Final Report on CICE Testing for NGGPS

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Introduction

A NGGPS Sea Ice Modeling Workshop organized by the Global Model Test Bed (GMTB) took place in Boulder, Colorado in February 2016 to make recommendations on the sea ice component to be used in the NCEP Unified Global Coupled System (UGCS), currently being developed under the auspices of the National Oceanic and Atmospheric Administration (NOAA) Next-Generation Global Prediction System (NGGPS). As described in the workshop's final report (link), given that the use of a community-contributed and supported model in UGCS was raised as a priority for model selection, participants recommended the tentative adoption of The Los Alamos Sea Ice Model (CICE; Hunke and Lipscomb 2008), pending follow-up testing and addressing concerns raised regarding model governance and differences in staggering between the grids used in the UGCS ocean models and CICE. A test plan (link) was devised jointly by GMTB, EMC, the workshop committee and interested workshop participants, and involved experiments over a one year period, in a standalone framework, forced by atmospheric and oceanic fields from the NCEP operational Climate Forecast System version 2 (CFSv2). GMTB conducted the model runs, and evaluation was performed jointly by GMTB, EMC, and ESRL.

Testing framework

The CICE experiments followed the global configuration used by Hebert et al. (2015), except for the following three changes made to make the tests most relevant for NGGPS:

1. The newest version of CICE (V5.1.2) was used instead of V4.0 used in Hebert et al. (2015); both the code structure and the state variables are similar in these two versions. CICE V5.1.2 includes a number of new physics options such as the mushy-layer thermodynamics and two new melt pond parameterizations. V5.1.2 is available at http://oceans11.lanl.gov/svn/CICE/tags/release-5.1.2;

2. The atmospheric forcings were from CFSv2 6-hour forecasts instead of NAVGEM;
3. CICE was run in standalone mode, so an active ocean model was not employed. Ocean boundary conditions were derived from CFSv2.

We decided to postpone utilizing the NOAA Environmental Modeling System (NEMS) mediator outlined in the test plan. This was due to limits on time and manpower for conducting the test, as well as to reports received from the group working on the development of a new version of the Climate Forecast System (CFSv3). These reports stated that, at the time, there were both technical and scientific issues related to the mediator that need to be addressed before it could be used with CICE.

Model Setup

The test plan called for 15-day-long simulations initialized twice per month. However, during the course of this work, we found the model error to be relatively small in most seasons. Therefore, we decided to extend the integration time to one month to expose model biases, and initialized the model on the 1st day of each month in the year 2015. The CICE model runs on a global domain with a tri-polar horizontal mesh as seen in Fig. 1 of Bleck and Sun (2004). The initial conditions for CICE, including the ocean and sea ice states, were derived from CFSv2. The prescribed atmosphere and ocean boundary conditions (forcings) were 6-hourly CFSv2 data (downloaded from http://rda.ucar.edu/datasets/ds094.0), specifically the following 12 fields:

- 10-m wind components, 2-m temperature and specific humidity, precipitation, and surface radiation (both shortwave and longwave);
- Surface ocean currents, sea surface temperature (SST) and salinity, and mixed layer depth.

The goal of NGGPS is to improve forecast accuracy for lead times ranging from a few hours to one month, using model configurations with horizontal resolutions between 1 and 100 km. Because the sea ice model component of NGGPS needs to be robust across this broad range of spatial and temporal scales, we tested CICE at both a coarse resolution (~30 km at the North Pole; Phase 1) and a finer resolution (~15 km at the North Pole; Phases 2 and 3).

Experiments

The experiment had three phases as described in Table 1, with varying model resolution and ways of initializing the atmosphere and ocean fields, as well as of constraining the SST.

Table 1. CICE model resolution at the pole (km), dataset for atmospheric initialization and forcing, dataset for ocean initialization, and method/dataset for ocean forcing.

		CICE	Atmos Init and Forcing	Ocean Init	Ocean Forcing
Phase	1	30 km	CFSv2 1.0^{0}	CFSv2 1.0^{0}	CFSv2 1^{0} 6-hourly forcing
	2	15 km	CFSv2 0.2^{0}	CFSv2 0.5^{0}	CFSv2 0.5^{0} 6-hourly forcing
	3	15 km	CFSv2 0.2^{0}	CFSv2 0.5^{0}	Freely evolving

Phase 1:

We carried out CICE simulations at a horizontal resolution of ~120 km at the equator, ~30 km at the North Pole, with CFSv2 forcings at 1° horizontal resolution (from the website listed above). The forcings were interpolated onto the CICE grid. Every 6 hours during the integration, an updated set of CFSv2 forcings was prescribed to CICE.

