GFDL Contribution to the September 2016 Sea Ice Outloook: June Report

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Note: This is an experimental prediction and is not an official NOAA forecast

1 Core sea ice outlook requirements

1. *Name of Contributor or name of Contributing Organization and associated contributors as you would like your contribution to be labeled in the report (e.g., Smith, or ARCUS (Wiggins et al.)).

   GFDL/NOAA, Bushuk et al.

   1b. (Optional but helpful for us): Primary contact if other than lead author; name and organization for all contributors; total number of people who may have contributed to your Outlook, even if not included on the author list.

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2. * Contributions submitted by a person or group not affiliated with a research organization, please self-identify here:
   ___Yes, this contribution is from Citizen Scientists.

3. * Do you want your contribution to be included in subsequent reports in the 2016 season?

   ___Yes, use this contribution for all of the 2016 SIO reports (this contribution will be superseded if you submit a later one).
   __X_ No, I/we plan to submit separate contributions for subsequent reports.
   ___ No, I only want to participate this time.

4. * "Executive summary" of your Outlook contribution: in a few sentences (using 300 words or less) describe how and why your contribution was formulated. To the extent possible, use non-technical language.

   Our June 1 prediction for the September-averaged Arctic sea-ice extent is 4.55 million km^2, with an uncertainty range of 3.86-4.94 million km^2. Our prediction is based on the GFDL-FLOR ensemble forecast system, which is a fully-coupled atmosphere-land-ocean-sea ice model initialized using a coupled data assimilation system. Our prediction is the bias-corrected ensemble mean, and the uncertainty range reflects the lowest and highest sea ice extents in the 12-member ensemble.

5. *Type of Outlook method:

   __X_dynamic model ___statistical___heuristic ___mixed or other (specify)

6. *Dataset of initial Sea Ice Concentration (SIC) used (include name and date; e.g., NASA Team, May 2016):

   No SIC data is explicitly used in our initialization procedure.

7. Dataset of initial Sea Ice Thickness (SIT) used (include name and date):

   No SIT data is explicitly used in our initialization procedure.

8. If you use a dynamical model, please specify:

   a) Model name: **GFDL-FLOR**

   b) Information about components, for example:

Component	Name	Initialization (e.g., describe Data Assimilation)
Atmosphere	**AM2.5**	**AMIP run forced with observed SST/sea ice**
Ocean	**MOM4**	**EnKF coupled data assimilation**
Sea Ice	**SIS1**	**EnKF coupled data assimilation (no ice data assimilated)**

   c) Number of ensemble members and how they are generated:

   12 ensemble members are generated from GFDL's ensemble Kalman filter (EnKF) coupled data assimilation system, which covers the period from 1960 to present.

   d) For models lacking an atmosphere or ocean component, please describe the forcing:

9. *Prediction of September pan-Arctic extent as monthly average in million square kilometers. (To be consistent with the validating sea ice extent index from NSIDC, if possible, please first compute the average sea ice concentration for the month and then compute the extent as the sum of cell areas $\geq$ 15%.)

   4.55 million km^2

10. Prediction of the week that the minimum daily extent will occur (expressed in date format for the first day of week, taking Sunday as the start of the week (e.g., week of 4 September).

    N/A (Our data is monthly averaged)

11. *Short explanation of Outlook method (using 300 words or less). In addition, we encourage you to submit a more detailed Outlook, including discussions of uncertainties/probabilities, including any relevant figures, imagery, and references.

