Assessment of summer 2021-2022 sea-ice forecasts for the Southern Ocean

Coordinating Seasonal Predictions of
Sea Ice in the Southern Ocean

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April 5, 2022

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1. The Sea Ice Prediction Network South (SIPN South)

Being much thinner than Arctic sea ice and almost entirely seasonal, Antarctic sea ice has long been considered unpredictable beyond weather time scales. However, recent studies have unveiled several mechanisms of sea-ice predictability at seasonal time scales and demonstrated some skill in predictions (Bushuk et al., 2021; Holland et al., 2013, 2017; Marchi et al., 2019; Zampieri et al., 2019). The study of sea-ice predictability does not only represent an academic exercise but has also many potential future applications. For example, knowledge of sea-ice presence from weeks to months in advance would be of great interest to Antarctic shipping operators, since sea ice is one of the many hindrances that vessels face operating in the Antarctic coastal regions. In that context, advance notice of seasonal sea-ice conditions would help reduce costs associated with providing alternative operational logistics.

The Sea Ice Prediction Network South (SIPN South, https://fmassonn.github.io/sipn-south.github.io/) is an international project endorsed by the Year of Polar Prediction (YOPP). One of its main goals is to make an assessment of the ability of current forecasting systems to predict Antarctic sea ice on hemispheric and regional scales, with a focus on the summer season. SIPN South has the ambition to **lay the foundations for a more systematic and coordinated evaluation of seasonal sea-ice forecasts in the Southern Ocean** in the coming years.

This technical report summarizes results from the fifth coordinated set of forecasts organized so far, for summer 2021-2022. This new experiment offers the opportunity to test the hypotheses that were proposed in the last report, and to consolidate the already large database of coordinated sea-ice forecasts in the Southern Ocean.

2. Summer 2021-2022 in context

SIPN South analyses focus on austral summer, a season of special interest due to the intense marine traffic at this time of the year. In summer, sea ice retreats to the point that it can expose Antarctic coastlines to the open ocean, thereby offering possible access to the Antarctic continent, ice sheet, or ice shelves.

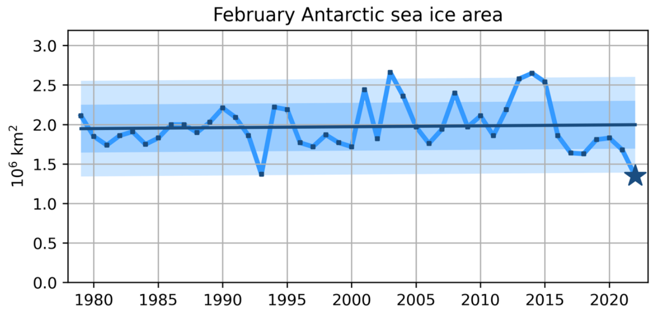

Figure 1. February Antarctic sea-ice area over the satellite observational record (1979-2020) (Fetterer et al., 2017). The star is February 2020. The dashed line is the linear trend and the two shaded intervals show 1 and 2 standard deviations of the residuals around the linear fit, respectively.

February mean sea ice area hit a record low in 2022 (1.35 million km^2) according to the National Snow and Ice Data Center sea ice index (Fig. 1). Negative sea ice anomalies have been observed as early as late September and have persisted since then. Spatially, the anomalies were pronounced in the Eastern Ross and Weddell Seas. (Fig. 2) although sea-ice area in other sectors was also anomalously low. See Raphael & Handcock (2022) for a discussion of the anomalously low sea-ice conditions.

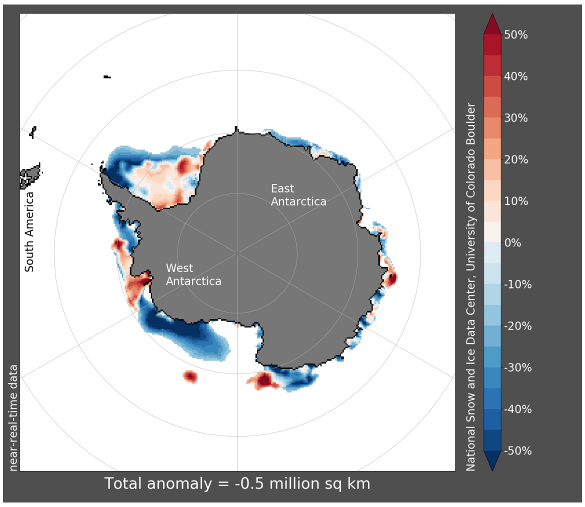

Figure 2. Anomalies of sea-ice concentration in February 2022 relative to the 1981-2010 mean (from www.nsidc.org; Fetterer et al., 2017)

