An anatomy of the forecast errors in a seasonal prediction system with EC-Earth

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R. Cruz-García[1] | P. Ortega[1] | J.C. Acosta-Navarro[1] | F. Massonnet[2] | F.J. Doblas-Reyes[1,3]

(1) Barcelona Supercomputing Center (BSC-CNS) | (2) Université catholique de Louvain, ELIC | (3) ICREA

Contact: ***ruben.cruzgarcia@bsc.es***

Motivation

- During the **first forecast day** there is a **large positive bias** (forecast vs NSIDC) for May (Fig. 1a) and November start dates. How can the first forecast day bias close to values that correspond to the monthly bias?
- We will investigate the different errors present in our forecast system during the **first month** in a set of seasonal predictions produced with EC-Earth3.2. We will also disentangle for how long initialization shock dominates over the systematic error as a function of forecast time.

Methodology

- Two sets of 7-months long seasonal forecasts (**1993-2008**, May and November start dates) run with **EC-Earth3.2**.
- Initial Conditions (**ICs**): **Sea Ice** → NEMO-LIM standalone reconstruction that assimilates Sea Ice Concentration (SIC) from ESA via EnKF. **Ocean** → ORAS4. **Atmos.** → ERA-Interim.
- Metrics: SIC differences, Sea Ice Area (SIA), Integrated Ice Edge Error (IIEE; Area where the forecast and the target disagree on the SIC above or below 15%) and spatial correlations.

Characterisation of the forecast errors

Particularities in the assimilation procedure

- Large initial bias between forecast and NSIDC (Fig. 1a) is related to the assimilation protocol and to observational uncertainty.
- Differences between the sea ice reconstruction (used as *sea ice ICs*) and its target data from ESA (Fig. 1b) reveal a weak assimilation at locations where:
  - Observational uncertainty is large (Fig 1c).
  - Ensemble spread is low (not shown).
  - Climatological differences (when uncertainty and spread are low).
- Given the large magnitude of the initial forecast biases (Fig. 1a), **the rest of errors will be quantified relative to the assimilation reconstruction.**

