Verification of Arctic sea ice seasonal predictive capacity in APPLICATE re-forecasts

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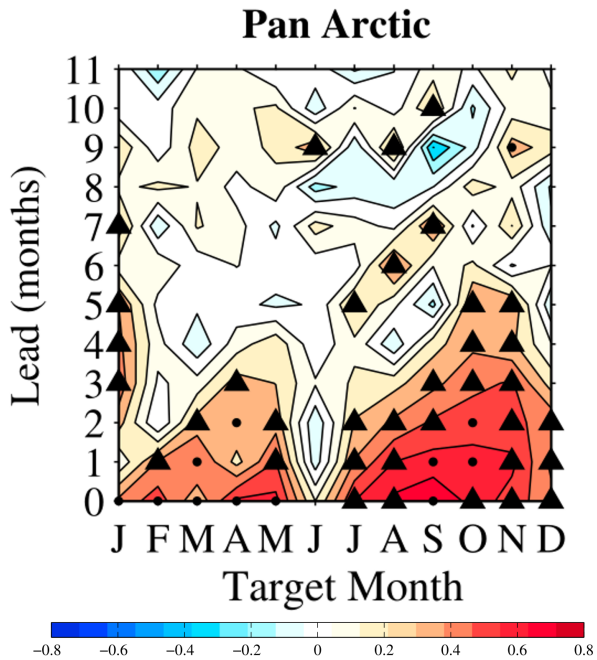
Preliminary thoughts

Pan-Arctic sea ice predictability

- Seasonal-to-decadal (S2D) scales : review by Guemas et al. (2014)
- Potential predictability studies (e.g. APPOSITE, Tietsche et al. 2014) find significant skill up to 1-2 years ahead
- Studies based on S2D ensemble hindcasts (e.g. SPECS, Guemas et al. 2016) generally show lower lead times for significant skill (1-6 months)
- Skill depends on initialization month, lead time, and area (Bushuk et al. 2017)



SIE correlation with NSIDC in GFDL FLOR
(adapted from Bushuk et al. 2017)

Several limitations

- Pan-Arctic SIE estimates give only a limited picture of actual forecast skill of coupled systems
- Is removing a linear trend the best way to not overestimate skill ?
- Growing interest for more user-oriented assessments (shipping routes, Melia et al. 2017)

Seasonal re-forecasts in the H2020-APPLICATE project

Common re-forecast period

- Re-forecasts initialized from May and November 1993-2014
- Up to 6 months forecast time
- This talk : focus on **May starts**
- Variable of interest : **Sea ice extent (SIE)** from 45°N to 85°N where SIC>0.15

Overview of re-forecasts

Model/System	CNRM-CM6-1	ECMWF SEAS5	MetO GloSea5	EC-Earth3.2.2
Atmosphere	ARPEGE 6.2	IFS Cy43r1	UM v6	IFS Cy36r4
Resolution	tl127l91r	TCo319L91	N216L85	T255L91
Ocean	NEMO 3.6	NEMO 3.4	NEMO 3.4	NEMO 3.6
Resolution	eORCA1	ORCA 0.25	ORCA 0.25	ORCA 1
Sea ice model	GELATOv6	LIM2	CICE 4.1	LIM3
Sea ice I.C.	Mercator-Ocean	ORS-S5	NEMOVAR	NEMO-LIM run w/ SIC assim.
I.C. dates	1 May	1 May	9,17,25/04 01/05	1 May
Ensemble size	30	25	28	10