The initial test was done with a standalone CICE and prescribed atmospheric and oceanic boundary conditions. CICE needs to operate with either an ocean model or its own mixed layer model. We chose the latter for this project.

Phase 2:

This set of experiments is similar to Phase 1, except for the higher resolution, both for the CICE model (~60 km at the equator, ~15 km at the North Pole) and the forcings prescribed (the highest CFSv2 resolution available: 0.2° for atmosphere and 0.5° for ocean). The forcings were interpolated onto the CICE grid.

Phase 3:

The test plan only called for the Phase 1 and 2 experiments. However, during the course of the experiment, we found the SST forcing from CFSv2 is not adequate to drive the sea ice model (as shown below), prompting us to run an additional ("Phase 3") set of experiments in which SST was allowed to evolve freely in the model as predicted by the CICE mixed layer model (resolution and all other forcings were as in Phase 2).

Results

In all phases, we saved (on theia: /scratch3/BMC/fim/sun/CICE_results_final) daily-averaged fields including sea ice concentration, thickness, velocity, surface temperature, and melting rate.

Fig. 1 shows the CICE-forecasted for Phases 1 and 2 ice extents in the Northern and Southern Hemispheres, for all 12 months of 2015, along with the CFSv2 initial conditions at the beginning of each month. Generally speaking, both the 30-km and 15-km forecasts at the end of the month-long integrations agree well with the CFSv2 initial conditions at the beginning of the next month, indicating a very good forecast for the end of the month. The major exceptions are in the summer seasons of both hemispheres, when excessive melting occurs.

The widespread summertime melting in the Northern Hemisphere during the month-long integration is further illustrated in Fig. 2, which compares ice area between CFSv2 initial conditions and the 31-day 15-km simulation from CICE (initialized July 1, 2015) -- both valid August 1, 2015.

The cause of this excessive melting can be seen in Fig. 3, which shows the three components of simulated ice melt: top, basal, and lateral. It is obvious from Fig. 3 that basal melting is the dominant process. This led us to hypothesize that there could be a bias in the prescribed CFSv2 SST. Fig. 4 shows the difference between that field and the optimum interpolation (OI) SST v2 (Reynolds et al. 2002) on August 10, 2015, as an example. SST from CFSv2 appears to be warmer than OI SST v2 under ice.

Since the CFSv2 SST dataset does not seem to be adequate as a forcing for the CICE model (we doubt the 6-hour forecast SST is in full equilibrium with the ocean and ice state; addressing this issue is beyond the scope of this study), we decided to allow the CICE mixed layer model to evolve SST freely rather than use 6-hourly SST forcings from CFSv2. As described above, these “Phase 3” runs are otherwise identical to “Phase 2”. Letting CICE control mixed-layer temperature results in a more realistic ice extent compared to Phase 2 during the summer months, as shown in Fig. 5. This confirms that a large part of simulation error comes from the SST forcings.

Fig. 6 shows the concentration bias and RMS, probability of detection, false alarm rate, false confidence rate and correct rate for ice extent in NH in all 3 phases of CICE simulations, compared against the NCEP operational analysis at 1/12° resolution. The model skill varies with season, from the lowest skills during the summer months to very decent ones in the rest of the year, which is consistent with the previous analysis.

Summary

We have carried out the proposed experiments of testing the CICE sea model in stand-alone mode, forced by atmospheric and oceanic fields from CFSv2. The experiments were month-long, initialized at the beginning of each month during the year 2015 with CFSv2 initial conditions. We tested the model at 2 different horizontal resolutions.

Comparing to CFSv2 data, the ice extent after a month-long integration is very close to the observed one in all seasons except for summer, when excessive basal melting occurs. This is the case in both hemispheres and at both coarse and fine horizontal resolutions.

The excessive basal melting is strongly related to a warm bias in the prescribed SST from CFSv2. In a follow-up experiment in which we allowed CICE to freely evolve the SST, the resulting ice extent turned out much closer to analysis than in the original planned experiments.

Overall, considering various errors in the forcing fields, and through an attempt to eliminate the impact of prescribed SST, we find that ice extent forecast skill from CICE in multiple month-long forecasts during the year 2015 is consistent with other CICE studies (e.g., Hebert et al. 2015, Metzger et al. 2014).

