**SEA ICE PREDICTION NETWORK (SIPN)**
**Pan-Arctic Sea Ice Outlook Core Contributions**
June 2015 Report

*REQUIRED

1. *Contributor Name(s)/Group – how you would like your contribution to be labeled in the report (e.g., Wiggins et al.) Yuan et al.

2. *"Executive summary" about your Outlook contribution (max 300 words)
   Say in a few sentences what your Outlook contribution is and why. To the extent possible, use non-technical language. The prediction is made by statistical models, which are capable to predict Arctic sea ice concentrations at grid points 4-months in advance with reasonable skills. The models employ 34 years of monthly time series of sea ice, SST and atmospheric variables. The Pan Arctic SIE calculated from predicted ice concentration in September 2015 is projected to be 4.99 million square kilometers, lower than the observed extents in 2013 and 2014, but still above the historical low in 2012. The ice concentration is significantly below the 34-year climatology in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea and Barents Sea.

3. *Type of Outlook projection
   ___dynamic model _x__statistical ___heuristic ____mixed or other: (specify)

If you use a model, please specify:
Model Name __Linear Markov Model __
Components of the model: Atmosphere_x_, Ocean_x_, Ice_x, Land__,
For models lacking an atmosphere or ocean, please describe the forcing: ___

4. *September monthly average projection (extent in million square kilometers. To be consistent with the validating sea ice extent index from NSIDC, if possible please first compute the average concentration for the month and then compute the extent as the sum of area of all cells > 15%.) 4.99

5. *Short explanation of Outlook method (max 300 words)
   In addition, we encourage you to submit a more detailed Outlook, including discussions of uncertainties/probabilities, including any relevant figures, imagery, and references.
   If this is a model contribution, please include method of method of initialization and variable used. A Linear Markov model is used to predict monthly Arctic sea ice concentration at all grid points in the pan Arctic region. The model is a stochastic linear inverse model that was built in the multivariate EOF space and

is capable of capturing the co-variability in the ocean-sea ice-atmosphere system. The model employs 6 variables (ice concentration, sea surface temperature, surface air temperature, 300mb height and wind vectors at 300mb) and 11 mEOF modes, and September SIE is calculated from predicted monthly mean ice concentrations. In addition, we also used a regional Markov model for the Pacific sector of the Arctic, which provides better skills than the pan Arctic model in this region. The results from the pan Arctic and regional models were then merged to produce the final prediction and predictive skill assessments.

6. Projection uncertainty/probability estimate for September extent (only required if available with the method you are using) The uncertainty is measured by RMS errors (RMSE) between predicted extent and observed extent. EMSE for September sea ice extent is 0.545 million square kilometers and the correlation is 0.8.

7. Short explanation/assessment of basis for the uncertainty estimate in #6 (1-2 sentences) The uncertainty is estimated based on the cross-validation experiments for four-month lead predictions of September ice concentration and sea ice extent using 34 years (1979-2012) of time series. The data used include SIC with a NASA Team algorithm, NCEP/NCAR reanalysis atmospheric variables and ERSST.

# September 2015 Arctic Sea Ice Prediction Based on May Observations: Pan Arctic Sea Ice Extent, Regional Ice Extent and Arctic Sea Ice Concentration

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Prediction model: Linear Markov model for Arctic Sea Ice Seasonal Prediction (Yuan et al., 2015).

Pan-Arctic Sea Ice Extent (SIE) Prediction: Based on the observations of sea ice concentrations, SST and atmospheric variables in May, the model predicts that the Pac-Arctic Sea Ice Extent (SIE) will be 4.99 million square kilometers.

Regional Sea Ice Concentration Prediction: Predicted September sea ice concentration anomalies and concentrations at grid point are displayed in figure 1. The negative anomalies of ice concentration are larger than 40% from the Beaufort Sea to the Laptev Sea. The concentration anomalies are relative to the climatology of 1979-2012.

