Assessment of summer 2019-2020 sea-ice forecasts for the Southern Ocean

Coordinating Seasonal Predictions of Sea Ice
in the Southern Ocean for 2017-2019

F. Massonnet, P. Reid, J. L. Lieser, C. M. Bitz, J. Fyfe, W. Hobbs

with contributions from

Nico Sun, NASA-GMAO, FIO-ESM, ECMWF, Lamont Sea Ice Group, NASA-GSFC, Modified_CanSIPS, Met Office, CNRM, Sandra Barreira, UCLouvain

April 22, 2020

Contact:

`francois.massonnet@uclouvain.be`

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 (Holland et al., 2017; Marchi et al., 2018; Holland et al., 2013). 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.

In February 2018, a first assessment took place (Massonnet et al., 2018). 13 groups contributed 160 forecasts. Forecasts of the total Antarctic sea-ice area appeared consistent with observational verification data, but this agreement was, in fact, hiding regional errors. In particular, observations of the Ross Sea showed it almost entirely ice-free in February 2018 due to the passage of a cyclone in late January. None of ensemble members of the model forecasts were able to forecast this anomaly, which suggested possible systematic shortcomings in the prediction systems in that sector.

In austral summer 2018-2019, a second coordinated experiment was announced. It received 198 forecasts from 12 different groups. Like the first experiment, forecasts of total sea-ice area appeared consistent with observations, but regional skill varied. This second experiment also revealed that forecasts based on dynamical models struggled to capture the total sea-ice area already at initialization time. Forecasts based on statistical methods appeared more consistent with observations.

This technical report summarizes results from a third experiment (summer 2019-2020). 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 2019-2020 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.

The winter sea-ice conditions were slightly below average (13th lowest September mean sea-ice extent out of 41 years). Like the previous year, **sea ice retreated anomalously fast during austral spring**, with November 2019 ranking second lowest on record, just behind the exceptional low anomaly of November 2016. The sea-ice melt slowed down in December and January (5th and 11th lowest monthly mean sea-ice extents, respectively).

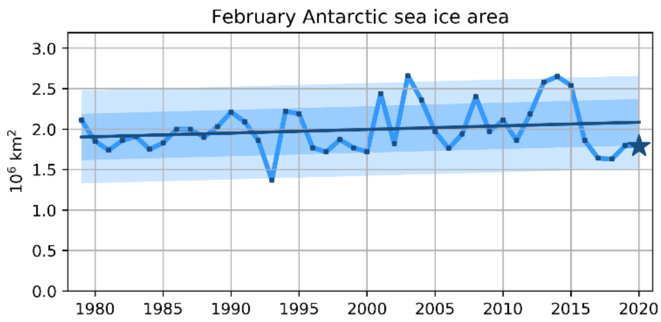

Figure 1. February Antarctic sea-ice area over the satellite observational record (1979-2020) (Fetterer et al., 2017). The star is February 2020. The dashed line is the linear trend and the two shaded intervals show 1 and 2 standard deviations of the residuals around the linear fit, respectively.

Fig. 1 shows the evolution of February sea-ice area since 1979 when satellite observations first became available. According to the NSIDC, **the monthly mean sea-ice area in February 2020 was the 11th lowest value on record** (1.79 million km^2) in

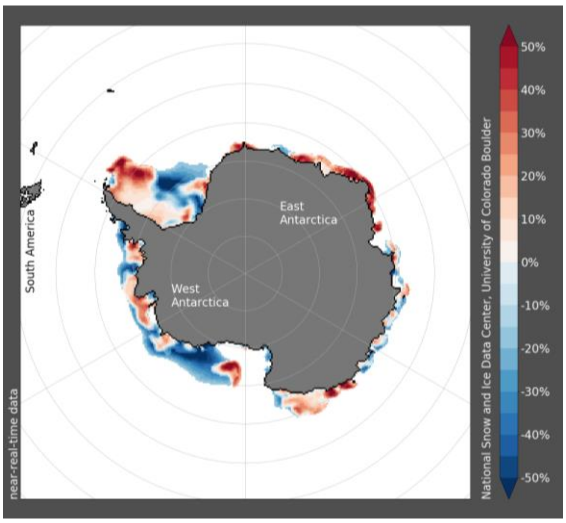

Figure 2. Anomalies of sea-ice concentration in February 2020 relative to the 1981-2010 mean (from www.nsidc.org; Fetterer et al., 2017)

a 41-yr long record time series. Spatially, the Ross Sea saw large negative sea-ice concentration anomalies, similar to 2018 and 2019, while positive sea-ice concentration anomalies occurred in King Haakon VII Sea and western East Antarctica (0°E to 60°E) (Fig. 2).

