September 2011 Sea Ice Outlook
July Report

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*Caveat: This is an experimental projection and **does not** represent an official UK Met Office forecast.*

1) Extent Projection

4.0 ± 1.2 million square kilometres (status quo from June Report)

2) Method/Techniques (Coupled Atmosphere-ice-ocean-land surface model ensemble runs)

This projection is an experimental prediction from the UK Met Office seasonal forecast system, GloSea4 (Arribas et al., 2011). GloSea4 is an ensemble prediction system using the HadGEM3 coupled climate model (Hewitt et al., 2011). A more complete description of the GloSea4 system can be found in the June report and accompanying references (http://www.arcus.org/files/search/sea-ice-outlook/2011/06 /pdf /pan-arctic/petersonetalpanarcticjune.pdf)

3) Rationale

Our forecast of 4.0±1.2 million square kilometres was based on the seasonal forecast data for September 2011 from a start date centred on 31/03/2011, and included two forecasts of seven month length initiated each day between 21/03/2011 and 10/04/2011. The hindcast dates used for calibration were initiated on 25/03, 01/04, and 09/04 of each of the hindcast years, with three ensemble members generated per start date. These **were not** the latest start dates available to us, and therefore neglect any useful initialization data available from April and May. Initial justification of this start date, based upon the initial ice thickness and the climatological bias in the September ice extent between model and observations was given in the June report. Here, we will provide further justification of the use of this start date, presenting verification data which is now available for April through June. Despite using the 31 March centred initialization of the system as the basis for our September outlook, we have continued to track later initialization dates, and as of the 23 June centred initialization, which uses start dates between 13 June and 3 July, we have a predicted September ice extent of 4.4±0.9 million square kilometres, although with less predicted skill (as shown in figure 3 below) then the 31 March centred initialization. In general, the system has predicted ensemble mean September ice extents between 2.4 and 4.4 million square kilometres, with varying degrees of implied skill.

Returning to our original forecast issued in June from the 31/03/2011 start date, Figure 1 is a plot of September sea ice extent for the hindcast period of 1996 through

2009 plus the forecast for September 2011 (blue line, ending in a blue diamond – the 2011 forecast). **Note** that there is no hindcast value for 2010. Also included on the plot are the observations in black, the persistence forecast (adding the March anomalies onto the September climatology) in red, and the linear trend in the observations (over the 1996-2009 period) in magenta. The correlation between the hindcast ice extents for September and observed ice extents was 0.63. This is significantly different from zero at the 94% confidence level, the number of effective degrees of freedom being lowered due to serial correlation (Zwiers and von Storch, 1995). For comparison, March persistence correlates with September ice extent again at 0.63, but this is significantly different from zero only at the 74% confidence level owing to a very high degree of serial correlation (trend) in the two time series. The detrended correlation between hindcast and observation is 0.73, while the detrended correlation between March persistence and observation is -0.24. The detrended correlation of the forecast with observations is non-zero at the 99% confidence level, and fairly obviously, the correlation between March persistence and September observations is completely related to the trend in both values.