Method: A linear Markov model has been developed to predict the ice concentration in the pan Arctic region at the seasonal time scale, which represents an original effort of forecasting Arctic sea ice year around with a reduced-dimension statistical model (Yuan et al, 2015, Chen and Yuan, 2004). The model was built to capture co-variabilities in the atmosphere-ocean-sea ice system defined by sea ice concentration, sea surface and air temperature, geopotential height and winds at the 300mb level. Multivariate empirical orthogonal functions (mEOF) of these variables served as building blocks of the model. A series of model experiments were carried out to determine the dimensions of the model. Based on these experiments, we selected the first 11 mEOF modes to construct the model. A linear Markov process predicted principle components of these modes, one month at a time. The predicted principle components were then combined with corresponding eigenvectors to produce the final prediction (Yuan et al., 2015). To enhance the prediction in the Pacific sector of the Arctic, a similar linear Markov model was developed for the Pacific region (40°-84°N, 120°W-120°E), which focuses on the regional dominant coupled relationships. The regional model significantly improves the season forecast skills in the region, compared to the pan Arctic model (Li et al., submitted). Both pan Arctic and Pacific regional models were developed using 34 years (1980-2012) of NASA team sea ice concentration, ERSST and NCEP/NCAR reanalysis atmospheric variables. The predictive skills of the models were evaluated in a cross-validated fashion, which is measured by anomaly corrections between predicted and observed ice concentration anomalies and two-model merged results are shown in figure 2a. The models show considerable skills within the Arctic Basin at the end of summer. Particularly, predictive skills for September forecast at 4-month lead are above 0.6 in the Beaufort Sea and Eastern Siberian Sea, and the maximum skill reaches 0.93 north of the Chukchi Sea. The skill of predicting the September Arctic SIE is 0.8 at the 4-month lead time.

Uncertainty: The uncertainty of the September Arctic SIE prediction, measured by RMS errors (RMSE), is 0.545 million square kilometers. The uncertainties of sea ice

concentration predictions, also measured by RMSE, are shown in figure 2b. Larger RMSE occurs in the marginal seas within the Arctic Basin, where RMSE ranges 20% to 30%. These uncertainties are based on cross-validated experiments using 34-year observations.

Executive summary: The prediction is made by linear Markov models, which are capable to predict Arctic sea ice concentrations at grid points 4-month in advance with reasonable skills. The models employ 34 years of monthly time series of sea ice, SST and atmospheric variables. The Pan Arctic SIE calculated from predicted ice concentration in September 2015 is projected to be 4.99 million square kilometers, lower than the observed in 2013 and 2014, but still above the historical low in 2012. The ice concentration is significantly below the 34-year climatology in the Beaufort Sea, Chukchi Sea, East Siberian Sea, Laptev Sea, Kara Sea and Barents Sea.

References:

Yuan, X., D. Chen, C. Li and L. Wang, Arctic Sea Ice Seasonal Prediction by a Linear Markov Model. In revision.

Chen, D. and X. Yuan, A Markov model for seasonal forecast of Antarctic sea ice. *Journal of Climate, 17(16), 3156-3168, 2004*.

Li, Y., X. Yuan, D. Chen, Q. Zhang, C. Li, F. Niu. and Y. Sun, A Regional Model for Seasonal Sea Ice Prediction in the Pacific Sector of the Arctic. Submitted to *JGR-Atmospheres*.

