Improving FOAM with the assimilation of satellite-derived sea-ice thickness from CryoSat-2 and SMOS

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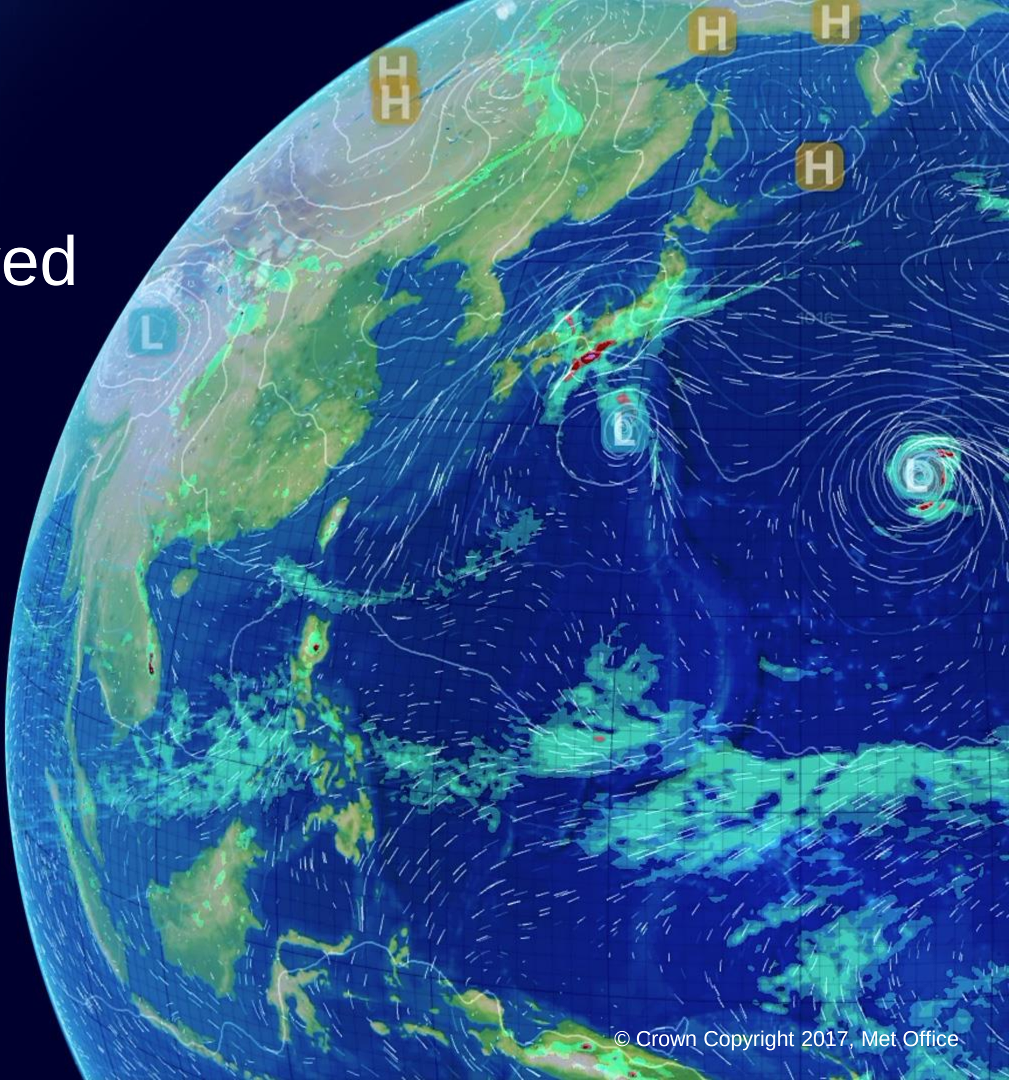
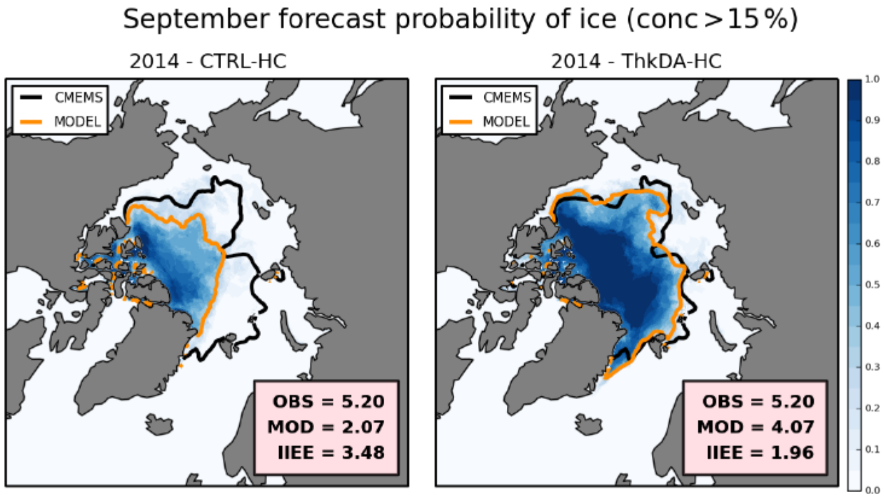


