Assimilation of sea ice in an Earth system model and its impacts for climate prediction

Kimmritz[1], **Counillon**[1,2], Wang [1] , Keenlyside[2,1], Bethke[3]
1. Nansen Environmental and Remote Sensing Center, Bjerknes Centre for Climate Research, Norway
2. Geophysical Institute, University of Bergen and Bjerknes Centre for Climate Research, Norway
3. Uni Research Climate, Bjerknes Centre for Climate Research, Bergen, Norway

Mail: Madlen.kimmritz@nersc.no

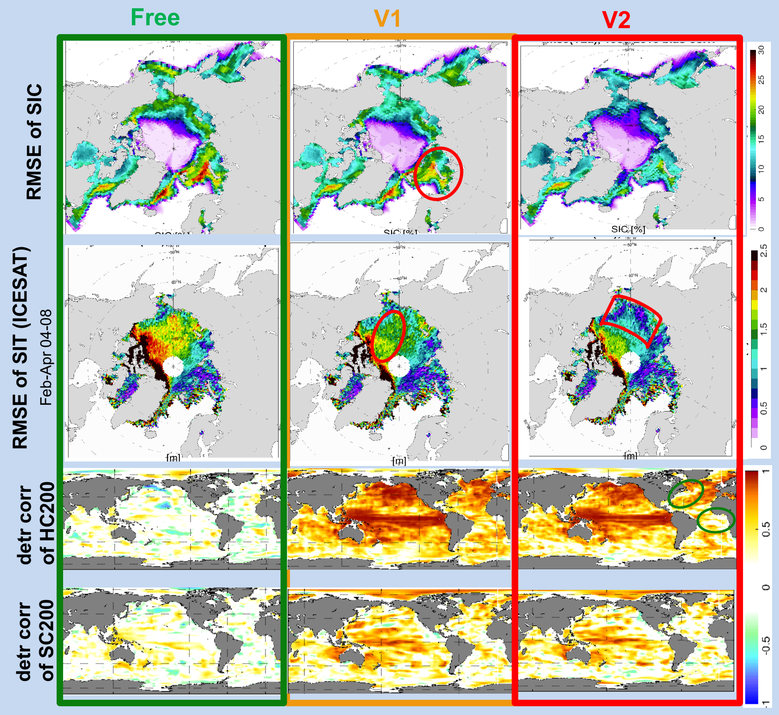
Bjerknes Centre for Climate Research

Summary

•NorCPM is complemented with assimilation of sea ice concentration for S2S and S2D predictions
•It is best to update the multicategory sea ice state and to carry strongly coupled data assimilation of ocean and sea ice
•Assimilation of SIC reduces error of SIT and improves the prediction skill of sea ice extent in all regions
•The largest impact is seen for regions that are semi enclosed (e.g. Kara Sea, Hudson Bay) and regions where sea ice is exported from the Arctic (e.g. Greenland Sea)
•There may be light degradations in the some oceanic region but this need to be further investigated

3. Added value of sea ice for Reanalysis

We compare the performance of reanalysis based on **FREE**, **NorCPMV1** and **NorCPMV2** for the period1985-2010, for SIT we use the idepedent ICESAT data set and for heat and salt content we use the EN4 objective analysis.

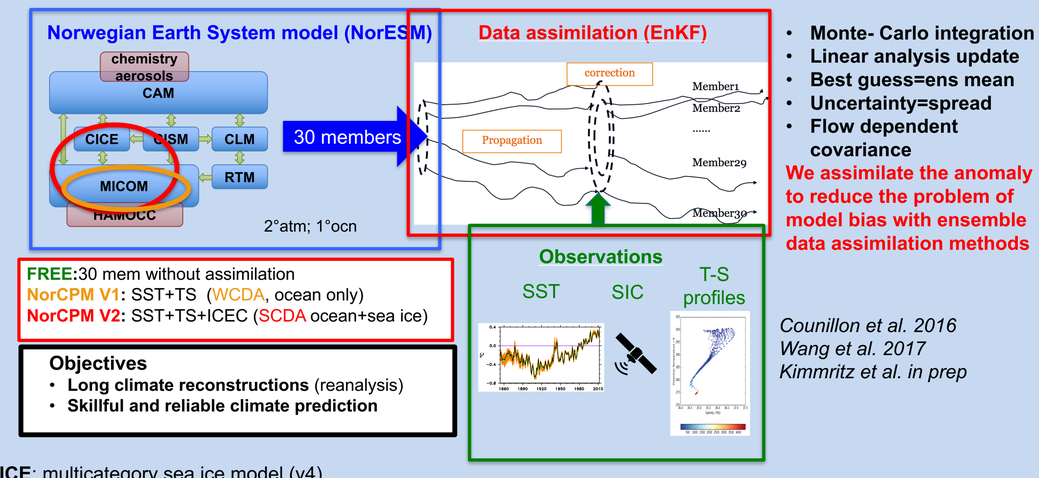


V1: Assimilation of ocean observation reduces RMSE of SIC in regions influenced by the ocean
V2 :Assimilation of SIC (V2) further reduces the RMSE everywhere

