Predictions for September 2022 Polar Sea Ice Concentration and Extent by Linear Markov Models: June Report

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Executive Summary: A linear Markov model is used to predict monthly Arctic sea ice concentration (SIC) at all grid points in the pan-Arctic region (Yuan et al., 2016). The model was retrained last year using the data from 1979 to 2021. The model is capable of capturing the co-variability in the ocean-sea ice-atmosphere system. The September pan-Arctic sea ice extent (SIE) is calculated from predicted SIC. The model predicts negative SIC anomalies throughout the pan-Arctic region, with negative anomalies exceeded 24% in the Kara, Leptev and East Siberian Seas. These anomalies are relative to the 1979-2021 climatology. The September mean pan-Arctic SIE is predicted to be 5.14 million square kilometers (mskm) with an RMSE of 0.50 mskm, at the four-month lead. Predicted Arctic SIE anomaly is 1.02 mskm. The Alaskan regional SIE is predicted to be 0.66 mskm, higher than the observation in 2022. A Similar statistical model was also developed to predict the SIE in the Antarctic (Chen and Yuan, 2004). The September mean pan Antarctic SIE is predicted to be 17.89 mskm, with a RMSE of 0.57 mskm based forward prediction from 2003 to 2017.

Predictions

Pan-Arctic Sea Ice concentration and Extent Predictions: Based on the observations of sea ice concentrations, SST, surface air temperature, GH300 and vector winds at 300mb in May, the model predicts negative sea ice concentration anomalies in all areas within the Arctic Basin relative to the climatology for the period of 1979-2021 (figure 1). Particularly large anomalies occur in the Kara Sea, Laptev Sea and East Siberia Sea. Negative SIC anomalies in other areas will be smaller than 24%. The model predicts that the pan-Arctic SIE will be 5.14 mskm in September 2023.

Alaskan regional Sea Ice Concentration and Extent predictions: The regional model predicts that the SIE in the Alaskan region will be 0.66 mskm (figure 2), which is significantly higher than the last year Alaska SIE. Large areas around the Chukchi Sea have SIC anomalies of 30% below the climatology. This regional model runs in the area of 40°-85°N and 120°-240°E with total area of 3.93 mskm. The Alaska region SIE is calculated using the regional mask provided by NSIDC.

Pan-Antarctic Sea Ice Concentration and Extent Predictions: Initialized by the observations of sea ice concentration, surface air temperature and GH300 and vector winds height at 300mb in May, the model predicts the Antarctic SIC in September (figure 3) and the total SIE is calculated from the predicted SIC. The Antarctic SIE is estimated to be 17.89 mskm in September 2023.

Models

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 6 variables: NASA Team sea ice concentration, sea surface temperature (ERSST), surface air temperature, GH300, vector winds at GH300 (NCEP/NCAR reanalysis) for the period of 1979 to 2021. It is built in multi-variate EOF space. The model utilizes first 11 mEOF modes and uses 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 four-month lead prediction of September sea ice concentrations, the model has the higher skill (anomaly correlation) and lower RMSE in the Chukchi Sea and Beaufort Sea than in other regions (figure 4). The skill of the four-month lead prediction of the pan Arctic sea ice extent in September is 0.92 (correlation) based on cross-validation experiments without grid point bias correction. The Alaskan regional SIE prediction is produced by a regional linear Markov model developed by using SIC, SST, SAT, and in a rotated-EOF space (unpublished). The Alaska SIE forecast is calculated from predicted SIC. The skill of the regional SIE is 0.90 (correlation) and RMSE of 0.22 mskm using 33 years cross-validated experiments. A similar model is used for Antarctic SIE forecast (Chen and Yuan 2004).

Uncertainty

The uncertainty of SIC prediction was measured by root-mean-square error (RMSE). They were estimated based on 42 years (take-one-year-out) cross-validated model experiments (updated from Yuan et al. 2016). RMSE in figure 4b is based on 42-year predicted SIC in September. Bias corrections at grid points were applied. The SIE uncertainty measured by RMSE is 0.50 million square kilometers for the four-month lead prediction based on cross-validation experiments. The uncertainty is reduced to 0.40 based on forward prediction from 2013 to 2020 with an additional SIE bias correction. The RMSE of the Alaska SIE prediction is 0.22 million square kilometers based on 33-yeasrs cross-validation experiments. For the Antarctic SIE prediction, the RMSE of 0.57 million square kilometers was estimated from the errors from the fifteen years' (2003-2017) forward predictions.