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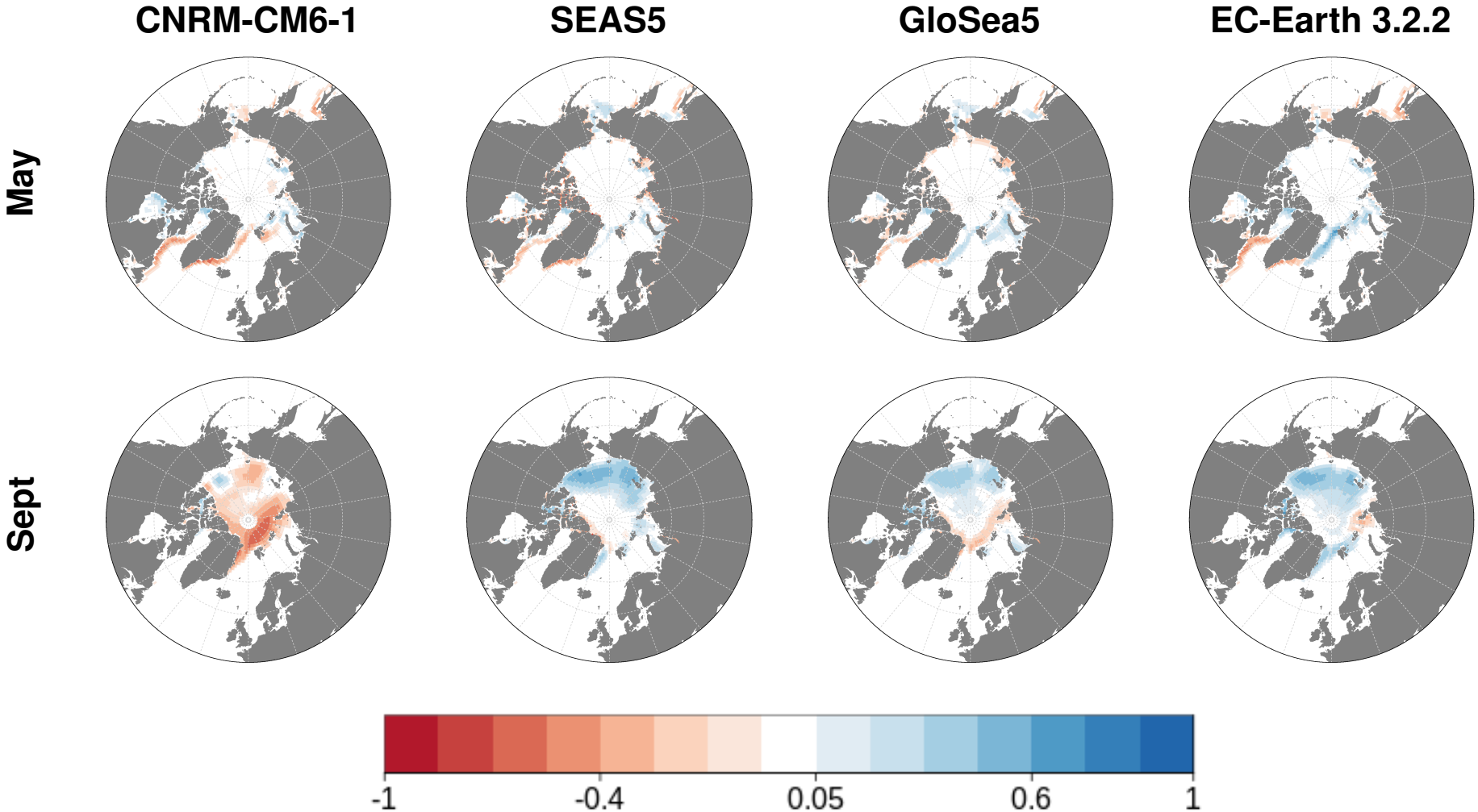
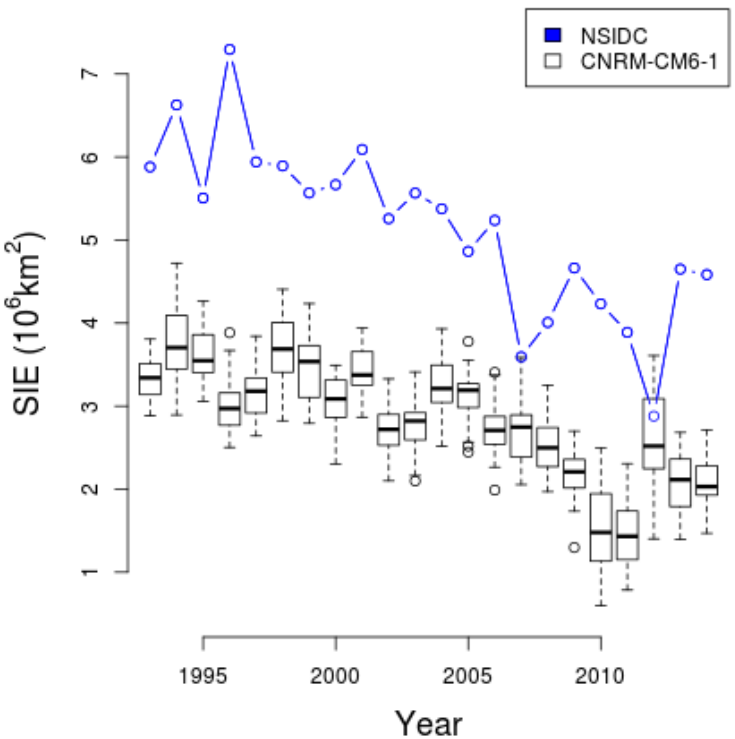
Sea ice concentration bias with NSIDC data