    Our forecast is based on the GFDL Forecast-oriented Low Ocean Resolution (FLOR) model (Vecchi et al., 2014), which is a coupled atmosphere-land-ocean-sea ice model. The model is initialized from an Ensemble Kalman Filter coupled data assimilation system (ECDA; Zhang et al., 2007), which assimilates observational surface and subsurface ocean data and atmospheric reanalysis data. The system does not assimilate any sea ice concentration or thickness data. The FLOR atmospheric initial conditions are produced from an AMIP run forced by observed SST and sea ice. Historical radiative forcing is used prior to 2005 and the RCP4.5 scenario is used for predictions after 2005. For the predictions initialized after 2004, the aerosols are fixed at the RCP4.5 scenario year of 2004. The performance of this model in seasonal prediction of Arctic sea ice extent has been documented in Msadek et al. (2014). For an

evaluation of the model's September sea ice extent prediction skill from a June 1 initialization, see Section 3 below.

12. If available from your method for pan-Arctic extent prediction, please provide:

a) Uncertainty/probability estimate such as median, ranges, and/or standard deviations (specify what you are providing).

Our range of September sea ice extent predictions is 3.86-4.94 million km^2, with a median value of 4.64 million km^2 and a standard deviation of 0.35 million km^2.

b) Brief explanation/assessment of basis for the uncertainty estimate (1-2 sentences).

These statistics are computed using our 12 member prediction ensemble.

c) Brief description of any post processing you have done (1-2 sentences).

These forecasts are bias corrected based on an additive correction using a suite of retrospective forecasts spanning 1980-2015. The bias is defined as the September sea ice extent difference between NSIDC NASA team observations and forecasts initialized on June 1.

d) Raw (and/or post processed) forecasts for this year and retrospective forecasts in an excel spreadsheet with one year on each row and ensemble member number on columns (specifying whether raw or post processed).

See Section 3 below for raw and bias corrected forecasts. We have also attached an excel spreadsheet with the raw and bias corrected forecasts initialized on June 1 spanning 1980-2016.

2 Regional Predictions: Sea-Ice Probability

We define the sea-ice probability (SIP) as the probability that a given grid cell will be covered by sea ice in a given target month. We define "ice-covered" as SIC greater than 0.15. Therefore, the SIP is given by:

$$SIP(x, y) = p(SIC(x, y) \geq 0.15) \quad (1)$$

This quantity is computed using our prediction ensemble as the number of ensemble members that are ice-covered divided by the total number of ensemble members (the ensemble mean sea ice extent).

See Fig. 1 for the GFDL-FLOR September sea-ice probability based on a June 1 initialization. Note that this sea ice probability map has not been bias corrected. We have also submitted a netcdf file of the GFDL ice grid and SIP field.

Figure 2 shows the sea ice concentration (SIC) bias of the FLOR model relative to NSIDC NASA team SIC observations. Specifically, this is the difference between the FLOR predicted September SIC from June 1 initialization and observed September SIC. This SIC bias field is computed using the last 10 years of observations rather than the full satellite record, in order to account for the trend in Arctic sea ice climatology.

Of particular note is the region in the East Siberian Sea, which is ice covered in some ensemble members ($0.2 \leq$ SIP ≤ 0.5) and represents a potential blocking of the Northern Sea Route. It is important to note that this region is also an area of positive model bias, and therefore the SIP in the East Siberian Sea may be an overestimate.