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References

Bleck, R. and S. Sun, 2004: Diagnostics of the oceanic thermohaline circulation in a coupled climate model, Global and Planetary Change, 40, 233-248.

Grumbine, R., 2013: Long Range Sea Ice Drift Model Verification MMAB Tech Note 315, 22 pp.

Hebert, D. A., R. A. Allard, E. J. Metzger, P. G. Posey, R. H. Preller, A. J. Wallcraft, M. W. Phelps, and O. M. Smedstad, 2015: Short-term sea ice forecasting: An assessment of ice concentration and ice drift forecasts using the U.S. Navy's Arctic Cap Nowcast/Forecast System, J. Geophys. Res. Oceans, 120, doi:10.1002/2015JC011283.

Hunke, E., and W. Lipscomb, 2008: CICE: The Los Alamos Sea Ice Model documentation and software user's manual version 4.0, Tech. Rep. LA-CC-06-012, Los Alamos Natl. Lab., Los Alamos, N. M.

Metzger, E., and 12 co-authors, 2014: US Navy operational global ocean and Arctic ice prediction systems, Oceanography, 27(3), 32–43.

Reynolds, R.W., N.A. Rayner, T.M. Smith, D.C. Stokes, and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. J. Climate, 15, 1609-1625.

Sun, S., A. Solomon, R. Grumbine and J. Intrieri, 2017: 30-day hindcast experiments with the uncoupled CICE ice model. AMS annual meeting, Seattle WA.

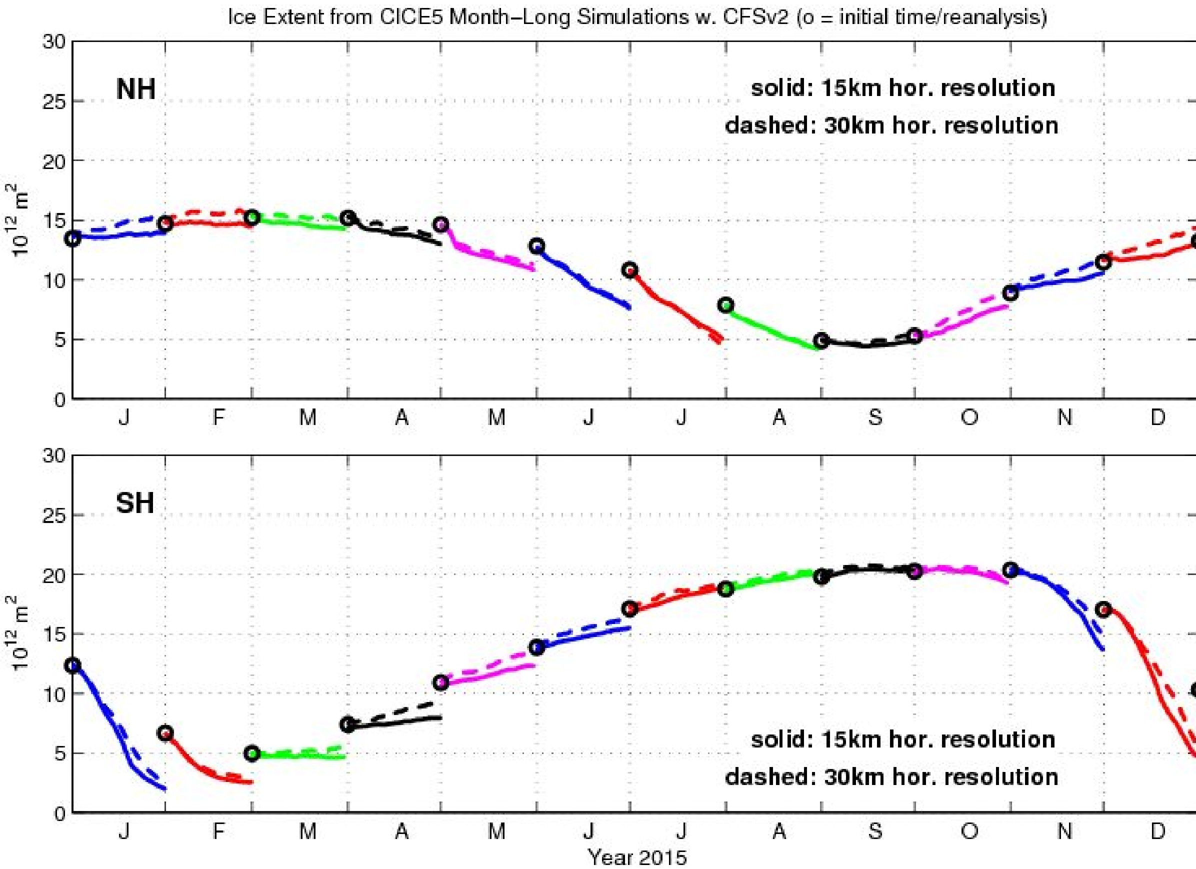

Fig.1: Ice extent (10^{12} m^2) during month-long integrations at 15-km (solid) and 30-km (dashed) horizontal resolution in the Northern hemisphere (top) and Southern hemisphere (bottom). "o" marks the initial conditions from CFSv2 at the beginning of each month.

