Efficient Ensemble-Based Data Assimilation for High-Dimensional Models with the Parallel Data Assimilation Framework PDAF

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PDAF is open source. The code, documentation, and a tutorial are available at **http://pdaf.awi.de**

Overview

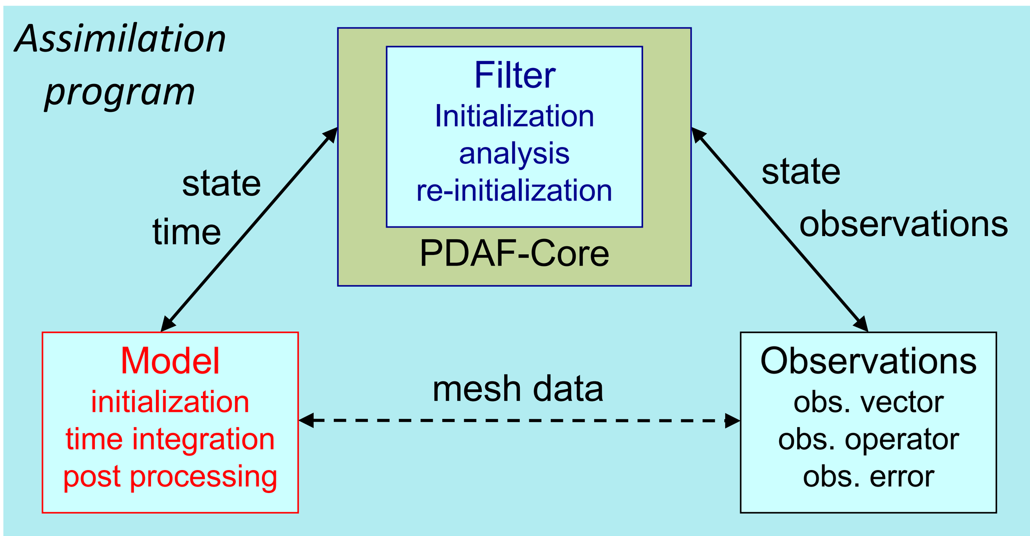
We show how we can build a data-assimilative model by augmenting a forecast model by data assimilation functionality for efficient ensemble data assimilation. The method uses a direct connection between the coupled model and the ensemble data assimilation framework PDAF [1, http://pdaf.awi.de]. Augmenting the model allows us to set up a data assimilation program with high flexibility and parallel scalability with only small changes to the model.

The direct connection is obtained by

1. adapting the source codes of the coupled model so that it is able to run an ensemble of model states
2. adding a filtering step to the source codes.

We discuss this connection for the ocean circulation models NEMO and MITgcm. We insert subroutine calls to the model code, adapt the parallelization, and add routines for the handling of observations.

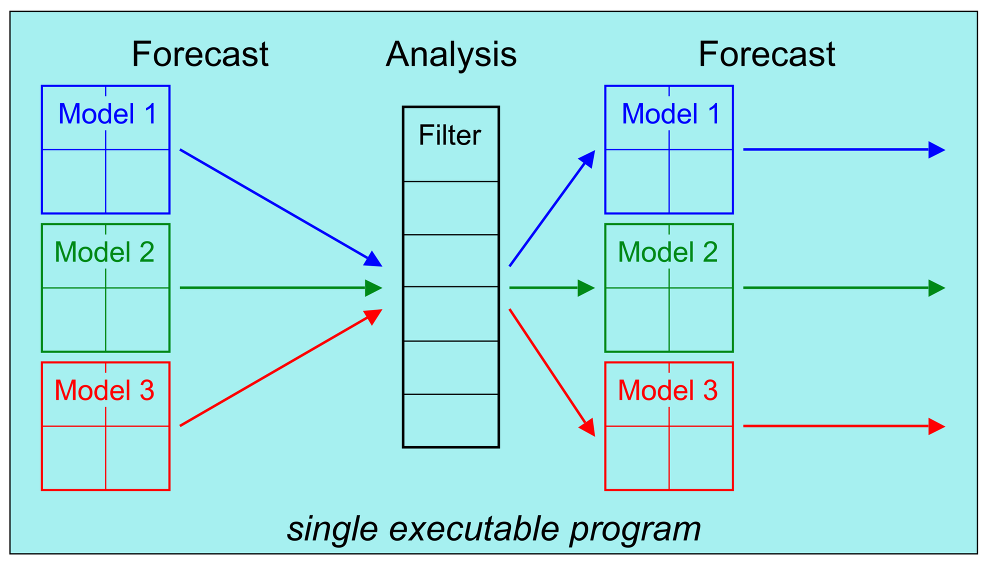
Data Assimilation Program



⟷ Explicit Interface (Subroutine calls)
⇠⇢ Indirect Exchange of information (Fortran modules)