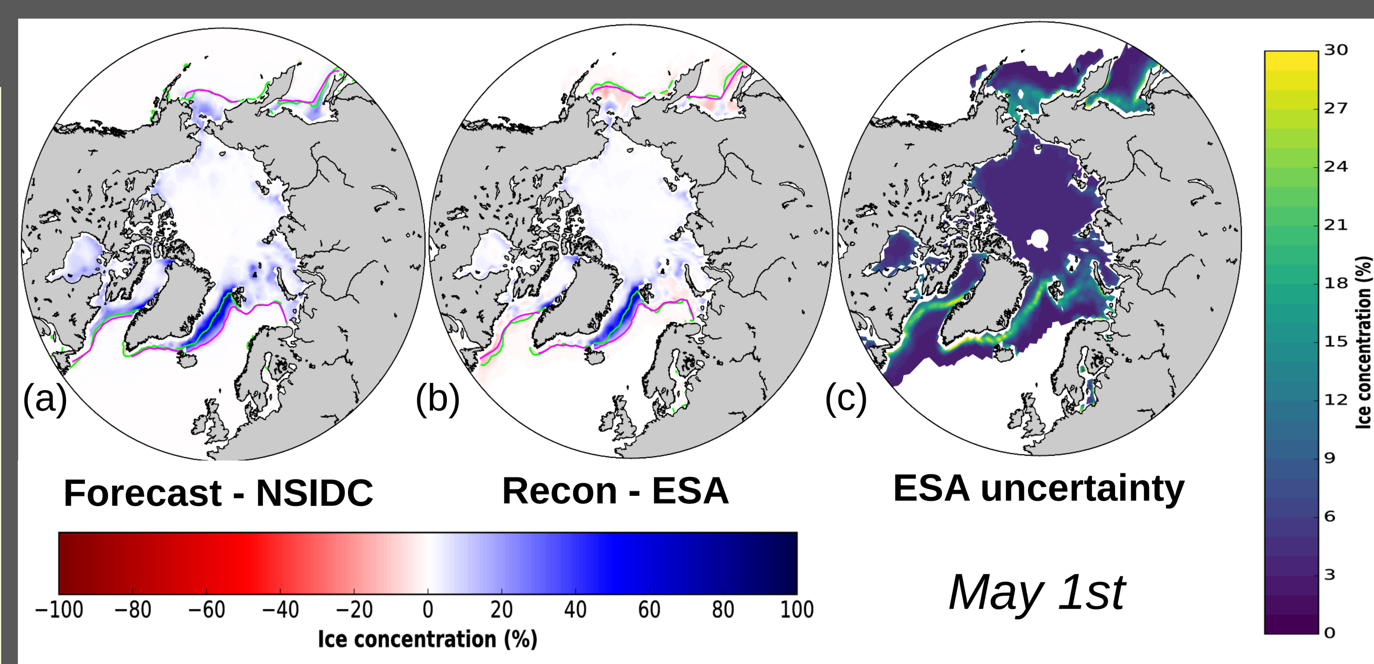
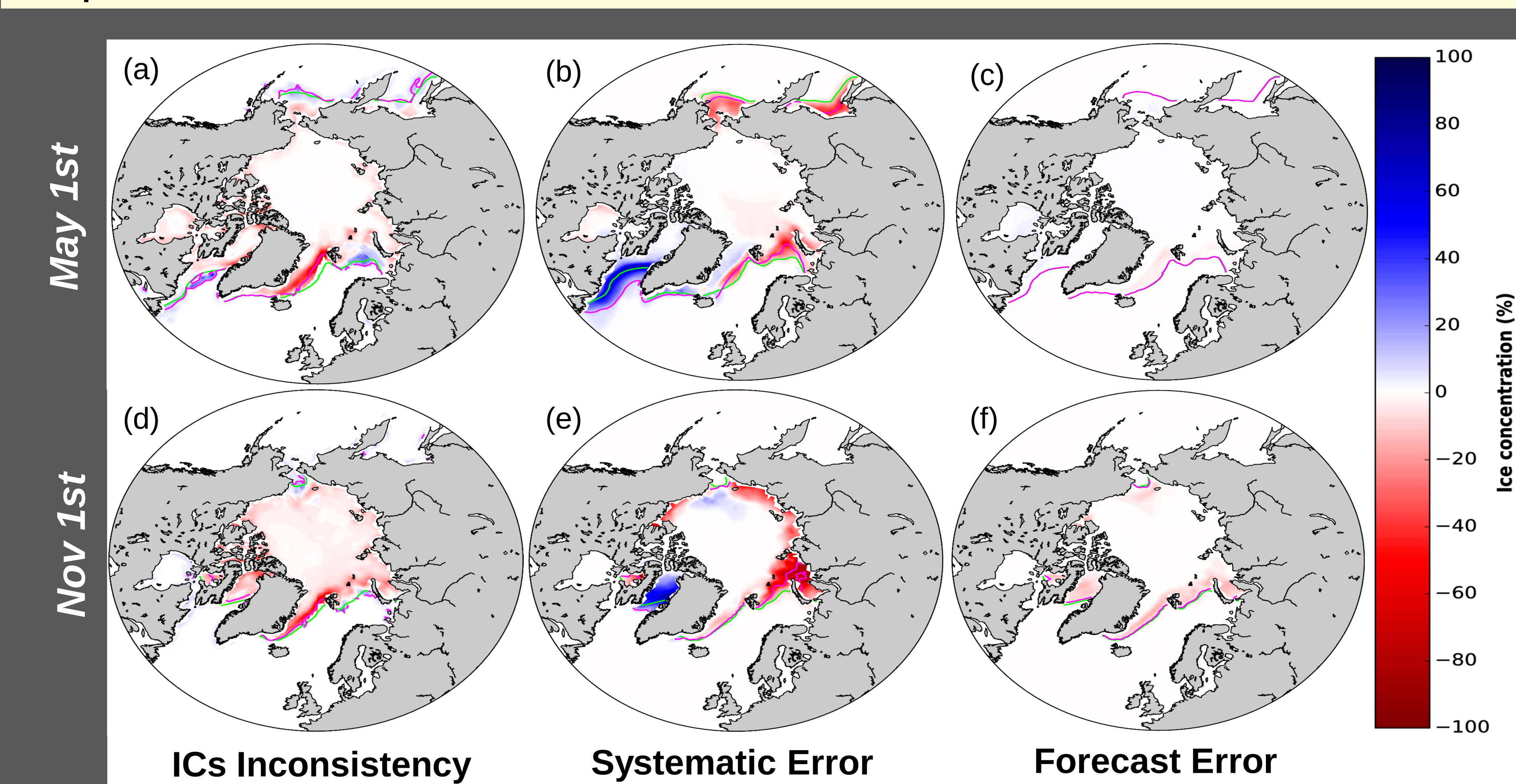


Fig. 1: (a) SIC difference between the forecast and NSIDC. (b) SIC difference between the assimilation reconstruction and ESA. (c) ESA SIC uncertainty. All figures correspond to May 1st.