Motivation

- Developments of sea-ice thickness (SIT) assimilation are much more incipient in operational sea-ice forecasting systems when compared to sea-ice concentration (SIC).

- Our first effort was to initialise the Met Office's coupled seasonal prediction system with CryoSat-2 winter thickness data.

- Winter sea-ice thickness provides important preconditioning for the evolution of Arctic sea-ice through the summer melt season.



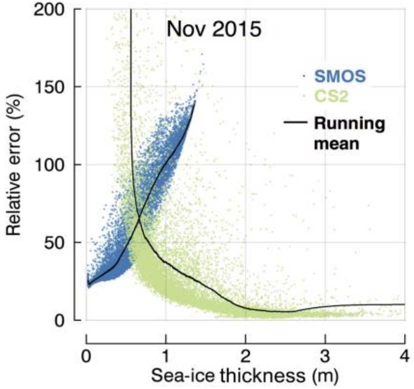
Blockley et al., 2018

Assimilating complementary satellites

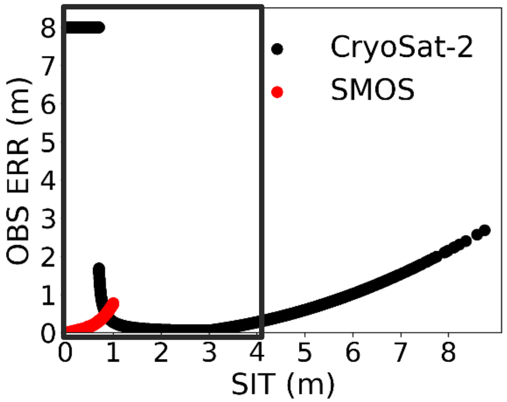
- **CryoSat-2** SITs are derived from ice freeboard measurements.
    - Retrieving method can have large uncertainties over thin ice regions!
    - **However, no observations uncertainties are provided.**

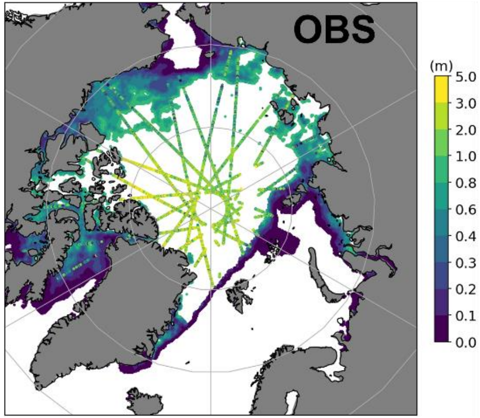
- **SMOS** SITs are derived from brightness temperatures.
    - Saturation of brightness temperatures with increasing SITs.
    - Assimilation of SITs only < 1 m

