GFDL Contribution to the September 2020 Sea Ice Outloook: June Report

Mitch Bushuk, Mike Winton, Rym Msadek, Tom Delworth, Liwei Jia, Colleen McHugh, Matt Harrison, Tony Rosati, Xiaosong Yang, and Yongfei Zhang

GFDL/NOAA, Princeton, NJ, USA

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 2020 season?

   ___Yes, use this contribution for all of the 2020 SIO reports (this contribution will be superseded if you submit a later one).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 3.50 million km^2, with an uncertainty range of 3.26-3.93 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 2020"):

   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	**MOM5**	**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%.)

   3.50 million km^2

10. *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), Bushuk et al. (2017), and Bushuk et al. (2018). For an evaluation of the model's September sea ice extent prediction skill from a June 1 initialization, see Section 2 below.

11. 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 3.26–3.93 million km^2, with a median value of 3.47 million km^2 and a standard deviation of 0.20 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 1980-2019. The bias is defined as the September sea ice extent difference between NSIDC NASA team observations and forecasts initialized on June 1.

2 Assessment of Arctic Sea-Ice Extent Predictions

2.1 Retrospective forecast skill from June 1 Initialization

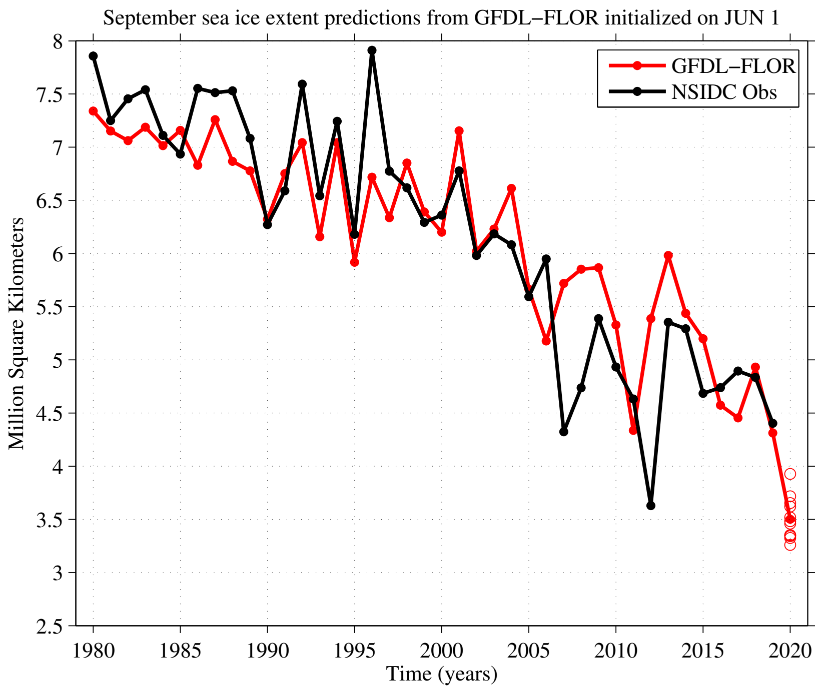

Figure 1: September pan-Arctic sea ice extent predictions from the GFDL-FLOR model initialized on June 1 (red dots) compared to NSIDC observations (black dots). The red circles show the September 2020 predictions from the 12 ensemble members. Note that the model predictions have been bias corrected.

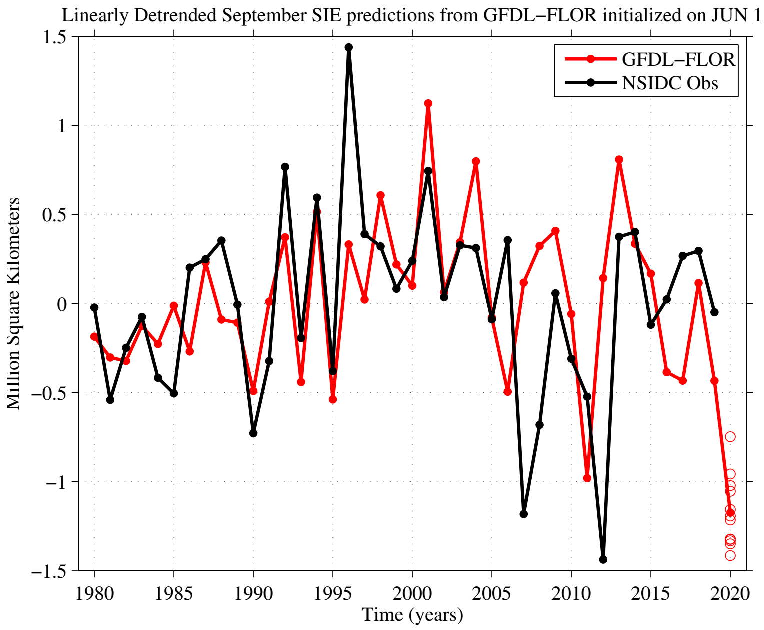

Figure 2: Linearly detrended September pan-Arctic sea ice extent predictions from the GFDL-FLOR model initialized on June 1 (red dots) compared to linearly detrended NSIDC observations (black dots). The red circles show the September 2020 predictions from the 12 ensemble members. The model has skill in predicting detrended extent (r=0.42), in addition to the full extent field shown in Fig. 6 (r=0.88).