3. Forecasting sea ice for summer 2019-2020

A call for contributions was issued in November 2019 to predict sea-ice conditions during the three-month period from December 1st, 2019 to February 28th, 2020 (the 29th of February was not included in the analyses). **We received 11 submissions (totaling 191 forecasts) and would like to thank all contributors for their participation.** Tab. 1 summarizes the contributions received for this exercise.

Table 1. Information about contributors to the summer 2019-2020 coordinated sea-ice forecast experiment.

	Contributor name	*Short name (in figures)*	*Forecasting method*	*# of forecasts*	*Initialization date*	*Diagnostics provided*
1	Nico Sun	NicoSun	Statistical model	3	Nov. 30th	SIA + SIC
2	NASA-GMAO	nasa-gmao	Coupled dynamical model	10	Nov. 27th	SIA + SIC
3	FIO-ESM	FIO-ESM	Coupled dynamical model	1	Nov. 15th	SIA
4	ECMWF	ecmwf	Coupled dynamical model	51	Nov. 30th	SIA + rSIA
5	Lamont Sea Ice Group	Lamont	Statistical model	1	Oct. 31st	SIA + rSIA + SIC (monthly, interp. daily)
6	NASA-GSFC	NASA-GSFC	Statistical model	1	Nov. 30th	SIA
7	Modified_ CanSIPS	Modified-CanSIPS	Coupled Dynamical Model	20	Nov. 30th	SIA + rSIA
8	Met Office	MetOffice	Coupled Dynamical Model	42	Nov. 25th	SIA + rSIA + SIC
9	CNRM	CNRM	Coupled Dynamical Model	51	Nov. 30th	SIA + rSIA + SIC
10	UCLouvain	ucl	Ocean—sea ice Dynamical Model	10	July 1st	SIA + rSIA + SIC
11	Sandra Barreira	barreira	Statistical model	1	Nov. 30th	SIA + SIC

Contributors were asked to provide, in order of descending priority, (1) the total Antarctic sea-ice area (denoted "SIA") for each day of December 2019-February 2020, (2) the regional sea-ice area per 10° longitude band (denoted "rSIA") for each day of December 2019-February 2020, and (3) sea-ice concentration (denoted "SIC") for each day of December 2019-February 2020. All contributors were able to submit (1), two submitted (1) and (2) only, three submitted (1) and (3) only, and four submitted (1), (2) and (3). One submission consisted of one monthly mean forecast. 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. Six groups used fully coupled dynamical models and four groups used a statistical model trained on past data. One group used an ocean—sea ice model forced by atmospheric reanalysis of previous years.

3.1 Circumpolar sea-ice area

Fig. 3 shows the total sea-ice area (SIA) forecast for each day of December 2019-February 2020 as submitted by the 11 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.