3. Forecasting sea ice for summer 2021-2022

A call for contributions was issued in November 2021 to predict sea-ice conditions during the three-month period from December 1st 2021 to February 28th 2022. **We received a record number of 15 submissions (totaling 279 forecasts) and would like to thank all contributors for their participation.**

Contributors were asked to provide, in order of descending priority, (1) the total Antarctic sea-ice area (denoted "SIA"), (2) the regional sea-ice area per 10° longitude band (denoted "rSIA"), (3) sea-ice concentration (denoted "SIC"), and (4) sea-ice thickness (volume per unit grid cell area, denoted "SIV") for each day of December 2021-February 2022. One submission (Lamont) consisted of monthly means instead of daily means. For this contribution, the forecasts were interpolated to daily resolution using a quadratic function passing at the given monthly values on the 15th of each of the three months. Eight groups used fully coupled dynamical models and six groups used a statistical model trained on past data (this includes machine learning approaches). One group used an ocean—sea ice model forced by atmospheric reanalysis of previous years. Tab. 1 summarizes the contributions received for this exercise.

Table 1. Information about contributors to the summer 2021-2022 coordinated sea-ice forecast experiment.

	Contributor name	*Short name (in figures)*	*Forecasting method*	*# of forecasts*	*Initialization date*	*Diagnostics provided*
1	Sandra Barreira	Barreira	Statistical	3	Nov. 30th	SIA+rSIA+SIC
2	CanSIPSv2	CanSIPSv2	Coupled dynamical	20	Nov. 26th	SIA+rSIA
3	CMCC	cmcc	Coupled dynamical	50		SIA+rSIA+SIC
4	CNRM	CNRM	Coupled dynamical	51	Dec. 1st	SIA+rSIA+SIC+SIV
5	ECMWF	ecmwf	Coupled dynamical	51	Nov. 30th	SIA+rSIA
6	FIO-ESM	FIO-ESM	Coupled dynamical	1	Nov. 1st	SIA
7	GFDL	gfdl	Coupled dynamical	30	Nov. 30th	SIA+rSIA+SIC+SIV
8	Lamont	Lamont	Statistical	1	Nov. mean	SIA+rSIA+SIC
9	Walt Meier	Meier-NSIDC	Statistical	1	Dec. 1st	SIA
10	Met Office	MetOffice	Coupled dynamical	42	Nov. 25th	SIA+rSIA+SIC
11	Alek Petty	NASA-GSFC	Statistical	1	Nov. 30th	SIA
12	Nico Sun	NicoSun	Statistical	3	Nov. 30th	SIA+SIC+SIV
13	SINTEX-F2	SINTEX-F2	Coupled dynamical	24		SIA+rSIA
14	Sun Yat-sen University	SYSU	Statistical	1	Nov. 30th	SIA+rSIA+SIC
15	UCLouvain	ucl	Forced dynamical	10	Nov. 1st	SIA+rSIA+SIC+SIV

3.1 Circumpolar sea-ice area

Fig. 3 shows the total sea-ice area (SIA) forecast for each day of December 2021-February 2022 as submitted by the 15 contributors. SIA is not a very sensible geophysical diagnostic as it does not reflect regional variations, but it gives a first indication of how the forecasts behaved. In this figure, two observational references are also included to provide a general idea of the importance of observational uncertainty. As seen in Fig. 3, observational uncertainty is small relative to inter-model spread. In the following analyses, we will, therefore, assume that observational errors are not a major cause for differences between forecasts and observations.

