Econometric Models for Sea Ice Forecasting

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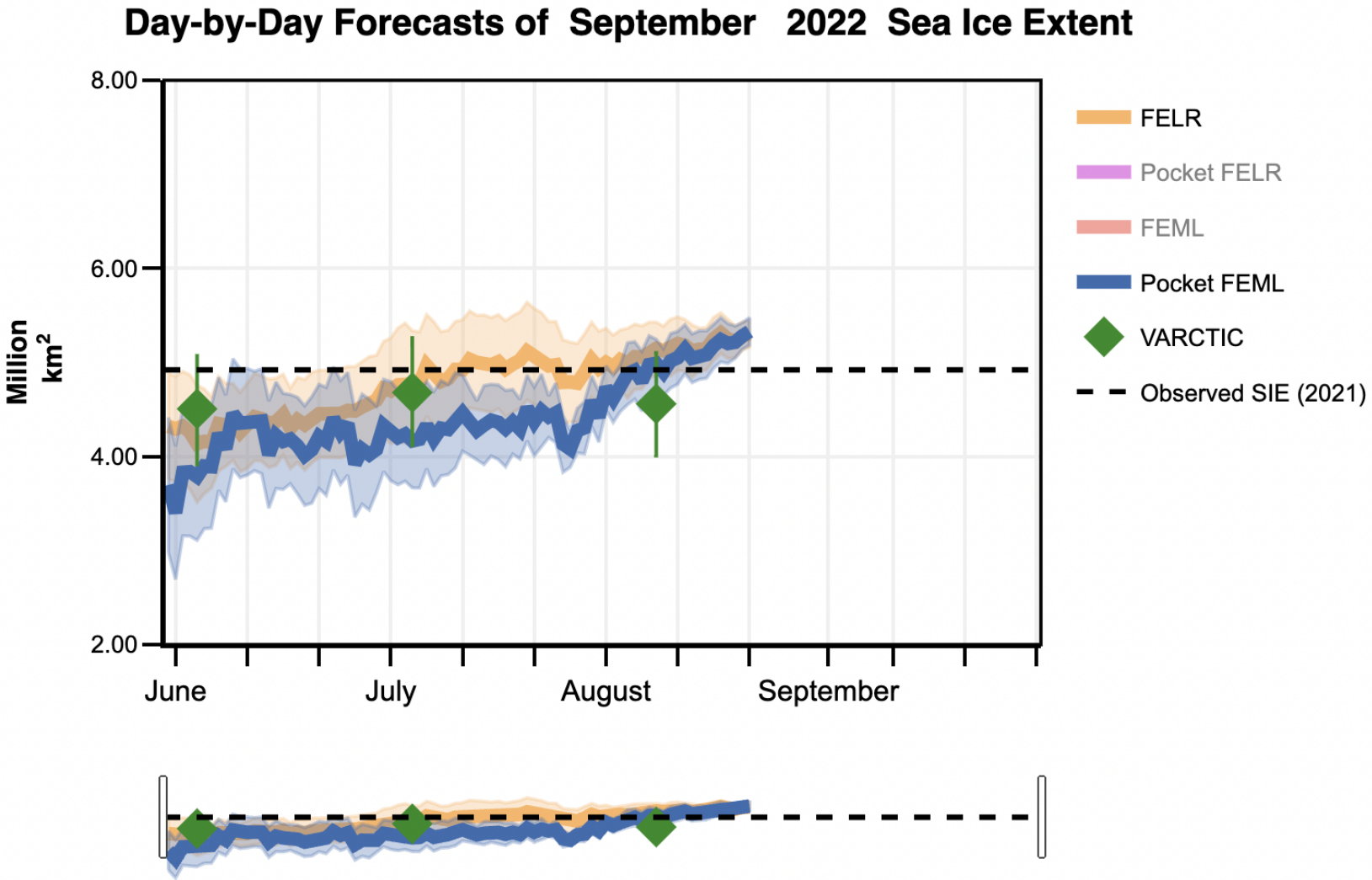
The UPenn-UQAM Forecasts



They are updated weekly during summertime on la Chaire's website.
`https://chairemacro.esg.uqam.ca/arctic-sea-ice-forecasting/?lang=en`

An Ensemble of Papers

I. **Arctic sea ice projections from statistical and climate models disagree**
"Probability Assessments of an Ice-Free Arctic: Comparing Statistical and Climate Model Projections," Diebold and Rudebusch. *J. Econometrics*, 2022, in press.