2.2 Raw sea ice extent forecasts (no bias correction)

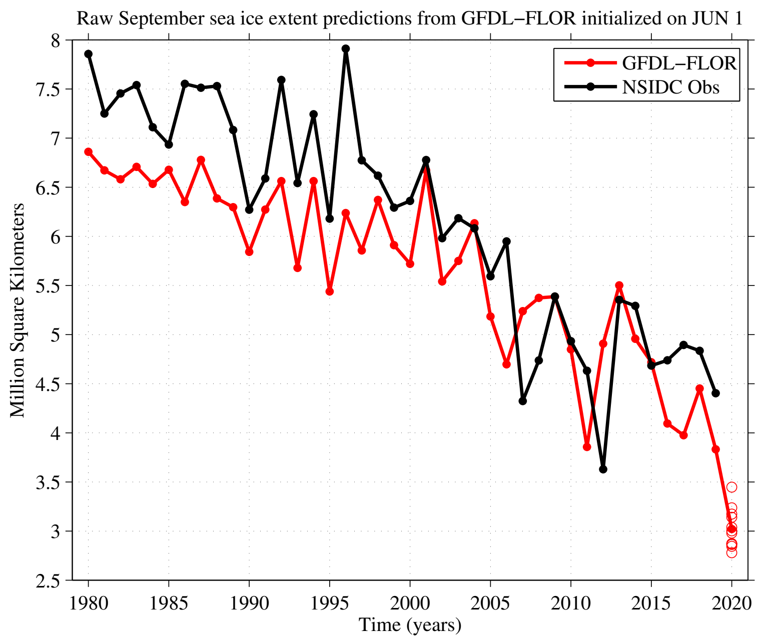

Figure 3: Same at Fig. 6, but without any bias correction applied to the model. The raw predictions have the same correlation with observations (r=0.88), but a larger RMSE (0.74 million km^2) compared with the bias-corrected predictions (0.56 million km^2).

3 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:

$$SIP(x, y) = p(SIC(x, y) \geq 0.15) \tag{1}$$

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. 4 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 submitted the spatial fields via the SIPN portal.

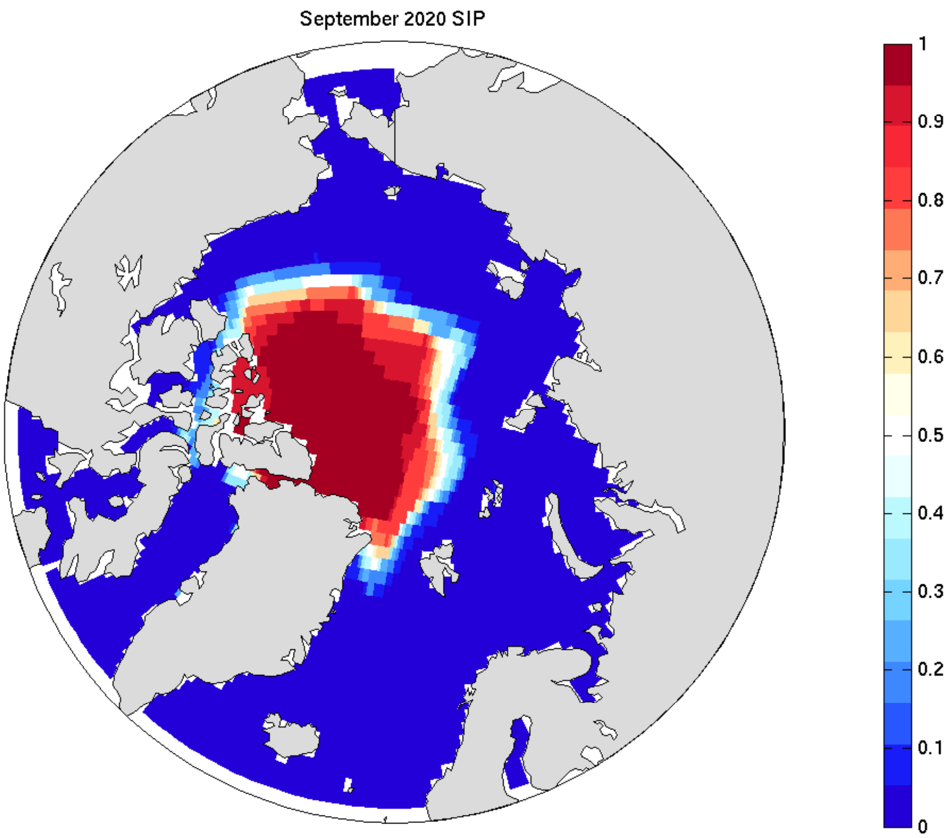

Figure 4: Sea ice probability for September sea ice, based on predictions initialized on June 1. No bias correction has been applied in producing this map.

