# Summer 2011 September Arctic Sea Ice Forecast

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## 1 Extent Projection

4.55 ± 0.51 million square kilometers

## 2 Methods

Our forecast uses a state-of-the-art General Circulation Model (GCM) initialized with average May 2011 sea ice area and volume anomalies obtained from the Pan-arctic Ice-Ocean Modeling and Assimilation System (PIOMAS). The GCM used is the National Center for Atmospheric Research (NCAR)'s Community Climate System Model version 4 (CCSM4) [1] at 1° resolution in all components.

Our strategy is to initialize the sea ice with anomalies with respect to the model mean that are good approximations to actual Arctic sea ice anomalies. Because our predictions are several months in the future, we make no attempt to initialize the atmosphere with true conditions. Instead we create an ensemble of predictions from integrations that begin on June 1 with identical sea ice, ocean, and land conditions but with variable atmospheric initial conditions, which are drawn from consecutive days near June 1 of an arbitrary model year. In other words, an ensemble is created by shifting the dates of the initial conditions of the atmosphere component relative to the other components. We utilize one of 6 hindcast runs with CCSM4 that have been submitted for analysis to the CMIP5 dataset for IPCC AR5. The hindcast was run with observed greenhouse gas and aerosols through the year 2005. We take 2005 as the arbitrary year, which is close enough to present to be used for seasonal prediction in 2011.

At this time we only apply anomalies to the sea ice and we apply no anomalies to the ocean or land. Without ocean anomalies in the initial conditions, the full ocean GCM of the model is not needed, so we carry out our integrations with a slab ocean model whose ocean heat flux convergences is specified from the CCSM4 hindcast for the years 1995-2005. We run the hindcast with slab ocean forward from 1 January 2005 through the end of May 2005, and then we begin create two ensembles. One, the 'control' ensemble, consists of (so far) 10 runs each initialized with the same unperturbed model sea ice, ocean and land conditions, but with variable initial atmospheric conditions. The second, the 'experiment' ensemble, consists of (so far) 18 runs just like the control, but with anomalous sea ice initial conditions based on PIOMAS.

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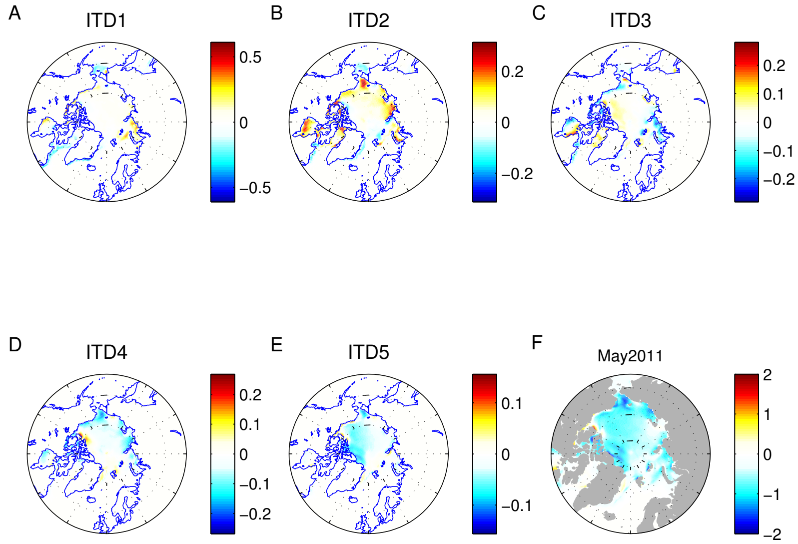


Figure 1: ITD anomalies from May 2011 obtained from PIOMAS. Panels A to E show the anomaly, in fraction of area, in category 1 through 5 respectively of the ITD (thinnest to thickest), while panel F shows the absolute thickenss anomaly for May 2011 from the 1979-2010 May ice thickness in PIOMAS.

Retrospective simulation of PIOMAS assimilate satellite ice concentration data and sea surface temperature and represent a close approximation to May 2011 observations. We calculate the May monthly mean anomalies in the ice-thickness distribution (ITD) from the linear trend in PIOMAS for the period 1979-2010 and input these anomalies for 1 June sea ice conditions in the CCSM4 (see Figure 1).

We run both ensembles for 4 months until September, and obtain two distributions, a 'control' and an 'experiment' of September sea ice area (see figure 2).

While May 2011 sea ice area (and extent) anomalies are close to zero relative to the linear trend (-0.7% anomaly), volume anomalies are noteworthy ($\sim$ -8%) and manifest in greater meltback by the end of summer in the experiment ensemble relative to the control ensemble (see Figure 2). The slight positive area offset at the ensembles initialization is a consequence of setting sea ice area to zero in grid cells where control value plus the input linear anomaly results in a negative area value. This happens around the June 1st sea ice edge but we do not expect it to affect our results for end of summer sea ice forecast.