II. **The VARCTIC: enlarging the information set (8 and 20 variables), a hybrid statistical-dynamical model approach.**
"Climate Models Underestimate the Sensitivity of Arctic Sea Ice to Carbon Emissions," Goulet Coulombe and Göbel, *Journal of Climate*, 2021 .

III. **Focusing on sparse carbon trends, key ice indicators and forcing forecasts self-consistency through basic physical constraints**
"When Will Arctic Sea Ice Disappear? Projections of Area, Extent, Thickness, and Volume," Diebold, Rudebusch, Goulet Coulombe, Göbel and Zhang. `arXiv:2203.04040`, 2022.

IV. **Machine Learning-based nonlinearities can help for short-run forecasts but overall plain linear models are very stubborn benchmarks. Also, there are seasonal thresholds of predictability.**
"Assessing and Comparing Fixed-Target Forecasts of Arctic Sea Ice: Glide Charts for Feature-Engineered Linear Regression and Machine Learning Mode," Diebold, Göbel , Goulet Coulombe, `arXiv:2206.10721`, 2022.

Model I – The VARCTIC

- Bayesian Vector Autoregression (VAR), a workhorse macroeconometric model
- *compromise* between fully structural and purely statistical approaches
- *models* a dynamic system **diverging** towards a physical constraint of 0 SIE
- *assess* the importance of different variables in amplifying various forcings – i.e., feedback loops

Some methodological choices

- Representation of external forcings and internal variability in

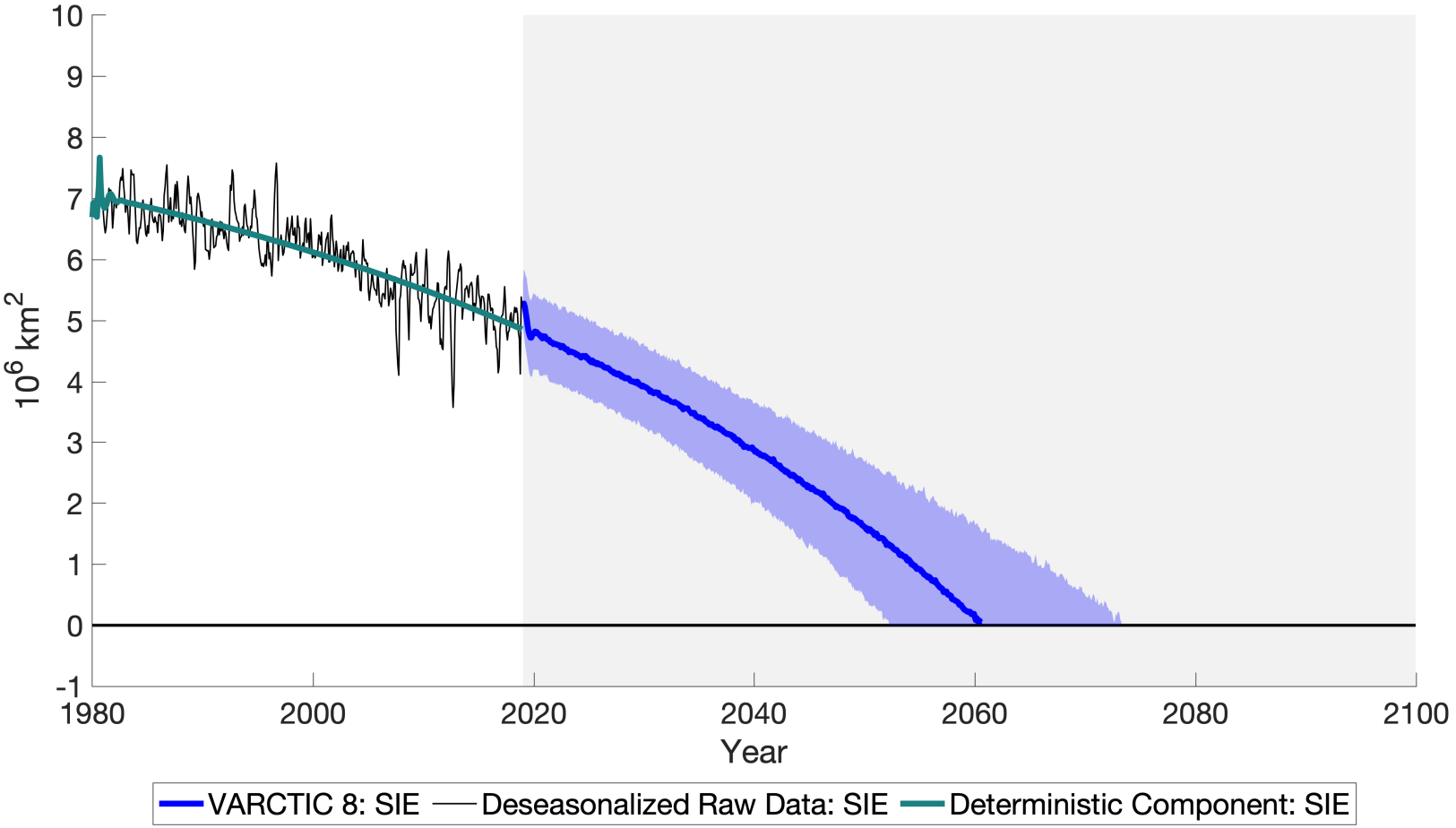
$$A\boldsymbol{y}_t = \Psi_0 + \sum_{p=1}^{P} \Psi_p \boldsymbol{y}_{t-p} + \boldsymbol{\varepsilon}_t$$