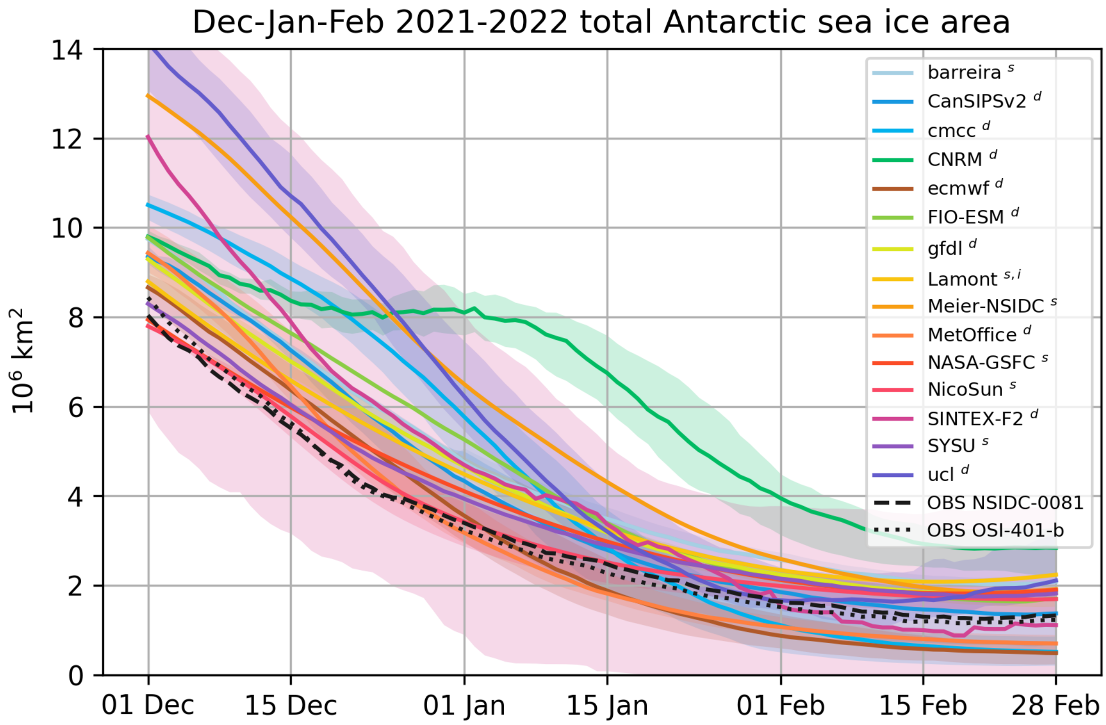

Figure 3. Total (circumpolar) Antarctic sea-ice area of the 15 ensembles of forecasts for each day of the period December 2021-February 2022. The lines are the ensemble medians and the shadings are the ensemble ranges (min-max). The superscripts in the legend indicate whether the submission is based on a statistical or a dynamical approach and, possibly, if monthly data has been interpolated to daily resolution. The black dashed lines are two observational references (Maslanik and Stroeve, 1999 and Tonboe et al., 2017).

Similarly to last year, an overestimation of sea-ice area is noted already at day 1 of the forecasting period for several dynamical model forecasts. Interestingly, the bias reduces over time and the distribution of forecasts is not incompatible with observations at the minimum, in February. During February, observed Antarctic sea-ice area lies in the full ensemble range. We note also that the full ensemble range of forecasted sea-ice area is larger than the historical range of sea-ice area (Fig. 1). This pattern of agreement is similar to previous years. It appears indeed that the forecasts, especially dynamical ones, manage to get the correct February mean sea-ice area by compensation of errors: the positive bias in sea-ice area at initial time is counterbalanced by excessive melt rates from mid-November to early January.

We also investigate the ability of the systems to forecast the date of the annual minimum of sea-ice area (Fig. 4). The timing of the minimum of the sea-ice area is a critical parameter from an operational point of view, as it represents the end of the window of opportunity before the oceans start to freeze up and sea ice becomes an increasing hindrance to the progression of vessels. Fig. 4 reveals the date of the minimum is subject to high variability according to dynamical model-based estimates. It is also found that the actual dates of minimum sea-ice area are within the range of most forecasts' distributions.