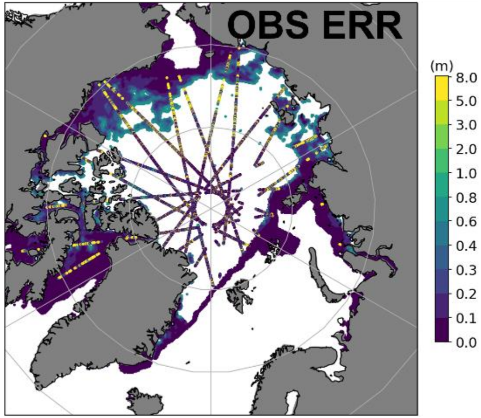
Ricker et al. 2017



Mignac et al. 2022







Assimilating complementary satellites

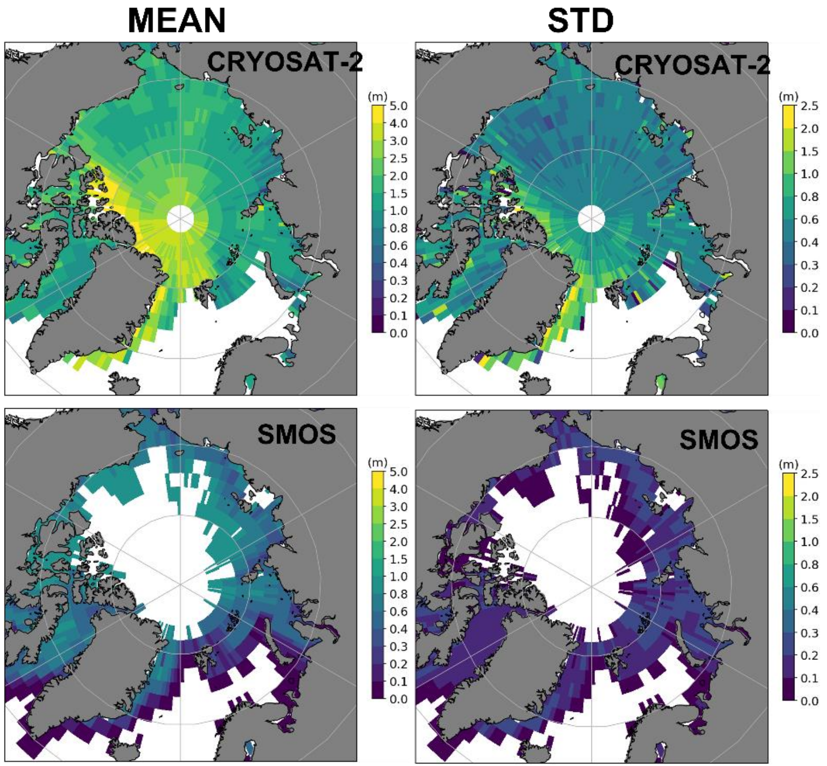
- **Along-track CryoSat-2 freeboard data (L2)**
  - Correction of the radar freeboard due to snow on sea ice (0.25*h_s)
  - Conversion from freeboard to thickness assumes the ice is floating in hydrostatic equilibrium:

from the model!

$$h_i = \frac{f_i \rho_w + h_s \rho_s}{(\rho_w - \rho_i)}$$

  - Super-observation within a radius of 10 km to reduce the **random noise** in the CS2 tracks

- **SMOS gridded data (L3)**
  - Resolution of 12.5 km
  - No need to apply super-observations



