ASSIMILATION OF HIGH-RESOLUTION ICE CHARTS IN A COUPLED OCEAN-SEA-ICE MODEL

Sindre Fritzner, Rune Graversen

UIT The Arctic University of Norway
Institute of Physics and Technology
Tromsø

Kai Christensen, Keguang Wang

MET Norway
Oslo and Tromsø

ABSTRACT

In this study, we show assimilation results from a coupled ocean sea-ice model. The model has a horizontal resolution of 2.5 km. In the assimilation system, we assimilate high-resolution ice charts, structured on a 1 km grid. We compare the assimilation of passive microwave observations with the assimilation of ice charts. It is shown that the ice charts have a larger impact on the assimilation system than the passive microwave observations. In addition, a few results from the assimilation system with ice charts are shown. These indicate improvements for the assimilation system assimilating ice charts compared to a free-run without assimilation and an assimilation system assimilating passive microwave observations.

***Index Terms*—** Sea-ice, data assimilation, DEnKF, Ice chart

1. INTRODUCTION

The Arctic sea ice is changing. In the last decades, several extent minimums have been seen with record minimums in both 2007 and 2012 [1]. This decrease in Arctic sea-ice leads to new opportunities in the Arctic for both shipping and tourism. As ships are getting close to the ice edge, there is a strong need for more information to provide safe travel. Today most operational models are of low resolution with the assimilation of low-resolution observations. When you are close to the ice edge, a model resolution of 20 km is not sufficient for accurate ice edge information. In this work, we use a model with a 2.5 km resolution covering a local area around the populated island of Svalbard. There have been several studies conducting model forecasts of Arctic sea-ice with the use of assimilation. Most of these studies have in common that they all utilize passive microwave observations for assimilation. The problem with the passive microwave is that the resolution is low. For low-resolution models, this has not been a problem because the utilization of higher resolution observations would only lead to small model improvements. In this study, we use a high-resolution model, taking advantage of the high-resolution observations. We assimilate ice charts, these are partly based on high-resolution Synthetic Aperture Radar (SAR) observations which provide significantly more details that can be obtained from the passive microwave observations. We show that these higher resolution observations provide more details to our analysis than the passive microwave observations.

2. MODEL

In this assimilation study, we use a coupled ocean-sea-ice model [2]. The ocean component is the Regional Ocean Modeling System (ROMS) [3] version 3.6, and as the sea-ice component, the Los Alamos CICE model [4] version 5.1 is used. The ocean component has 42 terrain-following vertical layers. The ice component uses 5 thickness categories, with 7 ice layers and 1 snow layer. This is a state-of-the-art coupled model system covering a local area around Svalbard and the Barents Sea, the model horizontal resolution is 2.5 km, distributed over 739x949 grid cells. An overview of the model area is seen in figure 1. In this figure an example of an ice chart from 24.04.2018 plotted on the model grid is shown. The image is showing ice concentration.

The model utilizes assimilation in order to constrain the model towards observations, with an assimilation time-step of 7 days. In this study, we use the deterministic ensemble Kalman filter (DEnKF) [5]. The benefit of using the DEnKF compared to the traditional EnKF is that the ensemble spread is maintained without perturbation of the observations. This is particularly useful when the ensemble size is small. The numerical code used for assimilation is the enkf-c made by Pavel Sakov [6]. For ensemble based assimilation the model error is estimated from the slightly different model states of the ensemble. In this study, we use 10 ensemble members, where each ensemble member has different atmospheric forc-

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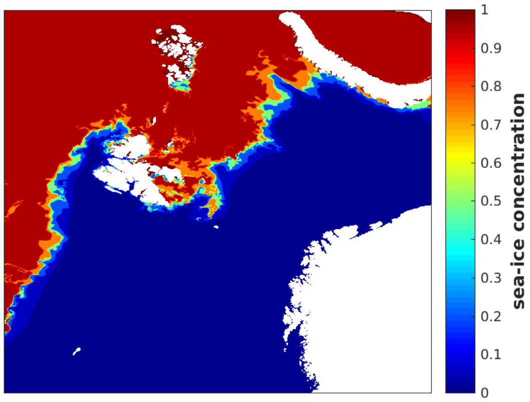


Fig. 1. Ice chart at 24.04.2018 extrapolated to model grid, the figure is displaying sea-ice concentration.

ing and ocean boundary conditions. The atmospheric forcing is 10 ensemble members from the ECMWF operational forecast. While the ocean boundary conditions are 10 ensemble members from TOPAZ model system [7]. During assimilation, both ocean and ice model parameters are updated based on correlation with the observed variable, which in this study is the sea-ice concentration. The updated variables include: ocean temperature, ocean salinity, ice concentration, ice volume and snow volume. We only use 10 ensemble members. A problem with using few ensemble members is that we can get insufficient model rank and spurious co-variance elements, and this can lead to noisy assimilation result. A method for overcoming this issue is localization [8] where the assimilation is done on local areas instead of the full model grid. In this work, a localization radius of 30 km is used when assimilating the ice chart observations and 40km is used for the passive microwave observations since these have lower resolution. The study period is from 20.03.2018-15.05.2018, assimilating observations every week. The model run is started from an ensemble of TOPAZ output from 20.03.2018.