The data assimilation system has three components: Model, filter algorithm, and observations. The filter algorithms are model-agnostic, while the model and subroutines to handle observations are provided by the user. The observation routines are called by PDAF as call-back routines.

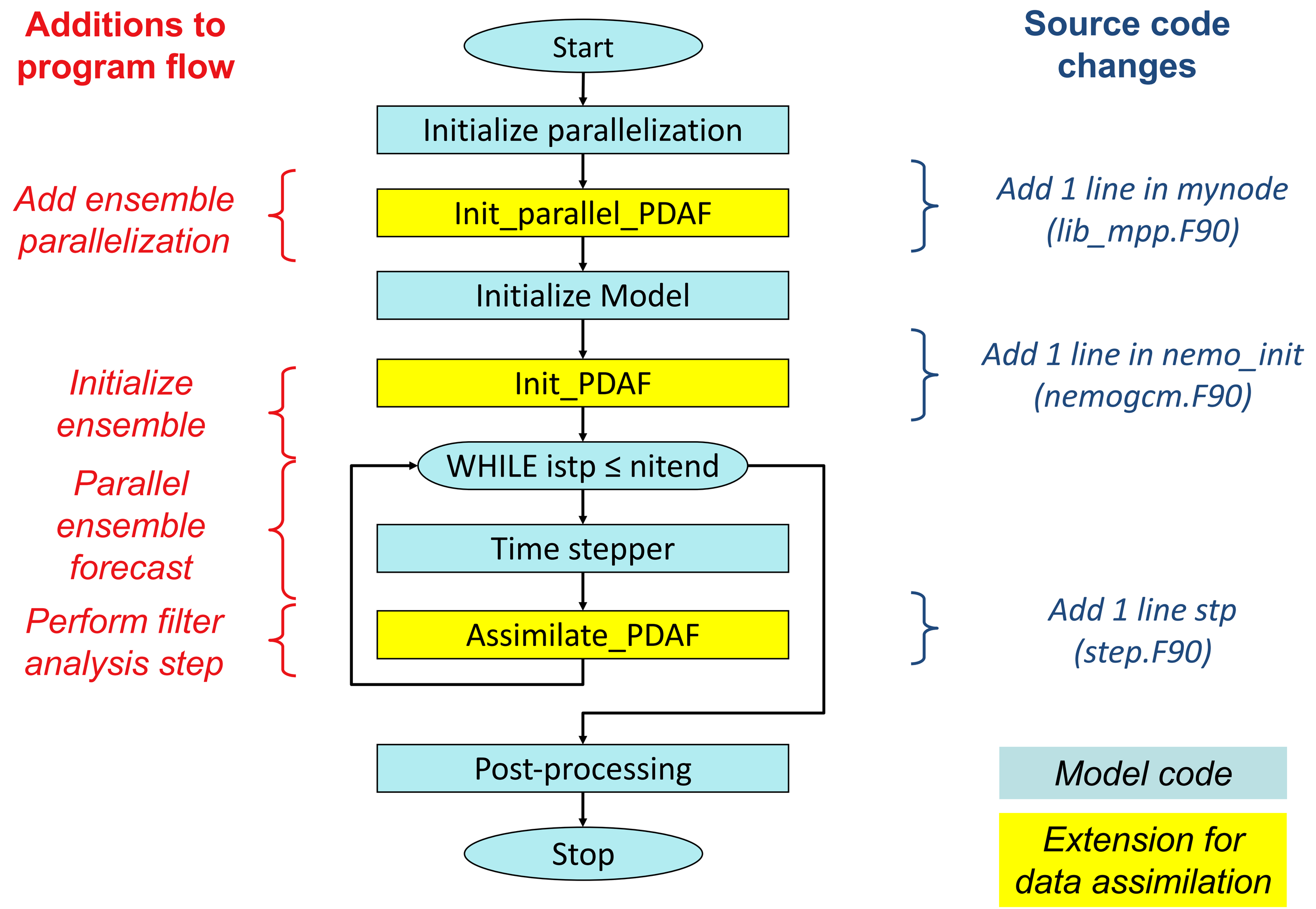
Parallel Ensemble Forecasts



Example of an ensemble integration with two ensemble members using a 2-level parallelization. The models and the filter are parallelized. The ensemble adds one level of parallelization to integrate all members at