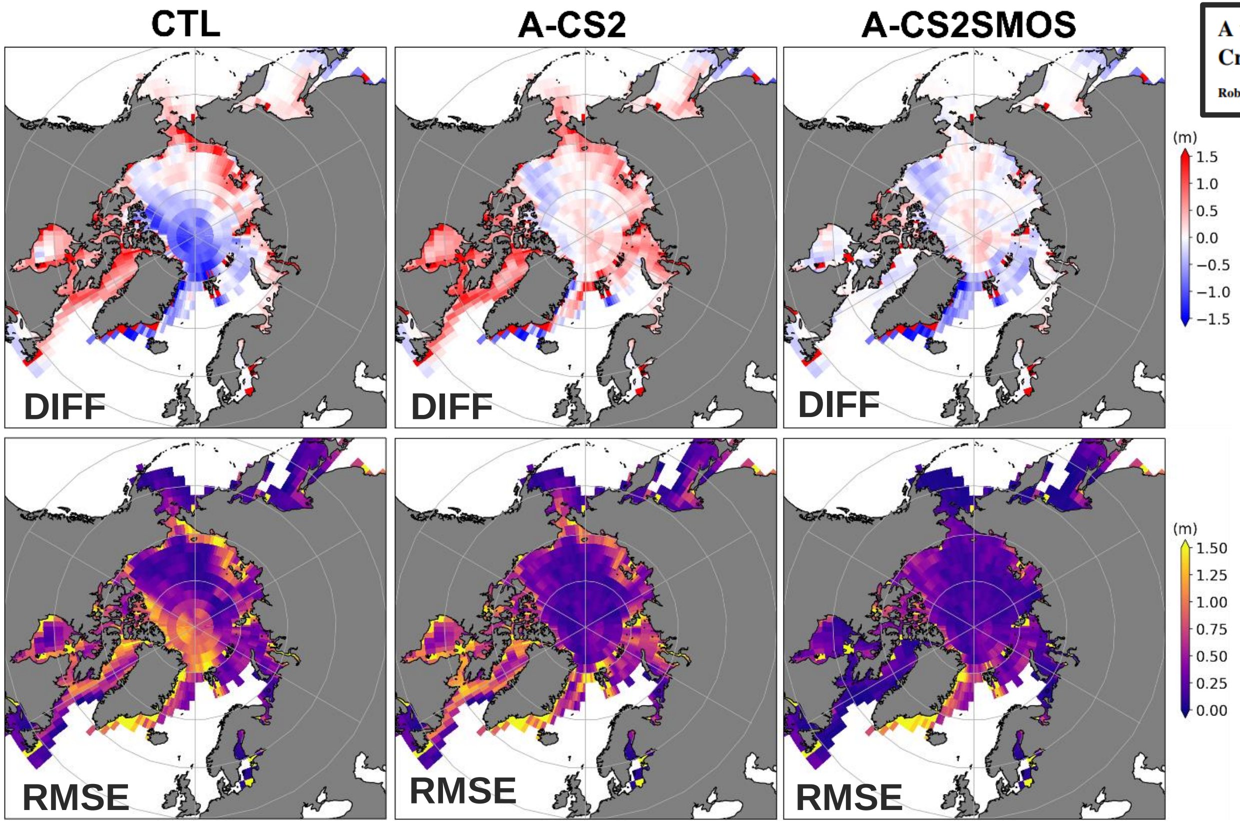
FOAM setup

- Coupled ocean-sea ice system
  - **NEMO** and **CICE** (increasing from ~25 km near the equator to ~10 km in the poles).
  - Surface forcing from Met Office NWP (~17 km during these experiments).
  - NEMOVAR: **3D-Var FGAT**

	Assimilated observations	Initial condition	Run period
CTL	SST, SLA, T/S and SIC	From a previous FOAM run	15 Oct 2014 – 15 Apr 2017
A-CS2	Same as CTL + CS2 SIT	From a previous FOAM run	15 Oct 2014 – 15 Apr 2017
A-CS2SMOS	Same as CTL + CS2 + SMOS SIT	From A-CS2	25 Nov 2016 – 15 Apr 2017

- The SIC and SIT assimilation are performed separately.
- SIT increments are added to each of 5 ice categories proportionally to their initial distribution.

Evaluation against SIT analyses (Ricker et al. 2017)



