Canadian Ice Service Contribution

to the

September 2011 Sea Ice Outlook

Environment Canada's Canadian Ice Service (CIS) is predicting the minimum Arctic sea ice extent to again be less than 5 million square kilometres in September, 2011. A value similar to or less than the average extents observed in September, 2008, and September, 2010, is expected. This value (≤4.9 million square kilometres) will make the Arctic sea ice extent in September, 2011, either the second or third lowest in the 1979-2011 record. This value lies well below the average September extent for 1979-2010 of 6.6 million square kilometres based on the NSIDC sea ice index.

As with CIS contributions in June 2009 and June 2010, the 2011 forecast was derived using a combination of three methods: 1) a qualitative heuristic method based on observed end-of-winter Arctic Multi-Year Ice (MYI) extents, as well as an examination of Surface Air Temperature (SAT), Sea Level Pressure (SLP) and vector wind anomaly patterns and trends; 2) an experimental Optimal Filtering Based (OFB) Model which uses an optimal linear data filter to extrapolate NSIDC's September Arctic Ice Extent time series into the future; and 3) an experimental Multiple Linear Regression (MLR) prediction system that tests ocean, atmosphere and sea ice predictors.

Based on end-of-winter MYI extents and SAT patterns, a September 2011 minimum ice extent value of $4.5 \leq x \leq 4.9$ million square kilometres is heuristically predicted. The CIS experimental OFB model predicts a September 2011 average ice extent of 4.8 million square kilometres. The CIS experimental MLR forecast system predicts a September 2011 minimum sea ice extent of 5.6 (5 model runs with a range of 4.9 to 6.1) million square kilometres. The OFB model prediction (4.8 million square kilometres) and the lowest of the 5 MLR predictions (4.9 million square kilometres) agree with the upper limit of the heuristically determined range of 4.5 to 4.9 million square kilometres. The average forecast value of the three methods combined is 5.0 million square kilometres.

The CIS will be continuing its verification studies of the predictions produced by these methods/models in the coming years. In 2009, the CIS empirical forecast of 5.0 million square kilometres verified better than all the other predictions submitted to SEARCH in June 2009, and in 2010 the CIS empirical forecast of $4.7 \leq x < 5.0$ million square kilometres once again verified very well. In 2009, the OFB model under-predicted the sea ice extent by ~1 million square kilometres, but in 2010 it accurately predicted the September average ice extent at 4.9 million square kilometres. In 2009, the MLR model only slightly over-estimated the minimum sea ice extent, while in 2010 it over-predicted it by nearly 1 million square kilometres.

