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Advanced prediction in polar regions and beyond

APPLICATE-benchmark Sea Ice Outlook 2021

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Scope

This document provides technical and supplementary information about the APPLICATE-benchmark forecast submitted to the Sea Ice Outlook 2021.

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 NSIDC sea ice index G02135 (https://nsidc.org/data/g02135) are used as input. This dataset is preferred over alternatives, like the OSI SAF sea ice index (https://osisaf-hl.met.no/v2p1-sea-ice-index) by the fact that the Sea Ice Outlook verification product used in the assessment done by the SIPN Leadership Team, is the NSDIC G02135 sea ice index.

1. Raw daily forecasts: damped anomaly persistence forecast

First, a daily Arctic sea ice extent forecast is produced for each day between June 8, 2021, and June 7, 2022, using data up to June 7, 2021. 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 the initial time (June 7 2021).
- 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 long-term trends in Arctic sea ice extent, we here take X_d^b as the quadratic trend of 1979-2020 extent for the relevant day, extrapolated to 2021.
- X_0^b is the background sea ice extent at the initial time. Therefore, the term $(X_0^o - X_0^b)$ represents the anomaly at initial time with respect to the quadratic trend line.
- r_d is the linear (Pearson) correlation coefficient between the 1979-2020 June 7 anomalies and the 1979-2020 anomalies for day d (again, anomalies are estimated relative to the respective backgrounds). By definition, r_d is 1 at initial time. For subsequent days, r_d 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:

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

This alternative form emphasizes that the damped anomaly persistence forecast can be viewed as a weighted mean between an 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 the 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 merely a trend extrapolation.

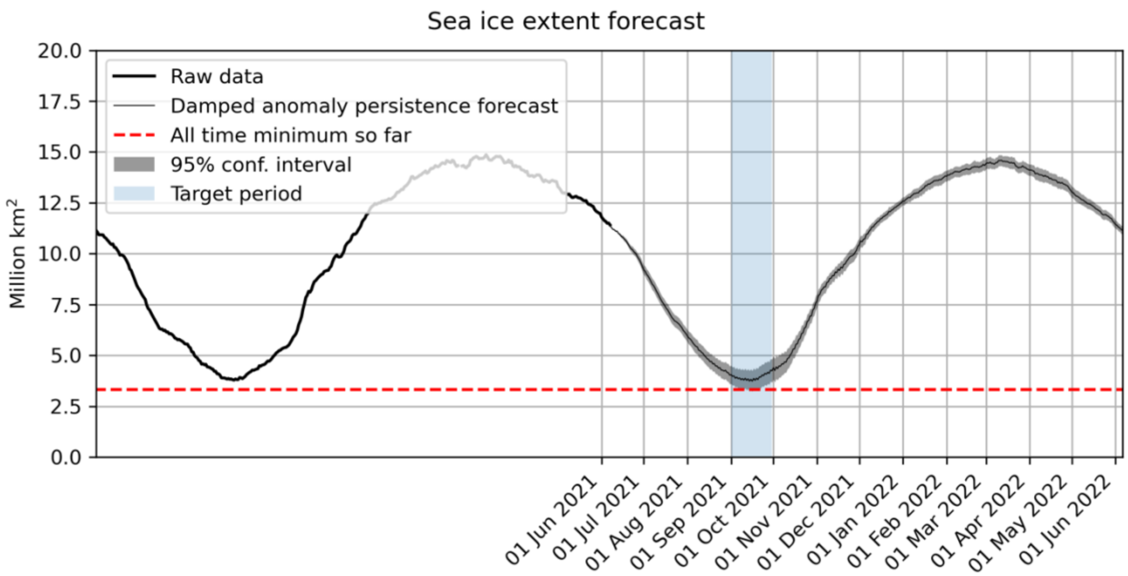
Forecast variance is estimated from the forecast equation (1), assuming that there is no error in the observed extent X_0^o [1] and that the correlation r_d is deterministically known (without sampling error). In this case, forecast variance becomes

[1] This hypothesis can certainly be questioned, since the observed extent is prone to instrument, representativity and algorithm errors. One justification behind this hypothesis is that the data used for forecast verification is the same as the data used to train the statistical model. In particular, events discussed below (breaking a record low, ending in the first tercile…) should be relatively insensitive to

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

where it was assumed that the correlation between the background errors is equal to the correlation of respective anomalies: $COV(X_0^b, X_d^b) = r_d\, \sigma(X_0^b)\, \sigma(X_d^b)$. The standard deviation background errors $\sigma(X_0^b)$ and $\sigma(X_d^b)$ 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 or less) to be broken. As we will see, this statement will be revised since the forecasting system is under-dispersive.



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 3.94 million km². For information, the corresponding value obtained when using the alternative OSI SAF sea ice index is 4.48 million km². This highlights that the absolute values of sea ice extent are quite product dependent.

