Assessment of summer 2018-2019 sea-ice forecasts for the Southern Ocean

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

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with contributions from

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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. Instructions to retrieve the data and process the analyses are given in the README.md file of this repository.

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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 (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, since sea ice is one of the many hindrances that face vessels 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) is an international project endorsed by the Year of Polar Prediction (YOPP). One of its main goals is to make an initial assessment of the ability of current 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, an initial 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 showed the Ross Sea to be almost entirely free of sea ice in February 2018 due to the passage of a cyclone in late January. All ensemble members of the model forecasts failed to forecast this anomaly, which suggested possible systematic shortcomings in the prediction systems in that sector.

The last milestone of SIPN South is the coordination of a seasonal sea-ice prediction exercise aligned with the YOPP Special Observing Period (YOPP-SOP) in the Southern Hemisphere, which spanned 16 November 2018 to 15 February 2019. The YOPP-SOP is a period of enhanced observational and modelling campaigns aiming at optimising future observing systems and understanding the impact that selected observations can have on the skill of atmospheric and ocean–sea ice forecasts. Similarly, one of the objectives of SIPN South is to establish whether seasonal forecasts can be of use to guide the location and timing of campaigns like those carried out during the SOP. The present document summarises the main outcomes of this exercise.

2 Summer 2018-2019 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 and exposes Antarctic coastlines to the open ocean, thereby offering possible access to the Antarctic continent, ice sheet or ice shelves.

According to the National Snow and Ice Data Center (NSIDC), the September 2018 sea-ice extent was the second lowest on record. During austral spring, sea ice retreated anomalously fast through December and January, setting record lows in early January. The melt slowed down in February.

Figure 1 shows the evolution of February sea-ice extent since 1979 when satellite observations first became available. According to the NSIDC, the monthly mean sea-ice extent in February 2019 was the seventh lowest value on record (2.66 million km²) in the 41-yr long time series. Spatially, positive sea-ice concentration anomalies occurred in the King Hakon VII and East Antarctic sectors (~0° E to 60° E), but anomalies were negative in the eastern Ross Sea, positive in the Amundsen Sea and mixed in the Weddell Sea (Figure 2).

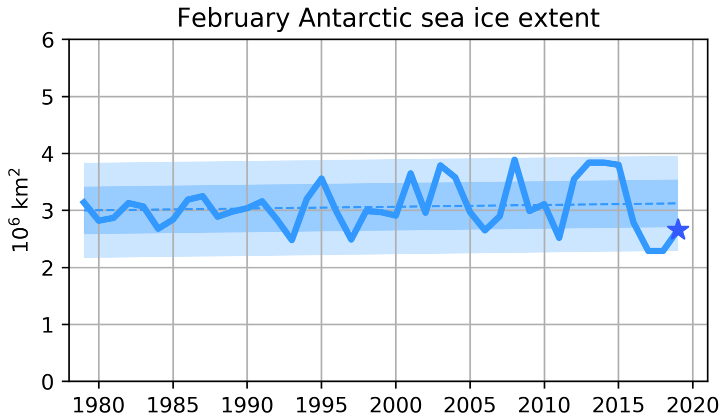

Figure 1: *February Antarctic sea-ice extent (Fetterer et al., 2017). The star is February 2019. The dashed line is the linear trend and the two shaded intervals show 1 and 2 standard deviations of the residuals around the linear fit, respectively.*

