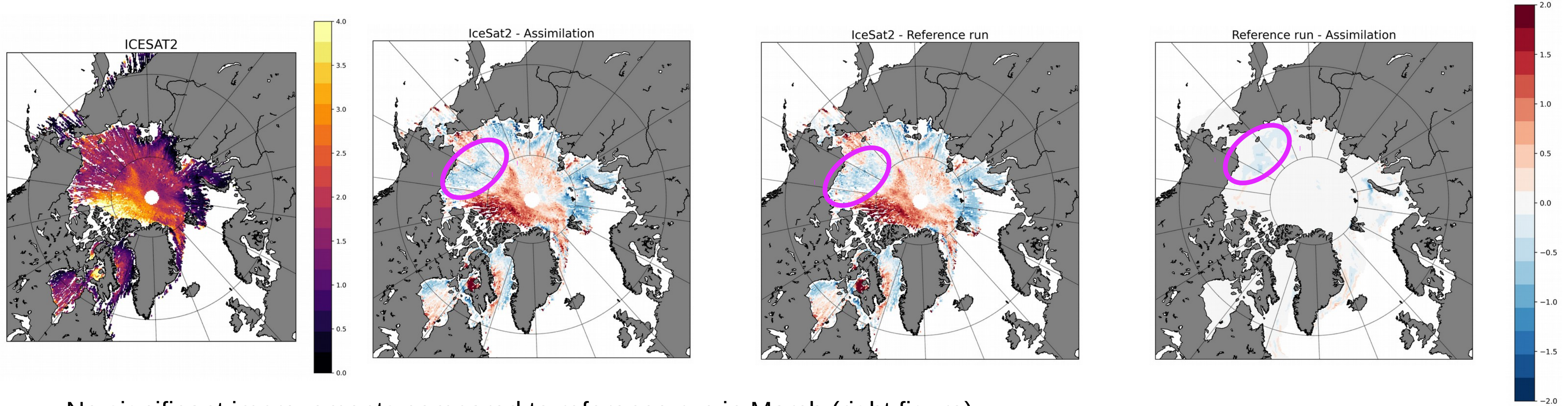
Results

- March 2020 -



- No significant improvements compared to reference run in March (right figure).
- The assimilation and reference run have thicker ice in the Beaufort sea and Russian Shelf region compared to observations. The right plot shows that the differences between the assimilation and the reference run are located in the same area.
- Following the evolution of sea ice thickness and snow thickness at the ice edge where new ice is formed during the freeze-up (no figures included) shows that the changes made by the assimilation lead to the overestimation of ice thanks to an underestimation of snow. In early winter this effects the area marked green in the right figure.
  The resulting differences between reference run and assimilation might originate from this feature.

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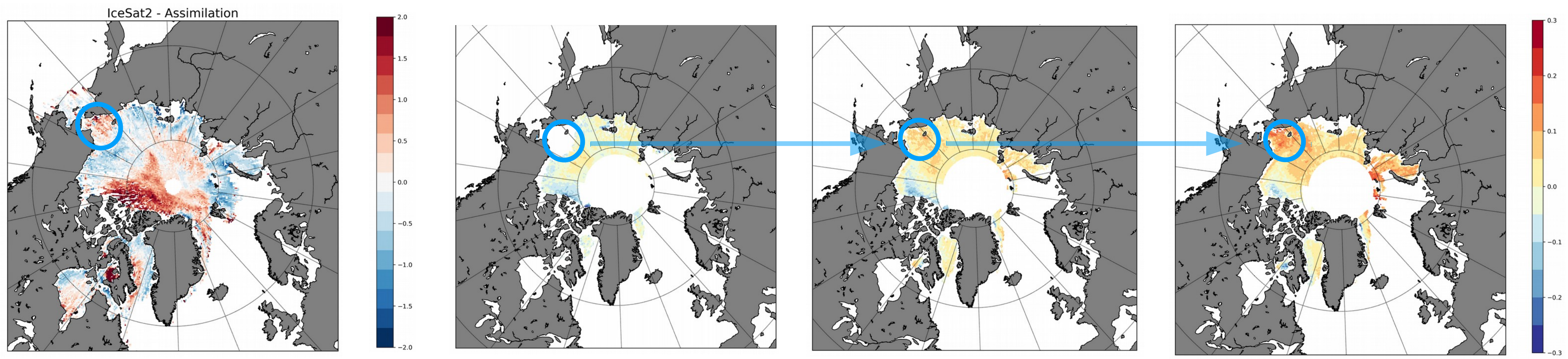
Results