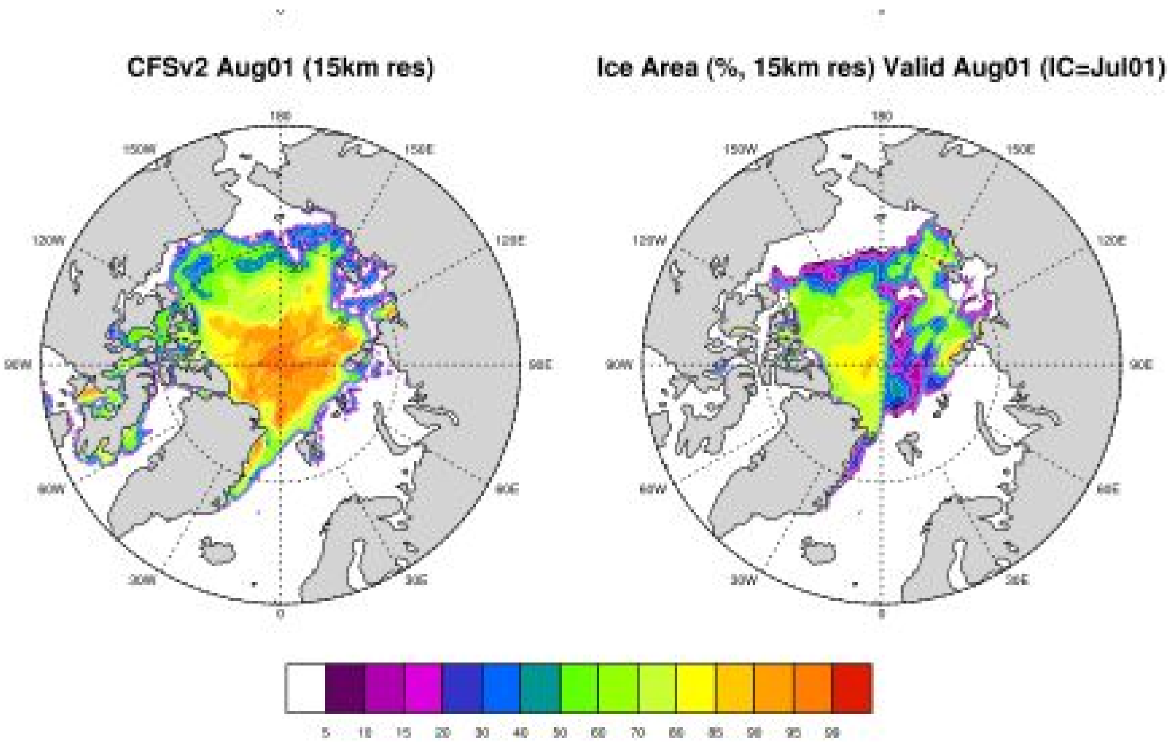

Fig.2: Ice area (%) on August 1, 2015. Left: CFSv2 initial condition; Right: 15-km CICE simulation at one month lead time.