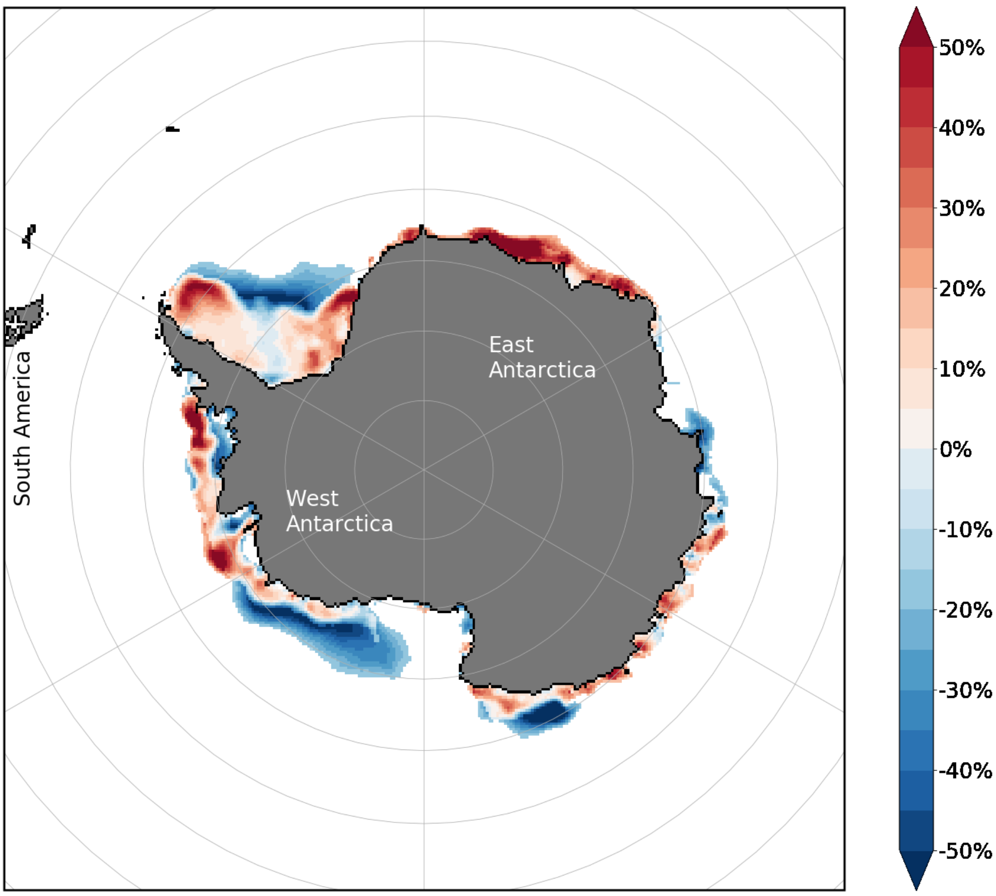

Figure 2: *Anomalies of sea-ice concentration in February 2019 relative to the 1981-2010 mean (from www.nsidc.org; Fetterer et al., 2017).*

3 Forecasting sea ice for summer 2018-2019

A call for contributions was issued in November 2018 to predict sea-ice conditions during the three-month period from 01 December 2018 to 28 February 2019 (thus overlapping the YOPP Special Observing Period by 2 months). We received a total of 12 submissions (198 forecasts) and would like to thank all contributors for their participation. Table 1 summarises the contributions received for this exercise.

Contributors were asked to provide, in order of descending priority, (1) the total Antarctic sea-ice area (denoted "SIA") for each day of December 2018 to February 2019, (2) the sea-ice area per 10° longitude band (denoted "rSIA") for each day of December 2018 to February 2019, and (3) sea-ice concentration (denoted "SIC") for each day of December 2018 to February 2019. All contributors were able to submit (1), two submitted (1) and (2) only, two submitted (1) and (3) only, and five submitted (1), (2) and (3). Three submissions consisted of monthly mean forecasts. These 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. Seven 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 reanalyses of previous years.

We take note that requesting contributions for the first of the month is not ideal for those groups that produce monthly forecasts initialised at the beginning of each month, and will change our guidelines for subsequent exercises accordingly.

3.1 Circumpolar sea-ice area

Figure 3 shows the total sea-ice area (SIA) forecast for each day of December 2018 to February 2019 as submitted by the 12 contributors. SIA is not a very sensible geophysical diagnostic as it does not reflect regional variations, but it gives a first indication on 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 Figure 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.

