SEA ICE OUTLOOK
2016 Report

September 2016 Prediction of Arctic sea ice concentration and extent Based on July Observations

1. *Name of contributor: Lamont (Yuan et al.)

1b. Primary contact: Xiaojun Yuan, Lamont-Doherty Earth Observatory of Columbia University. Other contributors: Cuihua Li and Lei Wang, Lamont-Doherty Earth Observatory of Columbia University, Dake Chen Second Institution of Oceanography, China, Wanqui Wang, NOAA/NCEP

2. * Contributions submitted by a person or group not affiliated with a research organization, please self-identify here:
   __N/A_____ Yes, this contribution is from "Citizen Scientists."

3. * Do you want your contribution to be included in subsequent reports in the 2016 season?
   _______ Yes, use this contribution for all of the 2016 SIO reports (this contribution will be superseded if you submit a later one).
   ________ No, I/we plan to submit separate contributions for subsequent reports.
   ________ No, I only want to participate this time.

4. *"Executive summary" of your Outlook contribution: in a few sentences (using 300 words or less) describe how and why your contribution was formulated. To the extent possible, use non-technical language. 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 is built in the multi-EOF space and is capable to capture the co-variability in the ocean-sea ice-atmosphere system. September pan Arctic sea ice extent is calculated from predicted sea ice concentration. The model predicts that large negative sea ice concentration anomalies (< -40%) will occur in the Beaufort Sea, Chukchi Sea, Laptev Sea, Kara Sea and Barents Sea in September 2016. The September mean total Arctic sea ice extent will be 4.55 million squared kilometers.
5. *Type of Outlook method:
   ___dynamic model __x_statistical ___heuristic ____mixed or other (specify)

6. *Dataset of initial Sea Ice Concentration (SIC) used (include name and date; e.g., "NASA Team, May 2016"): The linear Markov model is initialized by the monthly mean NASA Team sea ice concentration, ERSST and NCEP/NCAR reanalysis surface air temperature in July 2016.

7. Dataset of initial Sea Ice Thickness (SIT) used (include name and date): N/A

8. If you use a dynamical model, please specify:
N/A

   a) Model name:

   b) Information about components, for example:

Component	Name	Initialization (e.g., describe Data Assimilation)
Atmosphere	CAM5	2016 RCP8.5 integration
Ocean	NEMO2	DA - NCODA system
Ice	TED	DA - EnKF SIC only

c) Number of ensemble members and how they are generated:

d) For models lacking an atmosphere or ocean component, please describe the forcing:

9. *Prediction of September pan-Arctic extent as monthly average in million square kilometers. (To be consistent with the validating sea ice extent index from NSIDC, if possible, please first compute the average sea ice concentration for the month and then compute the extent as the sum of cell areas > 15%.) 4.55

10. Prediction of the week that the minimum daily extent will occur (expressed in date format for the first day of week, taking Sunday as the start of the week (e.g., week of 4 September). Not available. N/A

11. *Short explanation of Outlook method (using 300 words or less). In addition, we encourage you to submit a more detailed Outlook, including discussions of uncertainties/probabilities, including any relevant figures, imagery, and references. The linear Markov model employs 3 variables: NASA Team sea ice concentration, sea surface temperature (ERSST), and surface air temperature (NCEP/NCAR reanalysis) for the period of 1979 to 2012. It is built in multi-variate EOF (mEOF) space. The model utilizes first 11 mEOF modes and use Markov process to predict these principal components forward one month at a time. The total Arctic sea ice extent forecast is calculated by summarizing all cell areas where predicted sea ice concentration exceeds 15%. Bias corrections have been applied to ice concentration predictions at grid points as well as the total sea ice extent prediction. The predictive skill of the model was evaluated by anomaly correlation and root-mean-square errors in a (take one-year out) cross-validated fashion. On average, the model is superior to the predictions by anomaly persistence, damped anomaly persistence and climatology (Yuan et al., 2016). For two-month lead prediction of September sea ice concentration, the model has higher skill (anomaly correlation) and lower RMSE in the Chukchi Sea than other regions. Correspondently, the skill of the two-month lead prediction of the September pan Arctic sea ice extent is 0.94 with a RMSE of 0.33 million squared kilometers.

