Global Ocean Forecast System (GOFS) end of summer 2014 Ice Extent Projection – August Report

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Executive Summary

The Global Ocean Forecast System (GOFS) 3.1 was run in forecast mode without data assimilation, initialized with a July 1, 2014 analysis, for ten simulations using archived Navy atmospheric forcing fields from 2004-2013. The mean minimum ice extent in September, averaged across all ensemble members and corrected for forward model bias is our projected ice extent. The GOFS 3.1 outlook for September minimum ice extent is 4.5 $Mkm^2 \pm 0.3$ Mkm^2.

Rationale

The Global Ocean Forecast System (GOFS) 3.1 was run in forecast mode without data assimilation, initialized with a July 1, 2014 analysis, for ten simulations using archived Navy atmospheric forcing fields from 2004-2013. The mean minimum ice extent in September, averaged across all ensemble members and corrected for forward model bias is our projected ice extent. The standard deviation across the ensemble ice extents is an estimate of the uncertainty of our projection given the unknown atmospheric conditions that will occur this summer. Please note, this is a developmental model that has not been fully validated in non-assimilative mode, but the assimilative system has been validated to provide an accurate 7 day ice forecast.

Introduction

GOFS 3.1 is a global coupled ice-ocean model that assimilates passive microwave ice concentration daily and is run with a horizontal resolution of approximately 3.5 km near the

North Pole. It was developed by the Oceanography Division of the Naval Research Laboratory to produce 7 day forecasts of the global ocean including the Arctic and Antarctic sea ice states. This system is scheduled to be transitioned to the Naval Oceanographic Office by the end of summer 2014. The system is configured and validated for its capability in producing an accurate 7 day sea ice forecast. The results presented in this report come with a 'health warning' that they are preliminary and additional work is required in validating the capability of this model for seasonal projections.

For the last few years, NRL has submitted a minimum ice extent estimate using the Arctic Cap Nowcast/Forecast System (ACNFS) (Posey et al., 2010; Metzger et al., 2014). GOFS and ACNFS have ~3.5 km resolution in the Arctic with ACNFS being an exact subset of GOFS in the Arctic region. Both forecast systems use similar ice and ocean components (see description below) and differ in the following manner: 1) the GOFS hindcast started from more realistic initial conditions (primarily a better ice thickness) than ACNFS, 2) GOFS assimilates ice concentration data across the full Arctic domain (not just along the ice edge as in ACNFS), 3) GOFS uses an up-to-date and improved version of the ocean model code, and 4) GOFS applies a monthly varying heat flux offset to CICE in an attempt to improve ice forecast skill.

For the August report, NRL is submitting two minimum September ice extents to the Sea Ice Outlook; one estimate from GOFS and one from ACNFS.

The Global Ocean Forecast System 3.1

The Navy's operational GOFS 3.0 (Metzger et al., 2014a) system uses a simple thermodynamic sea ice model and has not been used for Arctic ice minimum projections/estimates. It will be replaced by GOFS 3.1 within the next year.

The GOFS 3.1 ocean component is the HYbrid Coordinate Ocean Model (HYCOM) (Metzger et al. 2008, 2010), and is coupled to the Los Alamos National Laboratory Community Ice CodE (CICE) (Hunke and Lipscomb 2008) via the Earth System Modeling Framework (ESMF). The ocean and ice models are run in an assimilative cycle with the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings and Smedstad, 2013). The system is run once per day, assimilating SSMIS ice concentration into CICE to provide an initial condition for a 7 day forward model run (the forecast). Atmospheric forcing for all ensemble members used in the minimum extent estimate is provided by the Navy Operational Global Atmospheric Prediction System (NOGAPS) (Hogan et al. 1991).

Additional information on GOFS 3.1 and its performance is currently being documented and will be available by end of 2014 (Metzger et al., 2014b).

Ensemble Model Runs for End of Summer Projection

The seasonal projection was made using an ensemble of forward model simulations. Ten model runs were made, using NOGAPS forcing from 2004-2013. Each model run was initialized with the same assimilative analysis field from July 1, 2014 (Fig. 1), and run forward for 3 months from July 1 for each specific year.