once. Combining model and assimilation in one program avoids costly disk file operations. Further there is no need for a full model restart after the filter analysis step.

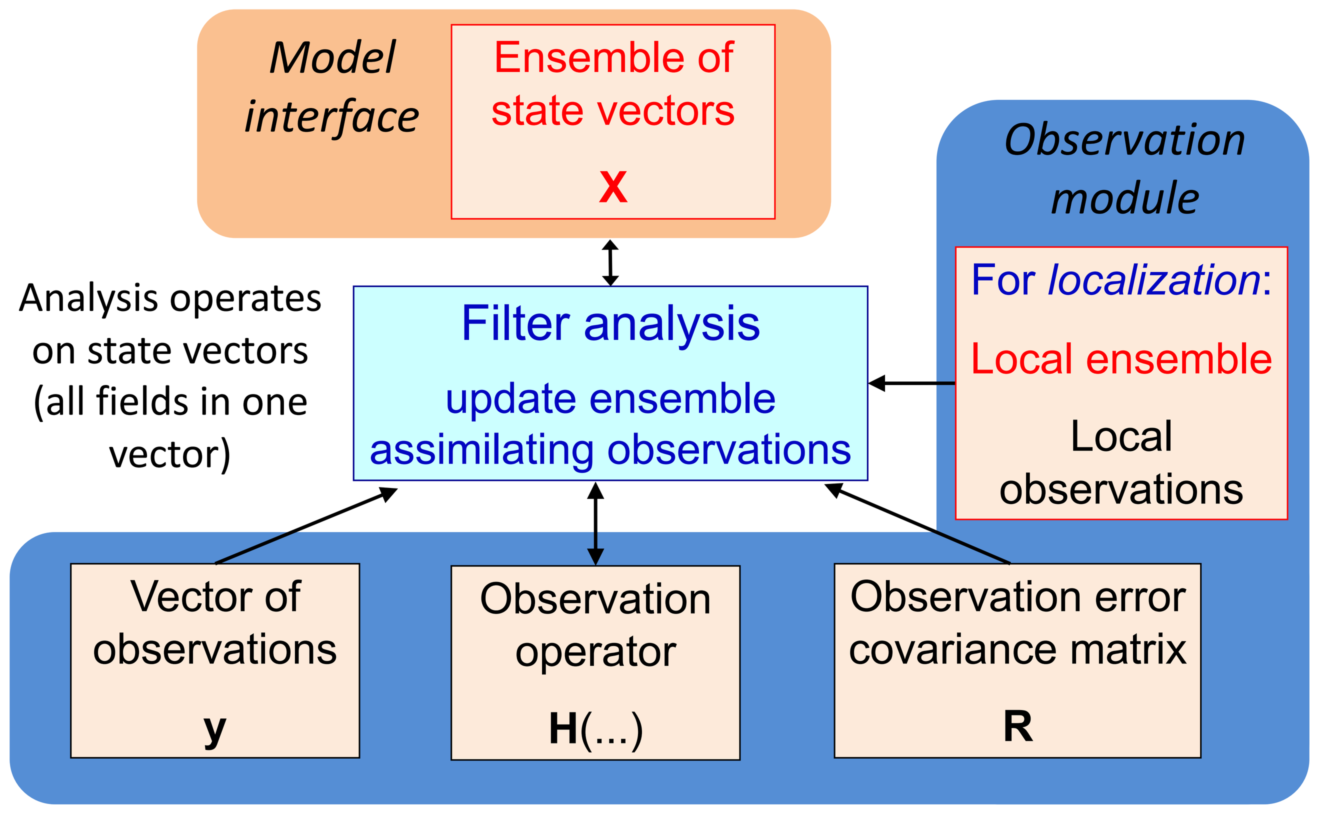
Direct (Online) Coupling of model and PDAF

PDAF provides parallelization support and fully-implemented and parallelized filters & smoothers. Ensemble assimilation without model restarts is enabled by adding a few subroutine calls to the model code. The additions are nearly identical for NEMO and MITgcm. In NEMO one has to account for the leap-frog time stepping.