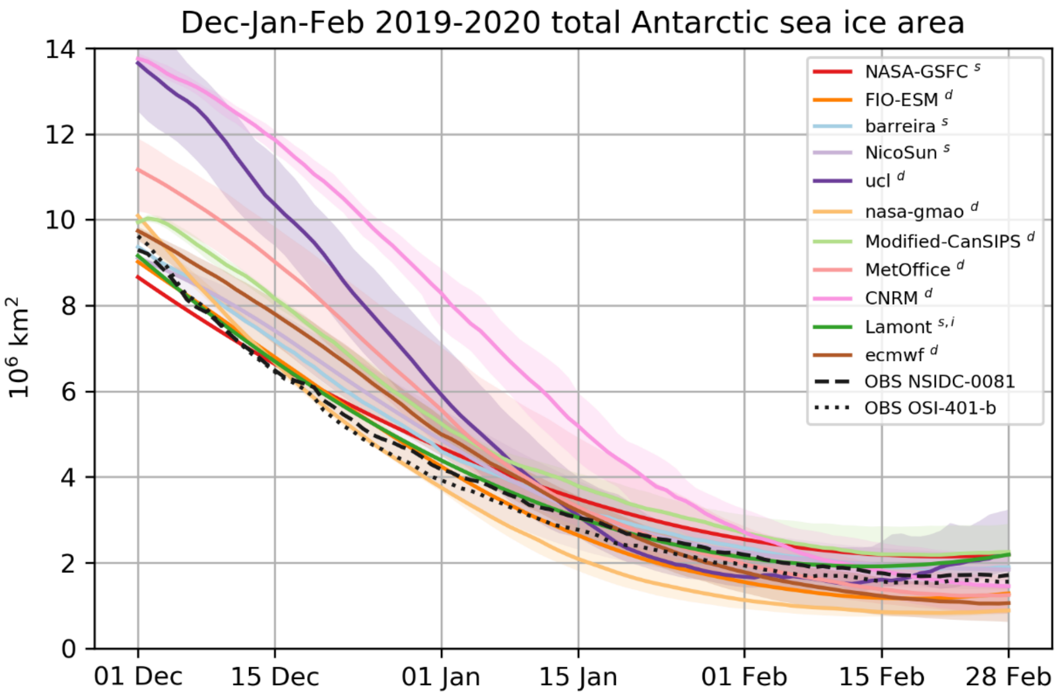

Figure 3. Total (circumpolar) Antarctic sea-ice area of the 11 ensembles of forecasts for each day of the period December 2019-February 2020. The lines are the ensemble medians and the shadings are the ensemble ranges (min-max). The superscripts in the legend indicate whether the submission is based 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 (ucl, CNRM, MetOffice). Note that none of these three forecasts has been bias-corrected. The other forecasts start around the observed values but have difficulties in capturing the rapid spring melt event. 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).

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 statistically compatible with most of the forecasts' distributions.