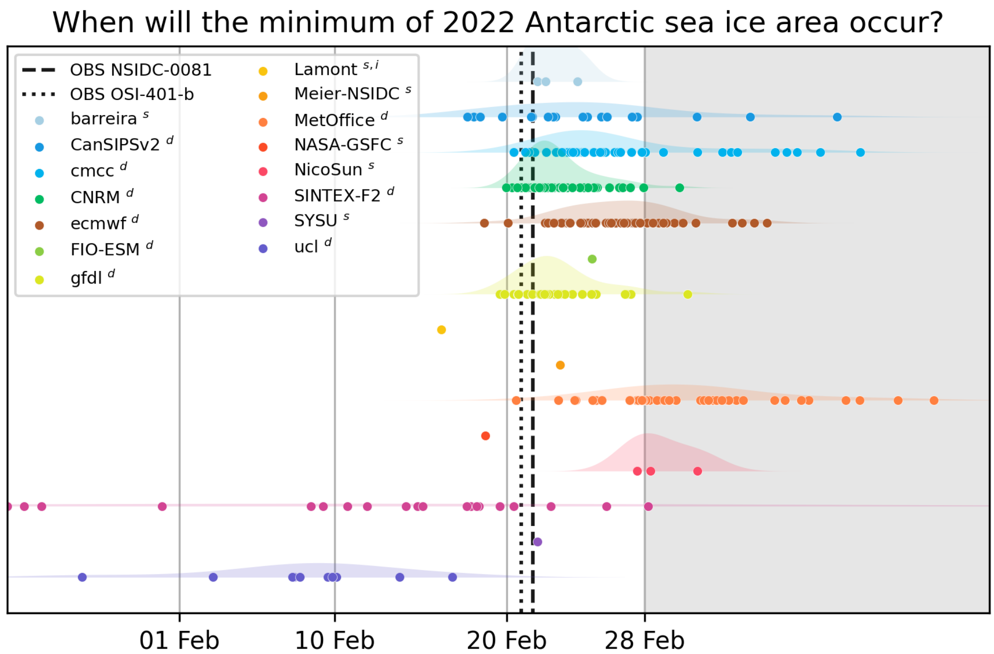

Figure 4. Timing of the 2022 annual minimum of Antarctic sea-ice area from forecasts (colored dots) and their estimated probability density function (shaded areas), as well as two observational references (vertical lines; Maslanik and Stroeve, 1999 and Tonboe et al., 2017). To filter out the effects of synoptic variability, the minimum was determined from a quadratic fit of the February daily sea-ice area time series. This is why, in some cases, the minimum is found to occur after the end of the period analyzed. Superscripts in the legend indicate whether the submission is based on a statistical or a dynamical approach and, possibly, if monthly data has been interpolated to daily resolution.

3.2 Regional sea-ice area

A convenient approach to render the time evolution of regional biases of the sea-ice area is to compute the Integrated Ice Edge Error (IIEE; Goessling et al., 2016). The IIEE is a metric that quantifies the spatial mismatch between two geophysical datasets. It is oriented positive (with lower values indicating lower errors) and corresponds to the area of all grid cells where a given forecast and a given reference disagree on either one of the two following events: "sea-ice concentration is greater than 15%" or "sea-ice concentration is lower than 15%". By design, the IIEE is not prone to cancellation of regional sea-ice area biases as is the total circumpolar area. Calculation of IIEE requires interpolation of the forecast and verification data to a common grid, which was chosen to be a regular 2°×2° grid.

The IIEE metric was applied to the nine contributions that provided spatial forecasts of sea-ice concentration, using the NSIDC-0081 observational product as reference. Fig. 5 displays the time evolution, over the forecasting period, of that metric. Again, to gauge the possible role of observational uncertainty in forecast evaluation, the metric was applied to another observational dataset (OSI-401-b). The IIEE of that dataset as compared to the other observational dataset is at least one order of magnitude smaller than that from the forecasts, hence observational error can, once again, be assumed small compared to the forecast error.

Consistently with the results of sea-ice area (Fig. 3), the error is already large at day 1 of the forecasting period for several dynamical model forecasts. The error first grows, as initial-condition information is lost progressively throughout the melting season. As discussed in Sec. 2 and seen from Fig. 3, observed sea ice retreated anomalously rapidly in December.

A striking result from Fig. 5, that was already hinted at in previous years, is that statistical forecasts outperform dynamical model forecasts. Similar to last year, the Nico-Sun forecast has a better IIEE than other contributions. This method assumes that past day-to-day sea-ice concentration changes are representative of the conditions that may prevail for the coming forecast period. Starting from the latest NSIDC estimates, sea-ice concentration is updated day after day by adding increments estimated from past years. There is another state variable in the model (sea-ice thickness), that is also updated based on sea-ice melt estimated from the locally varying albedo due to sea-ice concentration changes.