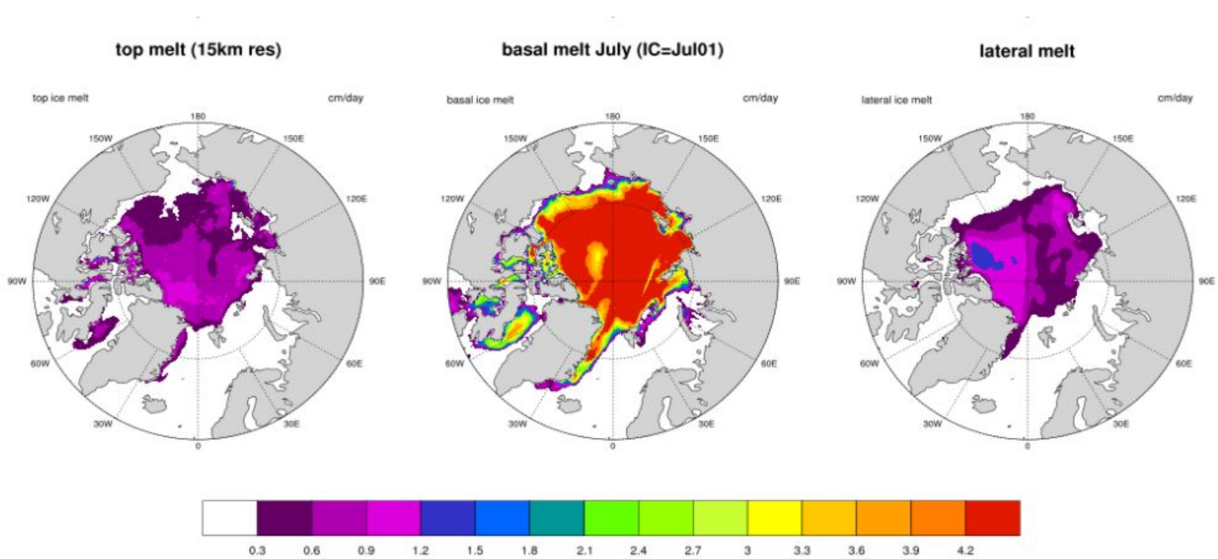

Fig.3: Ice melt (mm day^{-1}) from top, base and lateral (left to right) during the 1-month integration starting on July 1, 2015.

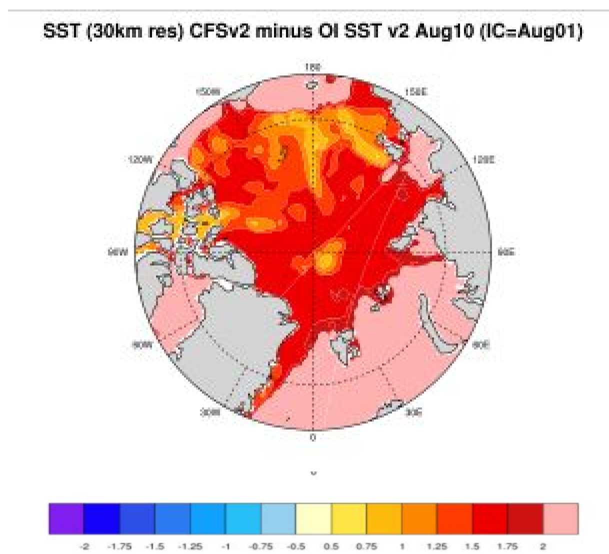

Fig. 4: Difference in SST (°C) between the CFSv2 analysis and OI SST v2, on August 10 2015.