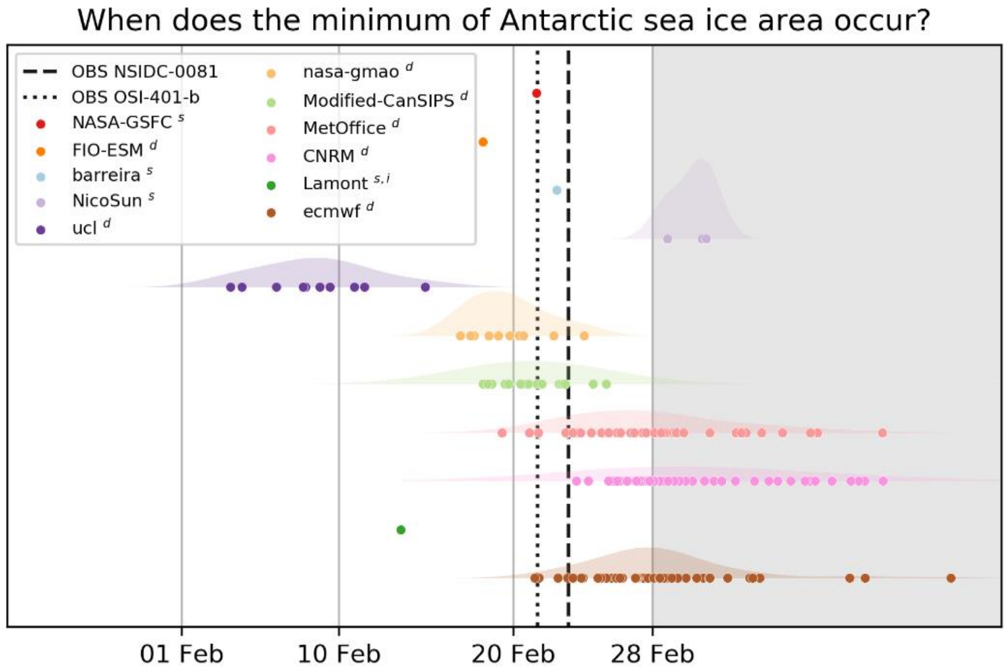

Figure 4. Timing of the 2020 annual minimum of Antarctic sea-ice area from forecasts (colored dots) and their estimated probability density function (shaded areas), as well as two observational references (vertical lines; Maslanik and Stroeve, 1999 and Tonboe et al., 2017). To filter out the effects 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 <u>s</u>tatistical or a <u>d</u>ynamical approach and, possibly, if monthly data has been <u>i</u>nterpolated to daily resolution.

3.2 Regional sea-ice area

Because of the strong regional character of Antarctic sea-ice variability, it is of importance to ascertain whether the overall agreement between forecasted and observed sea-ice areas in February (Fig. 3) is obtained for the good reasons or thanks to spatial error compensations. Fig. 5 shows the predicted February mean regional sea-ice area (rSIA), with the data expressed as an anomaly with respect to the 1979-2014 daily climatology estimated from the NASA Team sea-ice concentration dataset (Peng et al., 2013). The observations show reduced sea ice cover in the Weddell Sea and the eastern Ross Sea, with little difference from climatology elsewhere (in fact a very similar pattern to February 2019). As has been the case in the two previous reports, the prediction ensemble spread was particularly large in the Ross and Weddell Seas. The spread in ensemble-means for these sectors is not greatly larger than the ensemble spread for individual contributions, possibly indicating a fundamental lack of predictability in those regions.

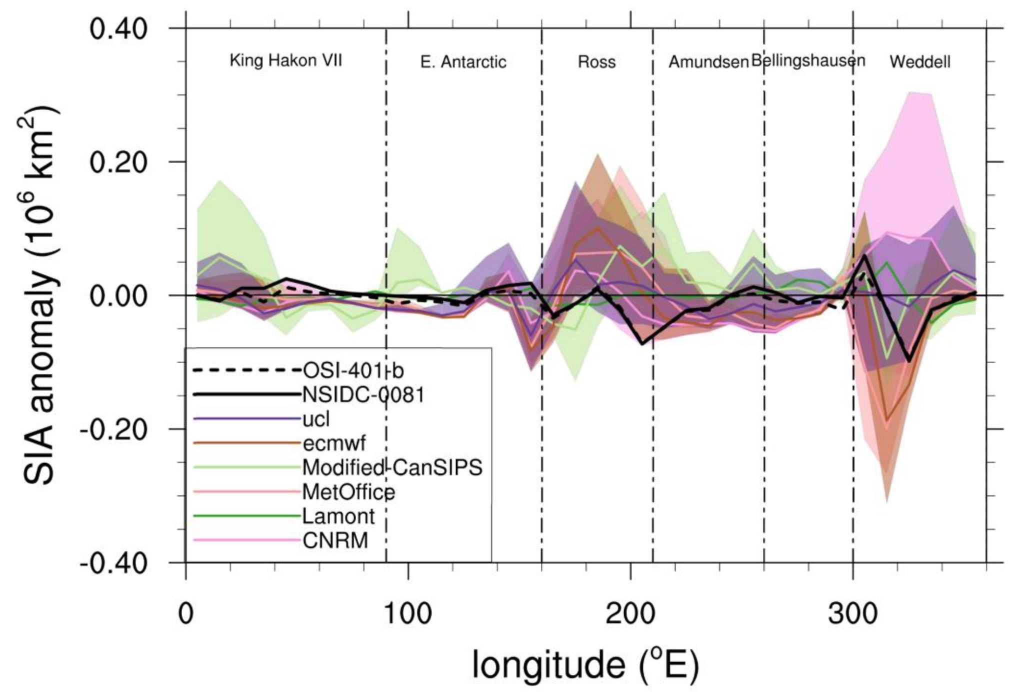

Figure 5. February 2020 mean rSIA by longitude for each submission; observed estimates are shown in black. Solid lines show the ensemble-mean for each contribution, with transparent shading showing the ensemble range. (Anomalies are calculated with respect to the 1979-2014 NASA Team climatology.)