Inconsistency between the initialization products

- Incompatibilities between the initialization products can introduce fast artificial shocks, as the different components adjust to each other in the first forecast days.
- There are significant differences between the sea ice IC and the sea ice used to produce the ocean IC from ORAS4 (Fig. 2a,d).
- This **inconsistency** implies that in the forecasts the relatively warm waters from ORAS4 will partly **melt** part of the sea ice imposed above.

Model drift

- The forecast experiments a drift as it adjusts towards its own (and biased) climatology. This attractor can be determined by analyzing a **historical simulation** (Fig. 2b,e).
- Both the **inconsistency of ICs** and the **model drift** will impact the forecasts: warmer ocean below degrades the overly extensive sea ice conditions from the assimilation reconstruction (Fig. 2c,f), and where colder conditions underneath can create sea ice.

Fig. 2: (a)/(d) SIC difference between ORAS4 sea ice and recon. (b)/(e) SIC difference between historical run and recon. (c)/(f) SIC difference between forecast and recon.

Understanding how the model errors develop

Error evolution in the Sea Ice Area

- Forecast error becomes apparent when comparing separately the SIA for the **predictions**, the reconstruction and the **historical run** the first 31 days of each start date.
- In **May**, forecasts simulate **correctly** the **SIA** decline as it transitions smoothly towards the historical run.
- In **November**, the forecasts evidence a **strong shock** characterized by a sharp fast decline in SIA during 2 to 7 days. Main reasons:
  1. Important climatological difference between reconstruction and historical run.
  2. Drift and shock go towards a melting the first days, opposing the general freezing up.