Variables (y_t)	**Data Source**
Sea Ice Extent	NSIDC Sea Ice Index
CO_2	NOAA/ESRL Global Trend
Total Cloud Cover	NCEP/NCAR 40-year Reanalysis Project
Sea Surface Temperature	Met Office Hadley Centre
Air Temperature	NCEP/NCAR 40-year Reanalysis Project
Precipitation	NOAA/OAR/ESRL
Thickness	PIOMAS
Sea Ice Albedo	MERRA-2

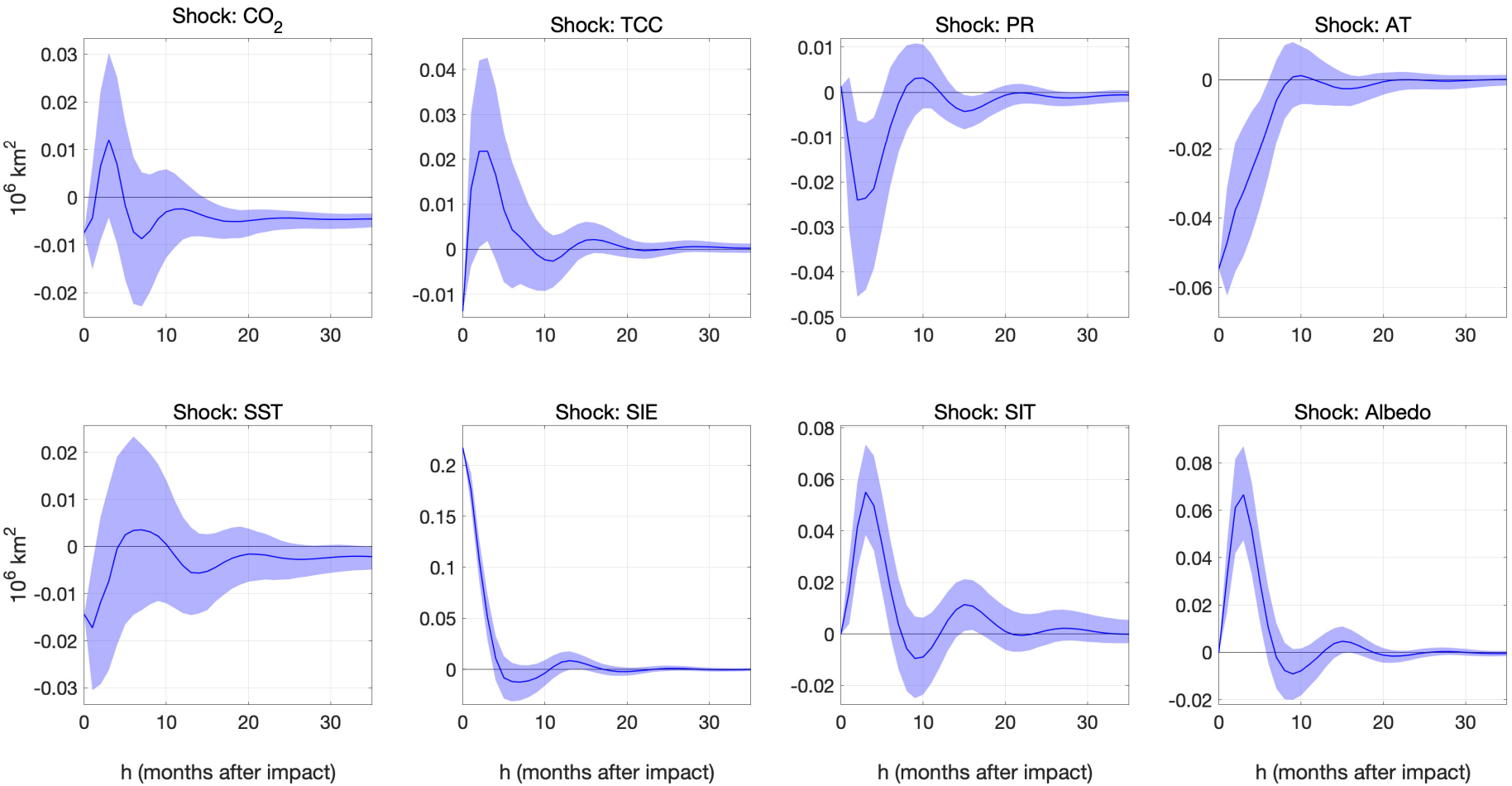
- We also consider a version with 20 variables.
- Could be augmented with economic indicators.

Forecast obtained by iterating the system forward

Figure: Trend Sea Ice Extent, adjusted for September level



Response of Sea Ice Extent to different impulses



Model II and III – FELR and FEML

- FELR (Feature-Engineered Linear Regression) is a simple model using features constructed from daily data

$$SIE_{Month} \rightarrow c,\ Time,\ SIE_{LastMonth},\ SIE_{Last30Days},\ SIE_{Today} \tag{3}$$