A striking feature in Figure 3 is the overestimation, already at day 1 of the forecasting period, of the total sea-ice area by several groups. More particularly, this appears to be a characteristic of several dynamical modelling contributions (ucl, CMCC, nrl, Modified-CanSIPS). A closer look at dynamical contributions at day one of the forecasts (not shown here) reveals that this overestimation in total area is, in most cases, due to an overestimation of sea-ice concentration in the Ross Sea and, in some cases, due to a too northward average position of the sea-ice edge. The presence of biases in sea-ice concentration already at day one of the forecasting period reveals the challenges related to initialisation of fully coupled or ocean–sea ice models. By contrast, forecasts based on statistical models start on average closer to the two observational references. Through the season, the high initial bias in the sea-ice area is progressively eliminated as the observed melt slows down from late December onwards, a feature not seen in the forecasts. 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 similar to the historical range of sea-ice extent (Figure 1).

Table 1: *Information about contributors to the February 2018 coordinated sea-ice forecast experiment.*

Contributor name	*Short name (in figures)*	*Forecasting method*	*number of forecasts*	*Initialization date*	*Diagnostics provided*
US Naval Research Lab	nrl	Coupled dynamical model	9	31 Oct 2018	SIA + rSIA + SIC
Nico Sun CryosphereComputing	Nico-Sun	Statistical model	3	30 Nov 2018	SIA + SIC
NASA Global Modeling and Assimilation Office	nasa-gmao	Coupled dynamical model	10	27 Nov 2018	SIA + SIC
First Institute of Oceanography Earth System Model	FIO-ESM	Coupled dynamical model	1	01 Nov 2018	SIA
European Centre for Medium-Range Weather Forecasting	ecmwf	Coupled dynamical model	50	01 Dec 2018	SIA + rSIA
Antarctic Gateway Partnership	Gateway	Statistical model	1	10 Dec 2017	SIA
Model for Prediction Across Scales Community Earth System Model	mpas-cesm	Coupled dynamical model	2	01 Dec 2018	SIA + rSIA
Lamont-Doherty Earth Observatory Sea Ice Group	Lamont	Statistical model	1	31 Oct 2018	SIA + rSIA + SIC (monthly, interp. daily)
Alek Petty Goddard Space Flight Center	Petty-NASA	Statistical model	1	30 Nov 2018	SIA (monthly, interp. daily)
Modified Canadian Seasonal to Interannual Prediction System	Modified-CanSIPS	Coupled Dynamical Model	20	30 Nov 2018	SIA +r SIA
UK Met Office	MetOffice	Coupled Dynamical Model	42	25 Nov 2018	SIA + rSIA + SIC
Université catholique de Louvain	ucl	Ocean-sea ice dynamical model	10	01 July 2018	SIA + rSIA + SIC
Sandra Barreora	Barreira	Statistical model	1	01 Dec 2017	SIA + rSIA + SIC (monthly, interp. daily)