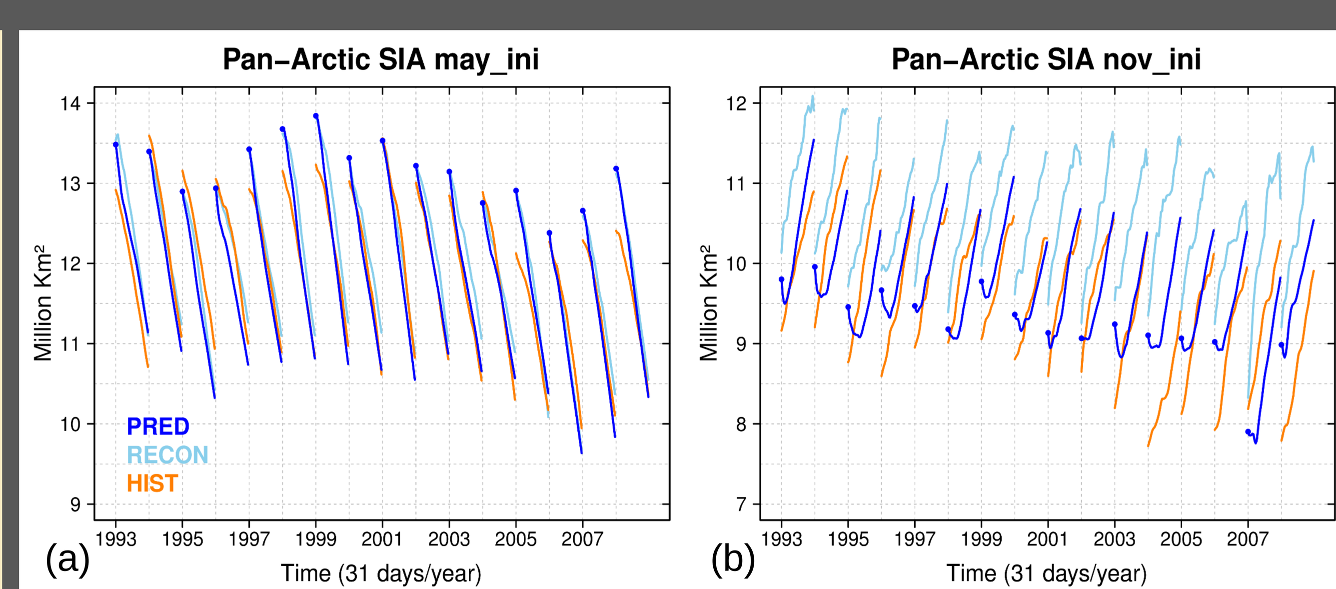
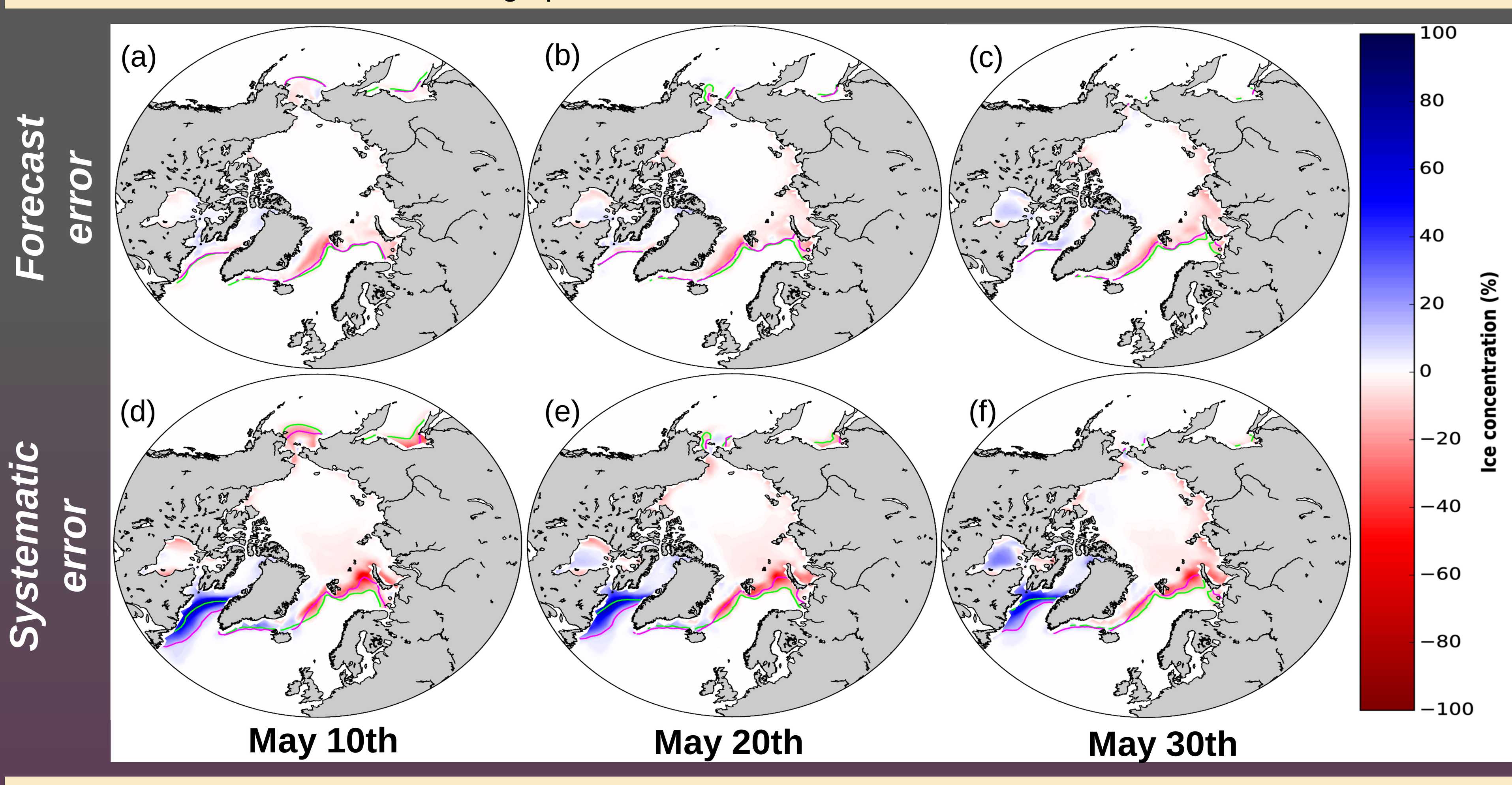


Fig. 3: Pan-Arctic SIA the 31 first days for the forecasts, the sea ice ICs and the historical simulation for the period 1993-2008 for (a) May and (b) November.