The mean September sea ice areas in the GCM are 5.31 $\times 10^6$ km$^2$ and 5.88 $\times 10^6$ km$^2$ in the experiment and control ensembles respectively, with a standard deviation of $\sim$0.43 $\times 10^6$ km$^2$ - given the design of our experiment, the difference between both ensembles (0.57 $\times 10^6$ km$^2$) is a result solely of the differing initial conditions, i.e. the different sea ice distributions, while the spreads in each ensemble are solely due to the (coupled) sea ice-atmospheric forcing in the June-September period. It is interesting that this atmospheric forcing is large enough to produce significant variability in September sea ice

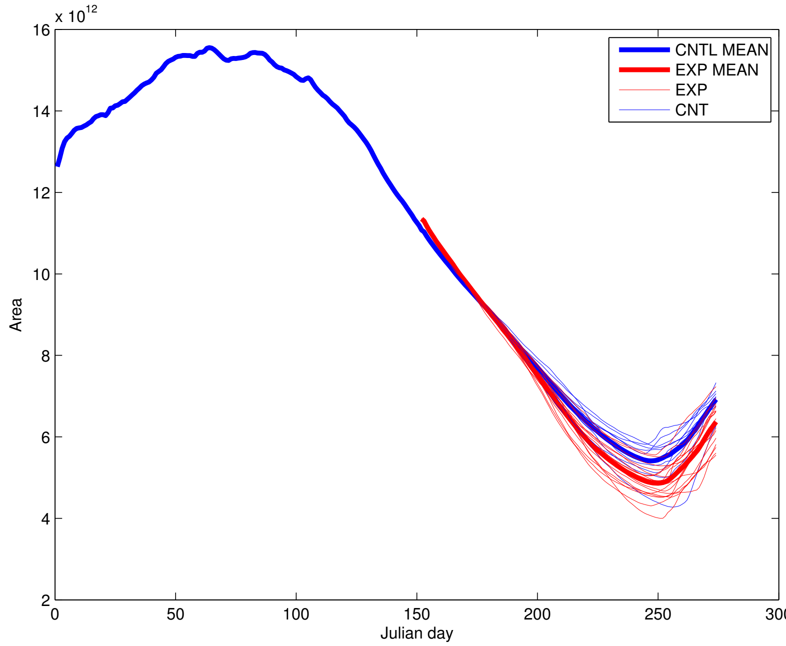


Figure 2: Daily sea ice area for the control (blue) and experiment (red) ensembles

area in the ensembles (see fig 2).

We make a prediction for September 2011 based on the difference between the ensembles and the standard deviation of the experiment ensemble. To translate from area to extent, rather than calculate the extent directly in the GCM, we apply the ratio between the extent and area linear anomalies for September in the observational record, which is $\sim 1.2$ (ie an extent linear anomaly is on average 20% greater in magnitude than the area linear anomaly). If we asume that the control run represents the 'linear' state, then the September forecast results from the linear value for September 2011 in observations plus the aforementioned difference, with an errorbar representing one standard deviation. Thus, our forecast for September 2011 is

$$Sep2011 = Sep2011\_linear + Ensemble\_diff \pm Ensemble\_stdev = 4.55\times10^6 km^2 \pm 0.51\times10^6 km^2, \tag{1}$$

This is visually shown in figure 3.

## 3 Executive Summary

Our 2011 September sea ice extent forecast is $4.55 \pm 0.51$ million square kilometers. This is based upon a forecast using the CCSM4 model initialized with sea ice anomalies obtained from the PIOMAS model for May for the period 1st June-1st October. The quoted error is obtained from the standard deviation of the ensemble distribution in September.

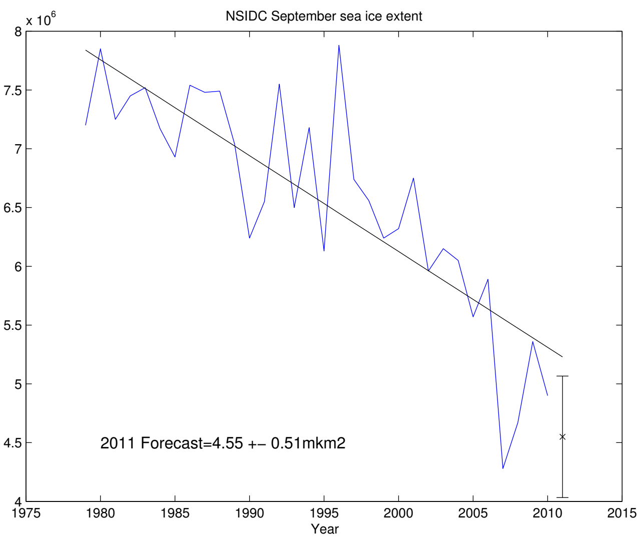


Figure 3: September sea ice extent in observations (1979-2010) together with a linear trend and 2011 forecast

# References

[1] Gent, P. R., et al. (2011), The community climate system model version 4, *Journal of Climate*, *N/A*.