Implementing the Analysis Step

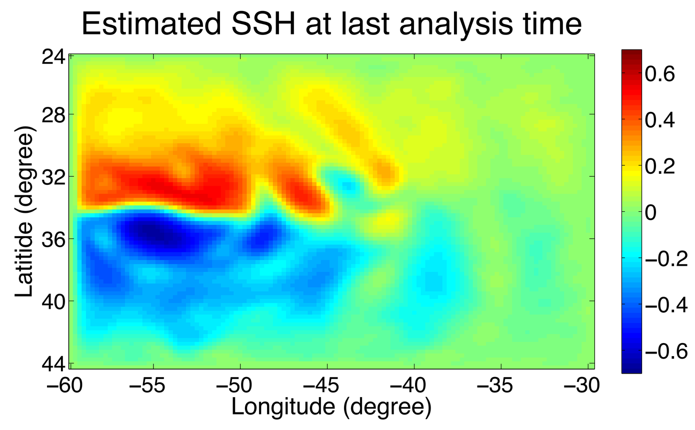
For the analysis step, we need to write model fields into the state vectors and back afterwards. Further, the analysis step needs information on the assimilated observations. PDAF uses call-back routines for this. They are implemented like model routines and utilize model information from Fortran modules. PDAF already provides model-binding routines for MITgcm.



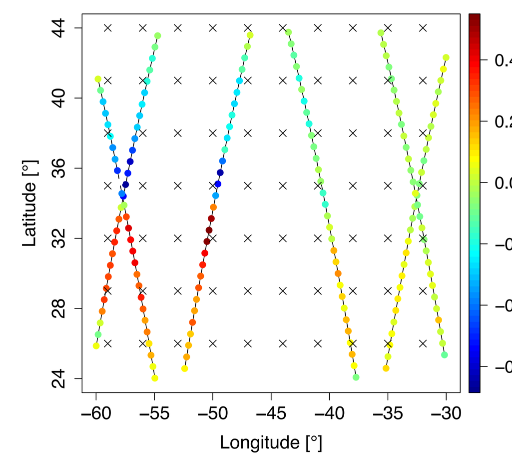
Example: Nonlinear Ensemble Smoother with NEMO

NEMO is used in a box configuration (double-gyre SEABASS) with the Nonlinear Ensemble Transform Filter (NETF) and its smoother extension [2]. Assimilated are simulated SSH observations on satellite tracks and temperature profiles over 1 year. NETF and LETKF reach the same accuracy; the smoother reduces the error by up to 11.5%