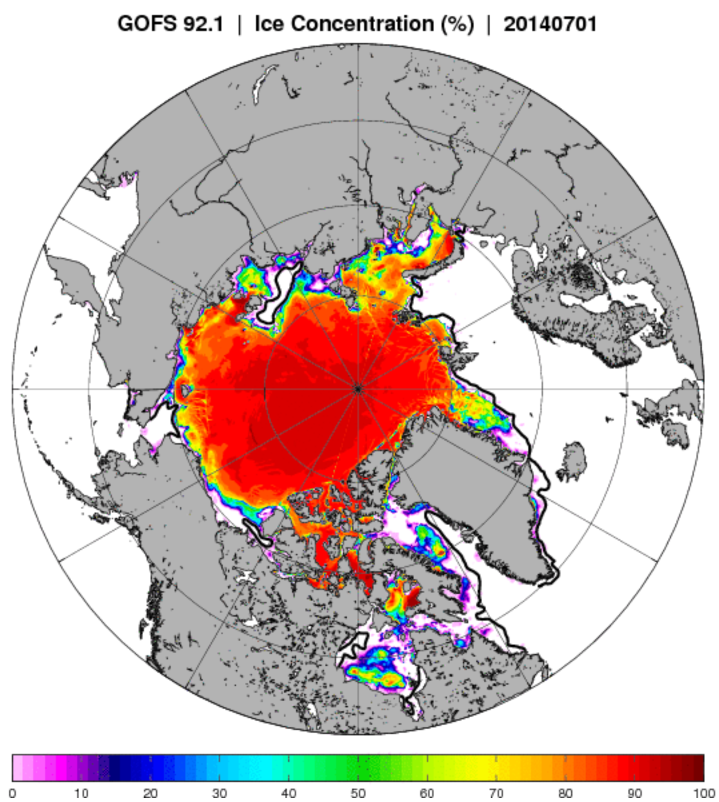

Figure 1: Ice concentration field (%) from GOFS 3.1 valid July 1, 2014. This is the initial condition for each ensemble member. The black line on the figure represents the independent ice edge provided in real time by the National Ice Center.

This ensemble of ten members gives an indication of how sea ice can respond to variable atmospheric conditions during summer. Fig. 2 shows examples of ice concentration for two extreme ensemble members.

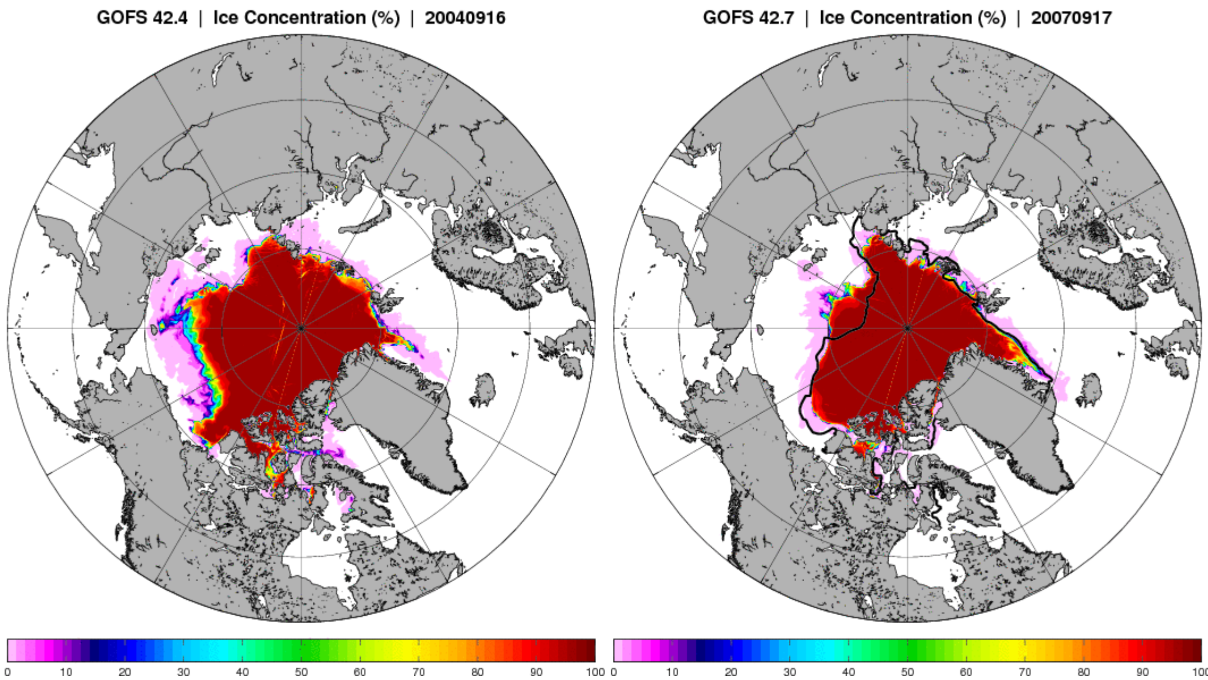

Figure 2: GOFS 3.1 ice concentration (%) on September 16, 2004 (left) and September 17, 2007 (right). The black line on the figure (on right) represents the independent ice edge provided in real time by the National Ice Center. These two simulations have the largest and smallest projected minimum ice extents out of the ten ensemble members, respectively.