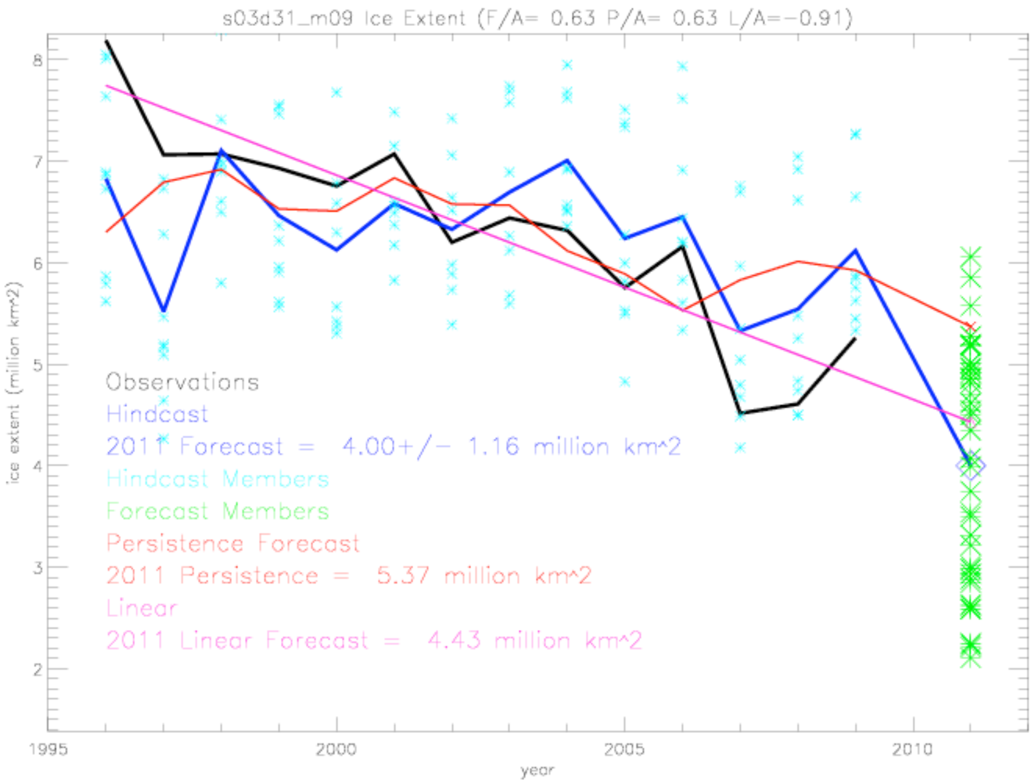
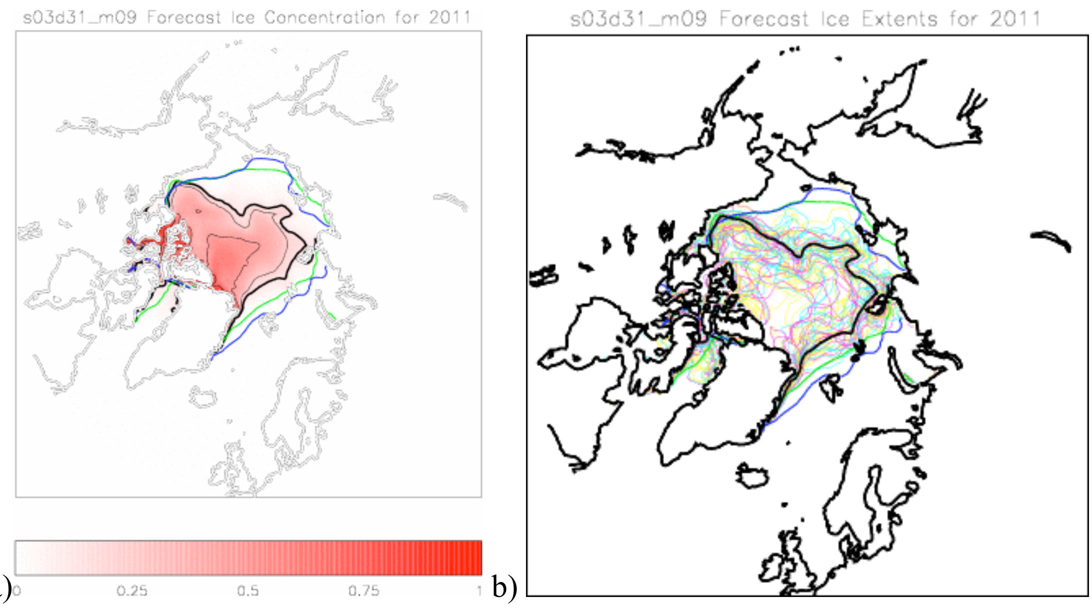


Figure 1: Time series of ice extents for the 1996-2009 hindcast, plus the 2011 forecast. The black line is the observations, and the blue line is the hindcast values, culminating in the 2011 forecast (blue diamond). There is no value for 2010. The cyan and green ∗'s are the hindcast and forecast ensemble members respectively. Also added to the graph is the persistence forecast (March anomalies added to September climatology) in red and the linear trend in the observations in magenta.