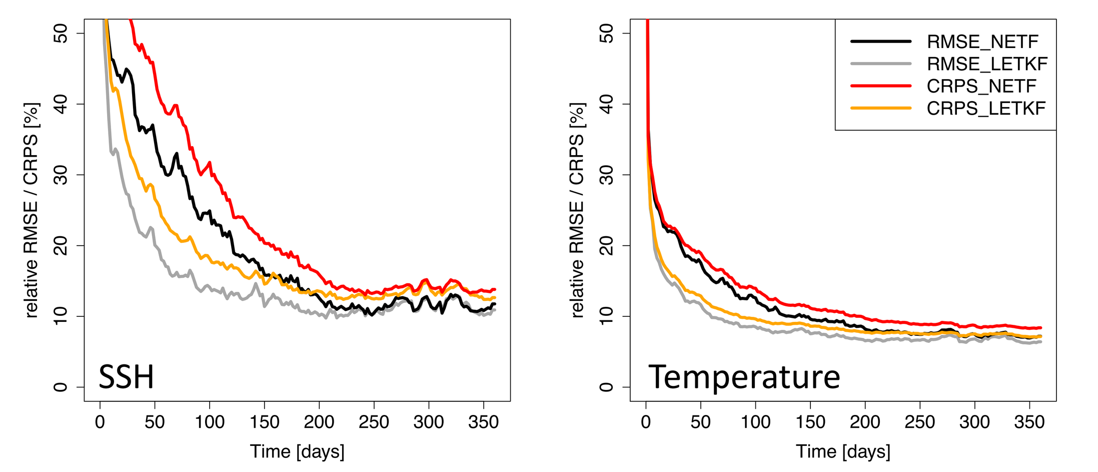
Estimated SSH at last analysis time



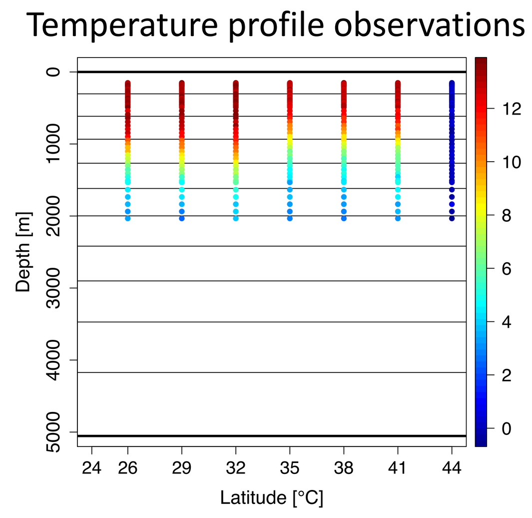
Surface Observations (SSH and SST)



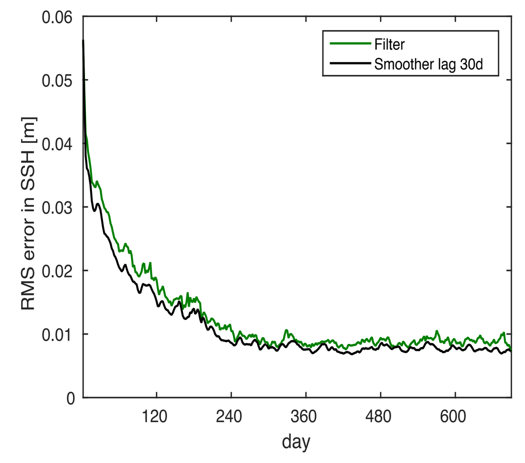
Filters: Error statistics (RMSE and CRPS)



