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Advanced prediction in polar regions and beyond

APPLICATE-benchmark
Sea Ice Outlook 2020

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Scope

This document provides technical and supplementary information about the APPLICATE-benchmark forecast submitted to the Sea Ice Outlook 2020.

This benchmark forecast comes along four other more elaborated forecasts submitted by the APPLICATE EU consortium (www.applicate.eu), each using a dynamical coupled climate model or a dynamical ocean—sea ice model. The extent to which such advanced forecasts are skillful has to be established based on their ability to outperform trivial, cheap forecasts produced without any knowledge of physics.

The goal of this benchmark forecast is precisely to establish such a baseline.

Forecasting method: recalibrated damped anomaly persistence forecast

The outlook is generated in three steps: (1) issuing raw daily forecasts, (2) diagnosing the September mean value as requested by the Sea Ice Outlook, and (3) recalibrating the forecast.

In our forecast, only the daily sea ice extents provided by the National Snow and Ice Data Center (ftp://sidads.colorado.edu/DATASETS/NOAA/G02135/north/daily/data/N_seaice_extent_daily_v3.0.csv) are used.

1. Raw daily forecasts: damped anomaly persistence forecast

First, a daily Arctic sea ice extent forecast is produced for each day between June 1, 2020, and December 31, 2020. The forecast for a given day d is calculated as:

$$X_d^f = r_d(X_0^o - X_0^b) + X_d^b \qquad (1)$$

In the above formula:

- X_0^o is the observed sea ice extent at initial time (June 1st 2020).
- X_d^b is the "background" sea ice extent for the target day d. In a stationary climate, this term would usually be taken as the climatological mean but given secular trends in Arctic sea ice extent, we here take X_d^b as the quadratic trend of 1979-2019 extent for the relevant day, extrapolated to 2020.
- X_0^b is the background sea ice extent for the initial time. Therefore, the term $(X_0^o - X_0^b)$ represents the June 1st 2020 anomaly with respect to the quadratic trend line.
- r_d is the linear (Pearson) correlation coefficient between the 1979-2019 June 1st anomalies and the 1979-2019 anomalies at day d (again, anomalies are estimated relative to the respective backgrounds). By definition, r_d is 1 at initial time (June 1st). For subsequent days, it measures the autocorrelation of the sea ice extent time series (after removing an estimate of the forced component) starting from June 1st.

Note that Eq. 1 can be in the equivalent following form:

$$X_d^f = r_d\left(X_d^b + (X_0^o - X_0^b)\right) + (1 - r_d)X_d^b$$

This alternative form emphasizes that the damped anomaly persistence forecast can be viewed as a weighted mean between a simple anomaly persistence forecast (that is, the initial time anomaly persisted until the target day), and the target day background itself. More weight is put on the anomaly term if the memory from initial time is high, and more weight is put on the background term if no knowledge can be gained from the autocorrelation of the time series.

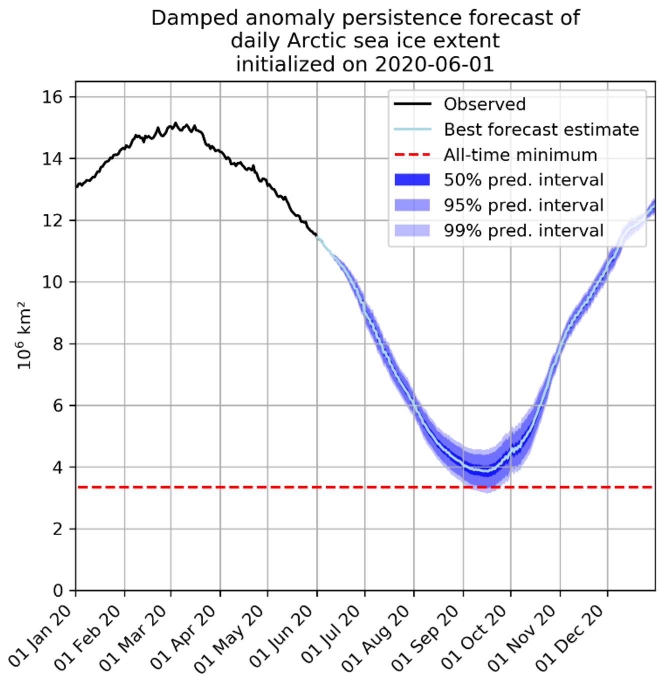
The damped anomaly persistence forecast thus captures two essential traits of the Arctic sea ice extent variability: the presence of long-term trends in the record and the existence of some memory in anomalies. Close to initial time, much weight is put on the anomaly term since $r_d \approx 1$. When anomalies for the target day are no longer correlated with the initial day anomaly in the observational record ($r_d \approx 0$), the forecast becomes a simple trend extrapolation.

