Sea Ice Outlook August 2024

Brief description of your outlook:

This prediction is made using a transfer operator that is trained to calculate statistical transitions in Arctic sea ice extent from July to September. The prediction is initialized in July 2024 and predicts a September 2024 sea ice extent of 4.44 +/- 0.38 MKm2. This prediction is higher (+0.52Mkm2) than that of a linear trend calculated from the September NSIDC Sea Ice Index over the 1979-2014 period.

Outlook methodology:

The transfer operator: We train a transfer operator to predict the internal variability of September Arctic sea ice extent. A transfer operator is a statistical model that calculates the probability of a given output state based on the value of the input state (Sevellec and Drijfhout, 2018). The transfer operator used for this outlook predicts September SIE (output state) from July SIE (input state). We apply the following steps to build the transfer operator: (i) bin the input and output metrics (July and September SIE) into a number of states; (ii) count the number of input states, N_i; (iii) for each input state, count the number of trajectories in each output state, $n_{i,j}$; (iv) calculate the probability of transitioning from the *i*th state to the *j*th state as $p_i = n_{i,j}/N_i$. Figure 1 shows a summary schematic for this transfer operator.

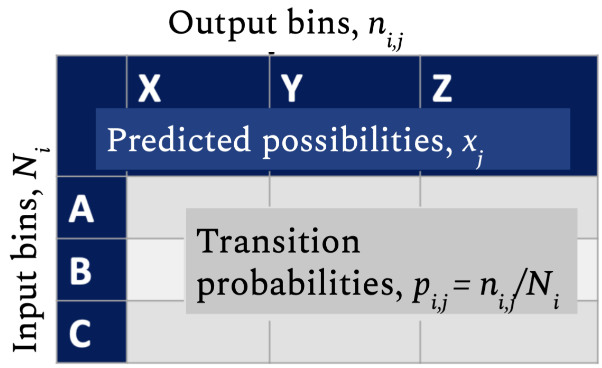

Figure 1. Schematic of the transfer operator method.

Model Inputs: The total variations in sea ice extent are decomposed into a forced contribution and a residual (internal variability). The model inputs and outputs are in the form of residuals, standardized to zero mean and unit standard deviation.

- *Training:* For the training phase we use sea ice extent from the historical runs of ten different models in CMIP6 (models listed below), where the residual is calculated as the difference between each ensemble member and the respective model ensemble mean (the forced contribution).
- *Testing:* The outlook prediction is made using a separate testing data set, where the input is the sea ice extent calculated from observations (NSIDC Monthly Sea Ice Index). Here, the forced contribution is different for the 1979-2014 and 2015-2024 period. For 1979-2014 the forced component is taken to be the weighted mean of the CMIP6 ensemble means, where the weights are based on the number of ensemble members used for each model. The historical CMIP6 runs do not have data past 2014, therefore we use the 5-year moving mean of the NSIDC observations as the forced component for 2015-2024.

Training Data: CMIP6 models used to train the transfer operator (Model name [number of members in brackets]): ACCESS-CM2[10], ACCESS-ESM1-5[40], CanESM5[25], CESM2-WACCM[3], IPSL-CM6A[33], MIROC6[50], MPI-ESM1-2-LR[30], MRI-ESM2-0[5], CNRM-CM6-1[10], CNRM-ESM2-1[5]

Model behavior: The model prediction is sensitive to how the forced contribution (and thus the residual) is calculated. Generally, if the residual is less than one the model has a higher probability of predicting a residual value that is lower than the climatological mean.

Performance metrics: We evaluate the performance of this transfer operator by comparing predictions to observations for previous years (1979-2024). We measure skill with a deterministic (coefficient of determination) and a probabilistic (reliability) metric. The coefficient of determination (i.e. R^2) shows the amount of variance in the observations that is explained by the prediction, where $R^2 = 1$ would indicate that the model explained 100% of the variance in the observations. The reliability measures the accuracy in the spread of the prediction and indicates how well the forecast probabilities match the observed relative frequencies. Here a reliability of 1 would indicate that the forecast probabilities perfectly match the observed frequencies. This particular transfer operator (July to September transition) has performance metrics: *$R^2 = 0.551$ and Reliability = 0.925.*

SIE Prediction: A transfer operator initialized in July 2024 and predicts a September 2024 sea ice extent of 4.44 +/- 0.38 MKm^2. This prediction is represented by the first point in Figure 2, where the other points show predictions of September 2024 SIE initialized in July of previous years. We use the first point as our outlook.

Uncertainty / probability:

- **Mean,** 4.44 Mkm^2
- **Median,** 4.37 Mkm^2
- **Low error bound,** 3.92 Mkm^2
- **High error bound,** 5.17 Mkm^2
- **Standard deviation,** 0.38 Mkm^2
- **Explanation of basis for uncertainty estimate:** The low and high error bounds represent an α = 95% confidence level. They are calculated as the value where the CDF is equal to: $F_{low} = (1-\alpha)/2$ and $F_{high} = 1-(1-\alpha)/2$.

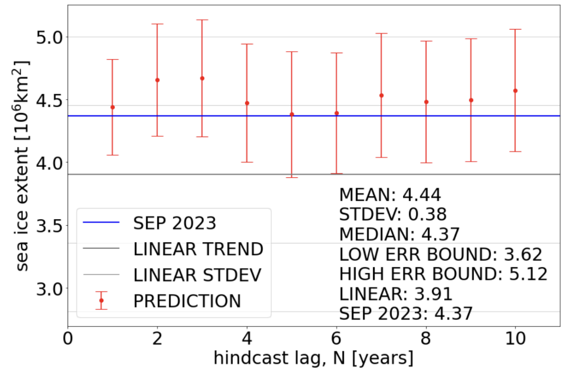

Figure 2. Transfer operator prediction of September 2024 sea ice extent initialized in July for a hindcast lag of 1-10 years (a 1-year lag refers to the July two months before the current September, etc.). The red error bars represent the prediction, from which we use the 1-year lag to represent our sea ice outlook. The grey lines show the mean and standard deviation of the linear trend from 1979-2014. The blue line represents the sea ice extent from September 2023. The statistics of our outlook prediction are shown in the legend.

- **Explanation of post-processing:**
    - *Pre-processing:* The total variations in sea ice extent are decomposed into a forced contribution and a residual (internal variability). The model inputs and outputs are in the form of residuals, standardized to zero mean and one unit standard deviation. For pre-processing we: (i) calculate forced component; (ii) calculate the residual as the total signal minus forced component; (iii) divide the residual by the standard deviation.
    - *Post-processing:* The model output is a probability distribution based on bins defined during model training. The overall mean prediction is the expected value, $\mu = \Sigma\, x*P(x)$, where x is the bin value and P(x) the bin probability. The standard deviation is calculated as $\sigma = (x-\mu)^2*P(x)$. This is still in the form of a ***standardized residual***, therefore we apply post-processing: (i) un-standardize (multiply by the standard deviation of the residuals); (ii) add the forced component back in. The forced component is different in the pre and post processing phase because the inputs are from July and the output is for September. For pre-processing we use the July forcing value. For hindcasts we use the September forcing for the output,but for forecasts of the future we do not have the September forcing value (it hasn't happened yet), so we use the September forcing from the previous year (i.e. 2023).

Difference from September linear trend:

We calculated the linear trend from the September NSIDC Sea Ice Index over the 1979-2014 period because the training data for our model did not extend past 2014. This linear trend predicts September 2024 SIE to be: 3.91 Mkm^2. The difference between our prediction and the September linear trend is: +0.52 Mkm^2

References:

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