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

Yuan, X., D. Chen, and C. Li, A Markov model for seasonal forecast of Arctic sea ice. In press, *Journal of Climate*, 2016.

12. If available from your method for pan-Arctic extent prediction, please provide:

a) Uncertainty/probability estimate such as median, ranges, and/or standard deviations (specify what you are providing). The RMSE for two-month lead prediction of September pan Arctic sea ice extent is 0.33 million squared kilometers.

b) Brief explanation/assessment of basis for the uncertainty estimate (1-2 sentences). The uncertainty is estimated based on cross-validated model experiments for 34 years of two-month lead September SIE predictions. RMSE for September SIE is based on 34 predicted pan Arctic sea ice extents including bias corrections and corresponding observations.

c) Brief description of any post processing you have done (1-2 sentences). A constant bias correction was applied to sea ice concentration prediction at each grid point. Then a bias predicted by a linear regression was corrected again in the sea ice extent prediction. Finally, a 0.1 million squatted kilometers correction due to the low model spatial resolution is applied to the final SIE prediction.

d) Raw (and/or post processed) forecasts for this year and retrospective forecasts in an excel spreadsheet with one year on each row and ensemble member number on columns (specifying whether raw or post processed). Raw prediction with grid point bias correction is 5.64, pan Arctic extent bias correction is 0.99 and resolution bias correction is 0.1, all in million squared kilometers.

Year, Raw prediction, post processed prediction

1980	6.88	6.13
1981	6.96	6.27
1982	7.21	6.57
1983	6.95	6.34
1984	7.03	6.23
1985	6.99	6.18
1986	6.98	6.26
1987	6.68	6.03
1988	7.66	7.03
1989	7.69	7.14
1990	7.13	6.39
1991	7.65	6.92
1992	7.58	7.10
1993	7.53	6.80
1994	7.55	6.95
1995	7.20	6.36
1996	7.94	7.38
1997	7.34	6.66
1998	7.07	6.30
1999	6.42	5.66
2000	7.00	6.28
2001	6.96	6.12
2002	6.37	5.60
2003	6.63	5.83
2004	6.76	6.00
2005	6.18	5.27
2006	6.39	5.42
2007	5.57	4.46
2008	5.96	5.05