Forecast variance is estimated from the forecast equation (1), assuming that there is no error in the observed extent X_0^o and that the correlation r_d is deterministically known. In this case, forecast variance becomes

$$V\left(X_d^f\right) = r_d^2 V\left(X_0^b\right) + V\left(X_d^b\right) - 2\,COV\left(X_0^b, X_d^b\right) = \left(r_d \sigma\left(X_0^b\right) - \sigma\left(X_d^b\right)\right)^2$$

where it was assumed that the correlation between the background errors is equal to the correlation of respective anomalies: $COV\left(X_0^b, X_d^b\right) = r_d\, \sigma\left(X_0^b\right)\, \sigma\left(X_d^b\right)$. The standard deviation background errors $\sigma\left(X_0^b\right)$ and $\sigma\left(X_d^b\right)$ were estimated based on the statistics of fitted parameters in the quadratic trend. Gaussian distributions are assumed in all cases.

With this, we are able to provide a daily forecast, shown below for convenience. This forecast is suggestive that the 2012 record minimum is very unlikely (1 % chance) to be broken. As we will see, this statement will be revised since the forecasting system is underdispersive.



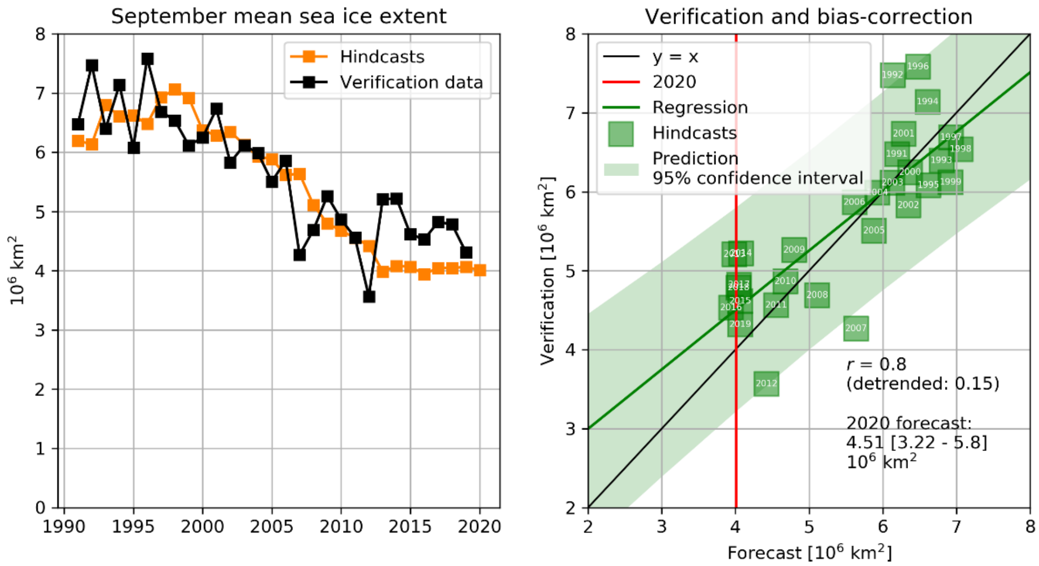
2. Diagnosing the September mean sea ice extent

As a second step, the daily September values of the forecast are averaged to produce a monthly mean value of 4.01 million km².

3. Verification and recalibration

Steps 1. and 2. allow to produce a forecast for 2020. In order to test the extent to which this forecast should be trusted, it is convenient to re-forecast (or "hindcast") previous years for which the verification data is known and, possibly, to modify the 2020 forecast to account for possible shortcomings in our procedure. Therefore, steps 1. and 2. are repeated for each year between 1991 and 2019, in a real operational context – that is, not using data posterior to the year that is forecasted. We do not produce hindcasts before 1991 because sea ice extent is unavailable every other day until 1988, making the estimation of background terms in Eq. (1) not possible for many days.