Figure 2 shows a plot of forecast ice concentration for September 2011 from the seasonal forecast system initialized on dates between 21 March and 10 April and centred around 31 March. The thick black line in the plot represents the ice extent.

The green line is the model ice extent climatology over the hindcast period of 1996-2009 and blue line is the observed ice extent climatology over the same period. The overall ice extent area is fairly well modelled in the hindcast with an observed ice extent of 6.3 million square kilometres versus a hindcast of 6.1 million square kilometres, for a bias of 0.2 million square kilometres. Nevertheless, there are regional differences in the climatological ice edge that one should take into account when viewing the ice concentration. The second plot of figure 2 is a spaghetti plot of sea ice extents of the various ensemble members for the September 2011 forecast, showing a multitude of modelled possibilities.



a) b)

Figure 2. a) Forecast ensemble mean September 2011 sea ice concentration from the seasonal forecast system initialized on dates between 21 March and 10 April. The thick black line is the forecast ensemble mean ice extent (ice concentration of 0.15) and the thinner black lines are contour intervals of 0.25. The green line is the model ice extent climatology during the hindcast period of 1996-2009, while the blue line is the observed climatological ice extent over the same period. b) Spaghetti diagram of ensemble member sea ice extents. Green, blue and thick black lines are as in a).

Figure 3 shows a plot of correlation as a function of start date for forecasts starting just prior to our chosen 31 March start date and continuing to the most recently available start dates. As is pretty clear from the correlation statistics, the chosen start date of 31 March presents itself as the best choice, certainly in terms of its ability to correctly track the interannual variability (green line), although not necessarily the trend. Note that the forecast lead time increases as one goes from right to left on the graph, and one would normally expect the skill to increase with shorter lead times. The forecast centred on 12 May, encompassing start dates from 2 May to 22 May, which is at the peak correlation between hindcast and observation, has an ice extent of 2.7 million square kilometres, which has been corrected upward by a 1.3 million square kilometre bias correction. The un-quantified uncertainties that arise between forecast and hindcast associated with a bias of this amount and detailed in our June report, plus a lower degree of interannual (detrended) predictive skill led to the decision not to use this forecast, or any of the more recent forecasts for this outlook. It is also worth mentioning, that the 12 May forecast represents the transition to a

September outlook dominated by the bias correction, which might partly explain the rapidly decreasing interannual correlations found after this start date.

Finally, since we are using a start date from near the beginning of April, we have the ability to track the performance of our forecast with time. Figure 4 shows a plot of ice extent as a function of forecast date over the course of the spring and summer. As can be seen, the observations (in black) have so far tracked lower then the forecast. In general, the (absolute value) of forecast error has been larger then the root mean square error of the hindcast and the model variance. It therefore might be advisable to increase our current estimate of September forecast uncertainty (which is the model variance). However, the hindcast skill, as measured by the correlation of the hindcast with observations, is less for the spring and summer months then for September, and indeed the hindcast error dips below the model variance in September, suggesting that the current estimate is likely accurate. Finally, note the bias between the observed and model forecast climatology is highest in July before decreasing significantly for September.