Ice extent was calculated using all grid cells with at least 15% ice concentration. Averaging the September minimum from each ensemble member yields a minimum extent of 4.9 Mkm^2, with a standard deviation of 0.3 Mkm^2. The ensemble appears to be doing a reasonable job of reproducing variability due to uncertainty in atmospheric forcing. The extent estimate, however, is high. We have applied a bias correction to our outlook to account for this. As GOFS 3.1 has been run in assimilative mode since July 2011, the analysis fields from this hindcast are used to identify forward model biases in mean September ice extent. GOFS 3.1 has demonstrated good skill at predicting ice extent, hence it is reasonable to use the assimilative run analysis fields as 'truth' for our bias correction estimate.

A set of control runs for 2011 through 2013 were performed using the July 1 analysis for initial conditions. Comparing the mean September extent from the control runs to that of the GOFS 3.1 analyses, an estimate of the forward model bias is -0.4 Mkm^2. Compared to ACNFS, the bias is smaller due to the improvements noted in the "Introduction" section; however, it has been calculated over fewer years (three in GOFS 3.1 vs. seven in ACNFS) and is less certain. As seen in Fig. 3, there is a spread in September minimum ice extent among the bias-corrected ensemble members. The mean of these values, 4.5 ± 0.3 Mkm^2, represents the projected minimum ice extent for September 2014.

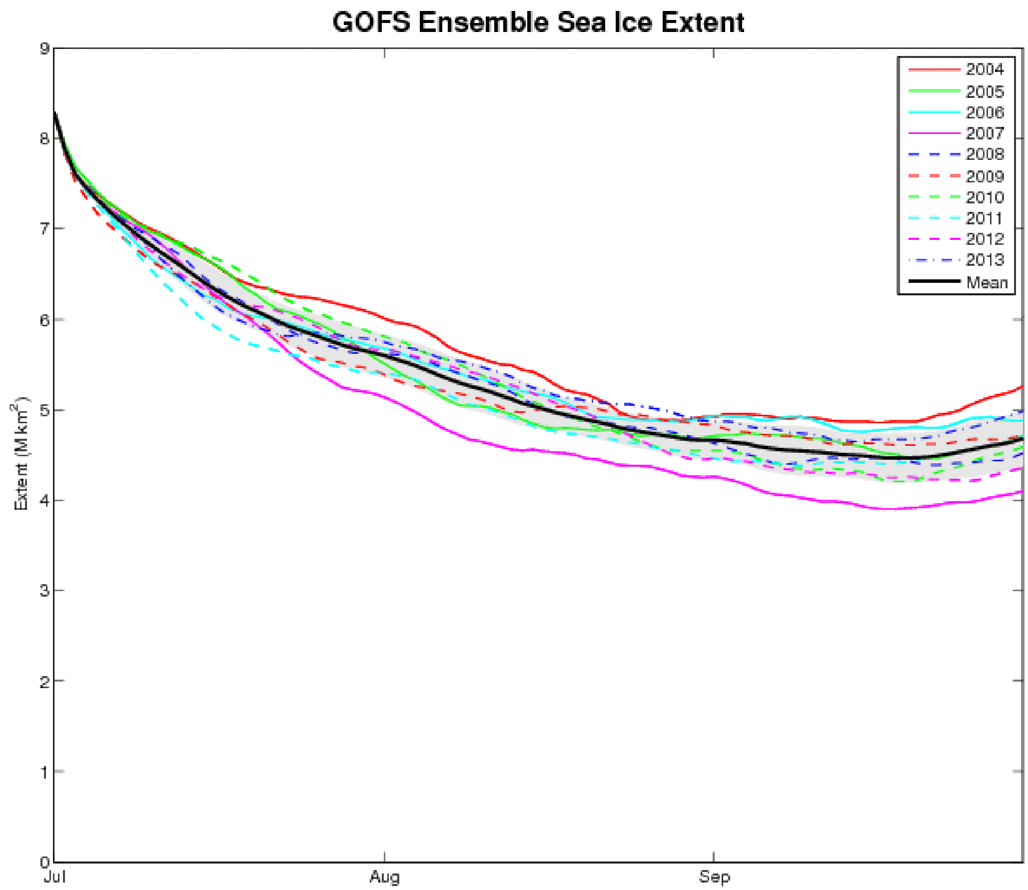

Figure 3: Time series of bias-corrected ice extent for each ensemble member. Black line represents the ensemble mean ice extent with the predicted September minimum of 4.5 ± 0.3 Mkm^2. The shaded area (± 1 standard deviation) denotes the variability during the June-Sept time period.

Also included (Fig. 4) is the spatial forecast map for the predicted minimum ice extent from GOFS 3.1 valid 19 September 2014.