Heuristic Forecast

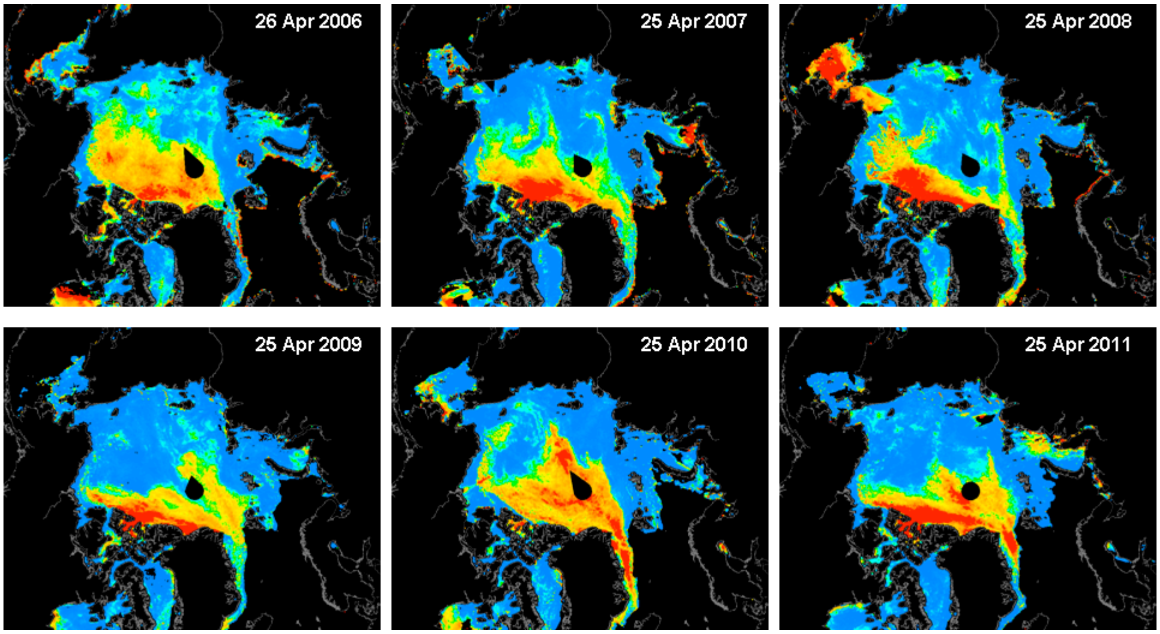

Figure 1. April 25 Multi-Year Sea Ice fraction derived from AMSR data (http://www.seaice.dk/test.N/). Red = 100%. Blue = 0%.

Arctic MYI history (Figure 1): In winter / spring 2007, there was a large wind-driven MYI export out of the Arctic Ocean through Fram Strait. This was followed by extensive in situ summer melting, partly as a consequence of warmer than normal air temperatures. This then resulted in a greatly depleted Arctic MYI ice pack by the end of the 2007 melt season, breaking all previous records in the 1979-2007 satellite database. Due to the events in 2007, a large area of First Year Ice (FYI) existed at the North Pole at the onset of the 2008 melt season and predictions for an ice-free North Pole and record-breaking minimum extents for September 2008 were made. However, not all the FYI at the North Pole melted in summer 2008 as expected and, as a result, the September extent record was not broken and a sizeable area of Second Year Ice (SYI) existed at North Pole at the onset of the 2009 melt season. This North Pole ice again did not all melt away in summer 2009. Additionally, a strong and persistent negative winter Arctic Oscillation (AO) in 2010 then caused divergence of the MYI pack away from Canada into central Arctic Ocean, so that the MYI extent at the onset of the 2010 melt season was larger than that of the two previous years (though the pack was less concentrated). The events of the previous 5 years have taught us that record-breaking September minimum Arctic sea ice extents do not necessarily follow as a result of very low beginning-of-melt-season MYI fractions (e.g. 2008), although in general well-below-normal September minimum extents can be expected.

In winter/spring 2011, periods of strong compression of the Arctic ice pack against the CAA and limited wind-driven ice losses through Fram Strait have resulted in a beginning-of-May MYI pack similar to that of 2009: one with a highly compacted region along the north Greenland and Canadian Arctic Archipelago (CAA) coasts, with limited recirculation into the Beaufort Sea and with an area of lower concentrations reaching around the North Pole. This reduced MYI pack, which has left the bulk of the Arctic Ocean covered in FYI, indicates that well below normal end-of-melt season ice extents can be expected in September 2011 (≤5 million square kilometres), though not necessarily record-breaking minimum extents.

The warmer than normal air temperatures that persisted over the bulk of the Arctic Ocean throughout the 2011 winter dropped to below normal values over the Canadian Arctic and Greenland this April before returning to generally warmer than normal values north of 70°N in May. This period of colder than normal spring temperatures on the Canadian/Greenland side of the Arctic Ocean, where the bulk of the MYI pack currently resides, may cause some delay in the progression of the melt season in these locations. However, it must be recalled that ice melt is not only dependent upon air temperatures but is also strongly driven by incoming solar radiation / cloud-free days as well as ocean circulation / temperatures.

Taking all the above into consideration, the staff at CIS are predicting a 2011 summer Arctic sea ice minimum extent similar to or slightly less than the average extents observed in September, 2008, and September, 2010 ($4.5 \leq x \leq 4.9$ million square kilometres).