V1: Assimilation of ocean observation reduces error of SIT in region of multicategory sea ice
V2: Assimilation of SIC further reduces the RMSE for first year ice regions

V1: Assimilation of ocean observations controls well the variability of the 200 m heat and salt content (HC200 & SC200)
V2: Assimilation of SIC may degrades the performance in the Gulf Stream and the Tropical Atlantic

NorCPM system & Experiment



- **Monte- Carlo integration**
- **Linear analysis update**
- **Best guess=ens mean**
- **Uncertainty=spread**
- **Flow dependent covariance**

We assimilate the anomaly to reduce the problem of model bias with ensemble data assimilation methods

Counillon et al. 2016
Wang et al. 2017
Kimmritz et al. in prep

FREE:30 mem without assimilation
NorCPM V1: SST+TS (WCDA, ocean only)
NorCPM V2: SST+TS+ICEC (SCDA ocean+sea ice)

Objectives
- **Long climate reconstructions** (reanalysis)
- **Skillful and reliable climate prediction**

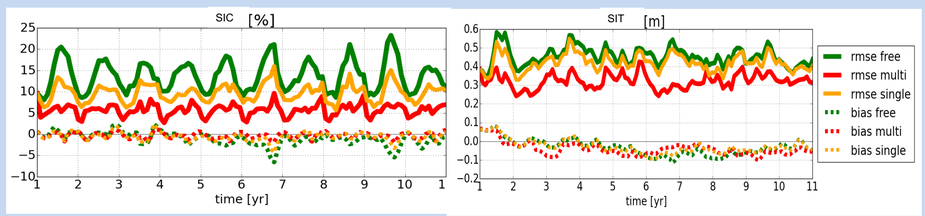
- **CICE**: multicategory sea ice model (v4)
- **NorESM-O:** isopycnic coordinate ocean model with bulk mixed layer on top, based on MICOM
- **SST+sea ice conc (SIC):** HadiSST2
- **T-S profiles:** EN4 objective analysis

Twin experiment: finding the optimal assimilation strategy to make best use of sea ice concentration

- **Synthetic observations are generated from an independent pre-industrial (PI) run from NorESM**
- **Testing the skill of data assimilation (DA) from multiple reanalyses with monthly assim using different state vector in PI condition**
- **Test the optimal performance by the run that: minimise the error of the whole state (ocean, sea-ice), does not introduce a bias and preserves reliability**

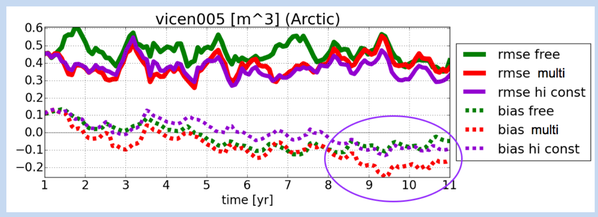
It is found that :

1. **Updating the multicategory sea ice state (multi) outperforms update of the aggregated sea ice state (single)**



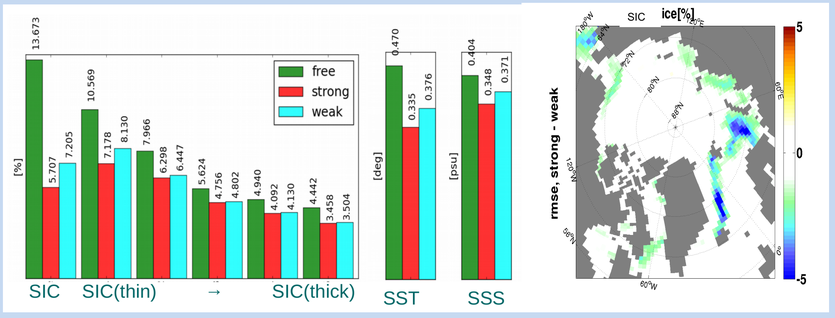
Time series of the performance of the two runs. **multi** outperforms **single**.