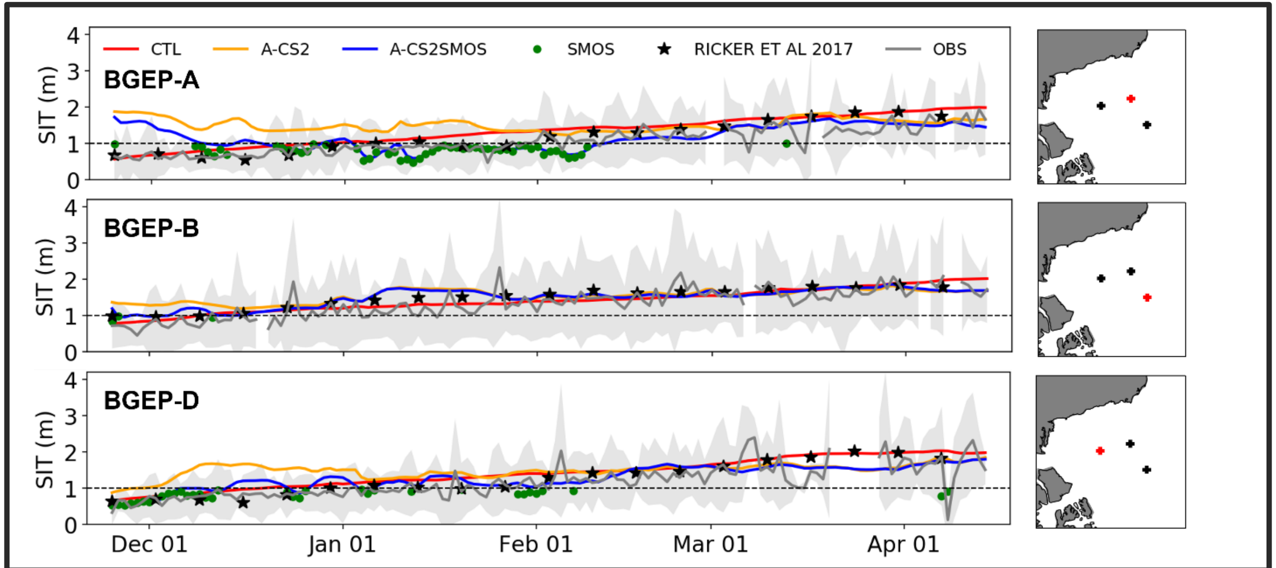
MARCH 2017

A weekly Arctic sea-ice thickness data record from merged CryoSat-2 and SMOS satellite data

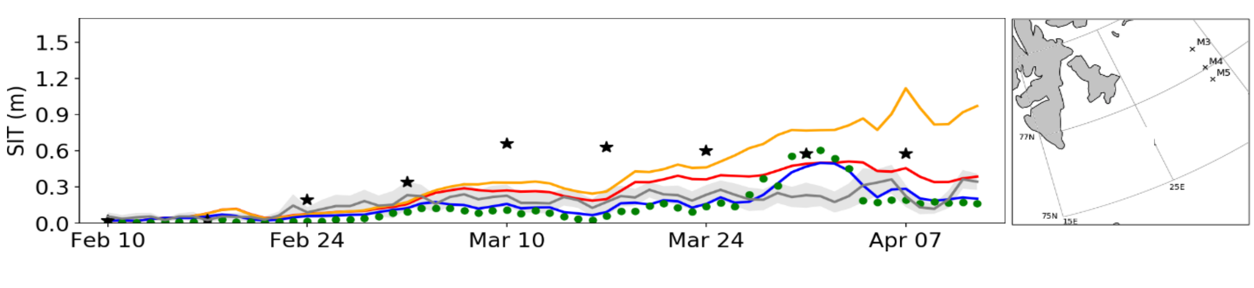
Robert Ricker[1,2], Stefan Hendricks[1], Lars Kaleschke[3], Xiangshan Tian-Kunze[3], Jennifer King[4], and Christian Haas[1,5]

- **A-CS2:** Reduction of model biases in the ice pack, but overestimating SITs near the ice edge.
- **A-CS2SMOS:** Improvements both in the ice pack and near the ice edge.

