Science and Technology Infusion Climate Bulletin
NOAA's National Weather Service
41st NOAA Annual Climate Diagnostics and Prediction Workshop
Orono, ME, 3-6 October 2016

Verification of Experimental Sea Ice Forecasts at the NCEP Climate Prediction Center

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1. Background

In March 2015 the National Centers for Environmental Prediction (NCEP) Climate Prediction Center began issuing experimental sea ice outlooks to the National Weather Service (NWS) Alaska Region. These outlooks have been received favorably and continued through 2016. The motivation behind these outlooks was to improve the sea ice prediction in the Climate Forecast System Model Version 2 (CFSv2) (Saha *et al.*, 2014), which has too high of a predicted sea ice extent. By using a more observationally consistent dataset of initial sea ice thickness, namely from the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS) (Zhang *et al.*, 2003) produced by the University of Washington, a more accurate sea ice prediction compared to the operational model output was achieved.

2. Work flow

For each month, March through October, a 10 year hindcast was generated using 5 ensemble integrations for the 2005-2014 period. Each model simulation was initialized from the 8th through the 12th of the month at 00 UTC and integrated through 9 target months. This yielded a total of 50 model integrations per initial hindcast month. Next, model simulated means were taken for each target month and compared to observations from the National Aeronautics and Space Administration (NASA) Team dataset (Cavalieri *et al.* 1996; available at ftp://sidads.colorado.edu/DATASETS) to determine model biases. These biases were then removed from the real time forecasts, which were also initialized from the 8th through 12th of each initial month March through October, with four ensembles per day for a total of 20 realizations for each initial forecast month. The biases are calculated and removed for each individual variable discussed in the next section and the final bias corrected forecast is sent to the NWS Alaska Region.

3. Forecast parameters

3.1 Sea ice concentration

Sea ice concentration is directly output from CFSv2 and represents the percentage of a grid cell covered by sea ice. 100% represents full ice coverage and 0% denotes open ocean. Sea ice concentration yields information on a local scale and is important for planning shipping routes in addition to other operations of Arctic interest.

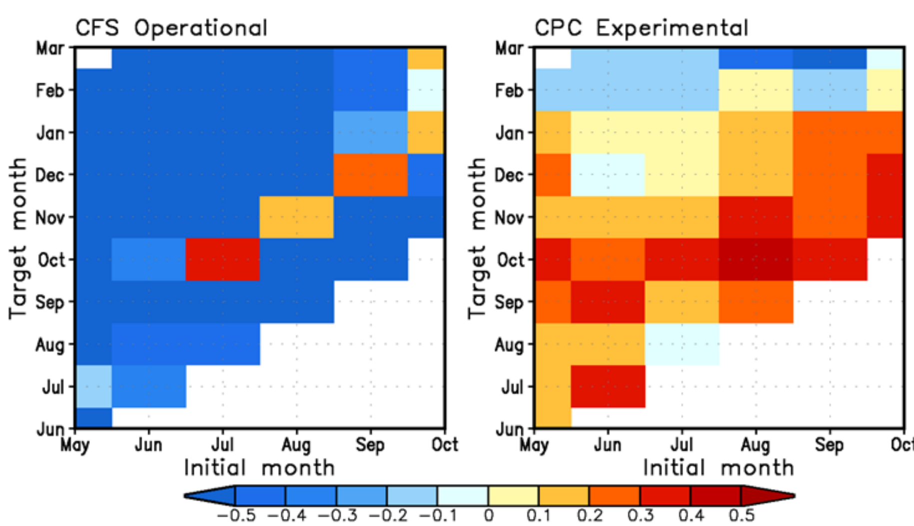

Fig. 1 Sea ice concentration Heidke skill scores for the 2015 forecasts. The x-axis denotes the initial month or the month that the model integration is started, and the y-axis denotes the target month or the month that is being forecasted.

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3.2 Sea ice extent

Sea ice extent is the areal coverage of sea ice across the Arctic. It is a cumulative value and does not yield information on a local scale. Sea ice extent is calculated by taking the sum of grid cells which have a sea ice concentration of 15% or greater in accordance with the definition published in the last IPCC assessment report (Vaughn *et al.*, 2013). Sea ice extent reaches its minimum in September before increasing during Arctic winter. The September sea ice extent value is of particular interest to many given its large downward trend since the 1980s, reaching a record low in 2012.