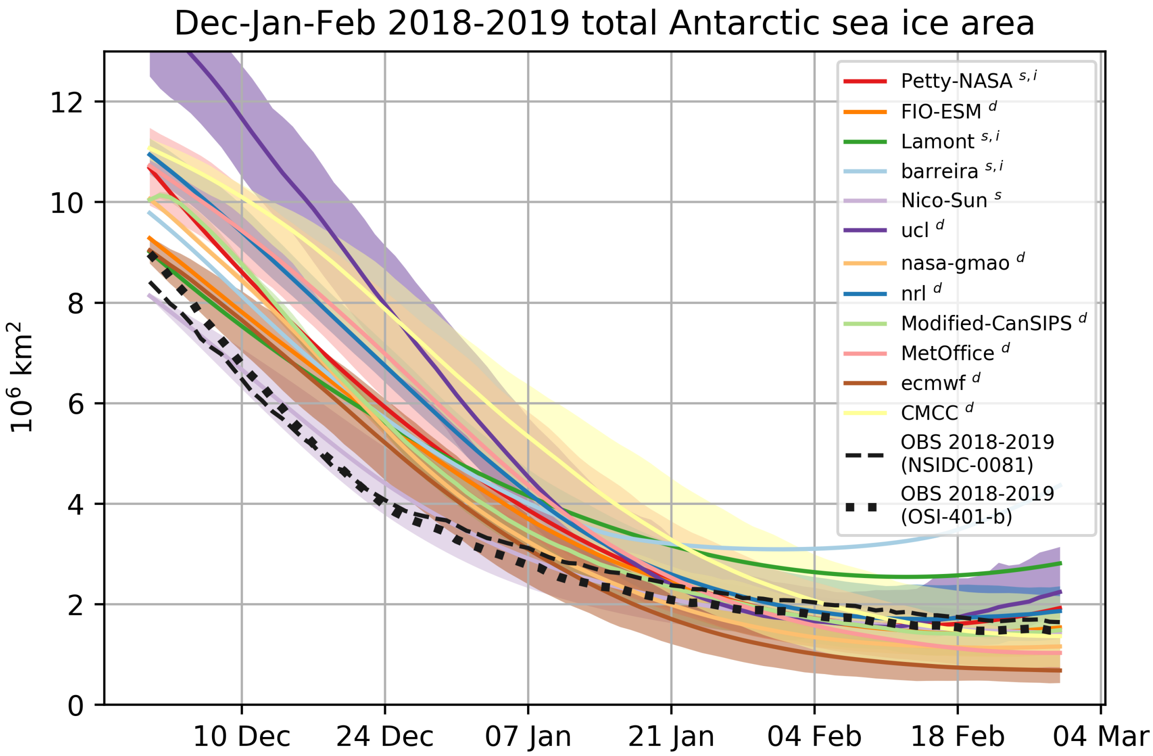

Figure 3: *Total (circumpolar) Antarctic sea-ice area of the 12 ensembles of forecasts for each day of the period December 2018 to February 2019. The lines are the ensemble means and the shadings are the ensemble ranges. Superscripts in the legend indicate whether the submission is based on a statistical 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; Tonboe et al., 2017).*

We also investigate the ability of the systems to forecast the date of the annual minimum of sea-ice area (Figure 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. Last year, the minimum occurred around 16 February 2018 and most groups forecasted it to occur later. This year, the minimum occurred late in the month (27 or 28 February depending on the observational source) but the systems tended to collectively forecast a too early occurrence.

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 (Figure 3) is obtained for good reasons or owed to spatial error compensations. Figure 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 spread of the ensemble is particularly large in the Ross Sea and Weddell Sea and none of the forecasts seems to capture the regional pattern of anomalies that occurred this year. The regional diagnostics presented in Figure 5 reveal that the circumpolar sea-ice area

