Canadian Ice Service Contribution

to the

September 2014 Sea Ice Outlook
(June Issue)

Environment Canada's Canadian Ice Service (CIS) is predicting the 2014 minimum Arctic sea ice extent to lie between the record minimum value set in 2012 and the recovery minimum value experienced in 2013. A value of **4.9 million square kilometres** is predicted, which will make the Arctic sea ice extent in September, 2014, tied for the fifth lowest in the 1979-2012 record (tied with 2010). A value of 4.9 million square kilometres still lies well below the 1981-2010 average September minimum extent of 6.3 million square kilometres based on the NSIDC sea ice index.

As with previous CIS contributions, the 2014 forecast was derived by considering a combination of methods: 1) a qualitative heuristic method based on observed end-of-winter Arctic ice thicknesses and 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 Model (OFBM) 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 winter air temperatures and sea ice extents and thicknesses, a September 2014 *minimum* ice extent value of **4.8 million square kilometres** is heuristically predicted. The CIS experimental OFB model predicts a September 2014 *average* ice extent of **4.37 million square kilometres**. The CIS experimental MLR forecast system predicts a September 2014 *average* sea ice extent of **5.6 million square kilometres** (4 model runs with a range of 5.2 to 5.9). The average forecast value of the three methods combined is **4.9 million square kilometres.** Therefore, the CIS is forecasting a 2014 pan-Arctic September sea ice minimum of **4.9 million square kilometres.**

The CIS will be continuing its verification studies of the predictions produced by these methods/models in the coming years.

Heuristic Forecast

- A significant amount of first-year ice survived the 2013 melt season (to become second-year ice on Oct 1, 2013). This nearly doubled the extent of the Arctic Ocean Multi-Year Ice (MYI) pack (Figure 1a).
- Partly because the Arctic Oscillation (AO) was on average in a positive phase, a distinct recirculation of the MYI pack (Old Ice + Second-Year Ice) took place within the Beaufort Sea during winter 2013-14. This resulted in the westward extension of a 500km-wide tongue of Old Ice (>2 years old) along 75N, from the compressed area along the Canadian Arctic island coasts towards the Chukchi Sea. In addition to causing an expansion of the area of Old Ice, this recirculation also meant that there was increased retention of total MYI amounts within the Arctic Ocean this past winter and a reduced export/loss of MYI through Fram Strait.
- However, in spite of the greater MYI extents, 2013-2014 winter air temperatures in the Beaufort Sea were well above normal. As a result, although FYI ice thicknesses are normal in the Canadian Arctic Archipelago at the start of the 2014 melt season, they are thinner than normal in the Beaufort Sea. For this reason, any delays in the Arctic Ocean melt season due to the greater fraction of MYI are expected to be offset by the warmer than normal air temperatures and thinner FYI fraction in the Beaufort Sea. The onset of melt in the southern Beaufort Sea is therefore expected to be "near-normal" to "earlier than normal" this summer, depending on the exact location.