3. Verification and recalibration

Steps 1. and 2. allow to produce a forecast for 2021. 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

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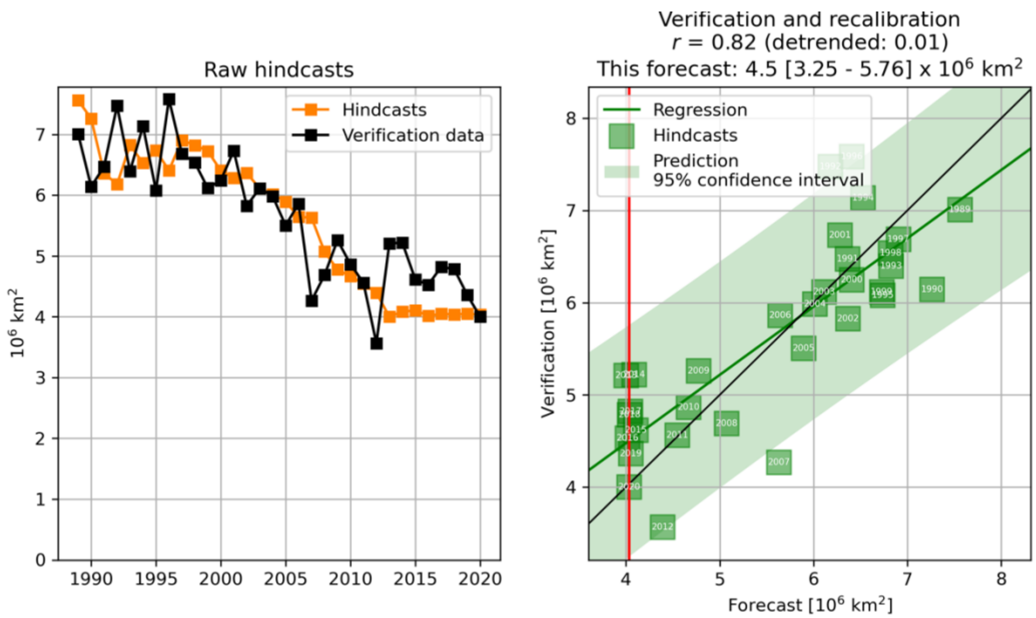
observation systematic bias as long as the historical distributions are derived from the same input product as the one used to make the forecast.

the verification data is known and, possibly, to modify the 2021 forecast to account for possible shortcomings in our procedure. Therefore, steps 1. and 2. are repeated for each year between 1989 and 2020, in a real operational context – that is, not using data posterior to the year that is forecasted. We do not produce hindcasts before 1989 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. With three years of data, we can estimate a quadratic background trend for each day but also the correlation term in Eq. 1. The statistical robustness for the first hindcasts should be taken with care, given the limited number of data points.

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



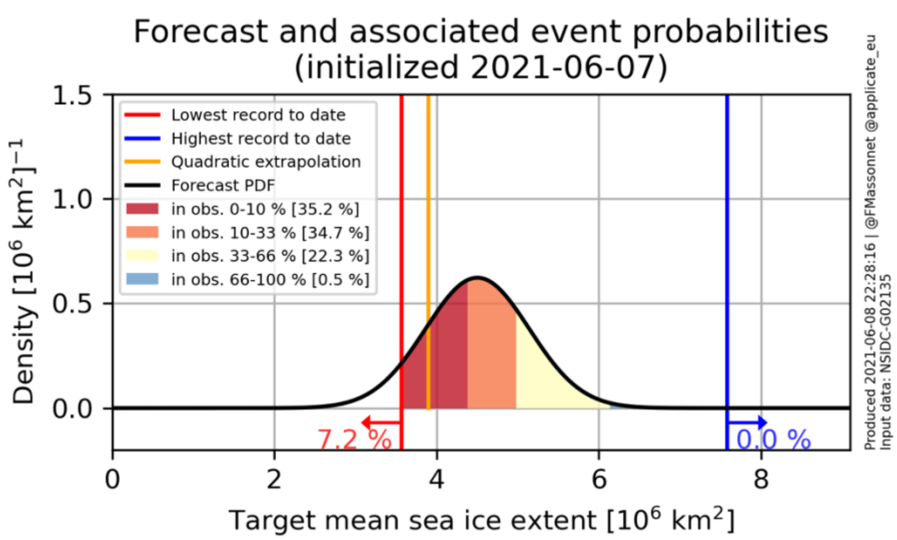
(Left) Re-forecasts of September mean sea ice extent and (right) comparison to verifying observations.

We note a positive association between forecast and verification values (correlation of 0.82), but this association comes from the presence of long-term trends in both the forecast and verification data: if the forecast and verification data are first quadratically detrended, the correlation drops to 0.01. This reflects the established 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. (Note that the same does not hold when sea ice thickness is used as predictor).

In order to correct for the biases in mean and variability, a simple linear recalibration scheme is applied to the 2021 forecast by regressing the 1989-2020 verification data on the matching forecasts. The recalibrated 2021 forecast is then defined as the raw 2021 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), corresponding to a 95% confidence interval under gaussian assumptions.

Our best estimate for the September 2021 mean Arctic sea ice extent is therefore 4.50 million km², with a forecast error standard deviation of 0.64 million km² (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 7 2021, is [3.25, 5.76] million km².

Our outlook is graphically summarized in the figure below. Adopting the Intergovernmental Panel on Climate Change (IPCC) parlance, we estimate that breaking the 2012 record of 4.14 million km² is *very unlikely* (7.2 % probability). The September mean sea ice extent is *likely* to lie in the first tercile of the observed record (69.9 %) and it is *exceptionally unlikely* that it will be in the upper tercile (0.5 %). 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.



Forecast probability density function for the September 2021 mean Arctic sea ice extent. The shadings refer to pre-defined events, like ending in the first 10% of the historical observed distribution. The numbers in brackets […] are the corresponding probabilities based on a gaussian distribution.

Antarctic forecasts

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

The best estimate is 18.52 million km² with the 95% confidence interval being [17.71,19.32] million km².

Code availability

The code used to generate this forecast is available at

https://github.com/fmassonn/APPLICATE/blob/5ea1cad3906efe1899a8cfba942d672f02e2605e/myForecast.py

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