Statistical Method #1: Optimal Filtering Based Model Forecast

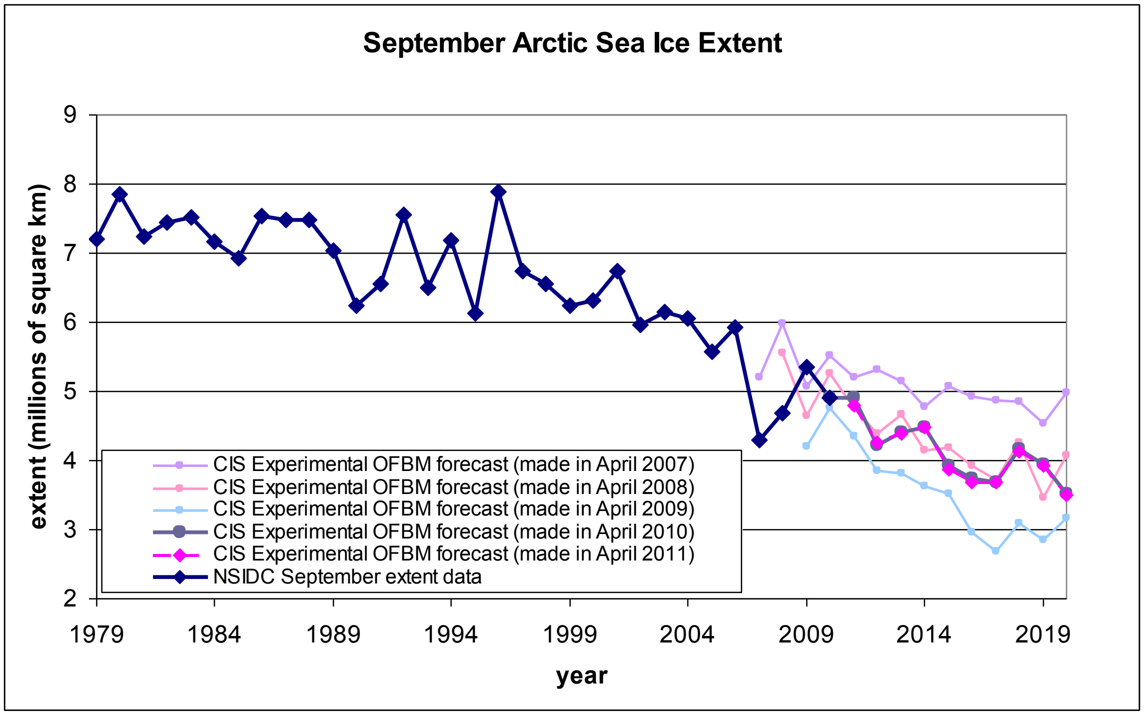

Figure 2. The Optimal Filtering Based model (OFBM) forecast for 2011-2020 (made in April 2011 – pink line, based on NSIDC September extent data – dark blue line). The **2011 forecast** is **$4.8*10^6$ km^2**. The forecasts out to 2020 made in previous years are also shown for comparison.

Model Details

Details of the Optimal Filtering Based Model (OFBM) used here, as well as the model code, can be found in Press et al. (1992). Models based on optimal linear data filters have proven skilful at predicting other climate indices (e.g. Nino3 and Nino3.4 SSTs – Kim and North, 1998; 1999).

year	forecast	observed	difference
2007	5.21	4.3	0.91
2008	5.56	4.68	0.88
2009	4.2	5.36	-1.16
2010	4.91	4.9	0.01
2011	4.8		

Table 1. Verification: CIS OFB model forecasts for past September sea ice extent (millions of square kilometres)

References:
Kim, K-Y., and G.R. North (1998): EOF-Based Linear Prediction Algorithm: Theory. *Journal of Climate*, **11**, 3046-3056.
Kim, K-Y., and G.R. North (1999): EOF-Based Linear Prediction Algorithm: Examples. *Journal of Climate*, **12**, 2076-2092.
Press, W.H., S.A. Teukolsky, W.T. Vetterling and B.P. Flannery (1992): Numerical Recipes in Fortran 77, Second Edition: The art of scientific computing. Cambridge University Press, Cambridge, UK. [Chapter 13, section 13.6].