2. **Preserving the prior thickness per category avoid introducing a drift in thick category and does not degrade the skill**



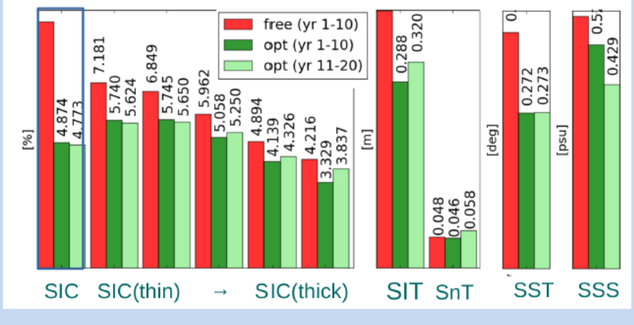
RMSE and bias of the volume of the thickest category.
The drift in the bias is well constrained when the prior thickness category is preserved.

3. **Joint update of ocean & sea ice (strongly coupled DA) outperforms sea ice only update (weakly coupled DA)**



Left: Averaged performance of the two runs for sea ice and ocean variables
Right: RMSE difference between strong and weak.
Strongly coupled DA of ocean and sea ice improves performance of thin sea ice in regions influenced by the ocean.

4. **Performance of the optimal setting for a longer reanalysis**

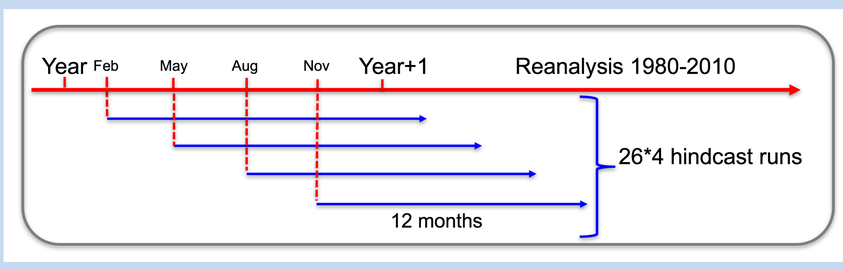


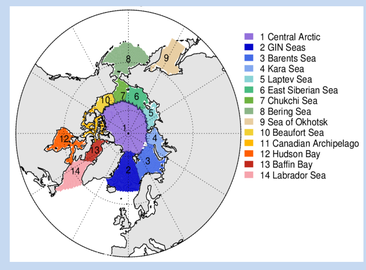
RMSE of the reanalysis state variables for two decades.
Performance is stable when comparing the two decades.
DA of SIC reduces effectively error of SIC (60%), thickness (25%), SST (30%), SSS (17%).
The reliability of the ensemble is preserved.