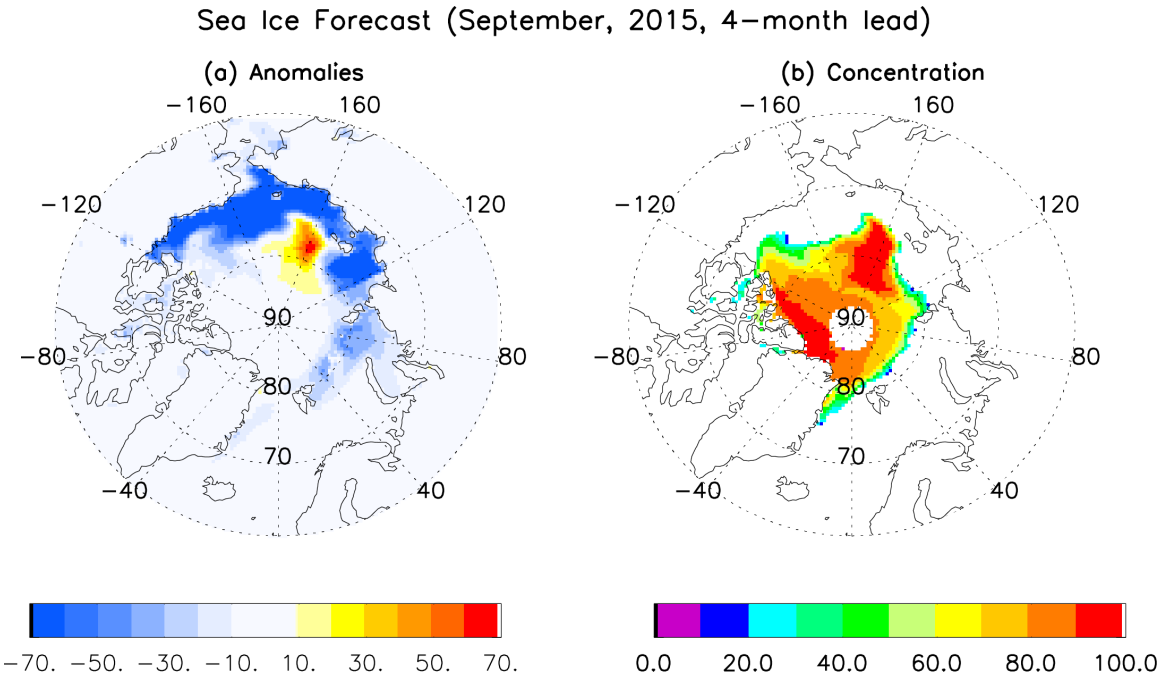


Figure 1. Four-month lead Prediction of September Sea ice concentration anomalies (a) and concentration (b) by the linear Markov model, initialized with May observations of

SIC, SST and geopotential heights and winds at 300mb surface. The units are in percentage in both (a) and (b). The results in the region between 120°W and 120°E and south of 84°N are derived from the Pacific regional Markov model and the results in the rest areas are from the pan Arctic model.

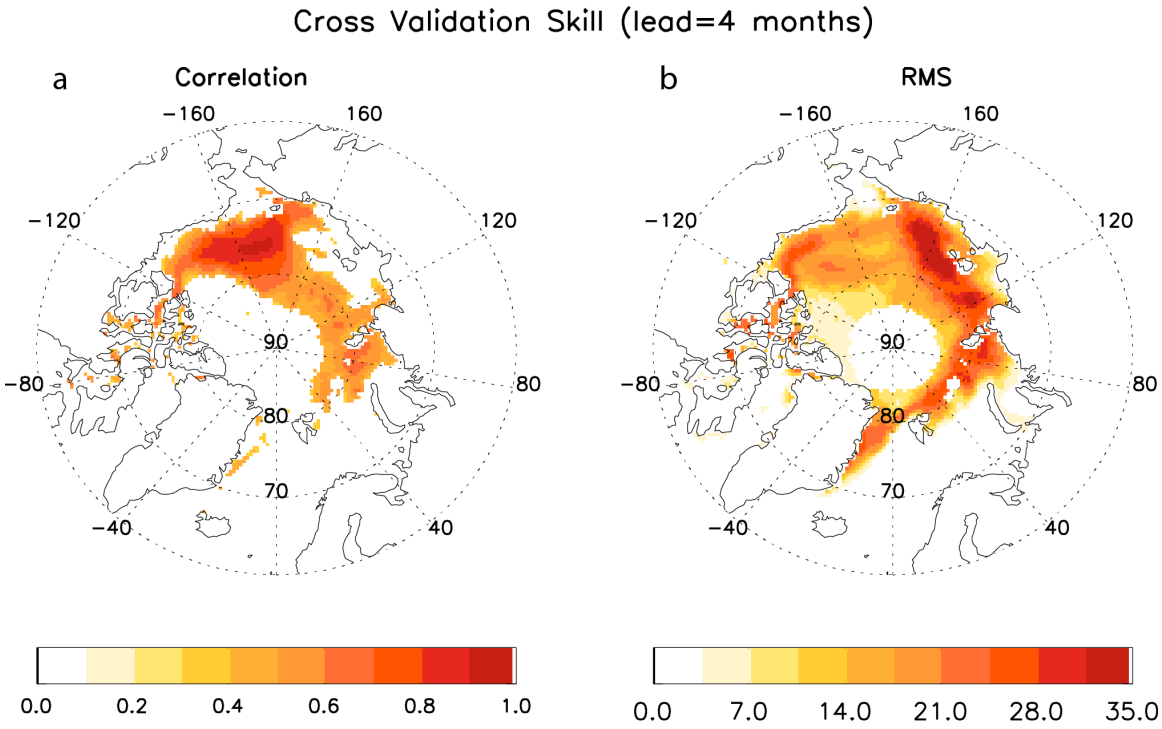


Figure 2. Cross-validated model skills measured by correlations between model predictions and observations of Arctic sea ice concentration anomalies (a) and model RMSE (b) for four-month lead prediction of September sea ice concentration. Only the correlations that pass the 95% confidence level are shown in (a). The units in (b) are in percentages. The low correlations and low RMSE near the North Pole Hole (the satellite blind spot) are due to low ice variability. The results in the region between 120°W and 120°E and south of 84°N are derived from the Pacific regional Markov model, and the results in the rest areas are from the pan Arctic model.