3. OBSERVATIONS

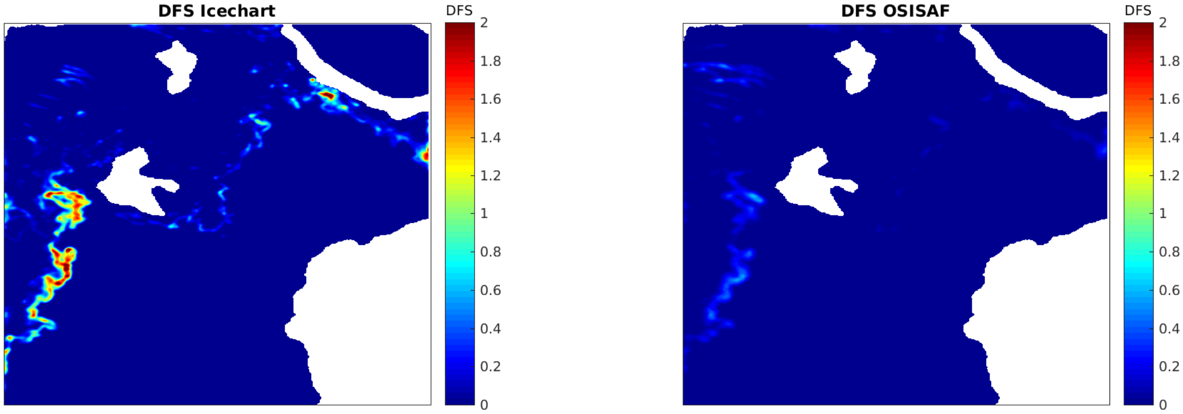
We apply the operational ice charts from the Norwegian meteorological service [9] for assimilation. These ice charts are manually hand-drawn maps of ice concentration based on several different data sources, including: SAR, Optical and Passive microwave. The dataset comes with a resolution of 1 km. An example of the observations on the model grid is shown figure 1. The concentration classes in the product follow the WMO concentration code for sea ice, and each class also has the accompanying WMO concentration intervals. In the assimilation analysis, these intervals are used as a basis for the observation uncertainty. Where the observation uncertainty is important to define the observation impact on the model.

For verification of the improvements due to high-resolution observations, we compare the results with the assimilation of passive microwave observations. The passive microwave observations are from the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Ocean and Sea Ice Application Facility (OSISAF) [10]. The product used is the operational global sea-ice concentration product, the observations are given on a 10 km grid, where each grid cell has an individual observation uncertainty.

4. RESULTS

For a high-resolution model, we show the advantage of assimilating high-resolution observations. In figure 2 the Degrees of Freedom of Signal (DFS) is plotted for assimilation on 24.04.2018 for both a) ice charts and b) passive microwave (OSISAF) observations. The DFS is a measure of the observation impact on the model during assimilation, or how far the model is pushed towards observations [11]. From the figure it is shown that the assimilation of ice charts have much larger DFS values than that of the OSISAF observations, indicating a higher impact on the assimilation system. This can also be seen by assimilating the two observation products separately. This result highlights the usefulness of high-resolution observations in high-resolution numerical models. The result is as expected since assimilation of sea-ice concentration mostly affects the ice edge, where most of the sea-ice concentration variations are found. Since the ice charts are able to resolve the ice edge better due to higher resolution, more information is gained from the ice charts.

In figure 3 the model output at 24.04.2018 is shown for the different model systems. In a) the analysis output after assimilation of ice chart is shown, this is an ensemble average over the 10 ensemble members. In b) an ensemble average of a 7-day forecast from the model assimilating ice charts is shown. In c) a 6-week forecast of the model without assimilation is shown. In d) a 7-day forecast of the assimilation system assimilating OSISAF observations is shown. Comparing figure a) and b) it is seen that the update during assimilation is small, the assimilation does not set the model to a perfect observation state, but moves it toward it based on the errors in both model and observations. Comparing figures b) and c) it is clear that with assimilation the model is significantly improved, errors are reduced all along the sea-ice edge. Figure 3b and 3d shows the same forecast interval, but are, respectively, model systems assimilating ice charts and OSISAF passive microwave observations. The visual differences between the two figures are small, and it is difficult to see any big improvements. This was also verified by the RMSE values, where the ice chart assimilation has an RMSE value of 0.14 and the OSISAF assimilation 0.15, only small improvement. Where the RMSE value is a measure of the



(a)

(b)

Fig. 2. The degrees of freedom of signal for assimilation of sea ice concentration from a) ice chart and b) OSISAF passive microwave observations.

squared distance from the ice chart observations divided by the number of observations. A problem with this verification is that the ice charts are used for verification, giving a positive bias towards the ice chart assimilation result. Thus it is more important that the results are different, indicating that there is an effect of the higher resolution observations. A reason for the limited improvement in the 7-day forecast is that no ocean observations are assimilated in this study. Assimilation of sea-ice concentration only affect the ocean close to the ice edge, thus a large memory is still retained of the ocean state after assimilation. This results in a model forecast slowly drifting towards the state before assimilation. Thus to further improve the model, observations of ocean parameters could be assimilated. This was verified by the RMSE values just after assimilation, where the ice chart assimilation gave an RMSE of 0.11 and the OSISAF assimilation 0.14, indicating the stronger influence of the ice chart observation, but most of this improvement was lost during the 7-day forecast.