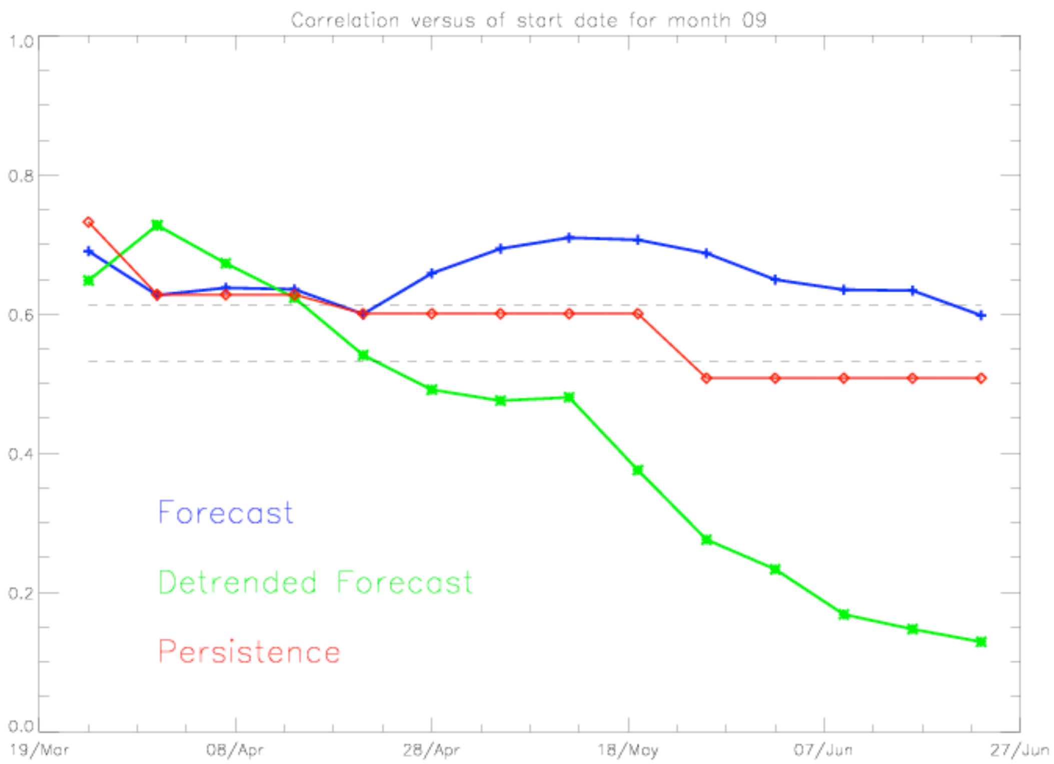


Figure 3: Blue Line: A plot of the correlation between September hindcast and observations versus the start date of the hindcast. Red Line: Plot of correlation between start month ice extent (persistence) with September observations. Note this is calculated on a monthly basis, so all April start dates with show the same correlation. Green Line: A plot of the correlation between the detrended hindcast with detrended observations as a function of hindcast start date. The correlations are based upon the 1996-2009 hindcast period. The two dashed lines are the significance levels for non-zero correlations at the 95% and 98% confidence levels assuming **no** serial correlation. Actual confidence levels will be lower.

4) Executive Summary

Our 2011 September ice extent forecast is 4.0±1.2 million square kilometres. This is based upon a forecast from the UK Met Office seasonal forecast system, GloSea4, using a coupled atmosphere/ocean/sea ice model initialized from observations between 21 March and 10 April. The quoted error is based on the standard deviation of the ensemble members' sea ice extent from their average value. A bias correction of 0.2 million square kilometres has been added to the forecast to account for the climatological bias of lower ice extents forecast in the model over the hindcast period. Although, more recently initialized forecast are available for use, this particular forecast appears to be the most skilful based on correlations with observations made over a 1996-2009 hindcast set. Verification of the forecast in the April through June period shows the forecast to be tracking high with regards to the observations, with forecast error larger then both hindcast error and model variance, which is our predictor of model uncertainty.

A more recent forecast initialized between 13 June and 3 July has a predicted 2011 September ice extent of 4.4±0.9 million square kilometres, but comes with a lower assessment of skill then the 21 March through 10 April initialized forecast. The uncertainty assigned to this forecast is the root mean square error during the hindcast, the standard deviation of ensemble member's sea ice extent for this forecast being unreasonably small.

5) Estimate of Forecast Skill

GloSea4 is an ensemble forecast system. The spread of the forecast members allows us to place an uncertainty error on the forecast. The standard deviation of the spread of ensemble members for 2011 is 1.2 million square kilometres, which we have assigned as the error in our forecast of 4.0 million square kilometres. This value is also comparable to the root mean square forecast error during the hindcast and the mean variance of ensemble members during the hindcast, both of which are 0.8 million square kilometres. Given the current observed forecast error for June of 0.9 million square kilometres (above observations) compared to both the root mean square error during the hindcast of 0.5 million square kilometres and a model variance of 0.25 million square kilometres for June, it might be advisable to increase this uncertainty. However, given the model variance grows significantly between June and September, we will stand firm with the estimated uncertainty of 1.2 million square kilometres quoted in the June report.