Kimmritz et al. 2018

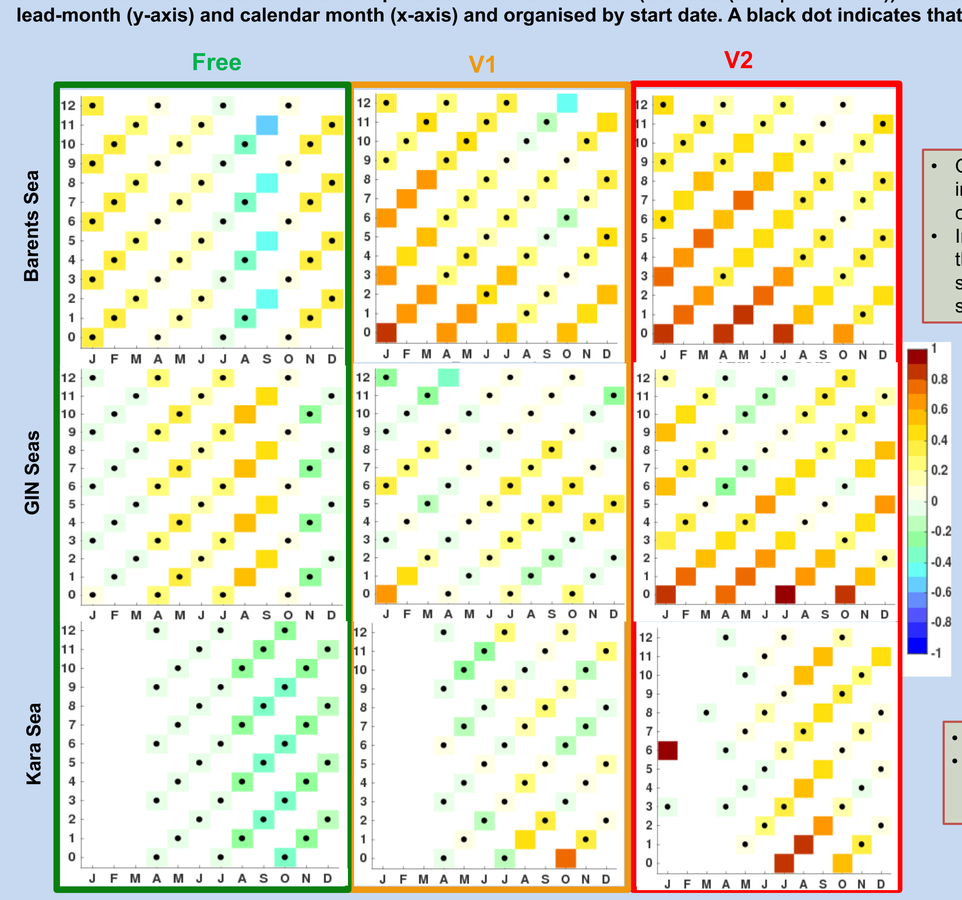
4. Seasonal predictions skill

Prediction skill is tested by retrospective forecast in the period from 1985 to 2010 with 9 members and 4 start dates per year; we compare NorCPMV1 and NorCPMV2 which depicts the added value of SIC assimilation





We look at the detrended correlation of prediction of sea ice extent (SIE=sum(area | SIC > 15%)) vs that calculated from HadiSST2 for each lead-month (y-axis) and calendar month (x-axis) and organised by start date. A black dot indicates that the correlation is not significant

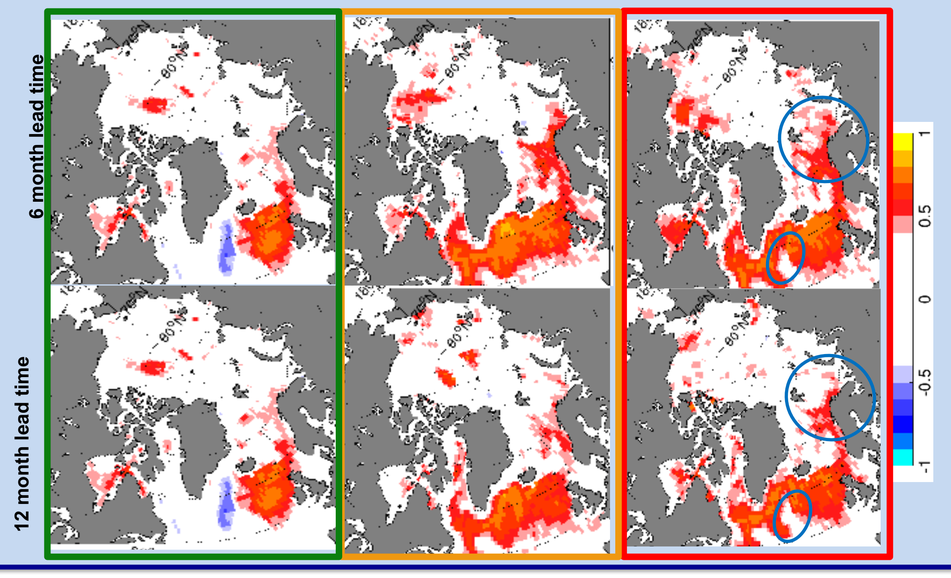


- Ocean initialisation achieves good skill in boreal winter because SIE variability controlled by HC.
- Initialisation of sea ice further improves the correlation and extends the significance period into the boreal summer.

- Ocean initialisation have little skill.
- Initialisation of sea ice leads to improved sea ice export from the Arctic.

- Ocean initialisation has little skill.
- Initialisation of sea ice may yields skill for boreal summer likely due to skill in SIT.

We look at the correlation of SST at 6 months and 12 months lead time



There is no big difference between the 2 systems for seasonal prediction of SST.
Skill in the Nordic Seas and Barents seas seems slightly improved, but degraded in the subpolar gyre region.

Reference :
- Counillon et al. "Flow-dependent assimilation of SST in isopycnal coordinates with NorCPM. Tellus A (2016)
- Wang et al. "Optimising assimilation of hydrographic profiles into isopycnal ocean models with ensemble data assimilation", OM (2017)
- Kimmritz et al. "Optimising assimilation of sea ice concentration in an ESM with a multicategory sea ice model". Tellus (2018)
- Kimmritz et al. "Added value of sea ice assimilation for seasonal prediction in the Arctic" in prep

Acknowledgments
This study was co-funded by the Center for Climate Dynamics at the Bjerknes Center , the Norwegian Research Council project SNOWGLACE (244166), SFE (270733) and INES (grant 270061), Bergen Research Foundation project BCPU and Nordforsk ARCPATH (76654). CPU and storage has been provided by UNINETT Sigma2 (nn9039k, and NS9039K)