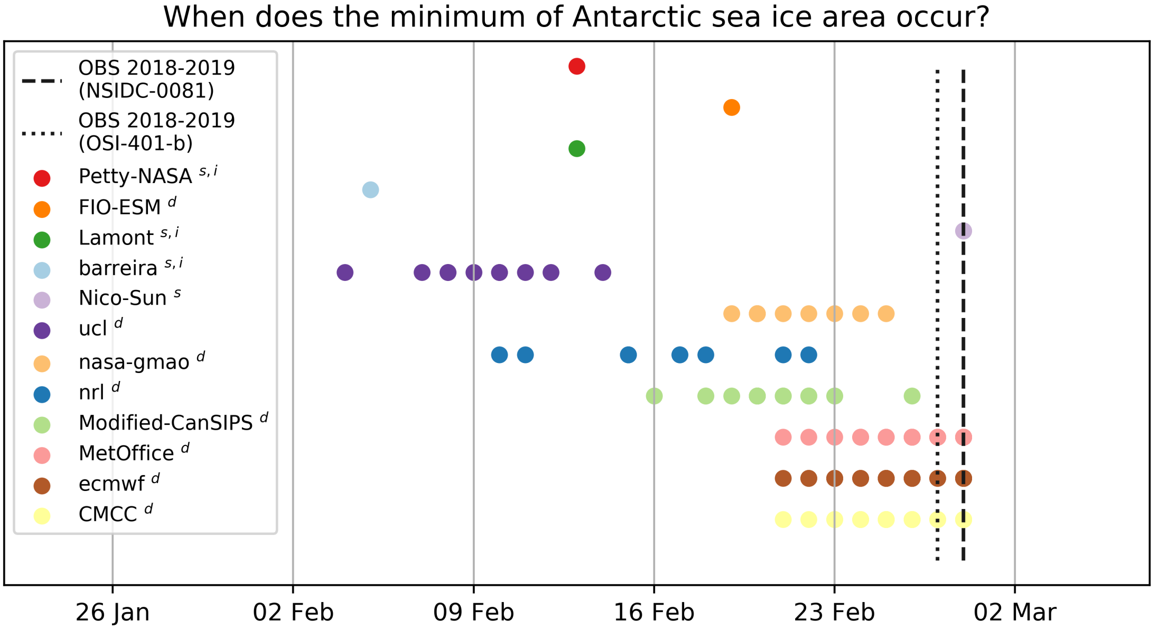

Figure 4: *Timing of the 2019 annual minimum of Antarctic sea-ice area from forecasts (colours) and two observational references (Maslanik and Stroeve, 1999; Tonboe et al., 2017). To filter out the effects of synoptic variability, the minimum was determined from a quadratic fit of the February daily sea-ice area time series. 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.*

indeed masks strong regional biases and that several forecasts have the right total Antarctic sea-ice area for the wrong reasons.

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 positively (always 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 less 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 was applied to the seven contributions that provided spatial forecasts of sea-ice concentration. Figure 6 displays the time evolution of that metric over the forecasting period. 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 be assumed small compared to the forecast error.

Consistent with the results of sea-ice area (Figure 1), the error is already large at day 1 of