The monthly mean hindcasts and matching verification data are shown for each year below.

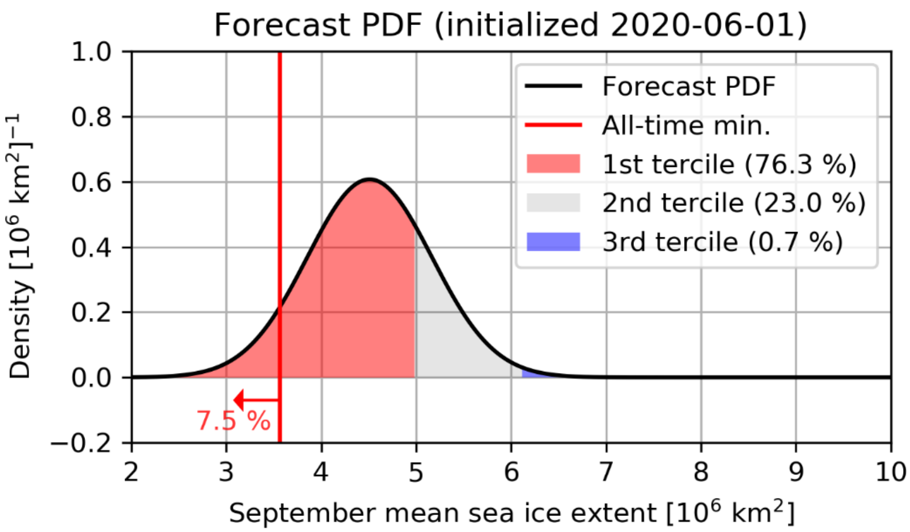


We note a positive association between forecast and verification values (correlation of 0.8), but this association comes in large part from the presence of secular trends in both the forecast and verification data. Indeed, if the forecast and verification data are first quadratically detrended, the correlation drops to 0.15. This reflects the well-known notion that, at the three month lead time (June for September) nothing much than the forced trend can be forecast using the sea ice extent time series only.

According to the scatter plot above, the forecasts exhibit a small negative bias but, more importantly, too little year-to-year variability compared to the verification data. Such a feature is common in forecasting systems and has to be considered carefully; indeed, overconfident forecasts tend to underappreciate the possibility of occurrence of extreme events. In order to correct for the biases in mean and variability, a simple linear recalibration scheme is applied to the 2020 forecast by regressing the 1991-2019 verification data on the matching forecasts. The recalibrated 2020 forecast is then defined as the raw 2020 forecast projected on the obtained regression line, and the uncertainty is taken as 1.96 standard deviations of the prediction (shaded green area in the figure above).

Our best estimate for the September 2020 mean Arctic sea ice extent is therefore 4.51 million km^2, with a forecast error standard deviation of 0.66 million km^2 (the error is assumed to follow a Gaussian distribution). Accordingly, our 95% confidence interval for the September 2020 mean Arctic sea ice extent value, based on the recalibrated damped anomaly persistence forecast initialized one June 1st 2020, is [3.22, 5.80] million km^2.

Our forecast is graphically summarized in the figure below. Adopting the Intergovernmental Panel on Climate Change (IPCC) parlance, we estimate that breaking the 2012 record of 3.57 million km^2 is *very unlikely* (7.5% probability). The September mean sea ice extent is *very likely* to lie in the first tercile of the observed record and it is *exceptionally unlikely* that it will be in the upper tercile. However, there is only *medium confidence* attached to these statements. Indeed, the linear framework of prediction adopted here is probably of limited use given the known nonlinear and nonstationary character of the Arctic system.



Antarctic forecasts

The exact same procedure is repeated for the September mean Antarctic sea ice extent.

The best estimate is 18.54 million km² with the 95% confidence interval being [17.58,19.50] million km².

Code availability

The code used to generate this benchmark forecast is available at

https://github.com/fmassonn/APPLICATE/blob/99055cd91aaad29b2c764ed2880181fb7a65901e/APPLICATE-benchmark_SIO.py

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