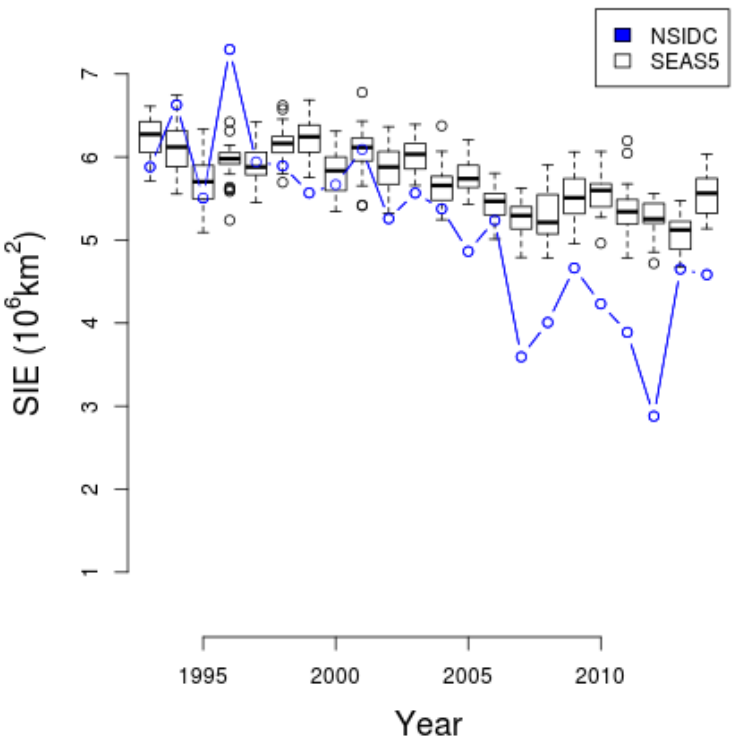


Pan-Arctic SIE spread and bias at month 5

CNRM-CM6-1

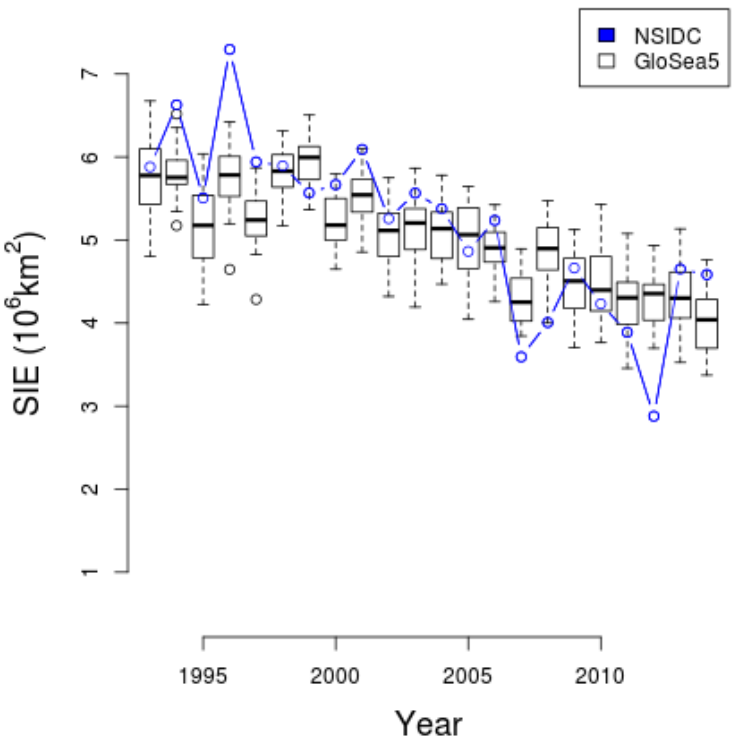


SEAS5

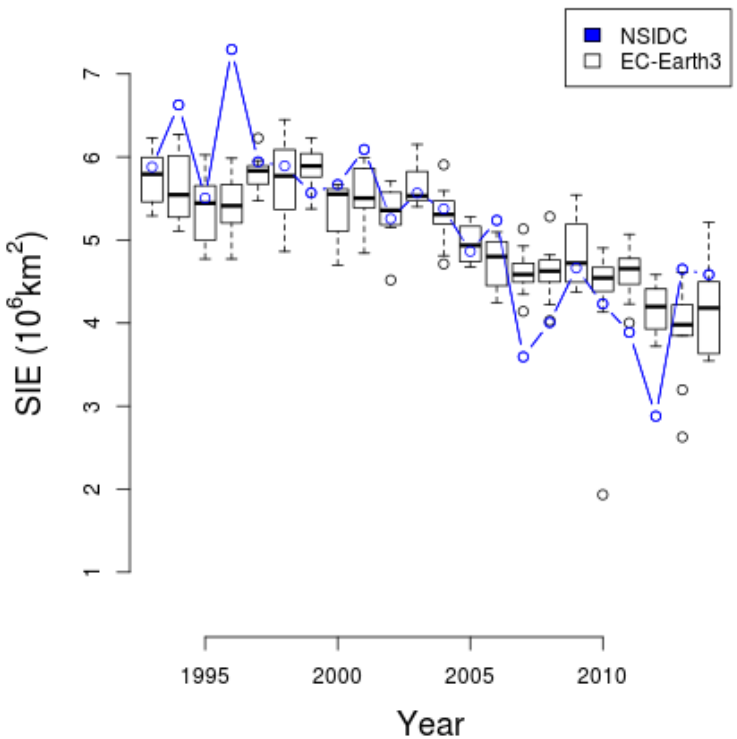


Pan-Arctic SIE spread and bias at month 5

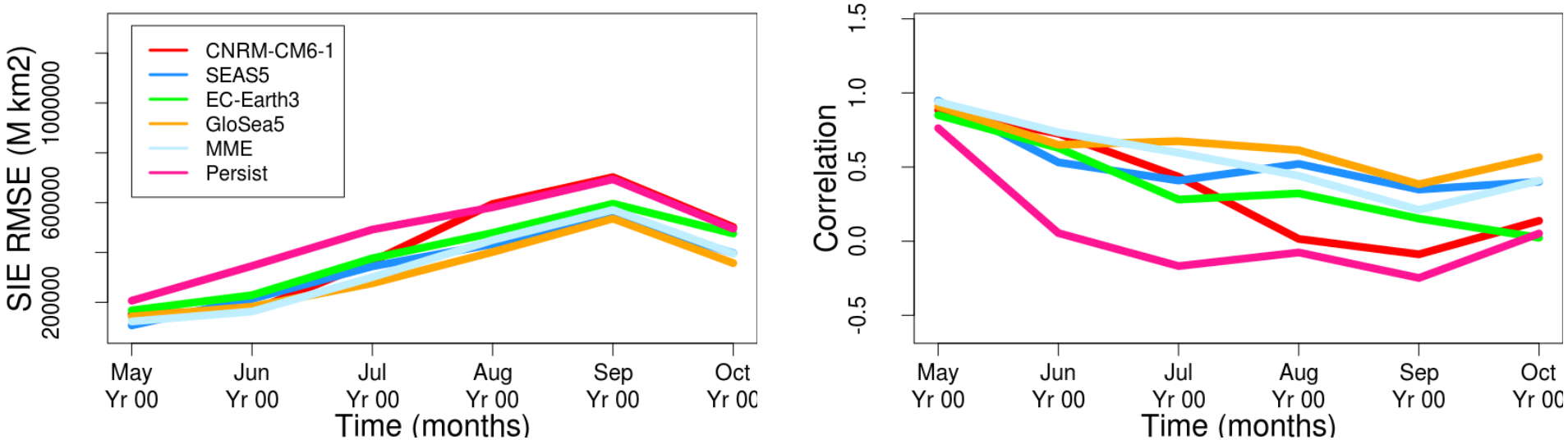
GloSea5



EC-Earth 3.2.2



Pan-Arctic SIE re-forecast skill : RMSE and correlation



RMSE and anomaly correlation coefficient according to forecast time for detrended SIE against NSIDC reference data for each model and a multi-model (including each member of each model)

Raw detrended SIE skill

- Models exhibit skill higher than persistence at most lead times
- Although not significantly better (short re-forecast period)
- Skill of a multi-model ensemble is comparable to the best models, not higher

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A more ambitious assessment : spatial scores

Rationale

- Forecasting systems can get total Pan-Arctic SIE right for the wrong reasons
- Providing information at the regional scale may not be the most useful approach
- Goessling et al. (2016) : method accounting for sea ice misplacement errors

Integrated Ice Edge Error

- Deterministic score
- Based on typical SIC > 0.15 threshold
- $IIEE = O + U$
- Decomposition : $IIEE = AEE + ME$ where $AEE = |O - U|$ and $ME = 2 \cdot \min(O, U)$
- AEE : absolute extent error
- ME : misplacement error