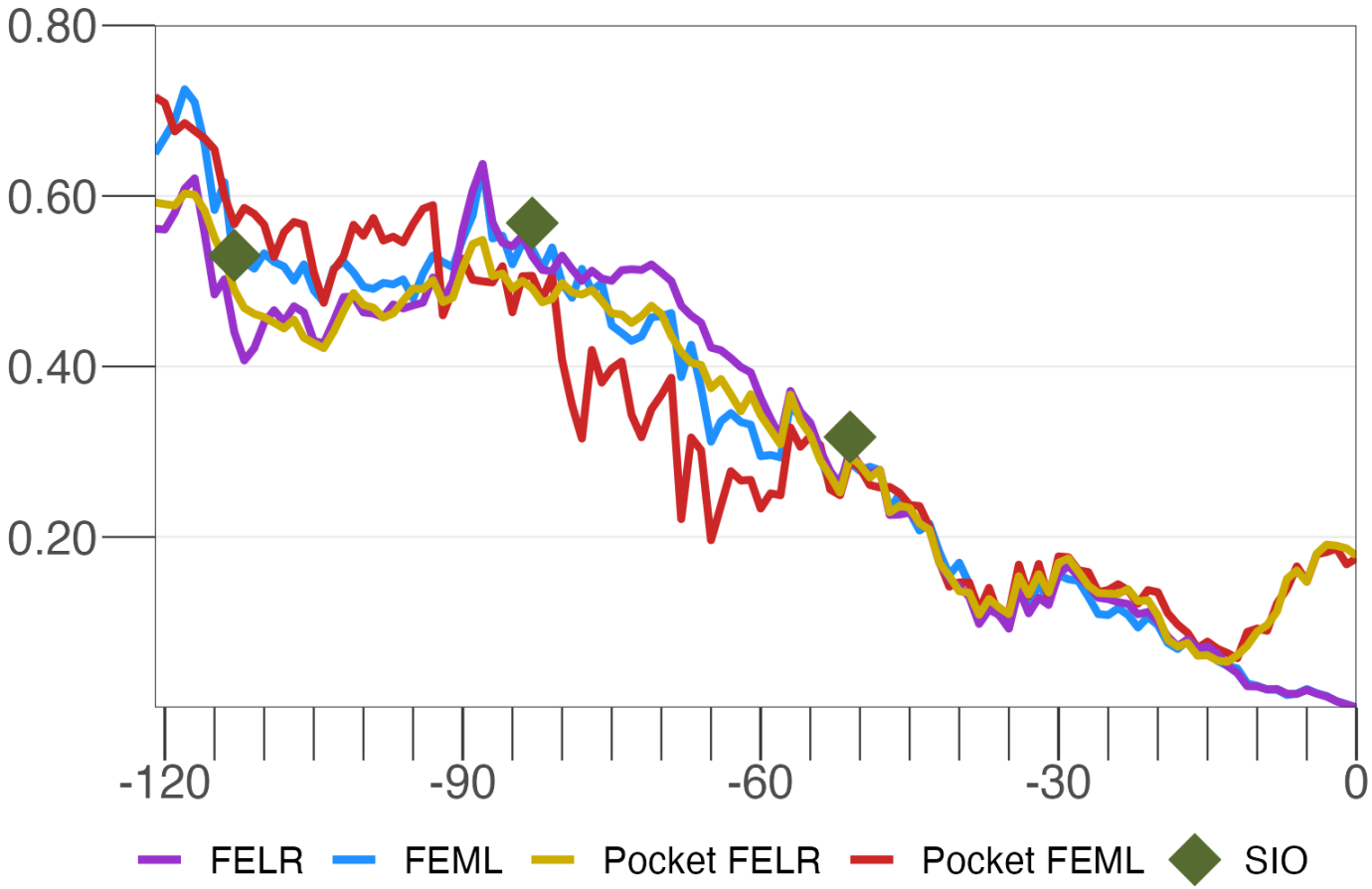
- FEML (Feature-Engineered Machine Learning) is the extension using Macro Random Forest of Goulet Coulombe (2020).

$$y_t = X_t \beta_t + \epsilon_t$$
$$\beta_t = \mathcal{F}(S_t)$$

- Macro RF is particularly well suited for modeling short time series (a statistical problem shared both by macroeconomists and climate scientists). There are packages in both `Python` and `R`.

- Both are easily implementable and provide good forecasts of aggregate sea ice, *all year long and at any horizon*