2009	6.05	5.11
2010	6.00	4.93
2011	5.59	4.42
2012	5.27	4.10
2016	5.64	4.55

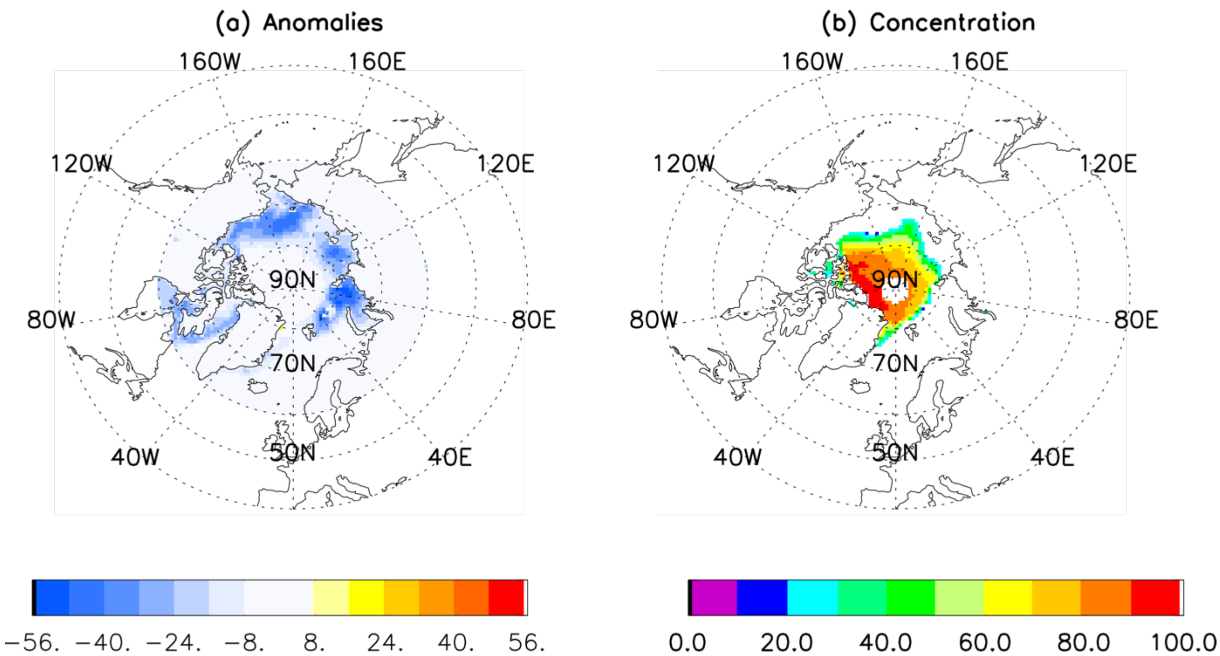

Figure 1 Two-month lead prediction of 2016 September Arctic sea ice concentration anomaly (a) and concentration (b) by the linear Markov model initialized with observed July sea ice concentration, SST and SAT data.

September 2016 Prediction of Arctic sea ice concentration and extent by a Linear Markov Model: August Report

Xiaojun Yuan and Cuihua Li
Lamont-Doherty Earth Observatory of Columbia University

Executive Summary: 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 is built in the multi-EOF space and is capable to capture the co-variability in the ocean-sea ice-atmosphere system. September pan Arctic sea ice extent is calculated from predicted sea ice concentration. The model predicts that large negative sea ice concentration anomalies (< -40%) will occur in the Beaufort Sea, Chukchi Sea, Laptev Sea, Kara Sea and Barents Sea in September 2016. The September mean pan Arctic sea ice extent will be 4.55 million squared kilometers.

Prediction model: Linear Markov model for Arctic Sea Ice Seasonal Prediction (Yuan et al., 2016).

Pan-Arctic Sea Ice concentration and Extent Predictions: Based on the observations of sea ice concentrations, SST and surface air temperature in July, the model predicts negative sea ice concentration anomalies in all areas within the Arctic Basin relative to the climatology for the period of 1979-2012 (figure 1). Particularly large anomalies (<-40%) occur in in the Beaufort Sea, Chukchi Sea, Laptev Sea, Kara Sea and Barents Sea in September, 2016. The model predicts that the pan-Arctic Sea Ice Extent (SIE) will be 4.55 million square kilometers.

Method: The linear Markov model has been developed to predict sea ice concentrations in the pan Arctic region at the seasonal time scale. The model employs 3 variables: NASA Team sea ice concentration, sea surface temperature (ERSST), and surface air temperature (NCEP/NCAR reanalysis) for the period of 1979 to 2012. It is built in multi-variate EOF space. The model utilizes first 11 mEOF modes and use a Markov process to predict these principal components forward one month at a time. The pan Arctic sea ice extent forecast is calculated by summarizing all cell areas where predicted sea ice concentration exceeds 15%. Bias corrections have been applied to ice concentration predictions at grid points as well as the total sea ice extent prediction. The predictive skill of the model was evaluated by anomaly correlation between predictions and observations, and root-mean-square errors (RMSE) in a (take one-year out) cross-validated fashion. On average, the model is superior to the predictions by anomaly persistence, damped anomaly persistence and climatology (Yuan et al, 2016). For the two-month lead prediction of September sea ice concentration, the model has higher skill (anomaly correlation) and lower RMSE in the Chukchi Sea than in other regions (figure 2). The skill of the two-month lead prediction of the pan Arctic sea ice extent in September is 0.94 with a RMSE of 0.33 million squared kilometers. The prediction for September 2016 is initialized with monthly mean NASA Team sea ice concentration, ERSST and NCEP/NCAR reanalysis surface air temperature in July 2016.