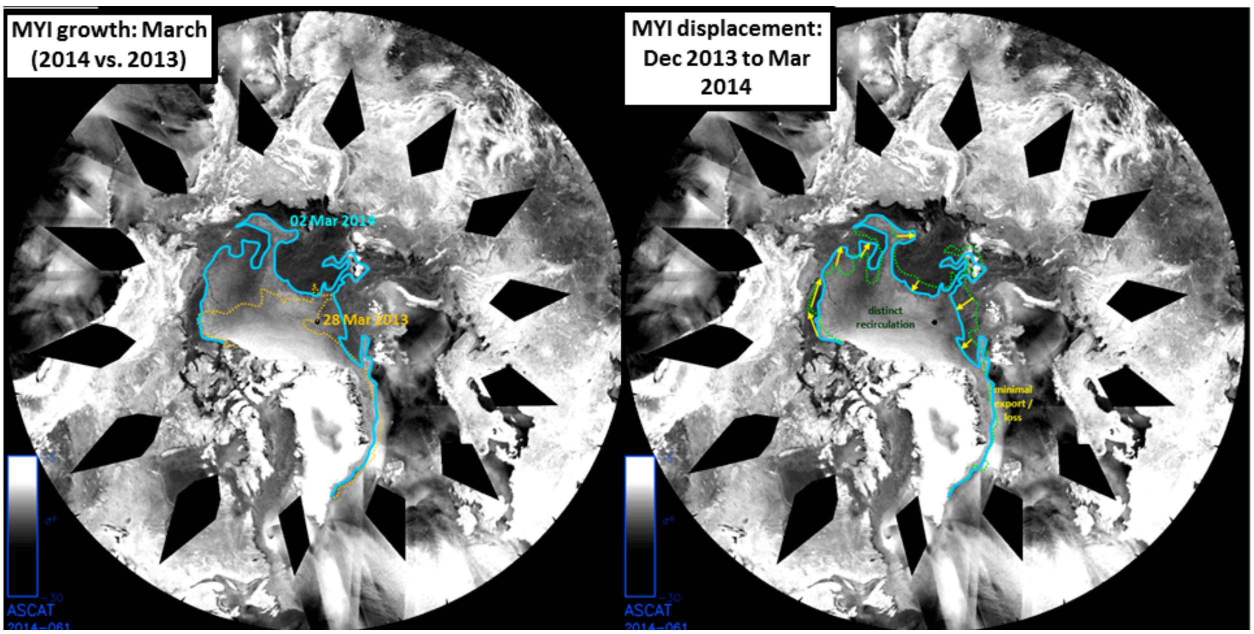

Figure 1. a) Difference in Arctic Ocean Multi-year Ice extent at the onset of the melt season (2013 (yellow) and 2014 (blue)); **b)** Displacement of the MYI pack between December 2013 (green) and March 2014 (blue), showing a distinct recirculation in the Beaufort Sea.

Based on the points above, 2014 September Arctic Ocean sea ice extents are expected to continue experiencing a slight recovery (similar to but slightly less than that of summer 2013), preventing a repeat of the 2012 record. The CIS heuristic forecast for the 2014 pan-Arctic end-of-melt-season minimum sea ice extent is therefore expected to lie between the 2012 (3.61 million square kilometres) and 2013 (5.35 million square kilometres) September extents, and is expected to be around **4.8 million square kilometres** (similar to 2008 and 2010). CIS heuristic forecasts are usually given as a range to indicate **uncertainty**, of approximately ±0.2 million square kilometres about a mean value. For 2014, the range is 4.6-5.0 million square kilometres.

Year	June forecast	observed	difference
2009	5.0	5.36	-0.36
2010	4.7-5.0 (4.85)	4.9	-0.05
2011	4.5-4.9 (4.7)	4.61	0.09
2012	4.6-4.9 (4.75)	3.61	1.14
2013	3.6	5.35	-1.75

Table 1. Verification: CIS Heuristic forecasts for past September average sea ice extent (millions of square km).