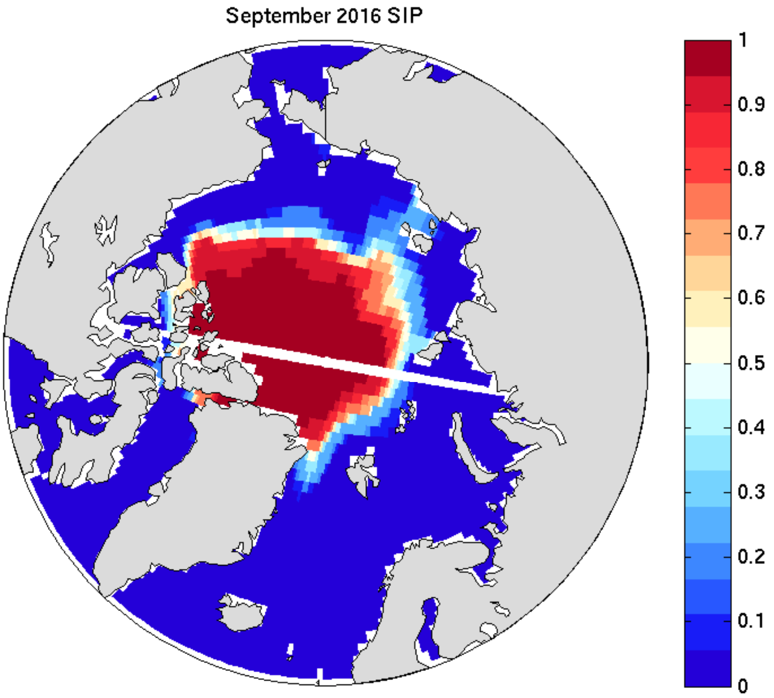

Figure 1: Sea ice probability for September sea ice, based on predictions initialized on June 1. No bias correction has been applied in producing this map.

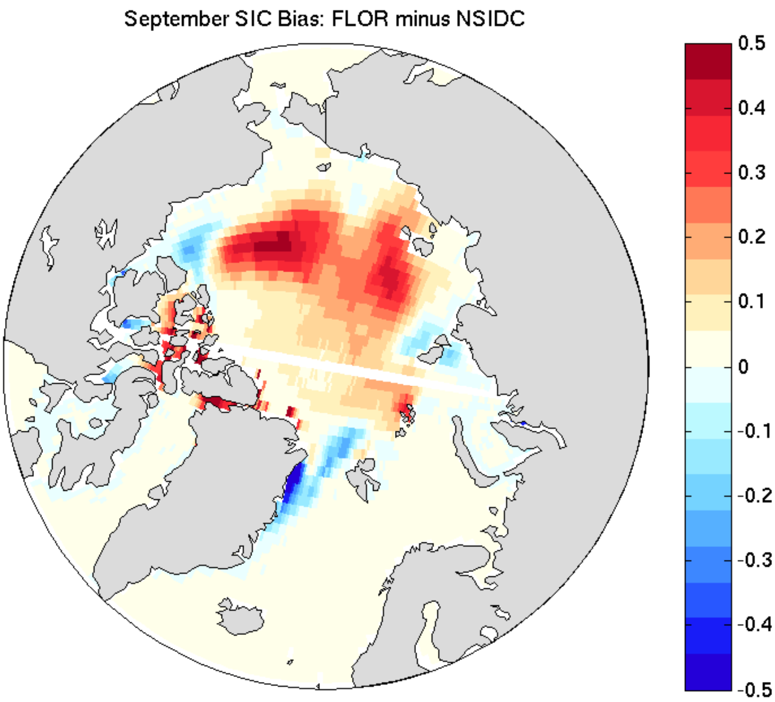

Figure 2: Sea ice concentration (SIC) bias in the GFDL-FLOR model. This bias is computed by differencing the June 1 model predictions of September SIC with the NSIDC September SIC climatology. The NSIDC climatology is computed using the latest 10 years of data.

