Met Office
September 2016 Arctic Sea Ice Outlook
June Report (Using May Data)

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Group: Met Office

Projection Type: Model based estimate.

September Monthly Averaged Extent Projection: $(\mathbf{3.6 \pm 1.0}) \times \mathbf{10^6}$ km^2

Model: HadGEM3, Global Coupled Model 2.0 [Williams et al., 2015] in use within the GloSea5 seasonal prediction system [MacLachlan et al., 2014].

- **Ice Component:** CICE [Hunke and Lipscomb, 2010], Global Sea Ice 6.0 [Rae et al., 2015]
- **Ocean Component:** NEMO [Madec, 2008], Global Ocean 5.0 [Megann et al., 2014]
- **Atmospheric Component:** Met Office Unified Model (UM) [Brown et al., 2012], Global Atmosphere 6.0
- **Land Component:** JULES [Best et al., 2011], Global Land 6.0
- **Coupler:** OASIS3 [Valcke, 2006]

Method: Ensemble coupled model seasonal forecast from the GloSea5 seasonal prediction system [MacLachlan et al., 2014], using the Global Coupled 2 (GC2) version [Williams et al., 2015] of the HadGEM3 coupled model [Hewitt et al., 2011]. Forecast compiled together from forecasts initialized between 15 May and 4 Jun (2 per day) from an ocean and sea ice analysis (FOAM/NEMOVAR) [Blockley et al., 2014, Peterson et al., 2015] and an atmospheric analysis (MO-NWP/4DVar) [Rawlins et al., 2007]

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using observations from the previous day. Special Sensor Microwave Imager (SSM/I) ice concentration observations from ESA OSI-SAF [OSI-SAF] were assimilated in the ocean and sea ice analysis, along with satellite and in-situ SST, subsurface temperature and salinity profiles, and sea level anomalies from altimeter data. No assimilation of ice thickness was performed. The forecast (Figure 1) has been bias correction downward by 0.4×10^6 km^2 due to a mean over forecast of the ice extent relative to the observed NSIDC ice extent over the hindcast period 1993 to 2015 [Peterson et al., 2015]. The bias tends to overpredict the sea ice extend in the Beaufort and Chukchi Seas, but underpredict it in the Laptev and Kara Seas (see Figures 2 and 3).

Projection Uncertainty: $\pm 1.0 \times 10^6$ km^2 representing two standard deviations of the (42 member) ensemble spread around the ensemble mean.

Executive Summary: Using the Met Office GloSea5 seasonal forecast systems we are issuing a model based mean September sea ice extent outlook of $(\mathbf{3.6 \pm 1.0}) \times \mathbf{10^6}$ km$^\mathbf{2}$. This has been assembled using startdates between 15 May and 4 Jun to generate an ensemble of 42 members.

Additional Information: Validation and calibration of the forecast was done using our extended 1993-2015 historical re-forecast (hindcast) using startdates of 17 & 25 May and 1 Jun (3 members each). Over the hindcast period, the correlation between the GloSea5 forecast and NSIDC sea ice extent observations was 0.89 which reduces to a correlation of 0.62 if the trend is removed from the time series. Figure 1 shows the time series of September sea ice predictions in the hindcast, along with the forecast for 2016. Both the full and detrended correlation values are significantly different from 0 at the 95% confidence level, and are both better predictors than respectively persistence and detrended persistence — using the May sea ice anomaly as a predictor of the September anomaly. Furthermore, the value of the full correlation between the two time series suggests that our forecast is historically a better predictor than simply predicting the trend. After bias correcting, the hindcast has a root mean square error (rmse) of 0.5×10^6 km^2 comparable to the quoted error. Although our skill in the hindcast has increased with decreasing lead time since our first forecast of the year in early April (Figure 4a), the actual forecast has remained relatively constant around the 3.6×10^6 km^2 value quoted here (Figure 4b).