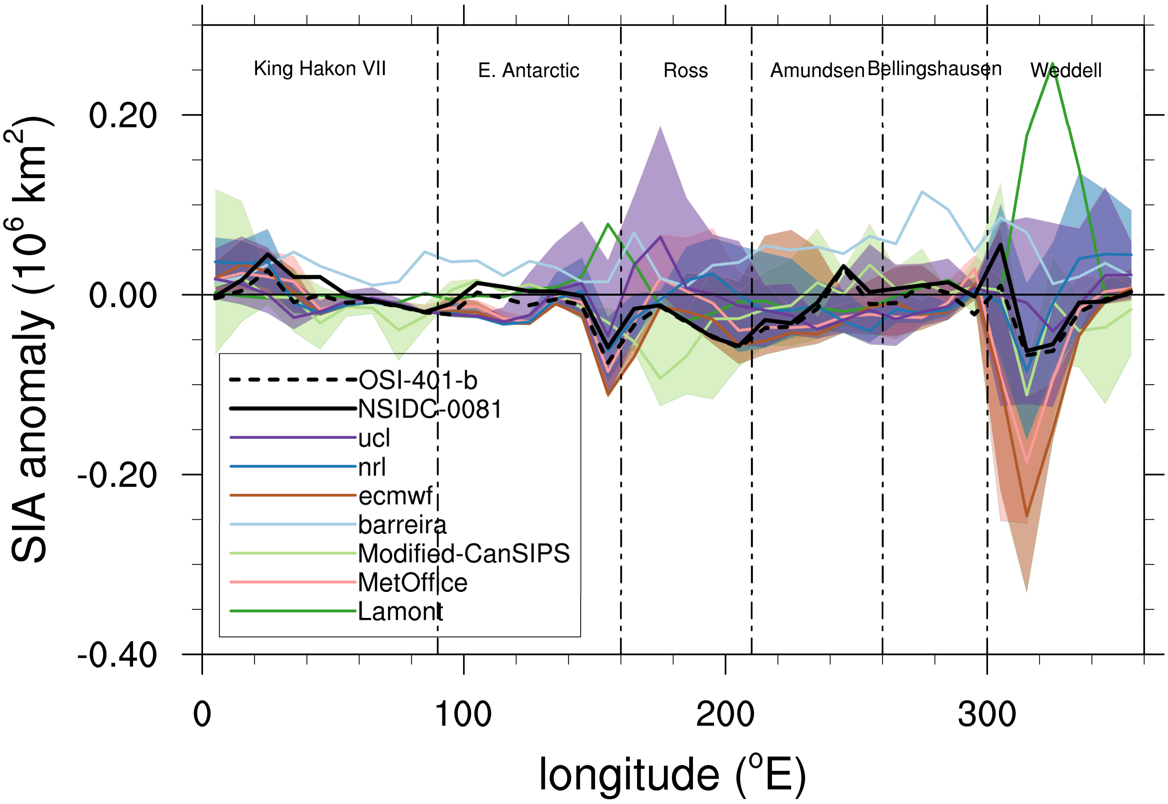

Figure 5: *February 2019 mean rSIA anomaly (compared to 1979-2014 NASA Team climatology) by longitude, for each submission, with observed estimates given in black. Solid lines show the ensemble mean for each contribution, with transparent shading indicating the ensemble range.*

the forecasting period for most of the forecasts. The error first grows, as initial-condition information is lost progressively throughout the melting season. As discussed in Section 2 and seen from Figure 3, observed sea ice retreated anomalously rapidly in December. From Figure 6, it is seen that all forecasting systems struggled to forecast the rapid ice retreat at the regional scale but that a few systems, likely thanks to error compensations, can simulate that rapid retreat at the circumpolar level (e.g. Nico-Sun; Figure 3). After the synchronous increase in IIEE during the month of December, the IIEE then decreases, for two reasons. First, observed ice melt slows down in January and February while forecasts keep melting ice at near climatological rates: the biases accumulated in December are progressively eliminated. Second, the surface of the ice to forecast evolves towards its minimum: with less ice to predict, there is less room for error. When normalising the IIEE by the observed area (not shown here), forecast errors reach a plateau after one month (01 January 2019) before slightly decreasing until the end of February. In any case, in all contributions, a rapid error growth occurs during the first month of the forecast, indicative of loss of predictive skill regardless of the prediction approach.

One forecast deserves particular attention as it outperforms the other ones (in the sense of the IIEE) through the entire period: Nico-Sun. This contribution is the only statistical one that provided daily information (the other statistical contributions were only available monthly and were interpolated to daily), so it is not possible at this stage to determine if statistical methods are generally superior to dynamical ones. The Nico-Sun 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. Despite its simplicity, the method appears to provide the most accurate forecast for this year. It is worth reminding that, for the exercise of last year, it was a dynamical contribution (NASA-GMAO) that was found to be the most consistent with observed data.

Drawing conclusions on which type of approach (statistical or dynamical) is superior to the other is therefore premature at this stage.