Statistical Method #1: Optimal Filtering Based Model Forecast

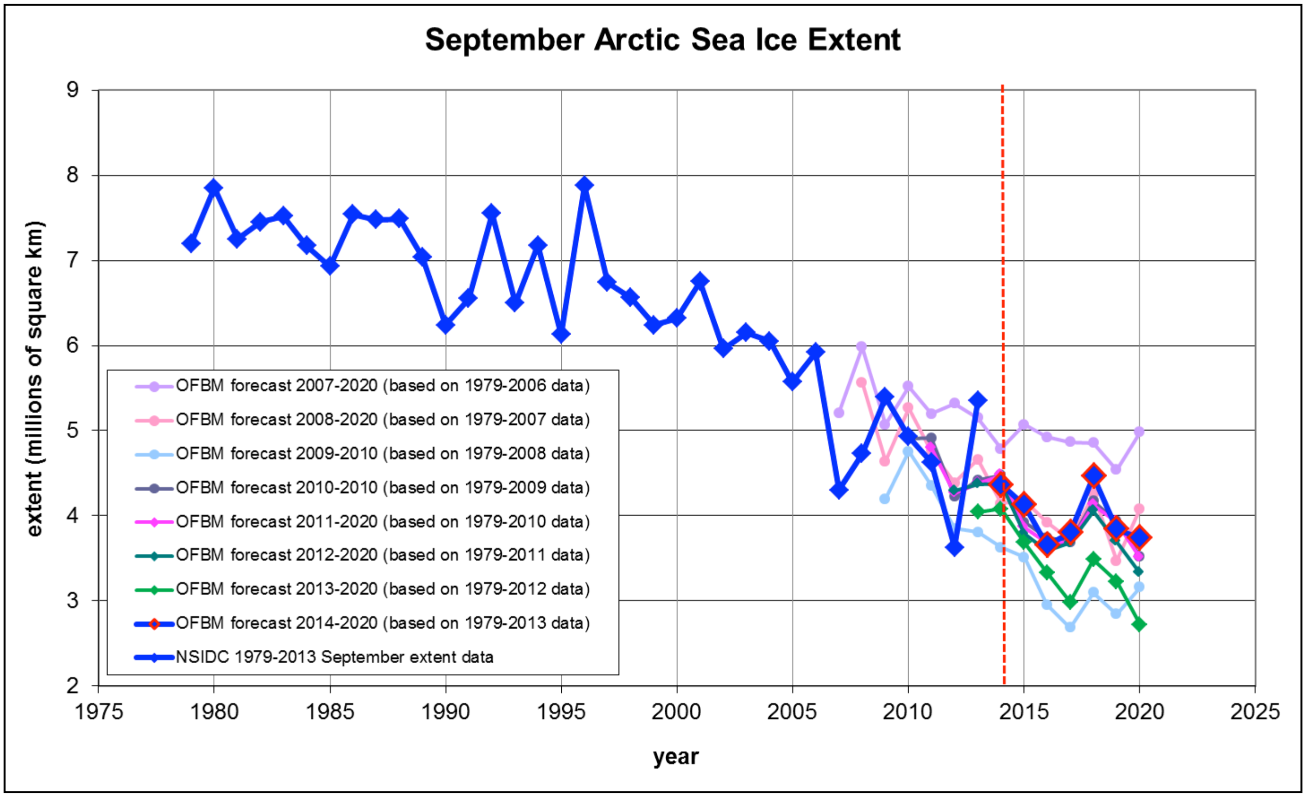

Figure 2. The Optimal Filtering Based model (OFBM) forecast for 2014-2020 (based on 1979-2013 NSIDC September extent data – thick blue line).

The **2014 forecast** for the September average sea ice extent is **$4.37*10^6$ km^2 ± ~$1.0*10^6$ km^2**. The forecasts out to 2020 made in previous years are also shown for comparison. **Uncertainty**: this is shown/estimated by the envelope of forecasts made each year out to 2020, with the upper bound being the forecasts made for 2007-2020, based on 1979-2006 data, and the lower bound being those made for 2009-2020, based on data for 1979-2008 (Figure 2). It is also indicated by the maximum differences between forecast and observed extents for the past 7 years (Table 2: +0.91 in 2007; -1.30 in 2013).

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	4.61	0.19
2012	4.3	3.61	0.69
2013	4.05	5.35	-1.3

Table 2. Verification: CIS OFBM forecasts for past September average sea ice extent (millions of square kilometres)

Model Details / References

- Details of the Optimal Filtering Based Model (OFBM) used here, as well as the model code, can be found in: 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].
- Models based on optimal linear data filters have proven skilful at predicting other climate indices (e.g. Nino3 and Nino3.4 SSTs): 1) Kim, K-Y., and G.R. North (1998): EOF-Based Linear Prediction Algorithm: Theory. *J Clim*, **11**, 3046-3056. 2) Kim, K-Y., and G.R. North (1999): EOF-Based Linear Prediction Algorithm: Examples. *J.Clim*, **12**, 2076-2092.