Example from Goessling et al. (2016) for computation of IIEE

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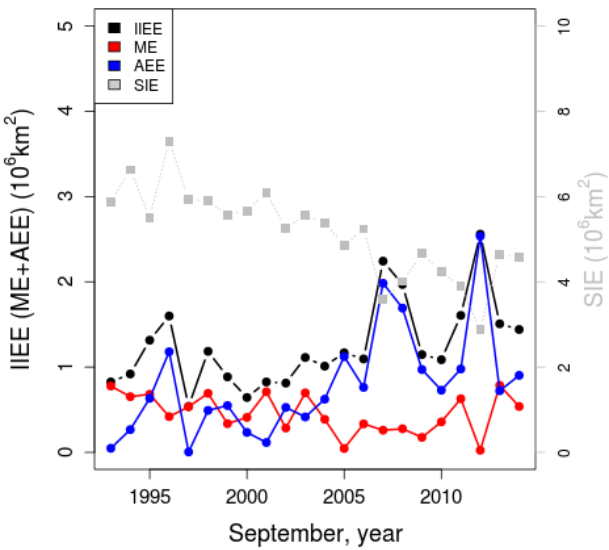
Ensemble mean September IIEE

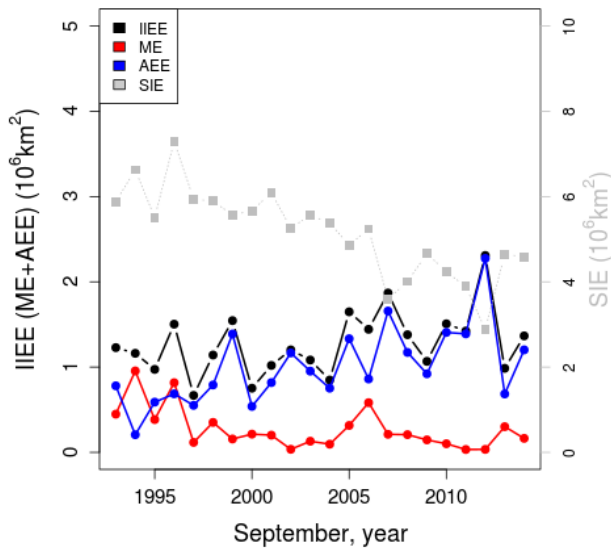
Use in seasonal re-forecasts

- Bias-correct SIC values vs NSIDC data to correct mean bias (leave-one-out)
- Determine ensemble mean sea ice contours using a 0.15 SIC threshold
- Compute "observed" sea ice edge based on NSIDC data

CNRM-CM6-1



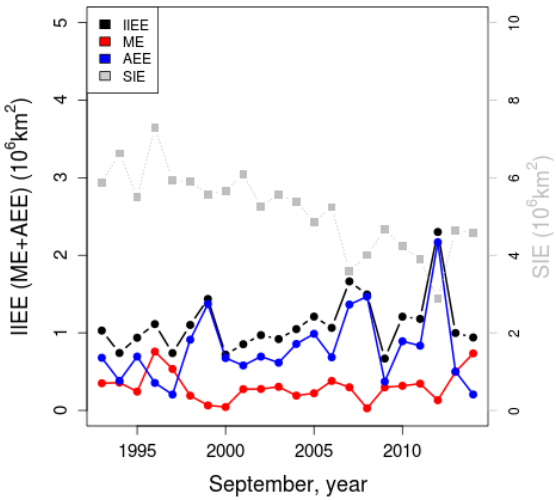
SEAS5



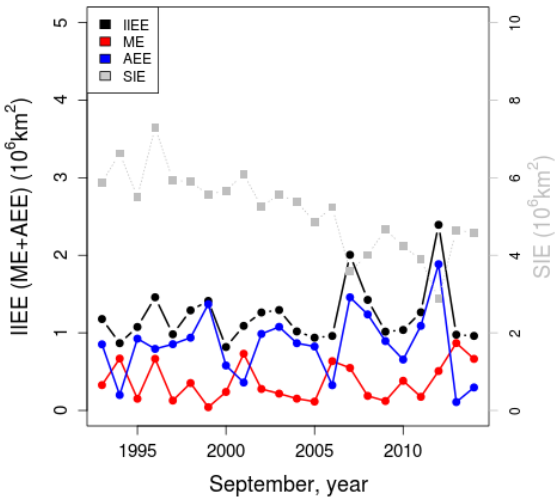
IIEE vs NSIDC data for ensemble mean September Arctic sea ice edge according to forecast year (black), and AEE (blue) + ME (red) decomposition for CNRM-CM6-1 and SEAS5. Grey lines show NSIDC total SIE between 45°N and 85°N (right y-axis).