Statistical Method #2: MLR Prediction System Forecast

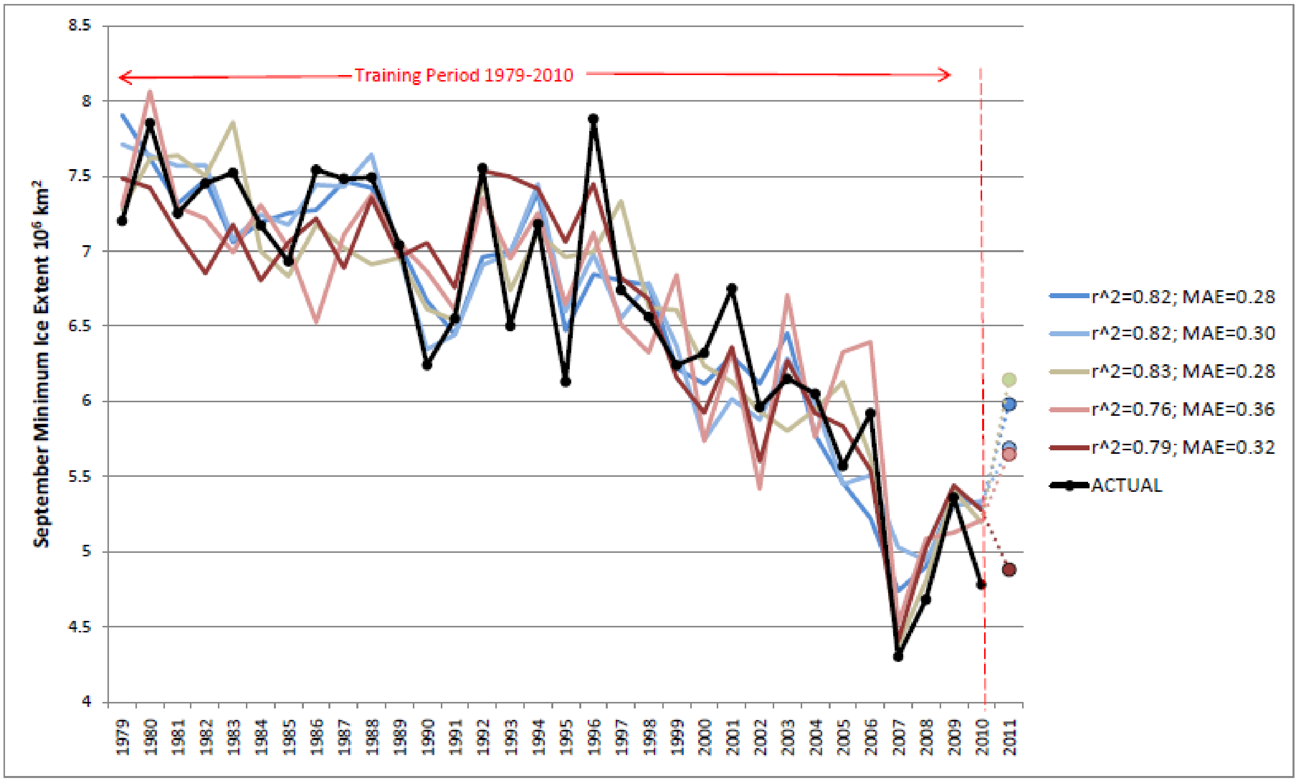

Figure 3. Regression based forecast for the 2011 September Ice Extent. The model is trained on the 32-year period from 1979-2010. The **2011 forecasts** from the 5 model runs range from 4.9 to 6.1 and average **5.6*10^6 km^2**.

Model Details

The regression models are generated using an automated selection scheme (Tivy et al., 2007) based in part on step-wise regression and where the maximum number of predictors is restricted to two. Predictors in the original predictor pool included: pan-Arctic sea ice concentration, SLP and z500, near-global SST, and indices for ENSO, the PDO, the AO, NAO and other atmospheric teleconnections. Each predictor was tested at lags ranging from 5 to 18 months. After each model run the first predictor was removed from the predictor pool, this process was repeated until no models were generated. Five regression equations were generated for the September minimum, it is important to note that they are not necessarily independent. The pairs of predictors for the 5 models are: MJJ SAT & JFM SIC, MJJ SST & JFM SIC, AMJ SIC & JFM z250, NDJ SLP & WLT FDD, JJA z700 & NDJ z500.

Reference:

Tivy, A., B. Alt, S.E.L. Howell, K. Wilson, and J.J Yackel. (2007). Long-range prediction of the shipping season in Hudson Bay: A statistical approach. Weather and Forecasting, 22, 1063–1075, doi:10.1175/WAF1038. WAF10