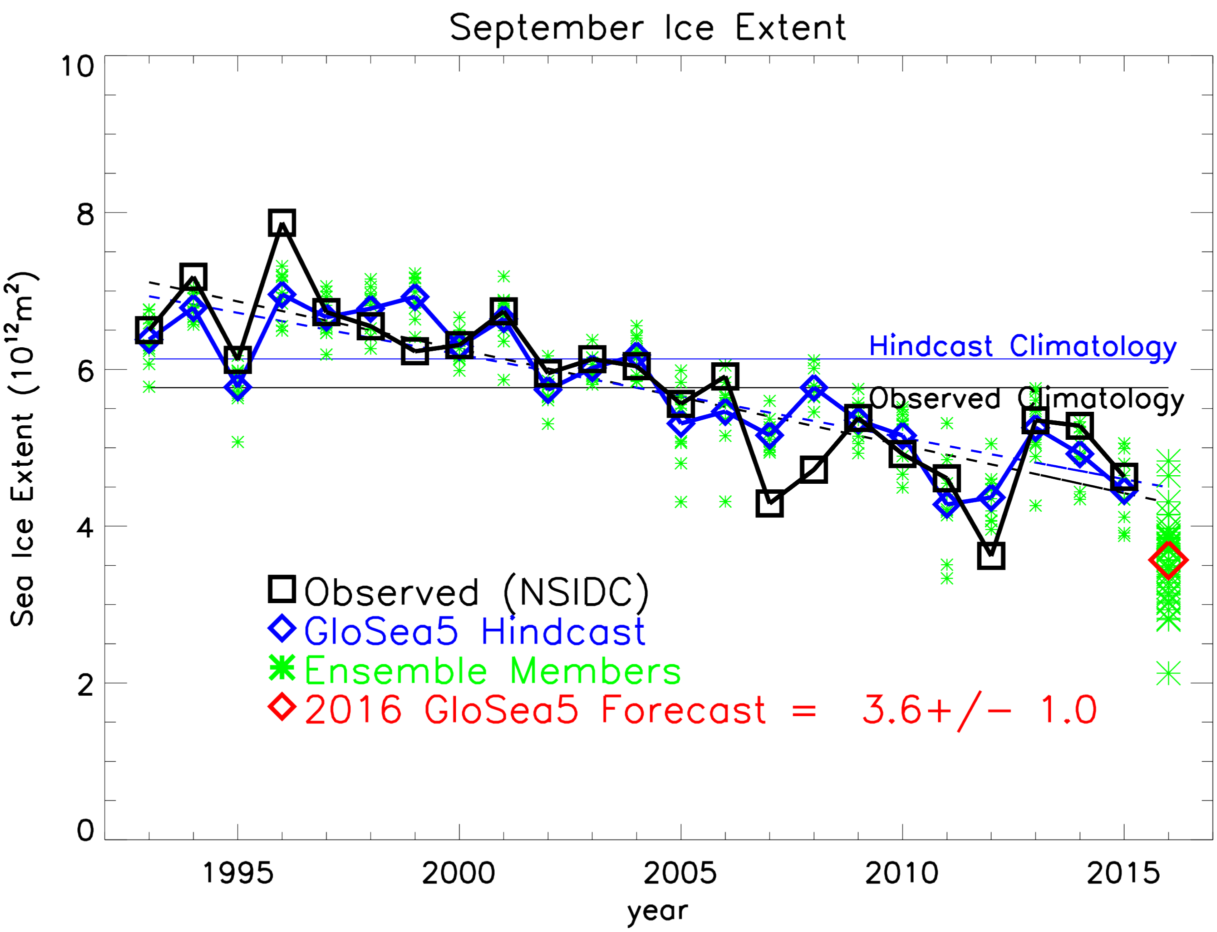


Figure 1: Time series of ensemble mean September sea ice extent from GloSea5 (blue and red $\diamond$) and observations (NSIDC; black $\square$). Individual ensemble member sea ice extents are denoted by $*$ (green). The blue and black horizontal lines denote the hindcast and observed (1993-2015) climatology respectively. The forecast and hindcast values have all been adjusted downward by the amount between the two lines ($0.4 \times 10^{12}\text{m}^2$). The blue and black dashed lines are the forecast and observed trends in the timeseries over the 1993-2015 hindcast period. **Note:** Our previously published 2010-2014 forecasts were made with different systems from the GloSea5-GC2 system used for the forecasts and hindcasts in this figure. Therefore, the values shown on this figure will not be the same as our published forecasts for those years.