- KaKu snow vs. modeled snow (Climatologies) -

March-ice | November -snow | January-snow | March-snow



- In the Chukchi Sea the snow thickness difference increases (3 right figures) through out the winter. The model has too much snow here. The over estimation in snow leads to a underestimation in sea ice thickness as seen on the left.
- Analyzes of day to day changes in sea ice and snow thickness have shown that the model in general underestimates the snow on newly formed ice leading to an overestimation of sea ice close to the ice edge.

Snow observation data: KaKu snow data combines Ka-band and Ku-band radar signals to monthly snow data sets. Here we used 2014-2019 monthly mean differences for both model data and observations. Calculated as model snow – observed snow.
Data is available through LEGOS (Garnier et. Al 2021).

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What’s next?

Since the snow seems to be one main cause for the resulting biases especially during the formation of new sea ice efforts are currently made to improve it in our assimilation. In this slide the options which are either tested or under implementation at the moment are discussed.

1) Similar approach as presented but assuming correct model snow / ice ratio in instead of assuming correct snow thickness: using the ratio of change from the freeboard to correct both sea ice thickness and snow thickness. (experiment currently running)

2) A 4 variable ensemble Kalmanfilter taking snow, ice thickness, concentration, and freeboard into account. Freeboard contains information of both snow and ice thickness. By adding snow and ice thickness to the PDAF state vector, but no observations the variables covariances of the state variables impacts the outcome of sea ice and snow thickness. (Set up under implementation)

3) A bias correction method: The sea ice is too thick in the Beaufort sea and Russian shelf area. This is also the area with the largest differences between reference run and assimilation occur in March. Following the evolution of sea ice thickness and snow thickness at the ice edge where new ice is formed during the freeze-up (no figures included) shows that the changes made by the assimilation lead to the overestimation of ice thanks to an underestimation of snow. By adding a realistic snow cover change throughout November and December from for example the KuKa product this effect might be counteracted. (future plans)

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Summery

- Compared to other sea ice thickness products using Cryosat, SMOS and IceSat data our method produces too thick sea ice in the Russian shelf area and the Beaufort gyre and too thin ice north of Greenland and the Canadian archipelago.
- The set up as it is by now needs a better snow model or better atmospheric forcing.
- To improve the snow layer we currently work on:
  - a method assuming correct snow – ice ratio instead of assuming correct snow thickness
  - A 4 variable ensemble Kalmanfilter taking snow, ice thickness, concentration, and freeboard into account
  - A bias correction method

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Sources

- ICESAT2 data: Petty, A. A., N. Kurtz, R. Kwok, T. Markus, T. A. Neumann, and N. Keeney. 2022. ICESat-2 L4 Monthly Gridded Sea Ice Thickness, Version 2. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. Doi: https://doi.org/10.5067/OE8BDP5KU30Q.
- KaKu snow data: Garnier, Florent, et al. "Advances in altimetric snow depth estimates using bi-frequency SARAL and CryoSat-2 Ka–Ku measurements." The Cryosphere 15.12 (2021): 5483-5512.
- CS2SMOS data: Ricker, R. , Hendricks, S. , Kaleschke, L. and Tian-Kunze, X. (2016): CS2SMOS: Weekly Arctic Sea-Ice Thickness Data Record