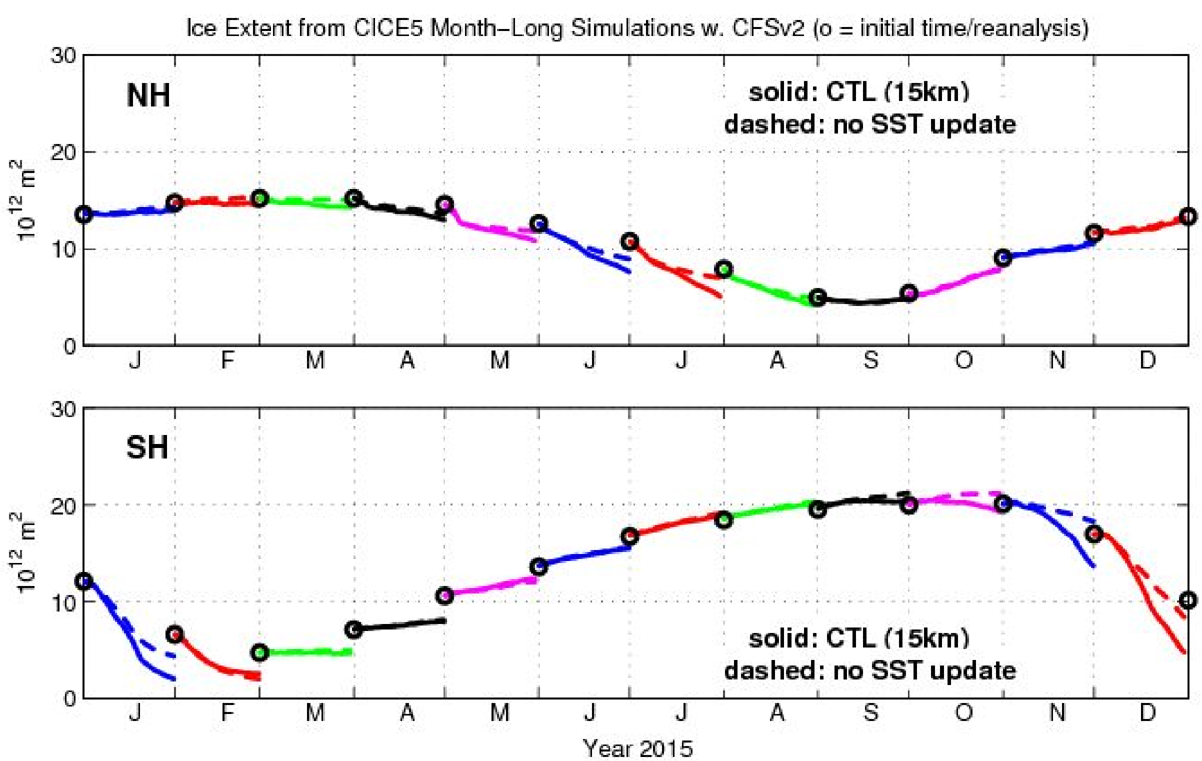

Fig. 5: Ice extent (10^{12} m^2) from CICE experiments with freely-evolving SST (Phase 3, dashed), and its comparison with the 15-km control runs (Phase 2, solid as shown in Fig.1).

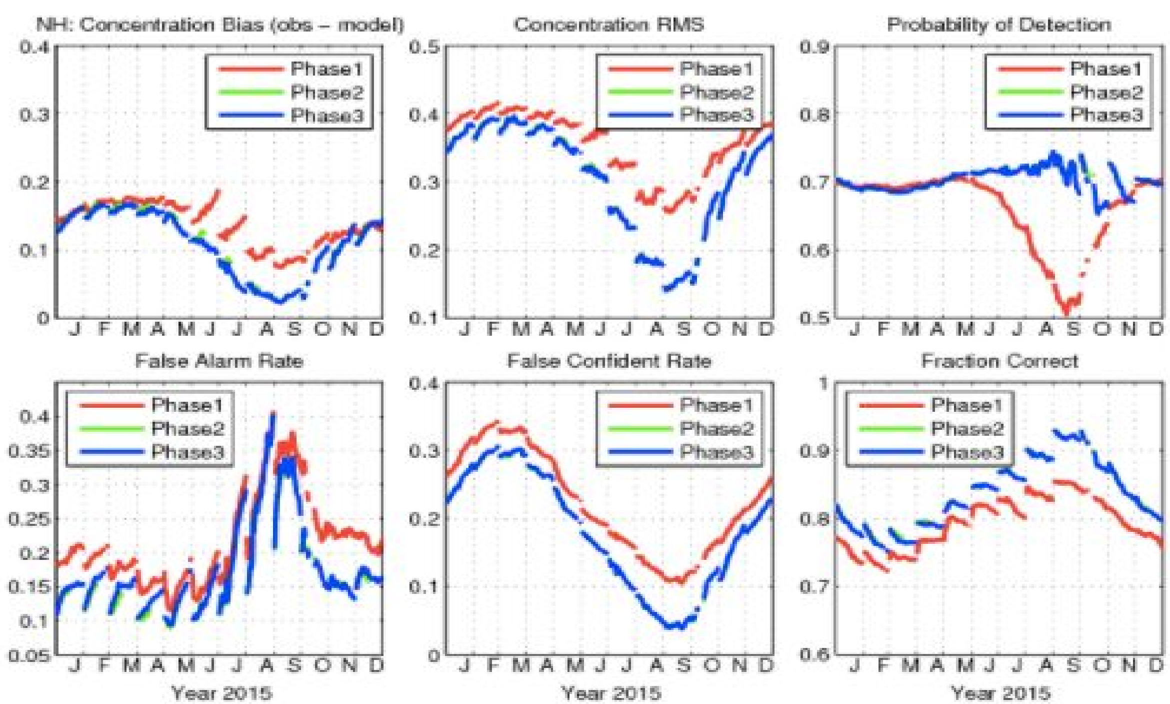

Fig. 6: Top row: concentration bias, concentration RMS, and probability of detection. Bottom row: false alarm rate, false confidence rate and correct rate. All results are for ice extent in NH in each of the three phase sof the experiment, based on the NCEP operational ice extent analysis (1/12°).