Ensemble mean September IIEE

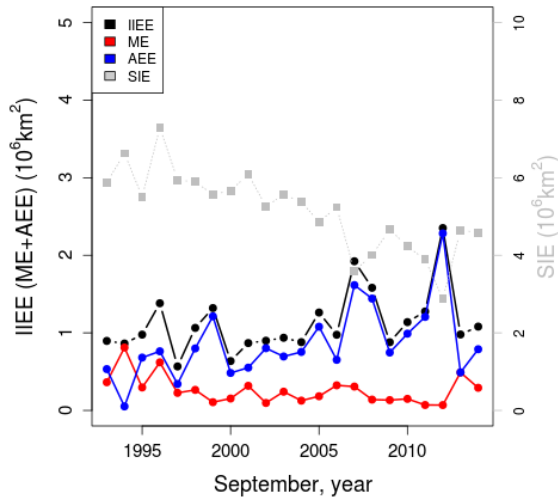
GloSea5



EC-Earth 3.2.2



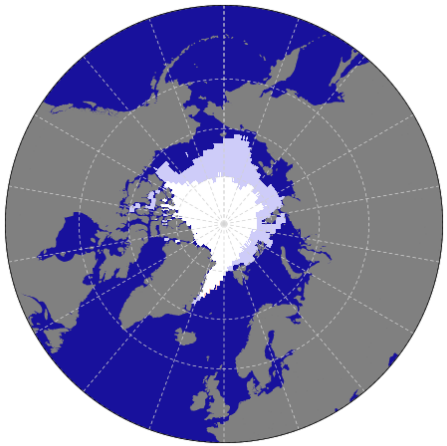
Multi-model



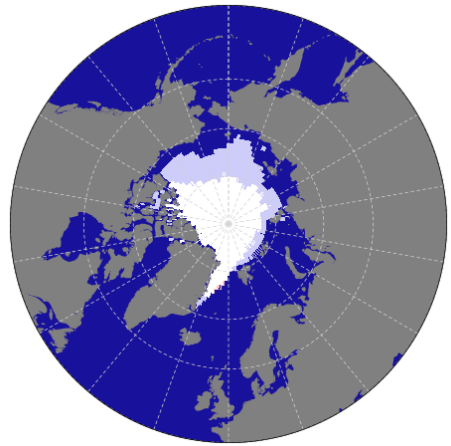
IIEE vs NSIDC data for ensemble mean September Arctic sea ice edge according to forecast year (black), and AEE (blue) + ME (red) decomposition for GloSea5, EC-Earth 3.2.2 and a multi-model grouping ensemble members of bias-corrected sea ice concentration for all 5 models. Grey lines show NSIDC total SIE between 45°N and 85°N (right y-axis).

September 2012 : maximum IIEE

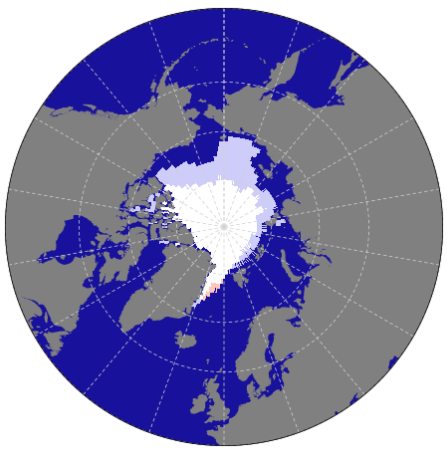
CNRM-CM6-1



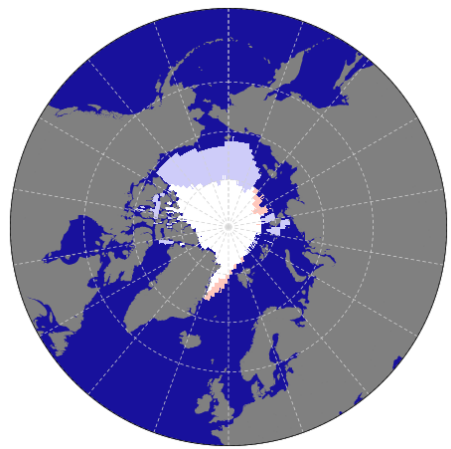
SEAS5



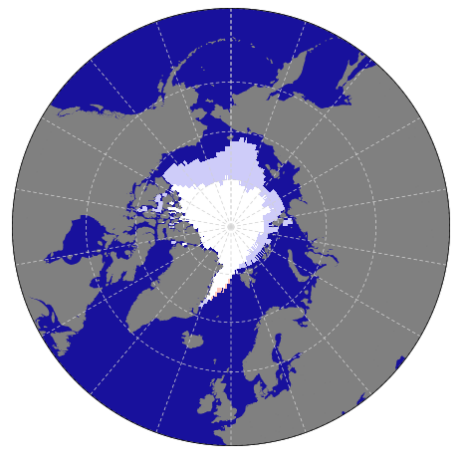
GloSea5



EC-Earth 3.2.2



Multi-model



Probabilistic approach : Spatial Probability Score

Extension of IIEE to probability forecasts

- Introduced by Goessling and Jung (2018)
- Computation after bias correction of *probabilities* with NSIDC as reference data

$$SPS = \int_x \int_y \left(P_{\mathrm{SIC}_f > 0.15}(x, y) - \mathbb{1}_{\mathrm{SIC}_o > 0.15}(x, y) \right)^2 \mathrm{d}y\mathrm{d}x$$