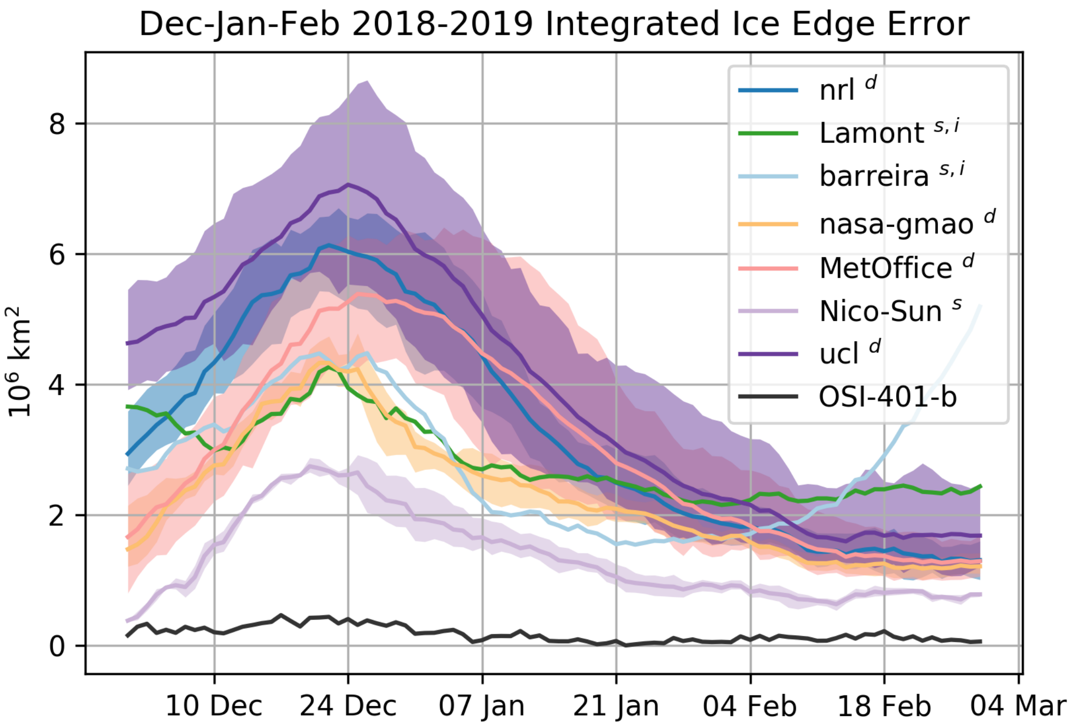

Figure 6: *Integrated Ice Edge Error (Goessling et al., 2016), defined as the area of grid cells where the forecasts and a reference (here, NSIDC-008; Maslanik and Stroeve, 1999) disagree on concentration being either above or below 15%. The shadings represent ensemble range (IIEE calculated on each member separately) and the thick lines are the mean of all IIEEs for a given forecast system. 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 dark grey line is the IIEE between the other observational product (OSI-401-b; Tonboe et al., 2017) and the NSIDC-0081 reference.*

3.3 Spatial information

We finally display in Figure 7 the probability of sea-ice presence for 15 February 2019. Green pixels are those where sea ice was forecast to be unlikely present, while red ones are those where sea ice was forecast to be likely present. The three statistical contributions (Lamont, Nico-Sun, Barreira) display sharp transitions between areas of certain ice presence and certain ice absence. By contrast, dynamical contributions suggest that, in some regions