Post processing

First, a constant bias correction was applied to Arctic SIC prediction at each grid point. These biases were estimated based on the take-one-year-out cross-validated predictions for 1979-2021. Then a constant SIE bias also derived from the cross-validation experiments from 1979 to 2021 was corrected from the September SIE prediction. Finally, the model uses lower resolution sea ice concentration data (2-degree longitude x 0.5-degree latitude), introducing a 0.10 million square kilometers bias compared to 25kmx25km original satellite data. This resolution bias is corrected in the final Arctic SIE prediction.

For the Antarctic SIE prediction, we applied a bias of 0.35 million square kilometers between Bootstrap and NASA-Team SIE climatology since the model was developed using Bootstrap SIC but initialized with NASA-Team SIC. Furthermore, like the post-prediction processing for the Arctic SIE, we also applied a resolution bias correction of 0.04 million square kilometers. Last, we apply a model systematic SIE bias correction of 0.56 million square kilometers to the final SIE prediction.

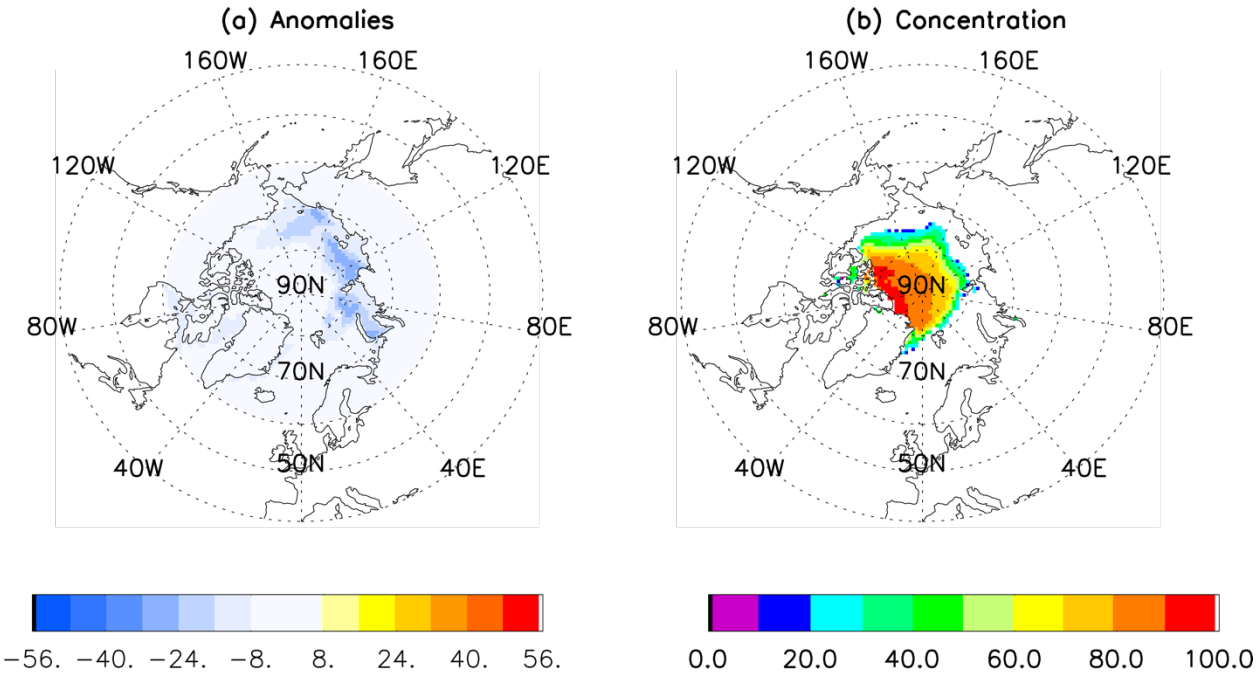

Figure 1 Four-month lead prediction of 2023 September Arctic sea ice concentration anomaly (a) and concentration (b) by the linear Markov model initialized with observed May SIC, SST, SAT, GH300 and vector winds at 300mb.

