Assimilation of sea-ice velocity in a Finite Element Sea-Ice Model

Katja Rollenhagen, Ralph Timmermann Tijana Janjić and Jens Schröter
Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven, Germany (katja.rollenhagen@awi.de)

Introduction

The Singular Evolutive Interpolated Kalman (SEIK) Filter has been used to assimilate Quikscat and SSM/I derived sea-ice drift data in a Finite Element Sea-ice Model (FESIM) of the Arctic region. A simulation of four month with data assimilation on every 3rd day was performed. The assimilation affects not only the drift, but also the ice thickness distribution. Compared to the ice thickness concentration the ice drift changes very frequently, depending on wind, ocean, and internal ice stress. Since the inertia of sea ice is small compared to the stresses, the system has very little memory beyond each assimilation step, making corrections by the filter very short-lived. Even a perfectly corrected drift field has very little effect on the model state in the next model integration step. However, ice-drift history is stored in the ice thickness and ice concentration distributions. A modified ice thickness distribution in turn affects the sea-ice drift.

Filter Method

A comparison of Kalman filter types (EnKF, SEEK and SEIK) done by Nerger et al. (2005) revealed advantages for the Singular Evolutive Interpolated Kalman Filter (SEIK) with respect to computing time for large ensembles. The SEIK filter is applied with 23 ensemble states (rank=22); dimension of one model state is approx. 1.7 M) and with a forgetting factor $\rho = 0.8$. Observations are 3 day mean sea-ice drift fields derived from Quikscat and SSM/I satellite data (from CERSAT/Iferem) so every 3rd day an update of model state is computed.

SEIK Algorithm:

INITIALISATION of FESIM and SEIK
- Generating a state ensemble of minimum size whose ensemble statistics until recently the long-term covariance matrix $\Sigma$ in a decomposed form $\Sigma = L L^T$, which is representative of estimated model variance.

model state ensemble (initial or analysed, SEIK)

analysed single ensemble member

Model FORECAST (FESIM)

Model forecast single ensemble member

forecasted model state ensemble (SEIK)

ANALYSIS (SEIK)

When observations $v$ are available compute the updated $P$ which only implicitly relates the model deviaion to the observation error $\epsilon$. The model state update $\delta$ is given by $\delta = L^T (L L^T + \epsilon)^{-1} (v - \bar{v})$.

RESAMPLING (SEIK)

Resample state ensemble with updated covariance matrix $P = L L^T$ which represents the updated model variance.

Drift Validation

Sea-ice buoy drift data were used to validate assimilation results (Fig. 4). Both model only and assimilated drift (green and blue) are very close to the buoy drift (red). Fig. 4b and 4c show that assimilation results in an improvement of drift direction and speed. In some cases the FESIM and assimilation derived trajectories stay close to each other and the improvement is small. This is due to a small ensemble spread (i.e. small deviations between observation and forecast which result in a smaller model error estimation) so that after some assimilation steps the filter has more "confidence" to the modelled drift than to the observation, which can have a larger observation error. On top of that, the filter only can influence drift sustainable by changing ice thickness (with respect to the updated covariance matrix) to accelerate or slow down the velocity. Nevertheless, the SEIK filter corrects the drift such that the result is closer to the observations.

Ice Thickness

Sea-ice thickness is modified every 3rd day during the resampling phase of the SEIK filter based on the updated ensemble mean state and updated covariance matrix. The mean ice thickness distribution in Fig. 3a shows a good result of ice thickness of the model only run but, compared with observations (Fig 3b) it does not show the typical winter pattern of the narrow band of very thick ice close to the Canadian Archipelago. In contrast to that, Fig. 3c agrees remarkably good with the winter mean ice draft map (Fig. 3b) derived from upward looking sonar (ULS) data (Bourke and Garrett, 1987) and is more realistic than the FESIM only thickness distribution. The isolated minimum in the East Siberian Sea is an averaging artefact. The time period of Fig. 3a and 3c corresponds to a 40 day period (20th January to 9th February) in which the ensemble spread of ice thickness estimation is constantly small. The spread increases with ongoing assimilation after 60 days. The compared draft maps results become worse. We conclude that for the presented filter setup the simulated ice thickness can be improved for a period of up to several weeks.