3.3 Sea ice probability

Sea ice probability is the percentage of ensemble members that have a sea ice concentration value greater than 15% in a particular grid cell, thus making it part of the calculated sea ice extent. Therefore if 10 out of 20 ensemble members have a sea ice concentration greater than 15%, then the sea ice probability value would be 50%.

3.4 First ice melt and ice freeze day

The final parameter in our experimental forecast package is the first calendar day of sea ice melt (IMD) and freeze (IFD), also termed retreat and advance. A summary of these variables and their importance can be found in Collow *et al.* (2016). IMD is defined as the first day in which a grid cell's sea ice concentration drops below 15% and IFD is defined as the first calendar day in which a grid cell's sea ice concentration increases above 15% during the following freeze season. Questions remain in terms of the method to define IMD and IFD, such as the proper melt/freeze threshold (15% is used here) or how long the state change should remain and how to accommodate marginal ice zones. IMD and IFD take sea ice concentration data a step further and can yield information locally on when a particular location will become free of ice (IMD) or become ice covered (IFD). While studying daily maps of sea ice concentration can deliver this information, it is much less time consuming to analyze a single map. Arctic stakeholders benefit greatly from knowing how long a particular location will remain ice free.

4. Verification

Experimental forecasts were verified for 2015 and 2016 using data from NSIDC. The NSIDC sea ice index is used to verify sea ice extent while the NASA Team real time sea ice concentration is used to verify sea ice concentration and sea ice retreat/advance days. For sea ice concentration, the experimental forecasts have skill much higher than the operational product, as shown by the Heidke skill scores in Figure 1. The experimental CFSv2 shows generally positive skill scores versus negative scores for the operational model.

Sea ice extent is also shown to have greater skill in the experimental model versus the operational model (see Collow *et al.*, 2015 for an extensive analysis of hindcasts). For the 2015 forecasts, the root mean square error was about $0.3 * 10^6$ km^2 for all target months in the experimental forecasts but varied greatly for the

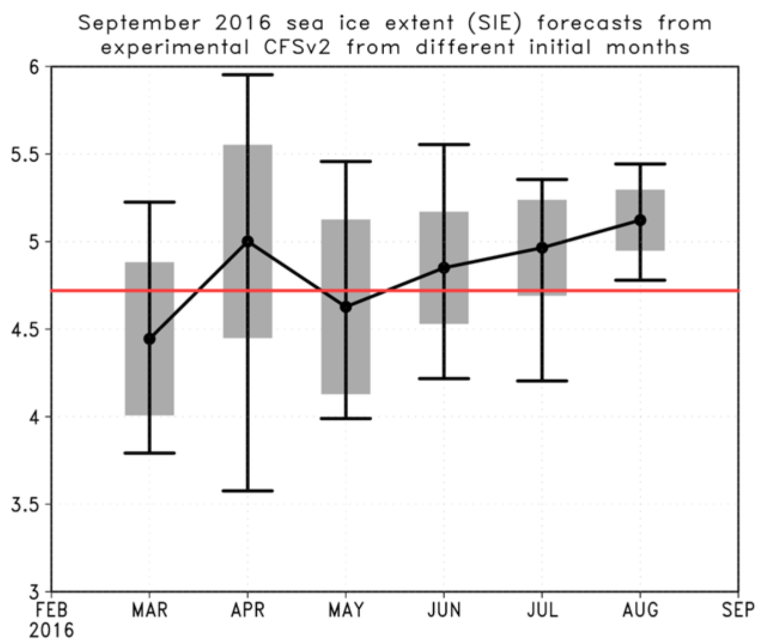

Fig. 2 September 2016 sea ice extent (10^6 km^2) forecast and verification for initial months beginning in March 2016. The x-axis denotes the initial month and the y-axis the sea ice extent. The black dot for each initial month represents the 20 member ensemble mean, the gray shading shows +/- 1 standard deviation from the mean, and the black error bars show the max and min out of all ensemble members. The horizontal red line denotes the observed September sea ice extent from NSIDC ($4.72 * 10^6$ km^2).

operational model with values as high as 1.2 $*10^6$ km^2. Figure 2 shows the prediction of September 2016 sea ice extent for initial months starting in March. Although ensemble uncertainty is much higher in March-May, less uncertainty exists starting in June that the 2016 sea ice extent would not be a record low. Sea ice extent achieved record low values in early 2016 which led many research groups to predict that the September minimum would set a new record (https://www.arcus.org/sipn). However, a reversal of atmospheric conditions to cool and stormy during the summer slowed the rate of sea ice melt and as a result the September minimum was much higher than the 2012 record low and closer to our experimental forecasts. This illustrates an important point regarding atmospheric variability, which is impossible to predict several months ahead of time and that enough ensemble members are necessary to provide a range of all possible outcomes, especially for longer time spans.

