Overview of the CPC Sea Ice Initialization System (CSIS) and Its Use in Experimental Sea Ice Forecasting at the NOAA Climate Prediction Center

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1. Background

One of the key factors that affect sea ice prediction at the sub-seasonal to seasonal time scales is sea ice thickness (SIT). Unrealistic initial SIT is a major reason for erroneous sea ice prediction from the National Centers for Environmental Predictions (NCEP) operational Climate Forecast System version 2 (CFSv2, Saha et al. 2014), which is initialized from the NCEP Climate Forecast System Reanalysis (CFSR, Saha et al. 2010). The Climate Prediction Center (CPC) developed a reconfigured sea ice experimental forecast system (CPC Experimental) using initial SIT from the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, Lindsay and Zhang 2006), together with modifications of the model physics to reduce systematic forecast bias. This experimental configuration is further documented in Collow et al. (2015). CPC started producing seasonal sea ice predictions for a nine-month target period in March 2015 using the CPC Experimental configuration, which showed a substantial increase in skill compared to the operational version (CFS Operational) as shown in Fig. 1. Despite this improvement, there are two disadvantages in using the PIOMAS data to initialize our system, namely, i) inconsistency of the ocean model (PIOMAS and CFSv2 use different ocean models with different SIT categories that require interpolation) which causes large initial shock at the beginning of the forecast, and ii) reliance on an outside source for data which may delay the availability of the real-time forecast. As a result, CPC has developed an in-house sea ice analysis product for initializing sea ice outlooks, known as the CPC Sea ice Initialization System (CSIS). In this extended summary, we provide a description of the CSIS and its evaluation against PIOMAS, CFSR, and CryoSat-2 satellite retrievals.

2. The CPC Sea ice Initialization System (CSIS)

The CSIS sea ice analysis is produced with the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model version 5 (MOM5, Griffies 2012). The MOM5 is run starting on 1 January 2005, forced by prescribed atmospheric near surface fields from CFSR. The first year of model integration (2005) is considered spin-up, and starting in 2006, the model fields are used for hindcasts. Observational analyses of sea ice concentration (SIC) and sea surface temperature (SST) are assimilated daily following the approach of Lindsay and Zhang (2006). The assimilation of SIC uses a nudging method with the final values calculated as a weighted
average of values from observations and model integration. For each grid point with defined SIC, the nudging is calculated as follows:

\[
C'_{\text{mod}} = C_{\text{mod}} + K \times (C_{\text{obs}} - C_{\text{mod}})
\]

\[
K = \left[ |(C_{\text{obs}} - C_{\text{mod}})|^\alpha \right] / \left[ |(C_{\text{obs}} - C_{\text{mod}})|^\alpha + R_{\text{obs}}^2 \right]
\]

K denotes the weighting factor, \(C_{\text{obs}}\) and \(C_{\text{mod}}\) denote the grid cell SIC from the observations and model respectively, and \(C'_{\text{mod}}\) represents the nudged SIC value. \(\alpha\) is set to 1, giving most weight to the observations, and \(R_{\text{obs}}^2\), the error variance of observations, is set to 0.0025, consistent with Lindsay and Zhang (2006).

The MOM5 utilizes the GFDL Sea Ice Simulator, which contains five categories for representing SIT. Specifically, the categories are 0-0.1 m, 0.1-0.3 m, 0.3-0.7 m, 0.7-1.1 m, and greater than 1.1 m. SIC is first adjusted in the lowest thickness category. If needed, the residual difference is changed in the next lowest category and so on until the total amount changed equals the nudged value. Newly added sea ice is initially assigned a SIT of 0.30 m. Due to the constraint that the CSIS is to provide initial conditions for real-time forecasts, CFSR atmospheric forcing, National Centers for Environmental Information (NCEI) SST (Reynolds et al. 2007), and NASA Team SIC (Cavaliere et al. 1996, available at ftp://sidads.colorado.edu/DATASETS) are used as the data sources. Other datasets were tested experimentally, with the above configuration having ideal performance. Figure 2 provides an illustration of the CSIS assimilation process.

3. Assessment of SIT from CSIS

It is important to consider that SIT is not directly assimilated into CSIS; it is recomputed within the model based on the changes to SIC in the various thickness categories. For this reason, it is imperative to evaluate the SIT in CSIS against other datasets. Here, mean March 2011-2018 SIT from CSIS is compared with that from CFSR, PIOMAS, and CryoSat-2. Based on Fig. 3, spatial patterns of SIT in PIOMAS and CryoSat-2 are characterized by relatively large SIT to the north of Greenland and the Canadian Arctic Archipelago, and smaller SIT elsewhere throughout the Arctic. The CSIS produces a pattern similar to that in PIOMAS and CryoSat-2, although the sea ice over parts of the Beaufort Sea appears to be too thick. In contrary, there exists a large positive SIT bias in CFSR compared to PIOMAS and

![Fig. 2 Flow chart for CSIS integration](image)

![Fig. 3 March 2011-2018 mean SIT (m) from CSIS (top-left), PIOMAS (top-right), CFSR (bottom-left), and CryoSat-2 (bottom-right).](image)
CryoSat-2 over most of the Arctic. This bias contributed to the errors in sea ice prediction from CFS Operational, which was initialized from CFSR (Collow et al. 2015).

In addition to the mean bias, SIT errors in interannual anomalies also exist in CFSR. One example of SIT anomaly errors and its impact on sea ice forecasts is shown in Fig. 4. In May 2017, both PIOMAS (Fig. 4b) and CSIS (Fig. 4c) produced negative SIT anomalies over most of the Arctic regions, while SIT anomalies from CFSR (Fig. 4a) show a clear dipole pattern with positive anomalies in the Pacific side and negative anomalies in the Atlantic side. When used as initial conditions for the CFSv2, these May 2017 SIT anomalies result in dramatic differences in the forecast of July 2017 SIC. Forecasts of July SIC with both PIOMAS and CSIS May initial SIT (Figs. 4f, g) compared well with the NASA Team observational estimate (Fig. 4d). However, the forecast with CFSR initial SIT (Fig. 4e) failed to capture the observed pattern. Forecasts for shorter time scales (weeks 3 and 4) initialized from CSIS also significantly improve skill over that from operational CFS (not shown).

4. Summary

Experimental sea ice outlooks at NOAA CPC have greatly benefited from the use of initial sea ice conditions from PIOMAS. An in-house product, CSIS, was created at CPC to maintain consistency with the CFS forecast model, remove reliance on an outside source, and further improve on current sea ice reanalysis systems. CSIS produces similar results in terms of seasonal cycle and interannual skill as PIOMAS and is
substantially improved over CFSR. Starting in 2018, CSIS has been used to initialize CPC’s experimental seasonal and week 3-4 sea ice forecasts.

Evaluations of the CSIS have shown that (1) the SIT from CSIS is reasonable compared to the SIT from PIOMAS and CryoSat-2, and (2) initialization with the CSIS SIT results in much improved sea ice predictions compared to those from operational CFS. Of note is that the current version of CSIS does not assimilate any observed SIT. It is likely that the SIT accuracy in CSIS would further improve with the inclusion of observational SIT data in the initialization system.

References