4 Reliability Analysis

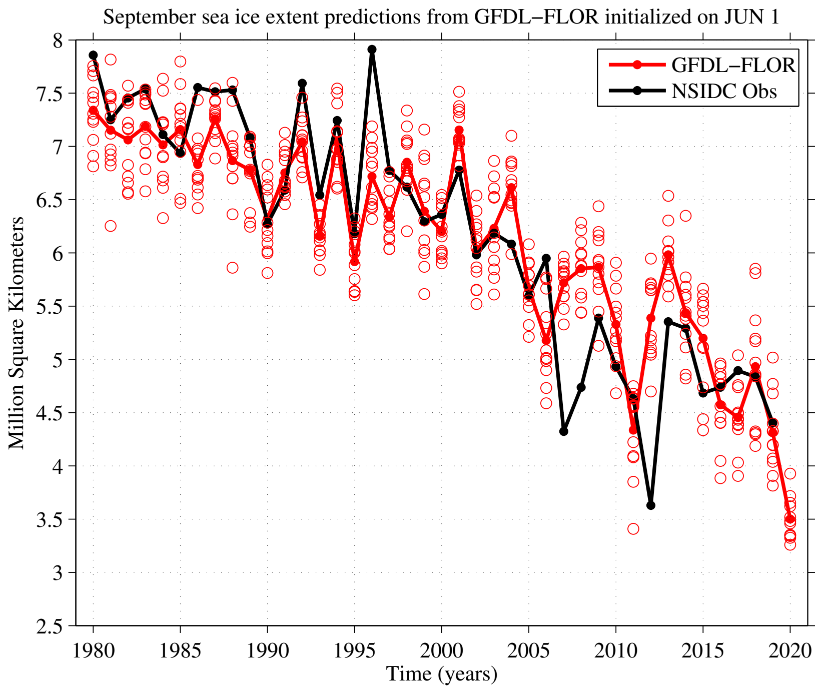

Figure 5: September pan-Arctic sea ice extent predictions from the GFDL-FLOR model initialized on June 1 (red dots) compared to NSIDC observations (black dots). The red circles show the September SIE predictions from the 12 ensemble members. Note that the model predictions have been bias corrected.

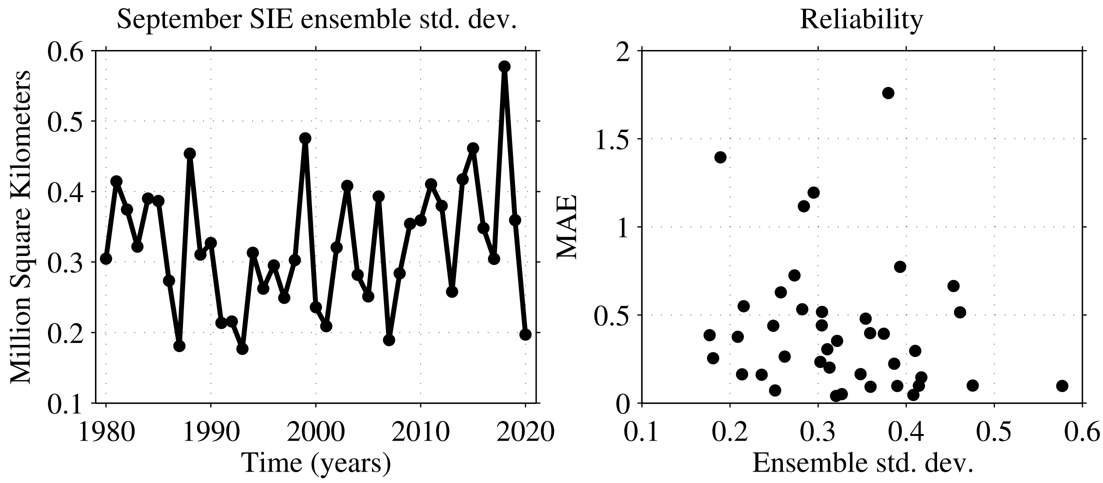

Figure 6: Reliability analysis. (A) Ensemble standard deviation for September SIE predictions vs time. (B) Forecast mean absolute error (MAE) versus ensemble standard deviation. The mean MAE is 0.42 million km^2 and the mean standard deviation is 0.32 million km^2, indicating that these forecasts are somewhat underdispersive.

References

Bushuk, M., R. Msadek, M. Winton, G. Vecchi, R. Gudgel, A. Rosati, and X. Yang, 2017: Skillful regional prediction of Arctic sea ice on seasonal timescales. *Geophys. Res. Lett.*, **44**, 4953–4964.

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