Finally, first IMD verification for March 2016 initialized forecasts for the 2016 melt season is shown in Figure 3. Generally the experimental forecast provided a good prediction of IMD over most regions, although there is some noise due to atmospheric uncertainty as previously discussed. For example, the Beaufort Sea had exceptionally early melt in 2016, which was not predicted by the model. However, standard deviation values were higher in this region than in the Bering Strait indicating there was more predicted uncertainty in the Beaufort Sea. The mean absolute error over the plotted domain in the bottom right panel (145° - 185°W, 50° -75°N) is 15 days, with a large number of points with an absolute error of less than 10 days in the Bering Strait. Not shown here, IFD prediction for the 2015-2016 freeze season based on September 2015 initialized forecasts had a mean absolute difference of 18 days over the same region. Most of the errors were in the southern part of the Bering Strait. Most regions in the Bering Strait and northward had generally lower biases and better prediction (using a region from 65° - 75°N, yielded a mean absolute error of only 10 days).

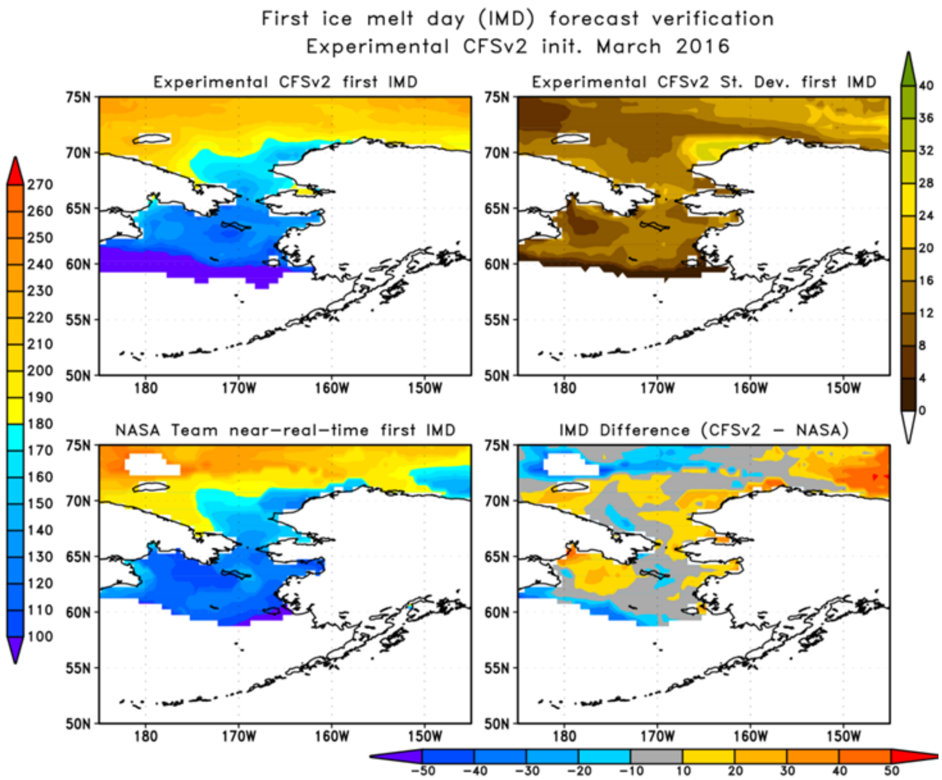

Fig. 3 First sea ice melt day (IMD) for 2016 (units are calendar day of the year), top left: experimental CFSv2 ensemble mean first IMD, top right: experimental CFSv2 first IMD standard deviation of all ensemble members, bottom left: observed first IMD from NASA Team, bottom right: difference between the experimental CFSv2 prediction and NASA Team.

5. Conclusion

As demonstrated experimental sea ice forecasts issued at the Climate Prediction Center are providing beneficial data to stakeholders in the Arctic and have verified better than the operational counterpart. The plan is to continue with experimental products in 2017, while also preparing to provide forecasts of week 3-4 sea ice. Also ongoing is the testing of new oceanic vertical resolutions and the development of a new in-house sea ice thickness dataset which will be used to initialize the CFSv2 model at a later time.

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