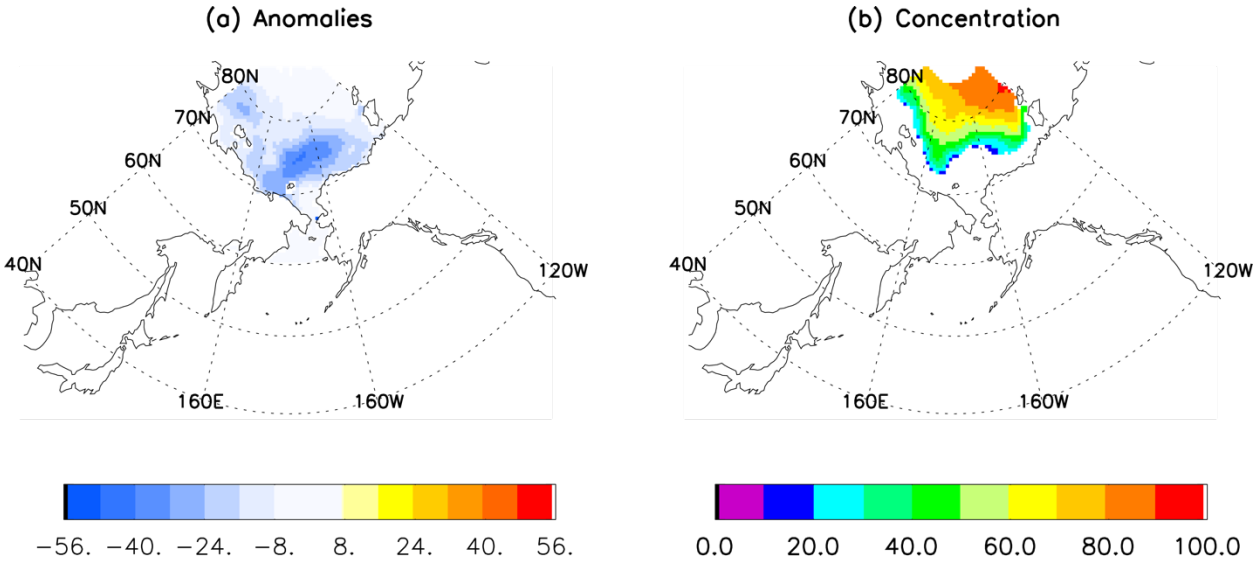

Figure 2 Four-month lead prediction of September 2023 sea ice concentration anomaly (a) and concentration (b) in the Alaskan region by a regional linear Markov model initialized with observed May SIC, SST, SAT, GPH and winds at 500mb and 200mb.

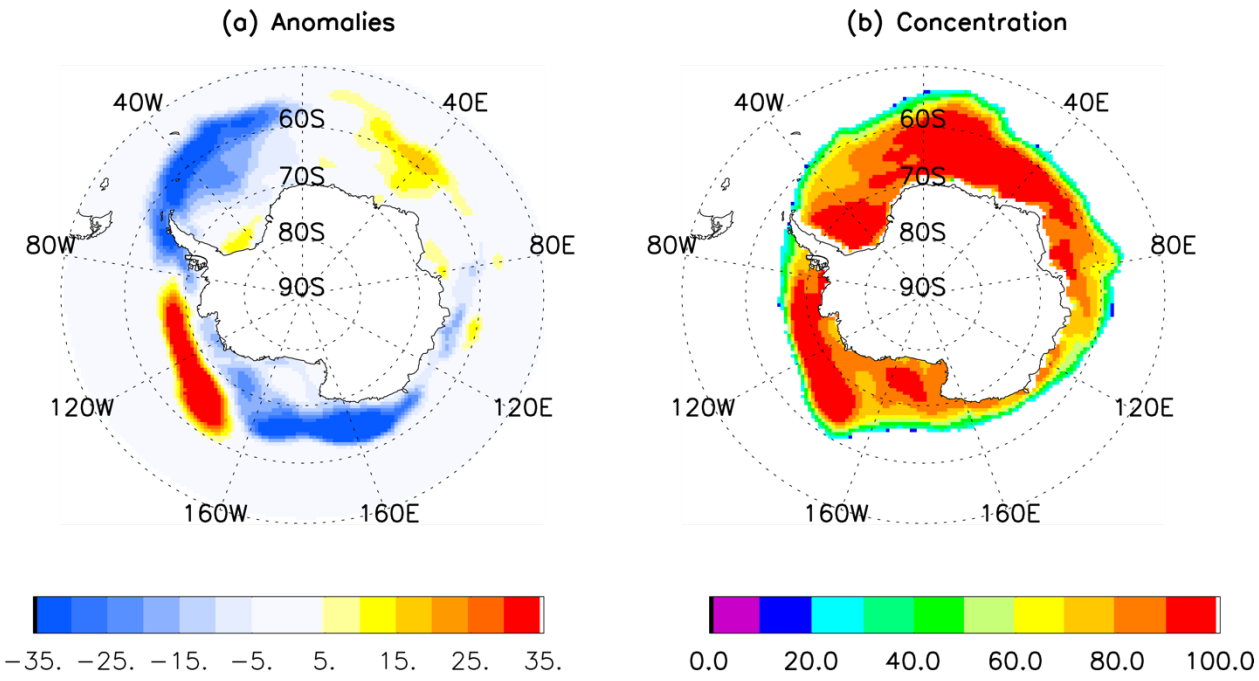

Figure 3 Four-month lead prediction of September 2023 Antarctic sea ice concentration anomaly (a) and concentration (b) by a linear Markov model initialized with observed May SIC, SAT, GH300 and vector winds at 300mb.