- Implementation :
  - Probabilities computed by counting the fraction of ensemble members exceeding SIC threshold (with raw outputs)
  - Bias correction in cross-validation mode of $P_{\mathrm{SIC}_f > 0.15}(x, y)$
  - Area-weighted average of Brier score with respect to NSIDC

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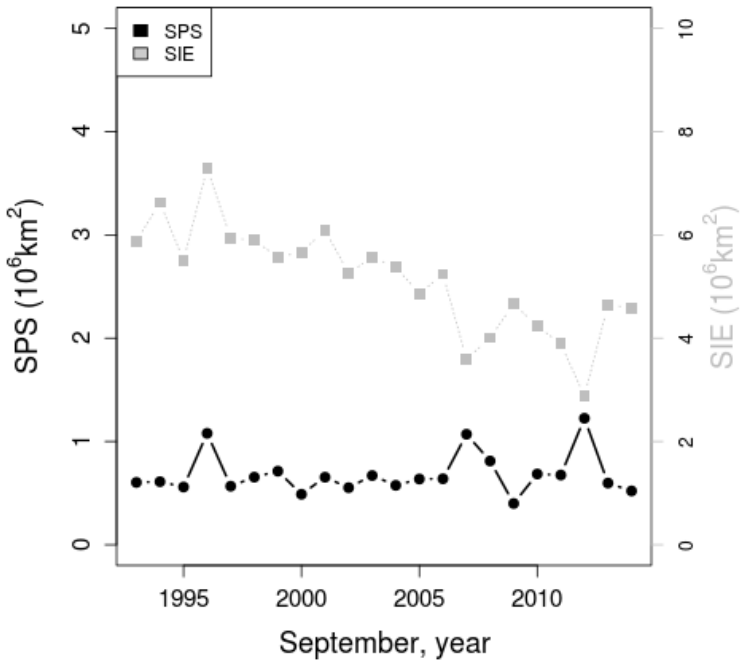
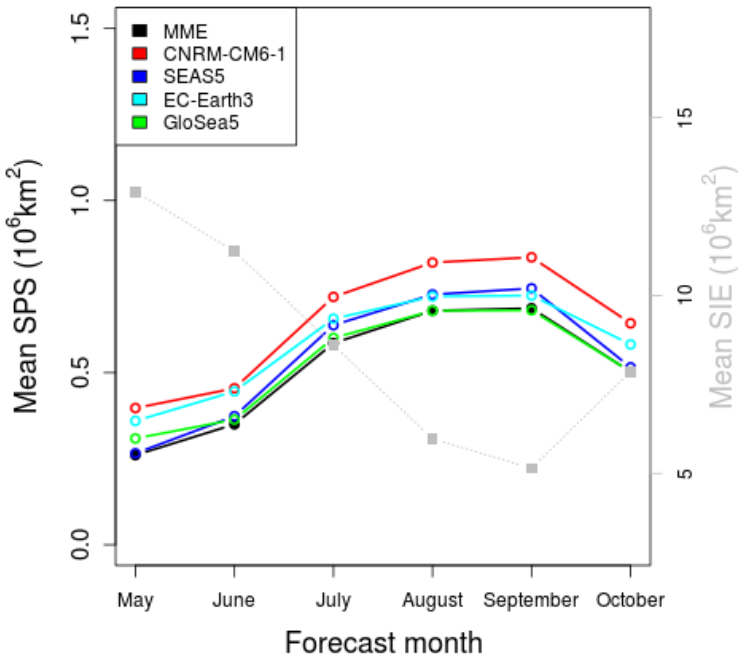
Spatial Probability Score results

GloSea5 (September)