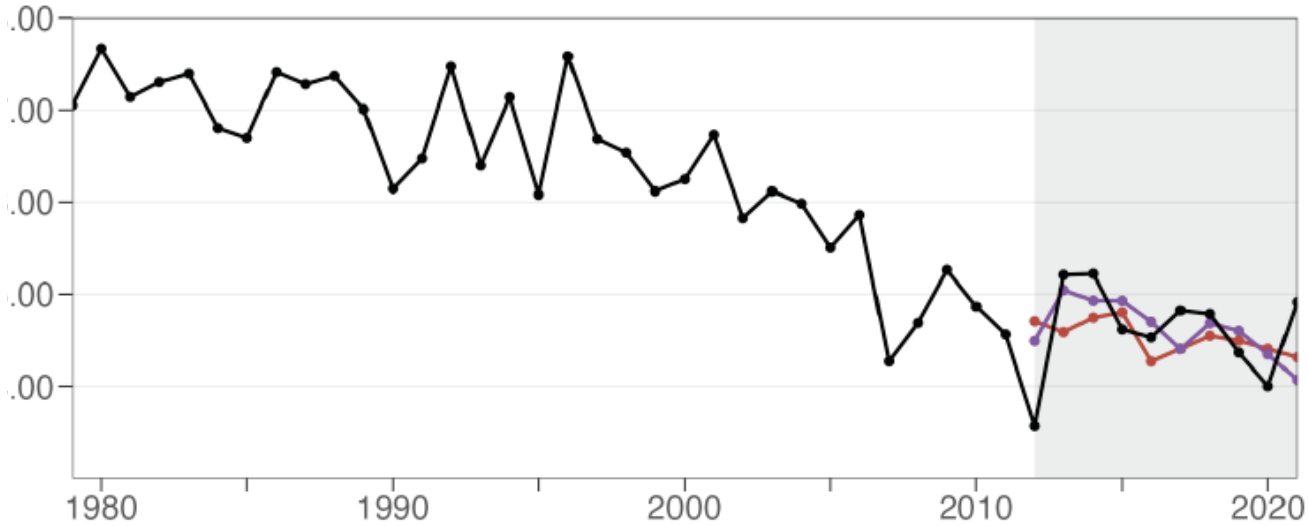
RMSE Glide Chart for September



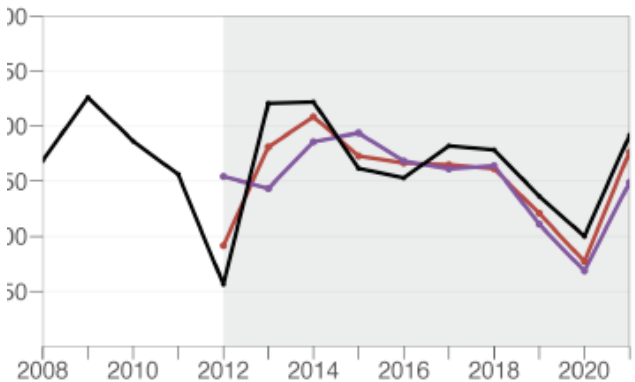
- Those models, re-estimated recursively to avoid look-ahead bias, outperform the SIO median for days for which the latter is available.
- Pocket FEML distinguishes itself from the pack when forecasting September's SIE in mid-July.

Looking at forecasts themselves

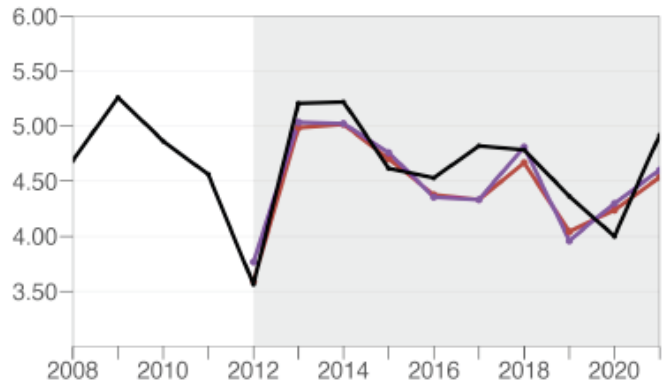
Figure 5: Annual Out-Of-Sample Forecasts on Different Days