Evaluation against moorings

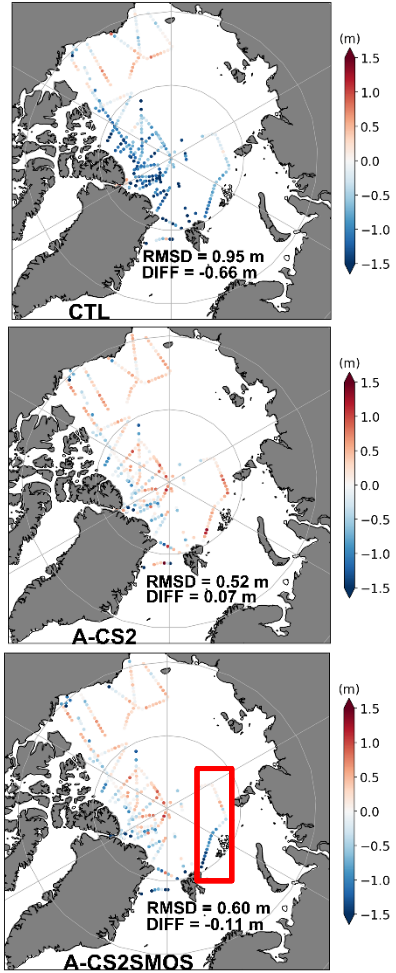


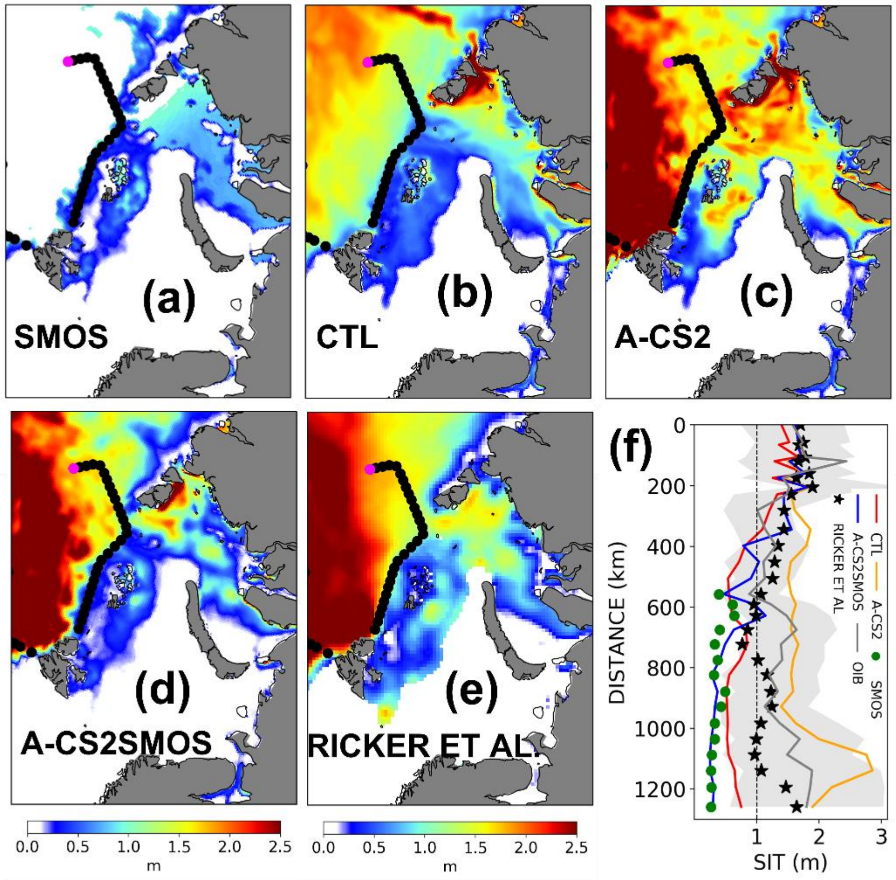
	RMSE (m)	MEAN DIFF (m)
CTL	**0.36**	**0.16**
A-CS2	0.50	0.32
A-CS2SMOS	**0.36**	**0.14**
RICKER ET AL.	0.33	0.11



	RMSE (m)	MEAN DIFF (m)
CTL	0.15	0.08
A-CS2	0.37	0.23
A-CS2SMOS	**0.13**	**-0.01**
RICKER ET AL.	0.56	0.28

Evaluation against airborne observations (OIB)





Transition regions

CS2 and SMOS obs errors need to be further improved, so the weights given to each type of observation are better accounted for in the assimilation.