Uncertainty: The uncertainty of sea ice concentration prediction was estimated based on cross-validated model experiments for 34 years of two:-month lead September predictions. It was achieved by subtracting one-year of data from principal components and re-build Markov model for that year's prediction. The process was repeated for each year of 34-year time series (Yuan et al., 2016). RMSE in figure 2b is based on 34 predicted September Arctic sea ice concentration including grid point bias corrections. The RMSE for the two-month lead prediction of the September pan Arctic sea ice extent, including grid bias and extent bias corrections as well as resolution bias correction, is 0.33 million squared kilometers.

Bias corrections

A constant correction was applied to sea ice concentration prediction at each grid point. The biases were estimated based on the cross-validated predictions for 1998-2012. Then a bias derived from a linear regression of prediction error as function of initial ice sea extent anomaly for the period of 1979-2012 was corrected again in the sea ice extent prediction. Finally, the model uses lower resolution sea ice concentration data (2 degree longitude x 0.5 degree latitude), which introduces a 0.1 million squared kilometers bias compared to 25kmx25km original data. This resolution bias is corrected in the final SIE prediction.

References:

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

Yuan, X., D. Chen, and C. Li, A Markov model for seasonal forecast of Arctic sea ice. In press, *J. Climate*, 2016.

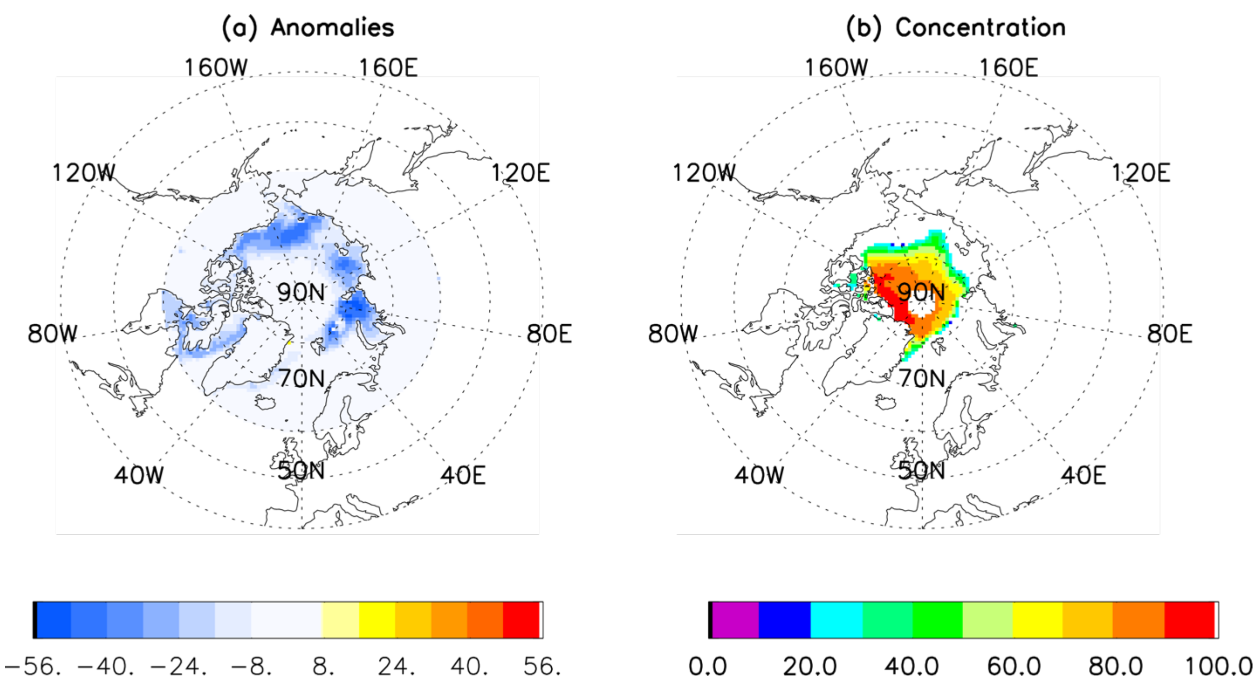

Figure 1 Two-month lead prediction of 2016 September Arctic sea ice concentration anomaly (a) and concentration (b) by the linear Markov model initialized with observed July sea ice concentration, SST and SAT data.