(a) Forecast-Day: June 14th



(b) Forecast-Day: July 25th



(c) Forecast-Day: August 13th

Parting Words

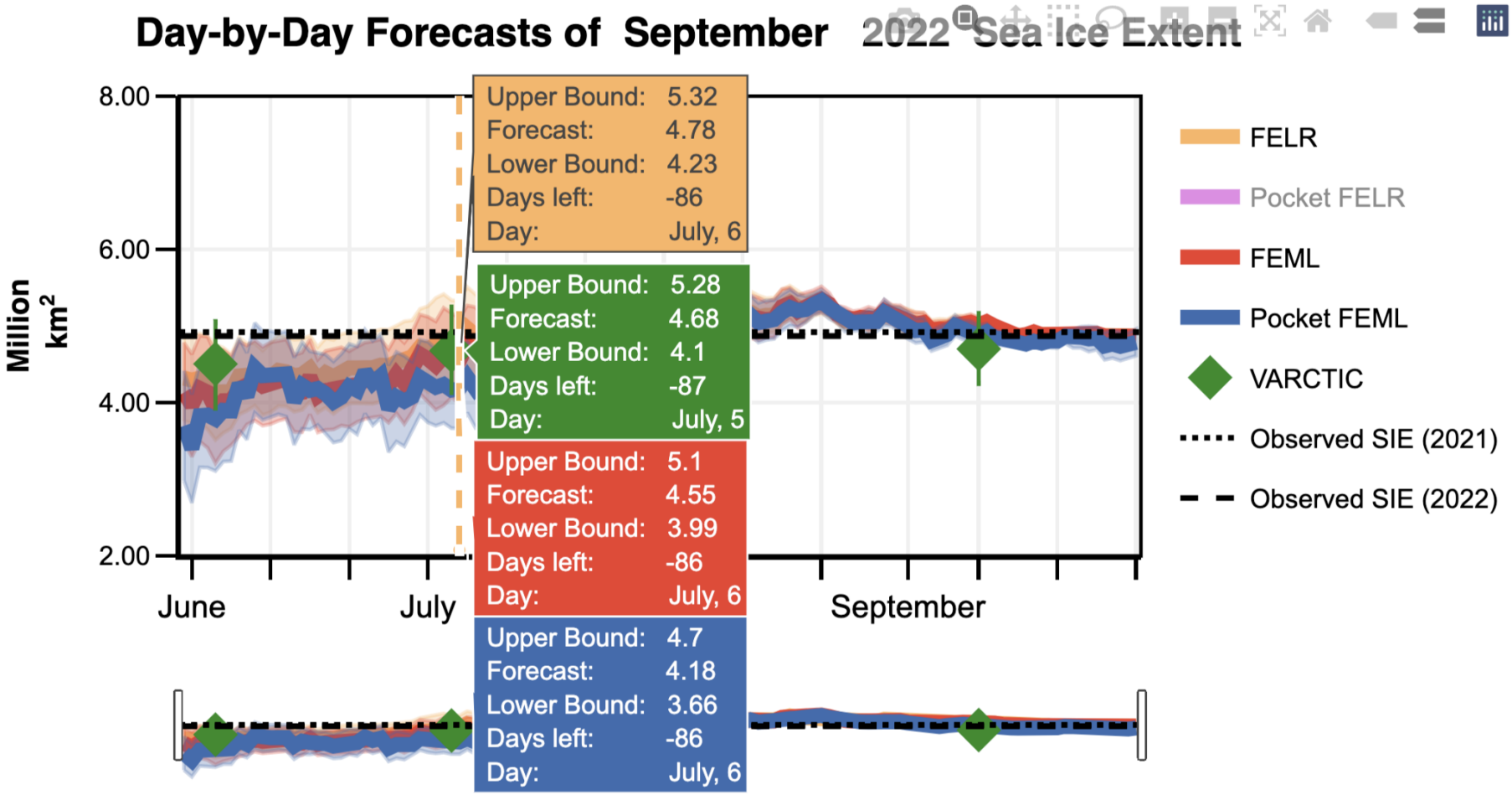


Figure 2 — Historique des prévisions et leurs intervalles de confiance pour septembre 2022. *L'axe des x correspond à la date à laquelle la prévision fut calculée. Le glisseur (slider) permet de zoomer sur certaines périodes historiques. L'utilisateur peut décider de l'inclusion ou l'exclusion de certains modèles en cliquant sur ceux-ci dans la légende.*

See `https://chairemacro.esg.uqam.ca/arctic-sea-ice-forecasting/?lang=en` to visualize forecasts and their history through an interactive interface.