September 2016 Monthly Mean Ice Edge

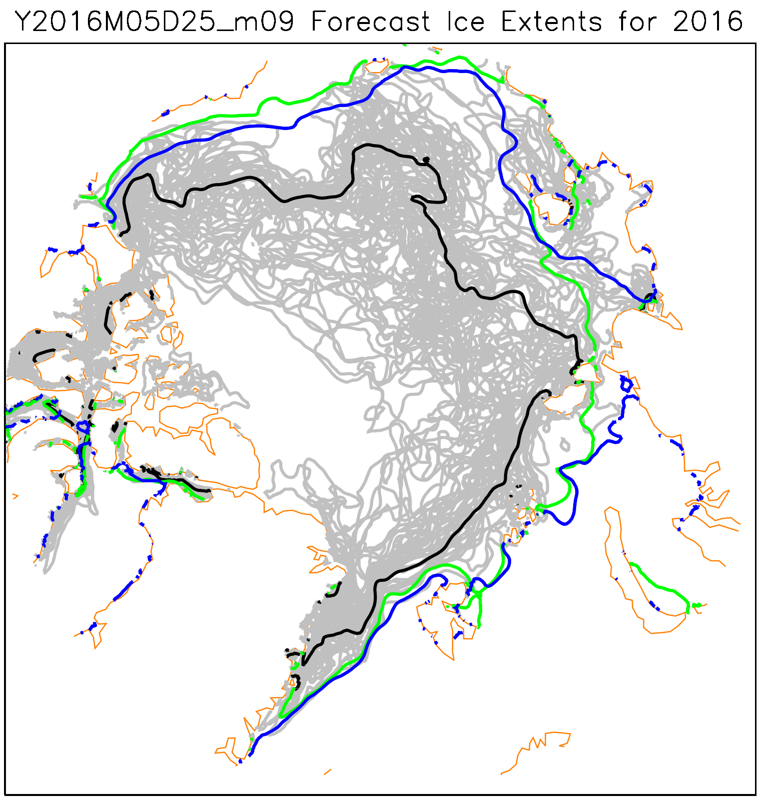


Figure 2: Plot of ice edge. Black line is the location of ice edge (ice concentration > 0.15) for the ensemble mean sea ice concentration. Individual grey lines are the ice edges for the individual ensemble members. No bias correction has been applied. The green and blue lines are the ice edges of the 1993-2015 sea ice concentration climatologies for the hindcast and observations respectively. Differences between these two climatological ice edges would indicate how and where the model climatology differs from the observed. Note: Ice extent is a non-linear quantity. The ice extent represented by the ensemble mean sea ice concentration is larger ($4.6 \times 10^{12} \mathrm{m}^2$) then the ensemble mean ice extent before bias correction ($3.9 \times 10^{12} \mathrm{m}^2$), which is the mathematical mean of the ice extent (area inside) of each of the grey ensemble member lines, upon which our forecast (before bias correction) is based.