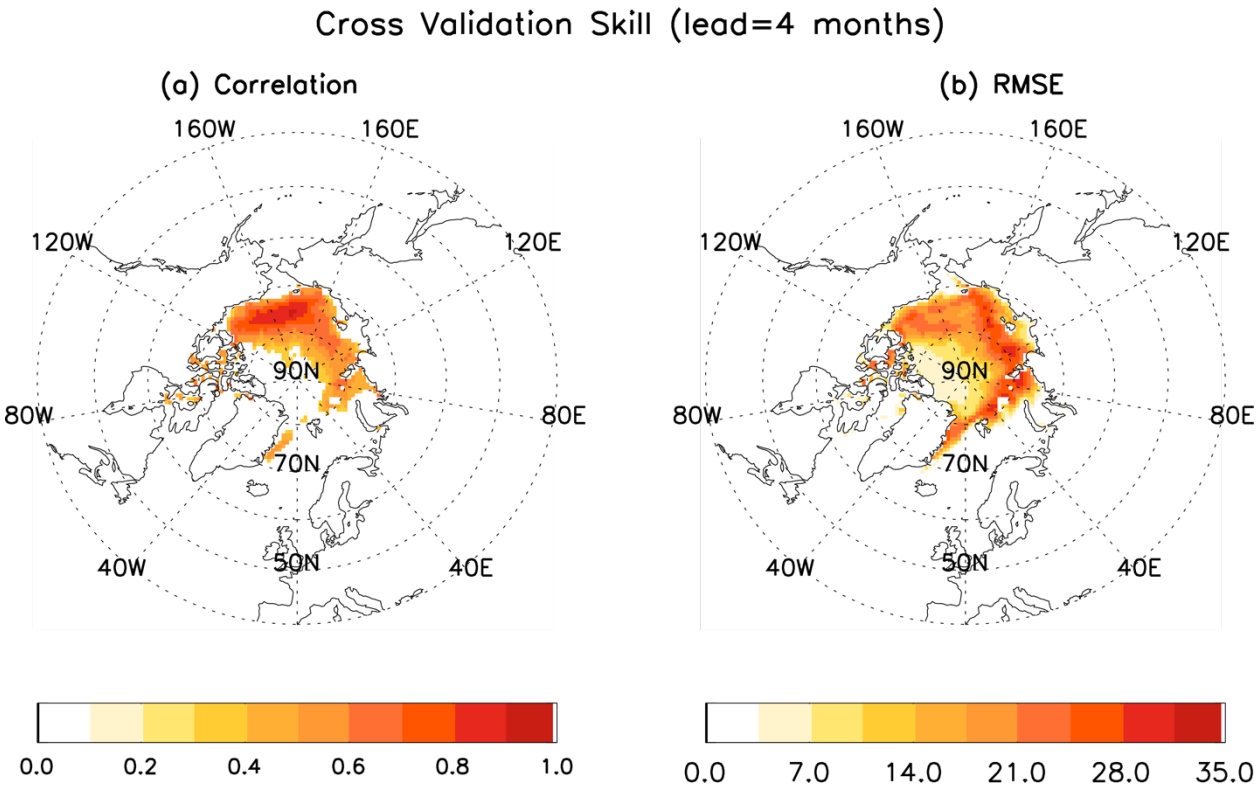

Figure 4. Cross-validated model skill measured by correlations between model predictions and observations of Arctic sea ice concentration anomalies (a) and model RMSE (b) for four-month lead prediction of September sea ice concentration. Only the correlations that pass the 95% confidence level are shown 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 (updated from Yuan et al. 2016).

Datasets

Sea ice concentration: NSIDC NASA Team, https://nsidc.org/data/nsidc-0081, https://doi.org/10.5067/U8C09DWVX9LM.

Atmospheric variables: NOAA NCEP/NCAR Reanalysis-1 http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP-NCAR/.CDAS-1/

Sea surface temperature: NOAA NCDC ERSST version3b: Extended reconstructed sea surface temperature data.

References

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

Yuan, X., D. Chen, C. Li and L. Wang, 2016: Arctic Sea Ice Seasonal Prediction by a Linear Markov Model. *J. Climate*, Vol. 29, DOI: 10.1175/JCLI-D-15-0858.1.