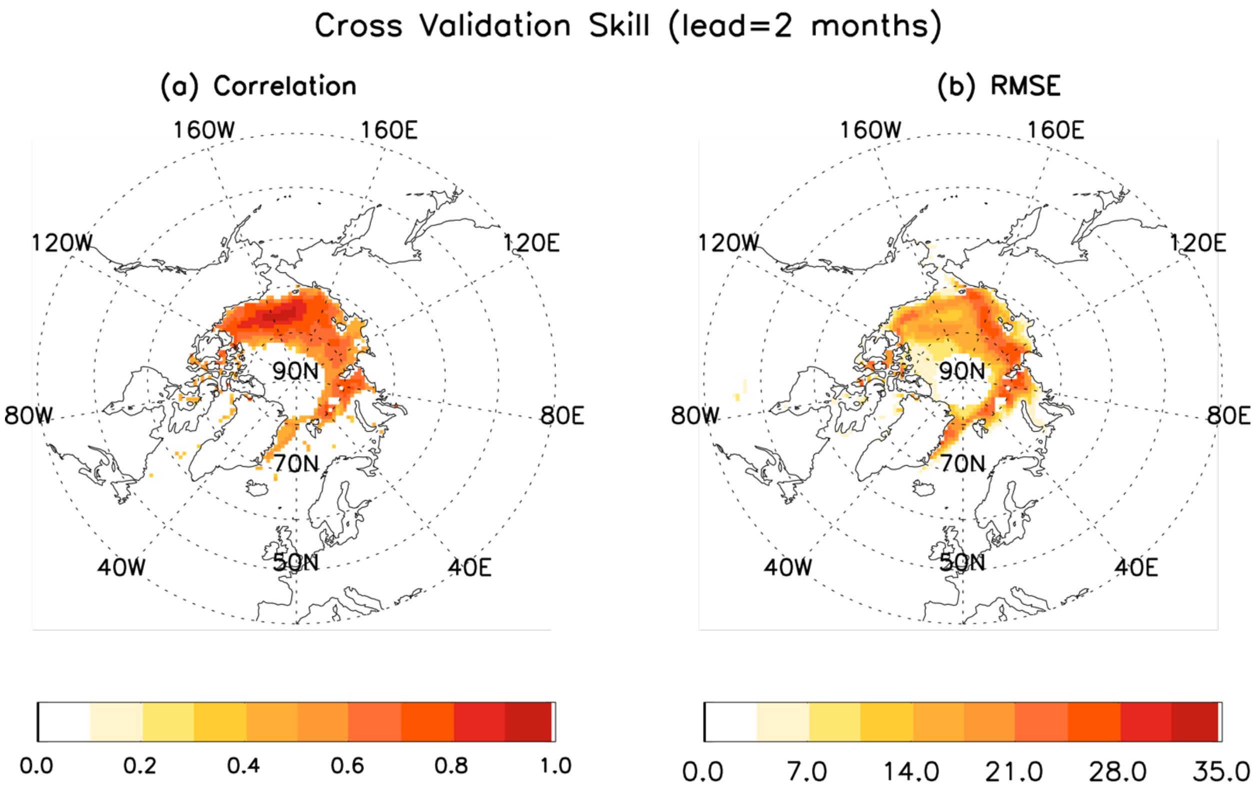

Figure 2. Cross-validated model skills measured by correlations between model predictions and observations of Arctic sea ice concentration anomalies (a) and model RMSE (b) for two-month lead prediction of September sea ice concentration. Only the correlations that pass the 95% confidence level are shown 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.