3 Assessment of Arctic Sea-Ice Extent Predictions

3.1 Retrospective forecast skill from June 1 Initialization

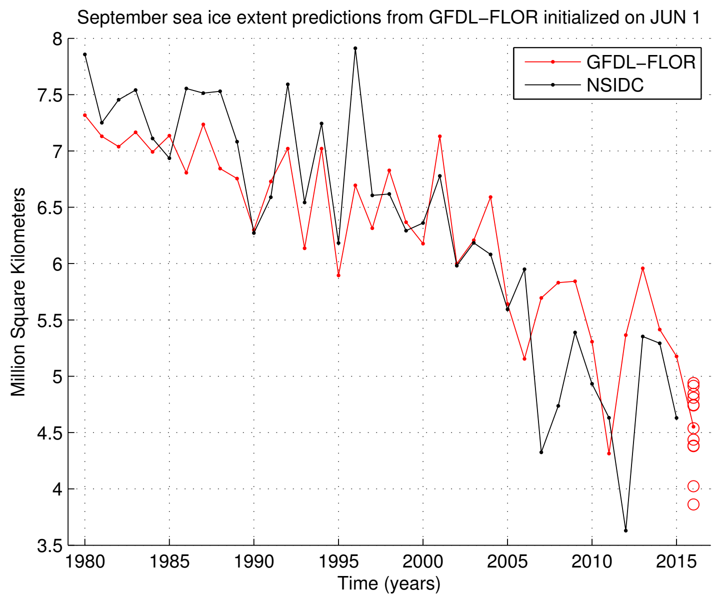

Figure 3: September pan-Arctic sea ice extent predictions from the GFDL-FLOR model initialized on June 1 (red dots) compared to NSIDC observations (black dots). The red circles show the September 2016 predictions from the 12 ensemble members. Note that the model predictions have been bias corrected.

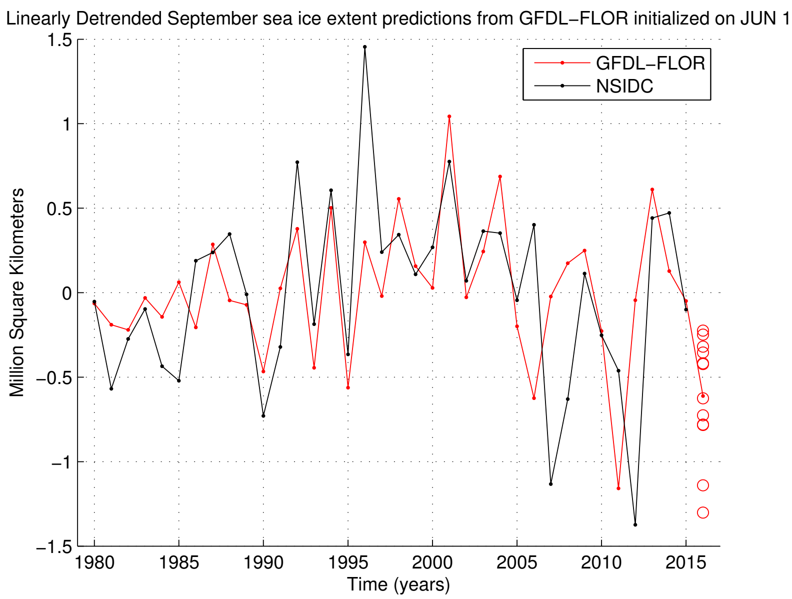

Figure 4: Linearly detrended September pan-Arctic sea ice extent predictions from the GFDL-FLOR model initialized on June 1 (red dots) compared to linearly detrended NSIDC observations (black dots). The red circles show the September 2016 predictions from the 12 ensemble members. The model has skill in predicting detrended extent (r=0.51), in addition to the full extent field shown in Fig. 3 (r=0.86).