Relative role of the model errors as a function of forecast lead time

- The ICs incompatibility in May (Fig.2a) has a remarkable impact on the forecast error still after 5 and 10 days in the Greenland Sea, which reduces progressively by May 30 (Figs. 4a,b,c).
- In the **Barents and Kara Seas** (**Baffin Bay**) the forecast error tends to be **negative** (**positive**) because **the error evolves towards the systematic bias** (Figs. 4d,e,f).
- By forecast day 30, the forecast bias is not yet fully developed, particularly in regions where the systematic bias attains the minimum/maximum values (i.e. Svalbard and Labrador Sea, correspondingly; Fig. 4d,e,f).

Fig. 4: SIC difference between the forecasts initialized in May and the sea ice reconstruction (top row) and the systematic error (bottom row) for lead times 10, 20 and 30 for the period 1993-2008.

- Influence of incompatibility shock decreases with forecast time. Response to model drift increases.
- The **systematic error** becomes the **largest contributor** to the forecast error after **26** days in **May**, after **21** days in **Nov**.

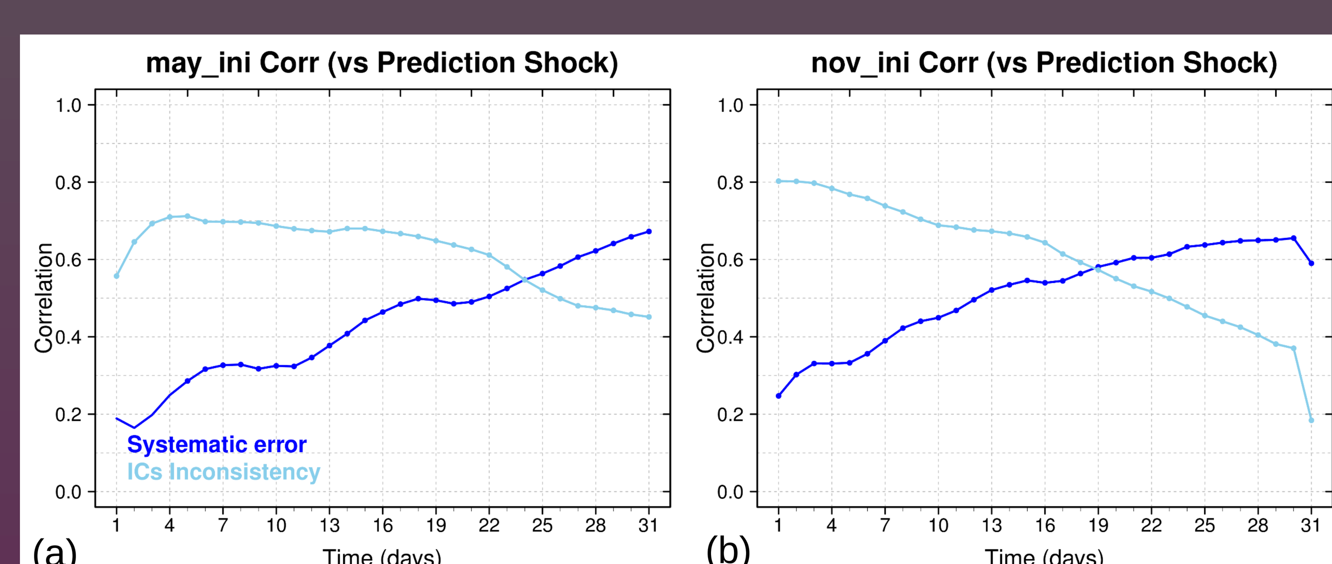


Fig. 5: Lagged correlation between the ICs shock and the forecast error (light blue) and synchronous correlation between the systematic bias and the forecast error (dark blue) during the first 31 days for (a) May and (b) November. Correlations were computed spatially.

Conclusions

- Discontinuous SIC assimilation for the sea ice ICs partially prevents the forecasts to be close to observations the first days.
- Inconsistent ocean and sea ice initial states generate a fast shock, in which the warmer ocean rapidly melts the sea ice above it. This effect is more evident for the November-initialized forecasts.
- During the first month, errors evolve differently to the systematic bias depending on the region, not reaching in any case their systematic error states. The ICs inconsistency also affects differently the distinct basins.
- Forecast error in November is exacerbated due to the important climatological difference between the reconstruction and the historical run in this month, and also to the melting effect caused by the incompatibility during a generalized freezing moment.
- The initialization shock dominates the forecast error the first ~20 days for both the May and November start dates. After that, the systematic error appears to be the major contributor to the total forecast error.