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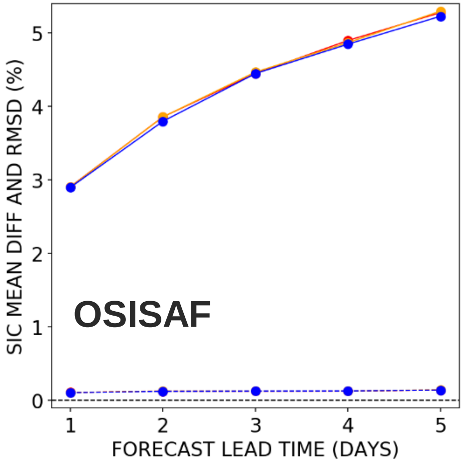
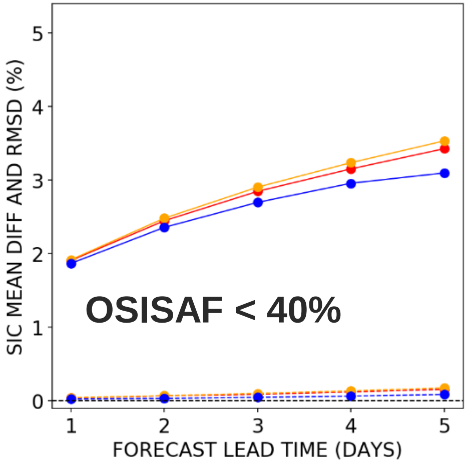
Impact of the SIT assimilation on the SIC forecasts





- Positive impacts on the **5-day forecasts** of SIC near the ice edge.
- Improvements of the ice edge position compared to the NSIDC ice edge product for 5-day forecasts.

MARCH 2017

25-31 MARCH 2017

Why CryoSat-2 SITs are biased near the ice edge?

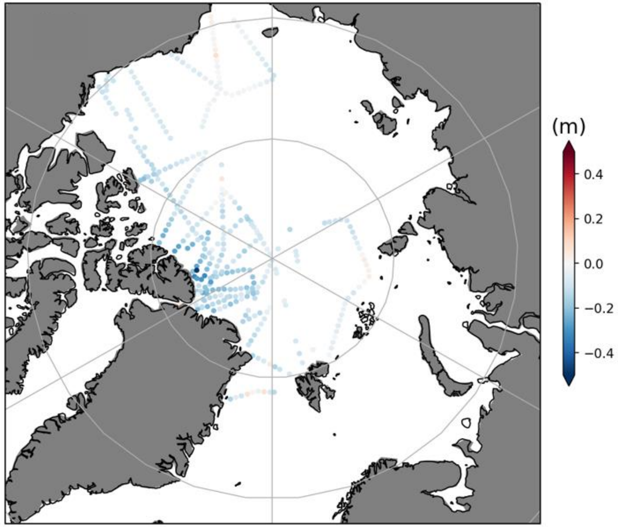
- Unlikely to be because of the model snow depth!

- We assume that the CS2 radar pulse fully penetrates into the snow layer, but this assumption does not always hold in the real system.

  - Snow depth penetration factors

- Along-track CS2 random noise may not be properly accounted for near the ice edge, where the number of observations is smaller compared to higher latitudes.

SNOW DEPTH: FOAM MINUS OIB



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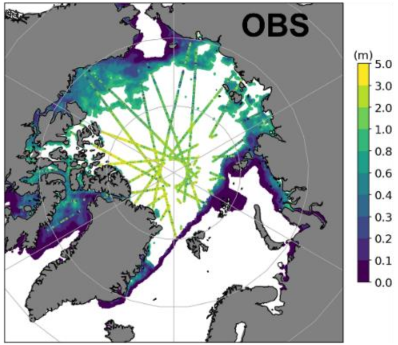

Met Office

Conclusions

- Although CryoSat-2 is biased towards the ice edge, the model SIT is successfully improved when both CryoSat-2 and SMOS are assimilated together into FOAM.

- Assimilation of CryoSat-2 substantially improves the representation of the ice pack, whereas the SMOS assimilation brings an enhancement to thin ice regions, including improvements of 5-day forecasts for marginal SIC.

- **Limitations from an operational perspective:**

    - CryoSat-2 along-track freeboard data should be provided with uncertainty estimates.

    - CryoSat-2 product used here has a latency of 72 hours, but FOAM needs data to be available within 24 hours of their validity time.

Future work

- Ongoing partnership with University College London:
    - Improving CryoSat-2 freeboard conversion into SITs by estimating spatially-varying snow depth penetration factors.
    - Including Sentinel-3 freeboard data to better account for the random noise near the ice edge.
    - Assimilation of snow thickness
- Coupled studies including the SIT assimilation to evaluate the broader impacts of the SIT assimilation on the polar weather.