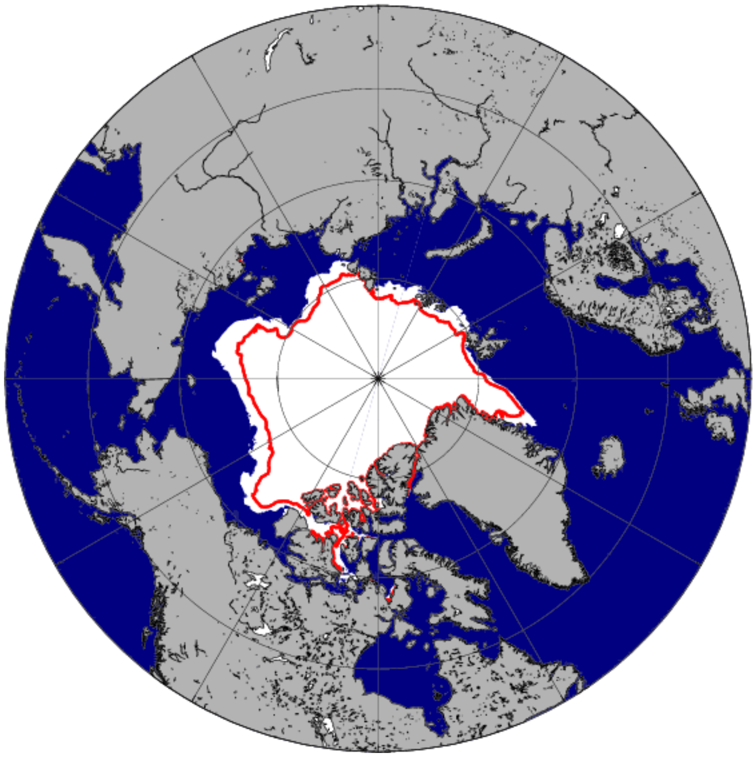

Figure 4: Spatial forecast map of the projected GOFS 3.1 September minimum ice extent for 19 Sept 2014. White area indicates ice concentrations > 15% in the uncorrected simulation. The red line represents the bias-corrected predicted ice extent of 4.5 Mkm^2. This represents the 55% concentration isoline.

References

Cummings, J.A. and O.M. Smedstad (2013). Variational data assimilation for the global ocean. In Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications (Vol. II). S.K. Park and L. Xu, eds., Springer-Verlag, Berlin, Heidelberg, http://dx.doi.org/10.1007/978-3-642-35088-7_13.

Hunke, E.C. and W. Lipscomb (2008). CICE: The Los Alamos Sea Ice Model, Documentation and Software User's Manual, Version 4.0. Los Alamos Technical Report, LA-CC-06-012, Los Alamos National Laboratory, Los Alamos, NM.

Metzger, E.J., O.M. Smedstad, P.G. Thoppil, H.E. Hurlburt, J.A. Cummings, A.J. Wallcraft, L. Zamudio, D.S. Franklin, P.G. Posey, M.W. Phelps, P.J. Hogan, F.L Bub and C.J. DeHaan (2014a). US Navy Operational Global Ocean and Arctic Ice Prediction Systems. *Oceanography*, Vol. 27, No. 3 – special issue on Navy Operational Modeling, (in press).

Metzger, E.J., P.G. Posey, P.G. Thoppil, T.L. Townsend, A.J. Wallcraft, O.M. Smedstad, D.S. Franklin, L. Zamudio and M.W. Phelps (2014b). Validation Test Report for the Global Ocean Forecast System 3.1 – 1/12° HYCOM/NCODA/CICE. Naval Research Laboratory Technical Report, NRL/MR/7320—14-????, Stennis Space Center, MS. (In preparation.)

Metzger, E.J., O.M. Smedstad, P.G. Thoppil, H.E. Hurlburt, D.S. Franklin, G. Peggion, J.F. Shriver, A.J. Wallcraft (2010). Validation Test Report for the Global Ocean Prediction System V3.0 - 1/12° HYCOM/NCODA Phase II. Naval Research Laboratory Technical Report, NRL/MR/7320—10-9236, Stennis Space Center, MS.

Metzger, E.J., H.E. Hurlburt, A.J. Wallcraft, J.F. Shriver, L.F. Smedstad, O.M. Smedstad, P. Thoppil and D.S. Franklin (2008). Validation Test Report for the Global Ocean Prediction System V3.0 – 1/12° HYCOM/NCODA Phase 1. Naval Research Laboratory Technical Report, NRL/MR/7320—08-9148, Stennis Space Center, MS.

Posey, P. G., E. J. Metzger, A. J. Wallcraft, R.H. Preller, O. M. Smedstad, M. W. Phelps (2010). Validation of the 1/12° Arctic Cap Nowcast/Forecast System (ACNFS), Naval Research Laboratory Technical Report, NRL/MR/7320—10-9287, Stennis Space Center, MS.