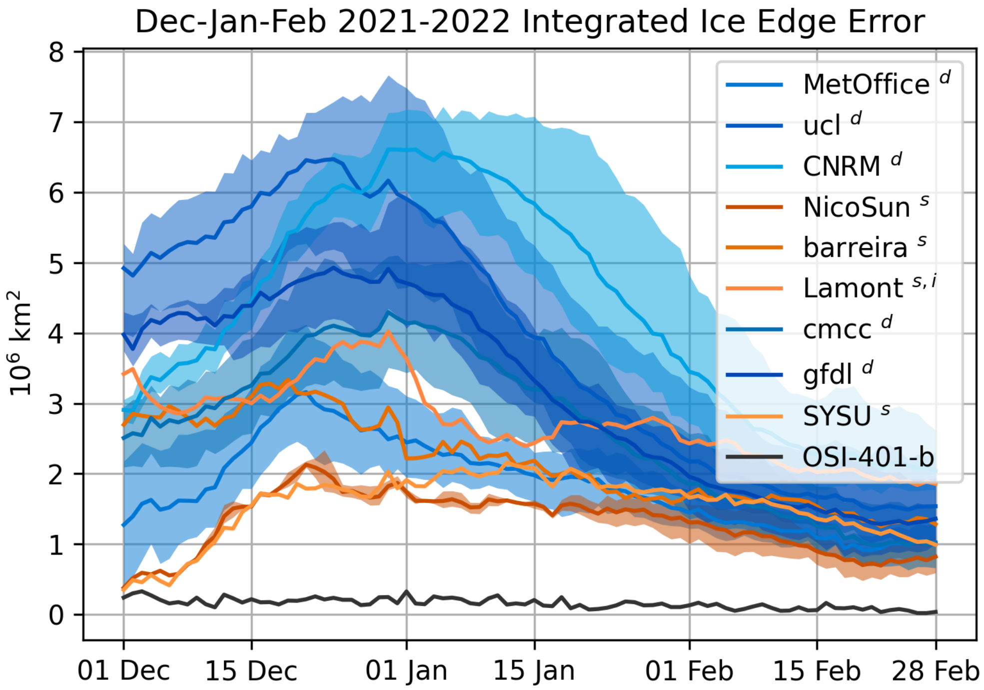

Figure 5. Integrated Ice Edge Error (Goessling et al., 2016), defined as the area of grid cells where the forecasts and a reference (here, NSIDC-0081; Maslanik and Stroeve, 1999) disagree on concentration being either above or below 15%. The shadings represent ensemble range (IIEE calculated on each member separately) and the thick lines are the mean of all IIEEs for a given forecast system. The superscripts in the legend indicate whether the submission is based on a statistical (orange tones) or a dynamical approach (blue tones) and, possibly, if monthly data has been interpolated to daily resolution. The dark grey line is the IIEE between the other observational product (OSI-401-b; Tonboe et al., 2017) and the NSIDC-0081 reference.

4. Conclusions

We warmly thank all 15 contributors to this third exercise of coordinated forecasts of sea ice in the Southern Ocean. The key conclusions from this third exercise are:

- When viewed as a group, the range of multi-model forecast of total February Antarctic sea-ice area includes the two observational verification datasets. However, errors can be large for individual submissions and the ensemble spread is larger than the observed climatological spread. Observational uncertainty alone cannot explain the forecast-data mismatch.

- The timing of the minimum of Antarctic sea-ice area is well predicted by the ensemble (in a probabilistic sense). Generally speaking, forecasts reproduce the circumpolar sea-ice area properties in February but struggle in November and December.
- Forecasts based on statistical approaches outperform those based on dynamical coupled models. Like the findings of last year, several dynamical models have difficulties in representing sea-ice concentration fields already on the first day of the forecasting period.
- At this stage, the SIPN South data set is not mature yet for practical use in applications like field trip planning or maritime route forecasting. Long records of retrospective forecasts are lacking to properly identify the origin of systematic forecast errors.

Data availability

The analyses presented in this report can be reproduced bit-wise by cloning the SIPN South Github project at https://github.com/fmassonn/sipn-south-public (branch develop_2021-2022, commit cc94301). Instructions to retrieve the data and process the analyses are given in the README.md file of this repository.

Citing this report

F. Massonnet, P. Reid, J. L. Lieser, C. M. Bitz, J. Fyfe, W. Hobbs (2022). Assessment of summer 2019-2020 sea-ice forecasts for the Southern Ocean. Technical Note, Université catholique de Louvain available at https://fmassonn.github.io/sipn-south.github.io/

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