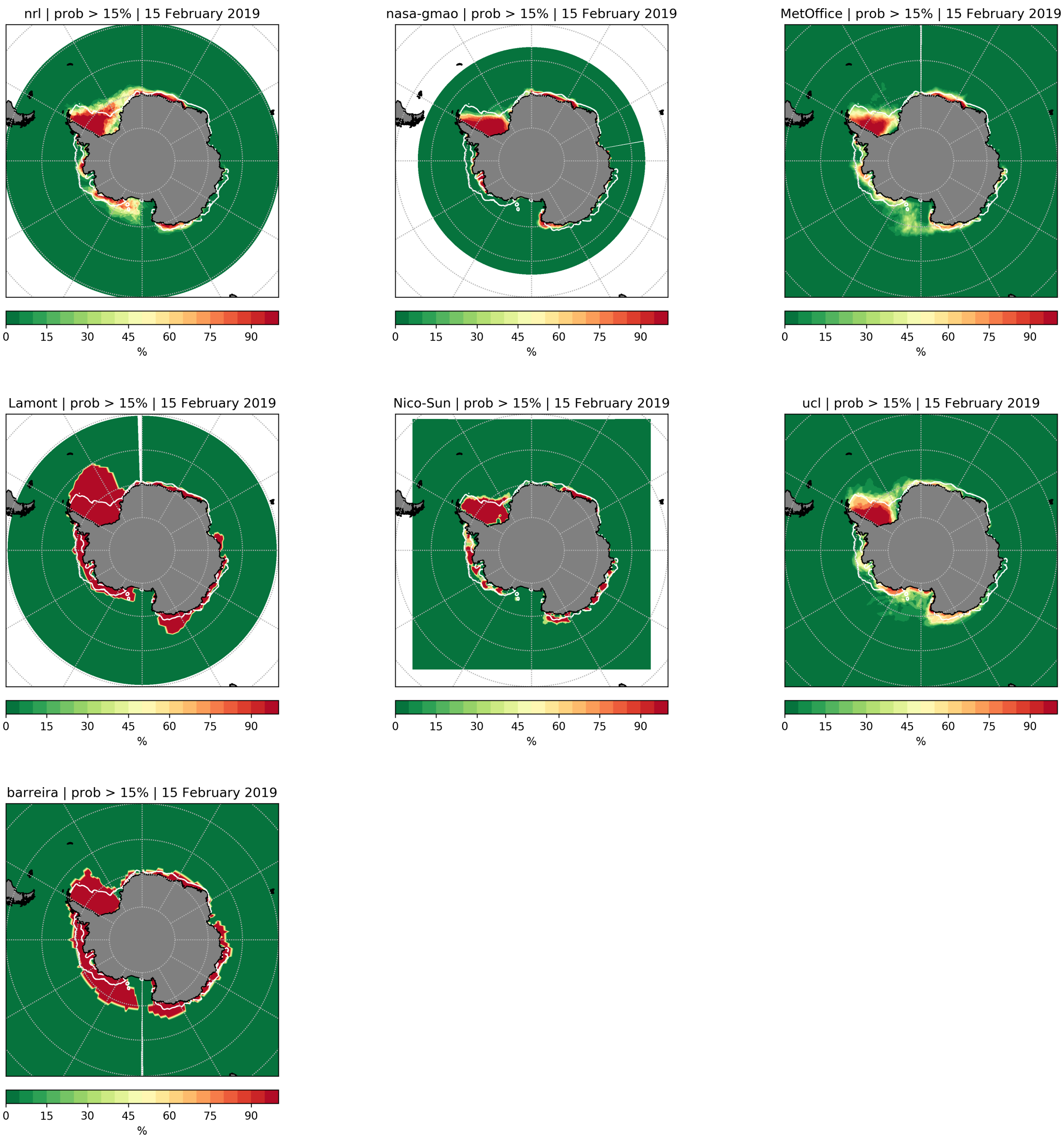

Figure 7: *Probability of sea-ice presence for 15 February 2019, as forecasted by the seven groups that submitted daily sea-ice concentration information. The white lines are the actual ice edges from the verification datasets on that day. The probability of presence corresponds to the fraction of ensemble members that simulate sea-ice concentration larger than 15% in a given grid cell, for that day. A dynamic animation of that figure for all 28 days of February is available at http://www.climate.be/users/fmasson/post-probability_2018-2019.gif*

like the Ross Sea, sea ice presence was very uncertain. The dynamical model ensembles are designed to sample weather variability and results from Figure 7 indicate that weather variability can imprint sea-ice variability in key sectors like the Ross Sea, a region that was already very difficult to forecast last year. Whether those ensemble forecasts are correctly calibrated will be investigated once more retrospective forecasts will be available.

4 Conclusions

We warmly thank all 12 contributors to this second exercise of coordinated forecasts of sea ice in the Southern Ocean. The great enthusiasm for SIPN-South is much appreciated and we are looking forward to continuing our activities. Indeed, more hindcasts are necessary to ensure the robustness of the results. Still, this analysis has already revealed several elements:

- 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. Observational uncertainty alone cannot explain the forecast-data mismatch;
- The timing of the minimum of Antarctic sea-ice area is not well predicted by the ensemble. The date of the minimum is in part driven by the change in insolation (which is predictable) and can be modulated by a few days by the passage of synoptic weather systems. Models, regardless of their nature, should capture weather uncertainty but it appears that the ensemble spread is generally too narrow, i.e. that the systems are under-dispersive;
- At the regional level, the range of forecasts includes the observations in most of the sectors but individual forecasts show errors that tend to compensate when zonal averages are performed. Thus, the total area is not a suitable diagnostic for evaluating SIPN-South forecasts;
- The only statistical contribution that provided daily information outperformed other contributions. 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 yet mature for practical use in applications like field trip planning or maritime route forecasting. Long records of retrospective forecasts are lacking in order to properly identify the origin of systematic forecast errors.

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