Statistical Method #2: MLR Prediction System Forecast

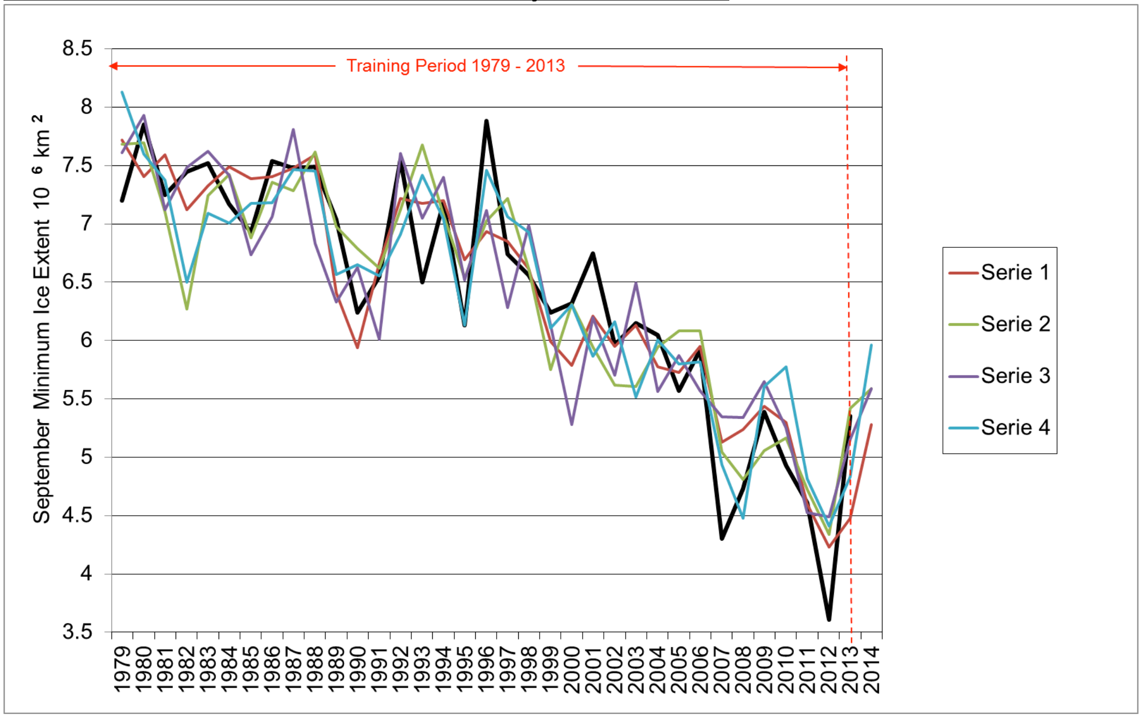

Figure 3. Regression based forecast for the 2014 Average September Ice Extent. The model is trained on the 35-year period from 1979-2013. The **2014 forecasts** from the 4 model runs range from 5.2 to 5.9 and average **5.6*10^{6} km^{2}**. As an indication of uncertainty: a) each series got respectively an R square of 0.83, 0.80, 0.79 and 0.80; b) each series got respectively a mean absolute error of 0.33, 0.35, 0.39 and 0.36. Black line on figure 3 is the actual from 1979 to 2013.

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. Four 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 4 models are: MJJ SST & Aug ZCP, MAM Z500 & NOV WAY, SON SLP & AUG SNOW, MAM Z250 & ASO YRB.

year	forecast	observed	difference
2009	5.65	5.36	0.29
2010	5.70	4.90	0.80
2011	5.60	4.61	0.99
2012	5.10	3.61	1.49
2013	5.00	5.35	-0.35

Table 3. Verification: CIS MLR forecasts for past September average sea ice extent (millions of square kilometres).

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