5. CONCLUSION

With the increased model resolution, we show that there is an advantage to higher resolution observations. This paper provides an introduction to the assimilation of high-resolution ice charts into high resolution coupled ocean and sea-ice models. It is shown that the assimilation of ice charts has a larger impact than the assimilation of passive microwave observations, but without ocean update the improvements to the 7-day forecast is limited. In addition, we show that the assimilation of ice charts gives an improved model forecast compared to a model without assimilation.

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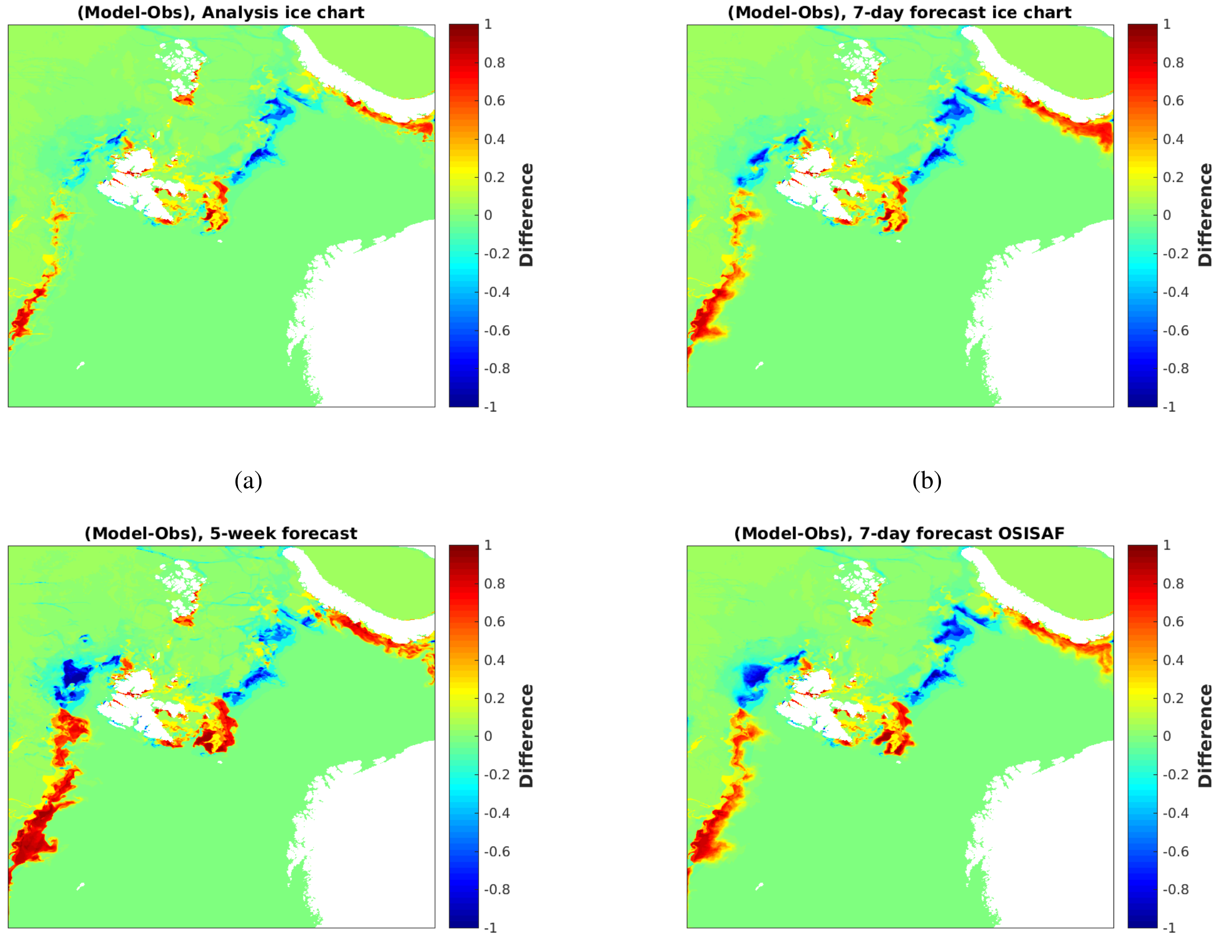

(a) (b)

(c) (d)

Fig. 3. All figures show ensemble average model sea-ice concentration output minus operational ice chart observations, where the observations are those shown in figure 1. The model outputs are a) Analysis result after ice chart assimilation on 24.04.2018. b) 7-day forecast result for the model with ice chart assimilation every 7th day on 24.04.2018, c) 6-week forecast of the model without assimilation on 24.04.2018, d) 7-day forecast result for the model with OSISAF assimilation every 7th day on 24.04.2018.

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