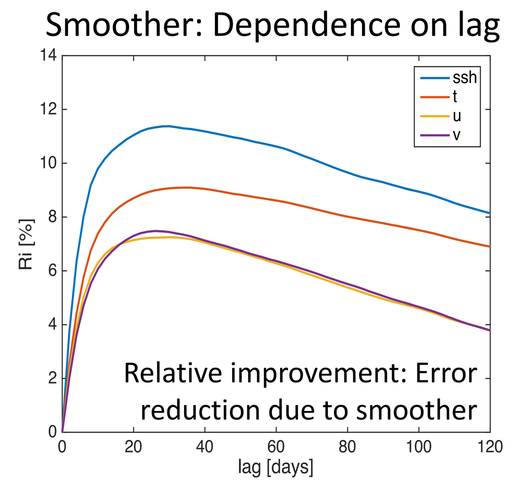
Temperature profile observations



Smoother: RMS errors



Smoother: Dependence on lag

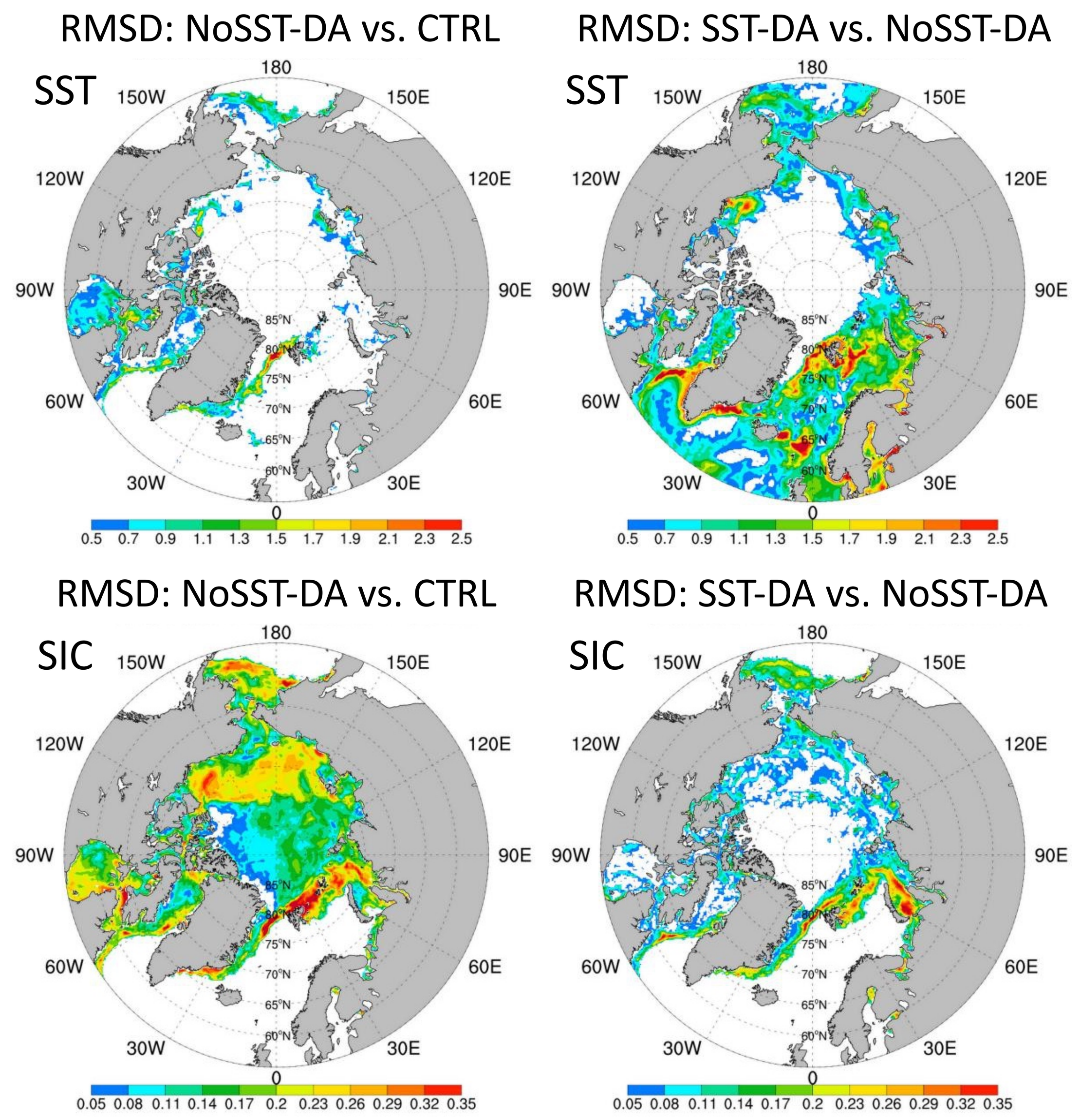


Example: Sea-ice assimilation with MITgcm

The MITgcm model is used with PDAF to assimilate sea ice concentration (SIC) from SSMIS and thickness from SMIS and CryoSat2. The effect of adding daily assimilation of SST data is examined for the year 2012 [3].

The model has a resolution of 18 km. An ensemble of 23 members is used.

Adding the assimilation of SST improves the ice condition at the sea ice edge. The figure shows the effect of sea-ice assimilation (left) and the additional effect of SST (right) in terms of RMS deviation.



References:

[1] Nerger, L., Hiller, W. Software for Ensemble-based Data Assimilation Systems - Implementation Strategies and Scalability. Comp. & Geosci., (2013) 55: 110-118

[2] Kirchgessner, P., Tödter, J., Ahrens, B., Nerger, L. (2017) The smoother extension of the nonlinear ensemble transform filter. Tellus A, 69, 1327766, 2017

[3] Liang, X., Losch, M., Nerger, L. Mu, L., Yang , Q., Liu, C. (2019) Using sea surface temperature observations to constrain upper ocean properties in an Arctic sea ice-ocean data assimilation system, in preparation