Final Caveat: As detailed in the June outlook report, there exists many differences between the hindcast system and the forecast system that might be expected to introduce further uncertainties in the forecast that cannot be quantified by the hindcast. Although these uncertainties are not known, it seems likely that due to a thinner ice initialization in the forecast, our predicted outlook might be biased towards too low ice extents, although the current comparison of forecast to observations seems to indicate the opposite.

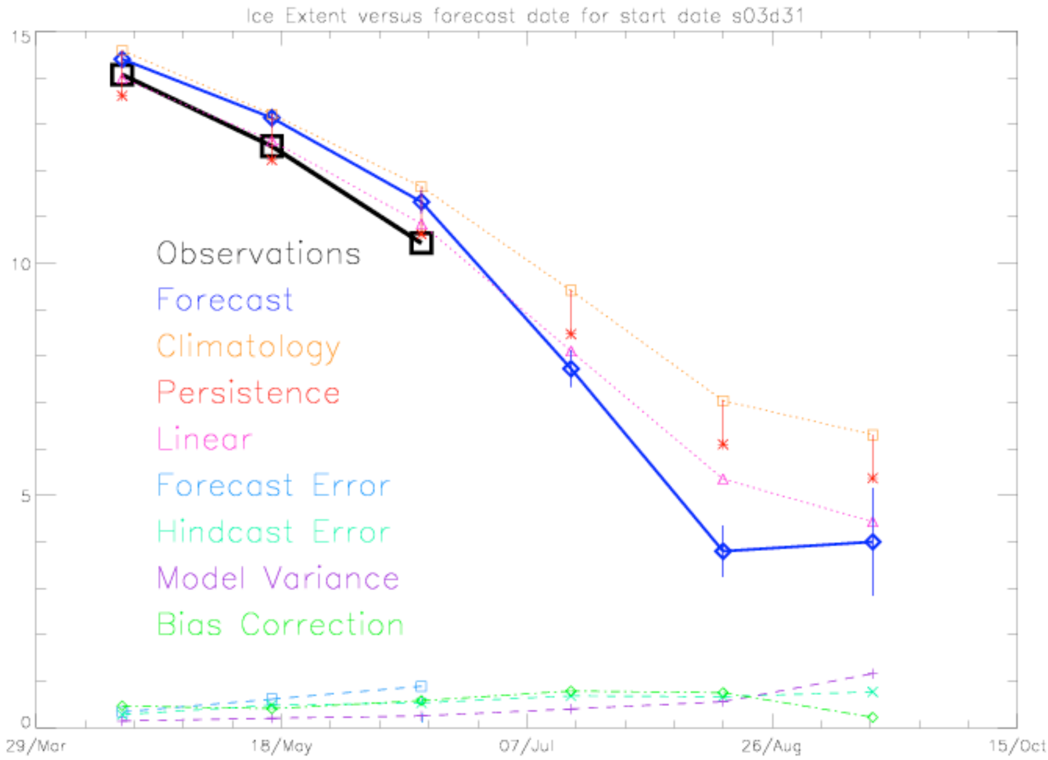


Figure 4: Monthly ice extent through the summer. Shown are the available observations (black line with) and the GloSea4 forecast (blue line with ◊). Shown as dotted lines are the climatology (orange line with) and the linear trend forecast (magenta line with Δ). The red ∗'s extending downward from climatology are the March persistence forecast (i.e. the March sea ice anomaly below climatology). Plotted at the bottom of the graph as dashed lines are the forecast error (light blue with), root mean square hindcast error (turquoise with ×) and the model variance (violet with +). Finally, plotted as a dash-dotted line is the model bias (green with ◊). This is the amount the GloSea4 hindcast has been adjusted upward by due to the higher observed climatology compared to model climatology. The error bars on the forecast are also given by the forecast model variance.

References

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