The contributions from ECMWF, UK Met Office, and Modified-CanSIPS capture the low anomaly in the Weddell Sea (although this is over expressed by the ECMWF and Met

Office predictions), but most of the submissions predicted a higher-than-average cover in the Ross Sea. As for previous years, the observed anomalies are largely within the spread of the ensemble prediction, but this is in large part due to large prediction uncertainty in some regions. **In summary, predicting sea ice anomalies at the regional scale continues to be a challenge, especially in the large and dynamically-complex Ross and Weddell Seas.**

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 seven contributions that provided spatial forecasts of sea-ice concentration, using the NSIDC-0081 observational product as reference. Fig. 6 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. 6, that was already hinted at last year, 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.

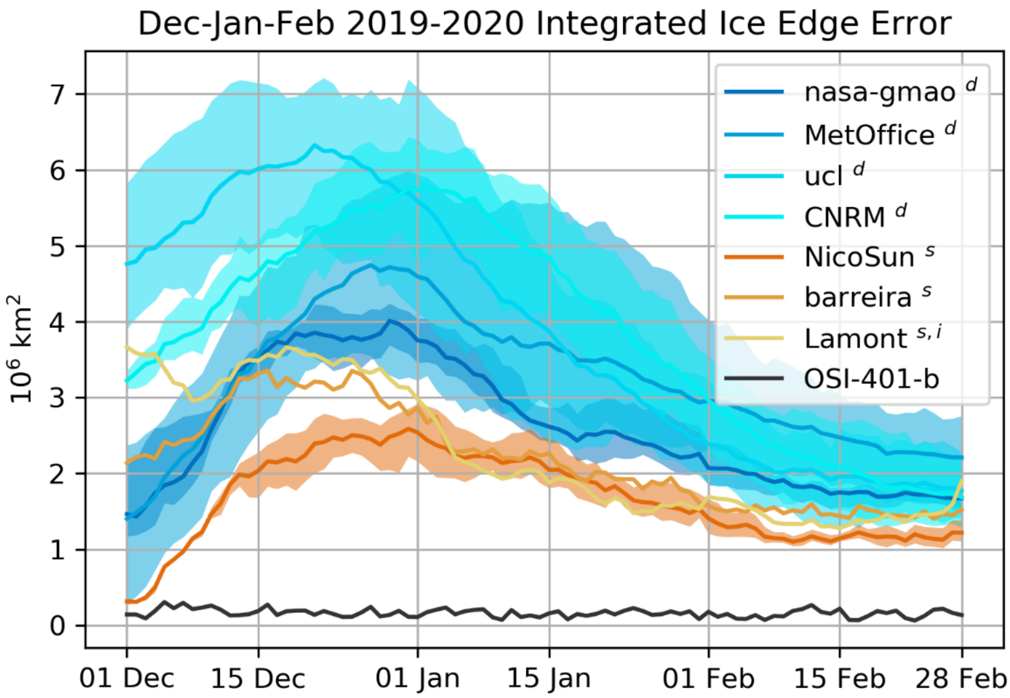

Figure 6. Integrated Ice Edge Error (Goessling et al., 2016), defined as the area of grid cells where the forecasts and a reference (here, NSIDC-0081; Maslanik and Stroeve, 1999) disagree on concentration being either above or below 15%. The shadings represent ensemble range (IIEE calculated on each 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 11 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), and this was not the case last year. Since the nature of last year's submissions are not fundamentally different from this year's, this success might be due to chance rather than truly reflecting skill.
- The ensemble spreads within individual contributions are markedly large in the Ross and Weddell Sea, confirming previous findings. Capturing the real world anomaly of sea-ice area in predictions in these regions seems challenging.
- Forecasts based on statistical approaches outperform those based on dynamical coupled models. Similar to 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 master, commit 6e9d8c002c25b3940c3893ceb4a667249d3361c4). 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 (2020). Assessment of summer 2019-2020 sea-ice forecasts for the Southern Ocean. Technical Note, Université catholique de Louvain (2018), available at https://fmassonn.github.io/sipn-south.github.io/

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