3.2 Raw sea ice extent forecasts (no bias correction)

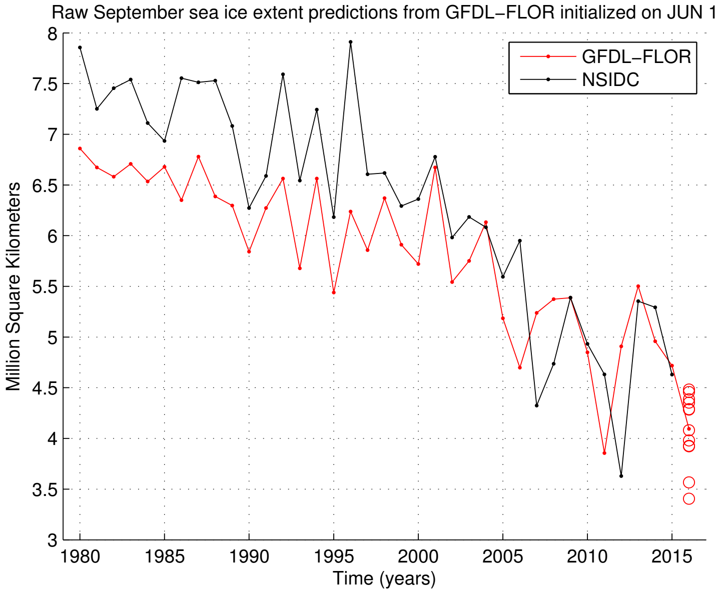

Figure 5: Same at Fig. 3, but without any bias correction applied to the model. The raw predictions have the same correlation with observations (r=0.86), but a larger RMSE (0.74 million km^2) compared with the bias-corrected predictions (0.59 million km^2).

3.3 Comparison to CM2.1 forecasts

For previous sea ice outlooks, the GFDL contribution was made using the GFDL-CM2.1 model. This model has similar skill in predicting pan-Arctic sea ice extent to GFDL-FLOR (Msadek et al., 2014). In this submission, we have opted to use FLOR, as this model has a smaller climatological bias and, therefore, provides better predictions of sea-ice probability.

The June 1 CM2.1 prediction of September sea ice extent is very similar to FLOR. CM2.1 predicts a September sea ice extent of 4.55 million km^2, with an uncertainty range of 3.86-5.04 million km^2. Figure 6 shows the 2016 extent prediction, along with the all predictions over the CM2.1 hindcast period of 1981-2015. Note that these predictions have been bias corrected, via an additive bias correction.

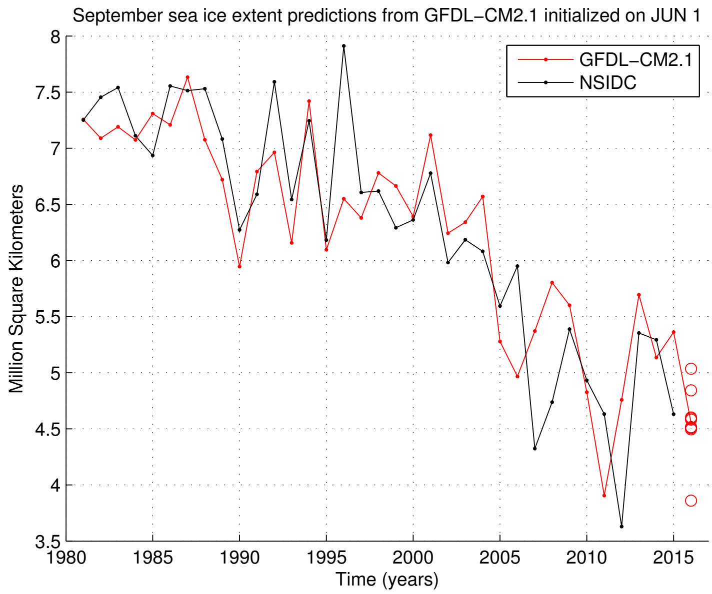

Figure 6: September pan-Arctic sea ice extent predictions from the GFDL-CM2.1 model initialized on June 1 (red dots) compared to NSIDC observations (black dots). The red circles show the September 2016 predictions from the 10 ensemble members. Note that the model predictions have been bias corrected.

References

Msadek, R., G. Vecchi, M. Winton, and R. Gudgel, 2014: Importance of initial conditions in seasonal predictions of Arctic sea ice extent. *Geophys. Res. Lett.*, **41 (14)**, 5208–5215.

Vecchi, G. A., et al., 2014: On the seasonal forecasting of regional tropical cyclone activity. *J. Climate*, **27 (21)**, 7994–8016.

Zhang, S., M. Harrison, A. Rosati, and A. Wittenberg, 2007: System design and evaluation of coupled ensemble data assimilation for global oceanic climate studies. *Mon. Wea. Rev.*, **135 (10)**, 3541–3564.