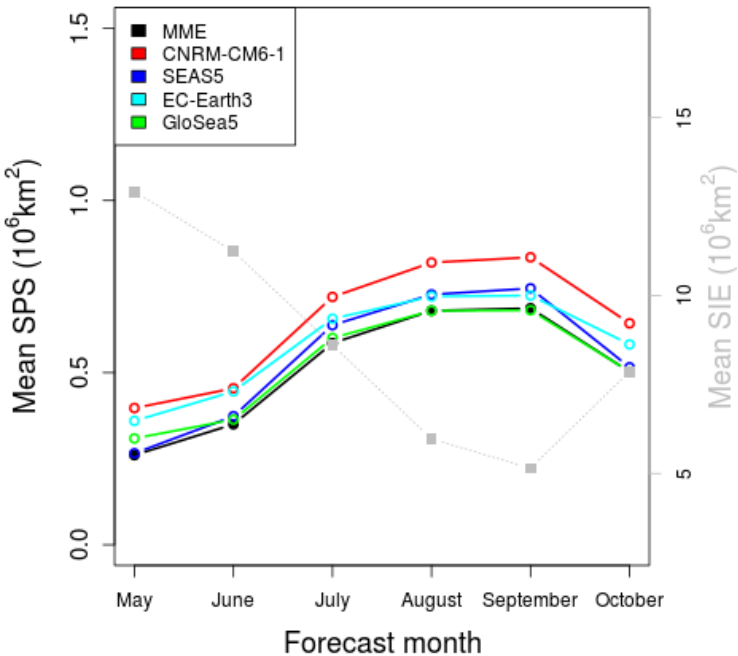
All models and lead times



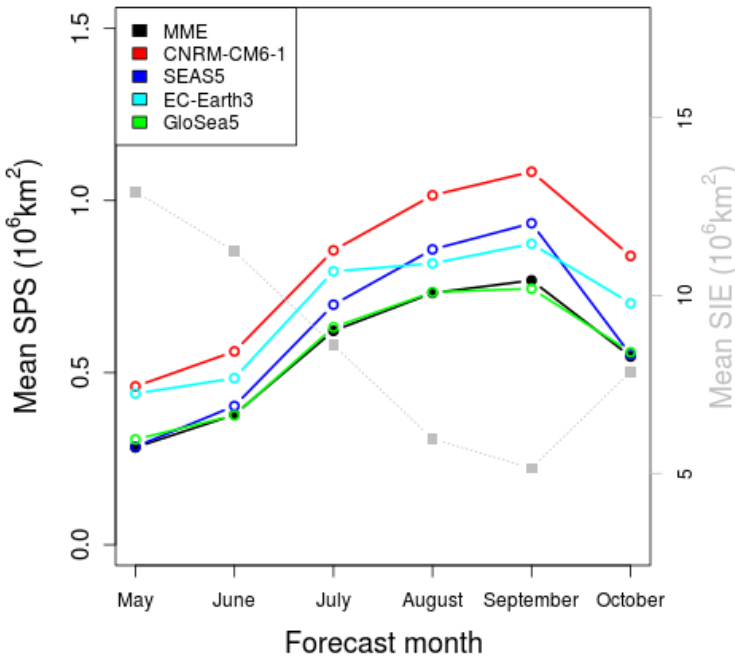
GloSea5 SPS for September (May initialization) for each year of the re-forecast period (left) and evolution of mean SPS of each system with forecast time (right).

Sensitivity to bias correction technique

Probability bias correction



SIC bias correction



Evolution of the 1993-2014 mean SPS of each system with forecast time, where probabilities are bias corrected (left) or SIC is bias corrected before computing probabilities (right).

Take home messages

Evaluation of APPLICATE seasonal re-forecasts skill

- Multi-model evaluation of SIE over Pan-Arctic region for May 1993-2014 starts
- Three models show very similar levels of skill and limited spread : multi-model ensemble provides little to no added value, but does correct part of the misplacement errors
- Spatial scores : evaluation of sea ice edge errors with IIEE and SPS
- Some sensitivity to the bias correction method for the probabilistic approach

Caveats and future work

- Threshold effects : better to overestimate than underestimate SIC with these scores
- CNRM-CM6-1 has too thin ice : partly loses source of predictability for September minimum
- Work in progress : linkages with Arctic and mid-latitudes atmosphere in these systems

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And thank you for your attention !

Bushuk, M. et al. (2017) Skillful regional prediction of Arctic sea ice on seasonal timescales. *Geophys. Res. Lett.* 44, 4953–4964, doi :10.1002/2017GL073155

Goessling, H.F. et al. (2016) Predictability of the Arctic sea ice edge. *Geophys. Res. Lett.* 43, 1642–1650, doi :10.1002/2015GL067232

Goessling, H.F. and T. Jung (2018) A probabilistic verification score for contours : Methodology and application to Arctic ice-edge forecasts. *Q. J. Roy. Meteorol. Soc., in press.* doi :10.1002/qj.3242

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