September 2016 Bias Corrected Probability of Ice

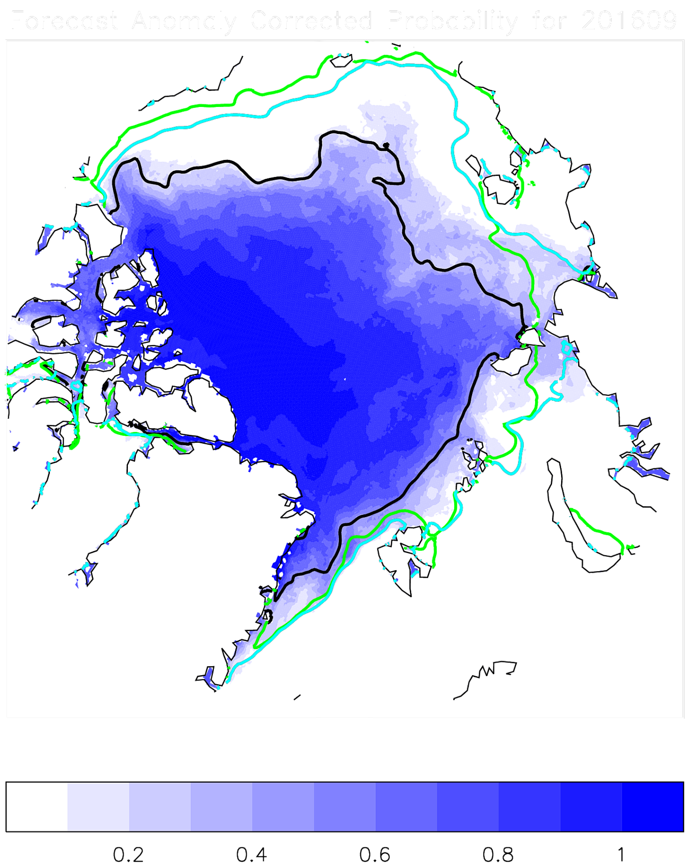
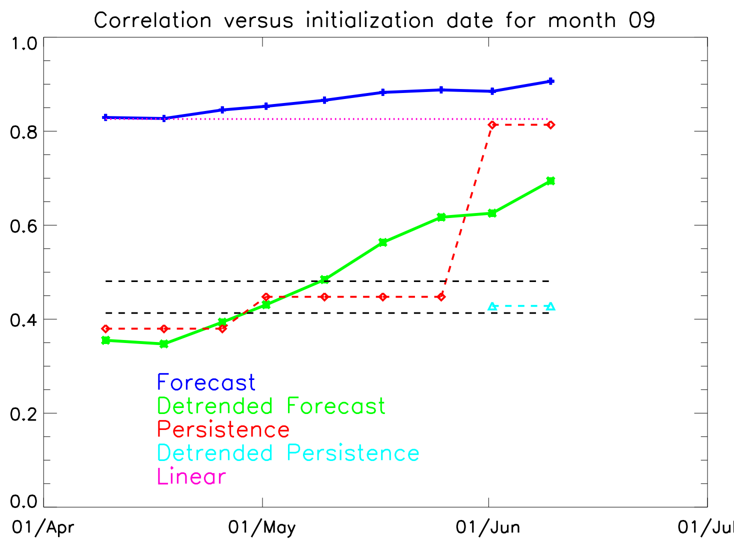


Figure 3: September 2016 monthly mean bias corrected probability of ice (fraction of ensemble members with ice concentration > 0.15). Model grid point probability has been adjusted downward or upward by the amount model historically over or under predicts the likelihood of ice in that grid box between 1993 and 2015. Note: The numerical value of our sea ice forecast, $3.6 \times 10^{12}\text{m}^2$, will be the area integral of the ice probabilities represented by this figure. The black line is the ice edge of the ensemble mean ice concentration as in figure 2. The green and cyan lines are the ice edges of the 1993-2015 sea ice concentration climatologies for the hindcast and observations respectively.

September Forecast Through April and May

a)



b)

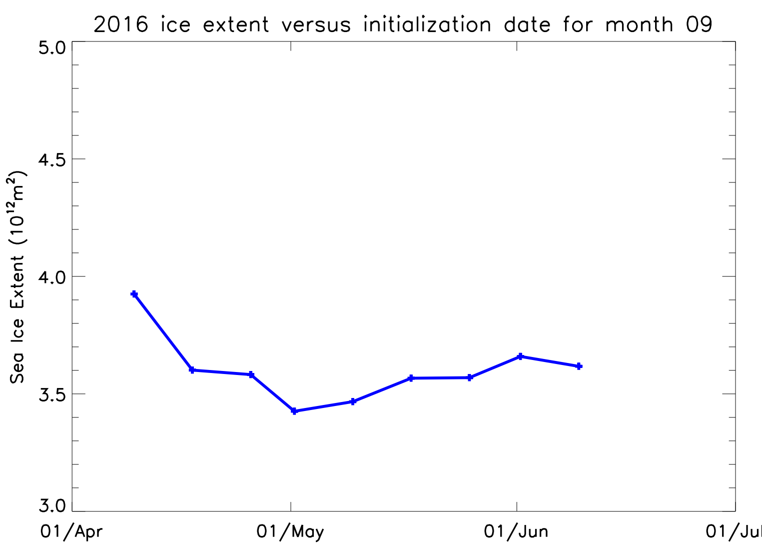


Figure 4: a) Correlation skill over the 1993-2015 hindcast for our September forecasts starting from dates in April and May. The blue line corresponds to the anomaly correlation for the full anomalies, while the green line corresponds to the correlation skill for detrended anomalies. The red dashed line is the skill of persisting the observed anomalies forward as the September forecast. The horizontal magenta dotted line is the correlation skill of simply forecasting the observed September trend. Horizontal black lines denote the threshold for the 90% and 95% confidence level that the correlations are significantly different from zero. b) The forecast September 2016 sea ice extent from forecasts starting from the same dates in April and May as in a).

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