Prospects for Improved Regional Predictions of Arctic Sea Ice

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With contributions from:

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SIPN2 Webinar

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION · U.S. DEPARTMENT OF COMMERCE · NOAA

Geophysical Fluid Dynamics Laboratory · GFDL · NOAA

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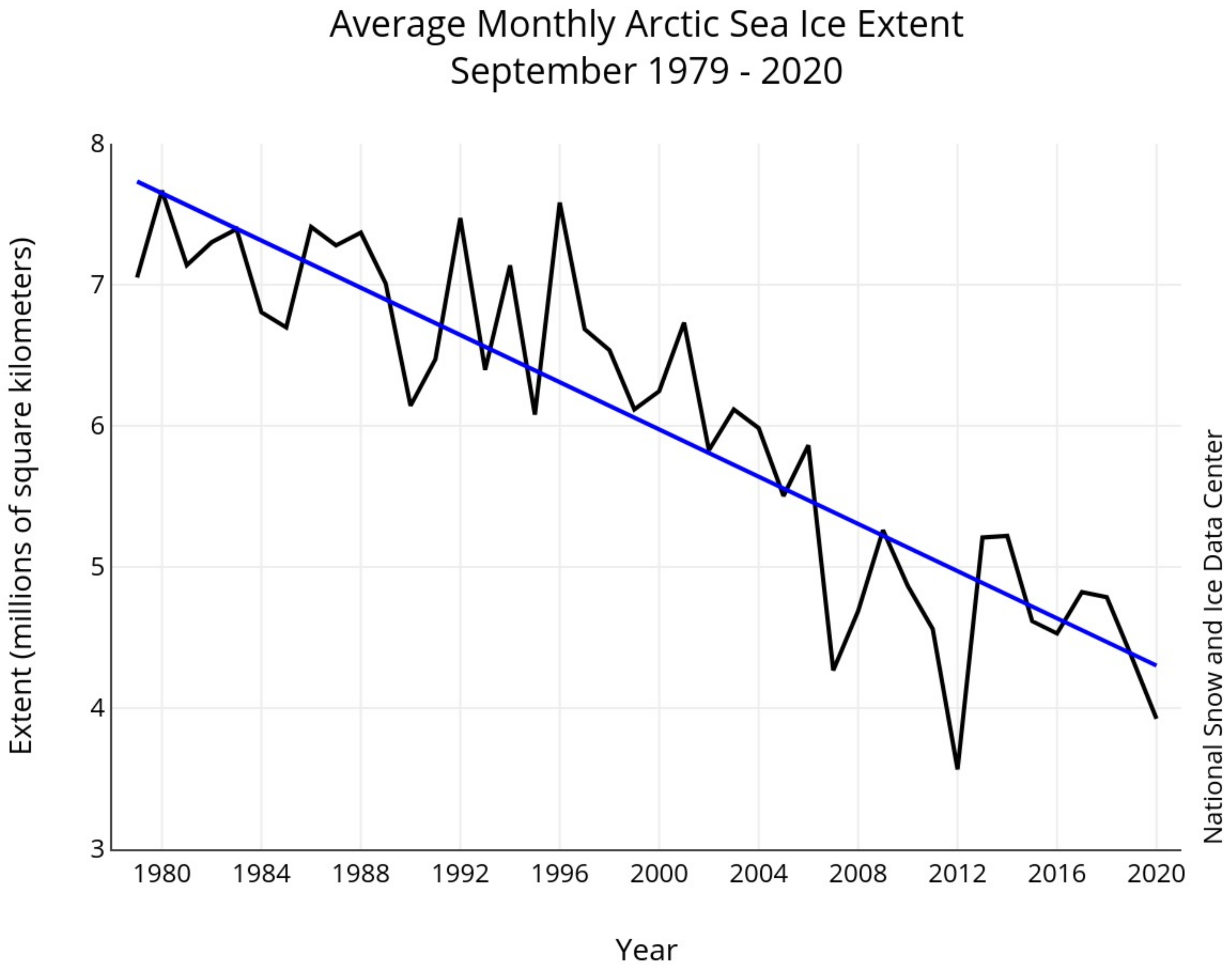
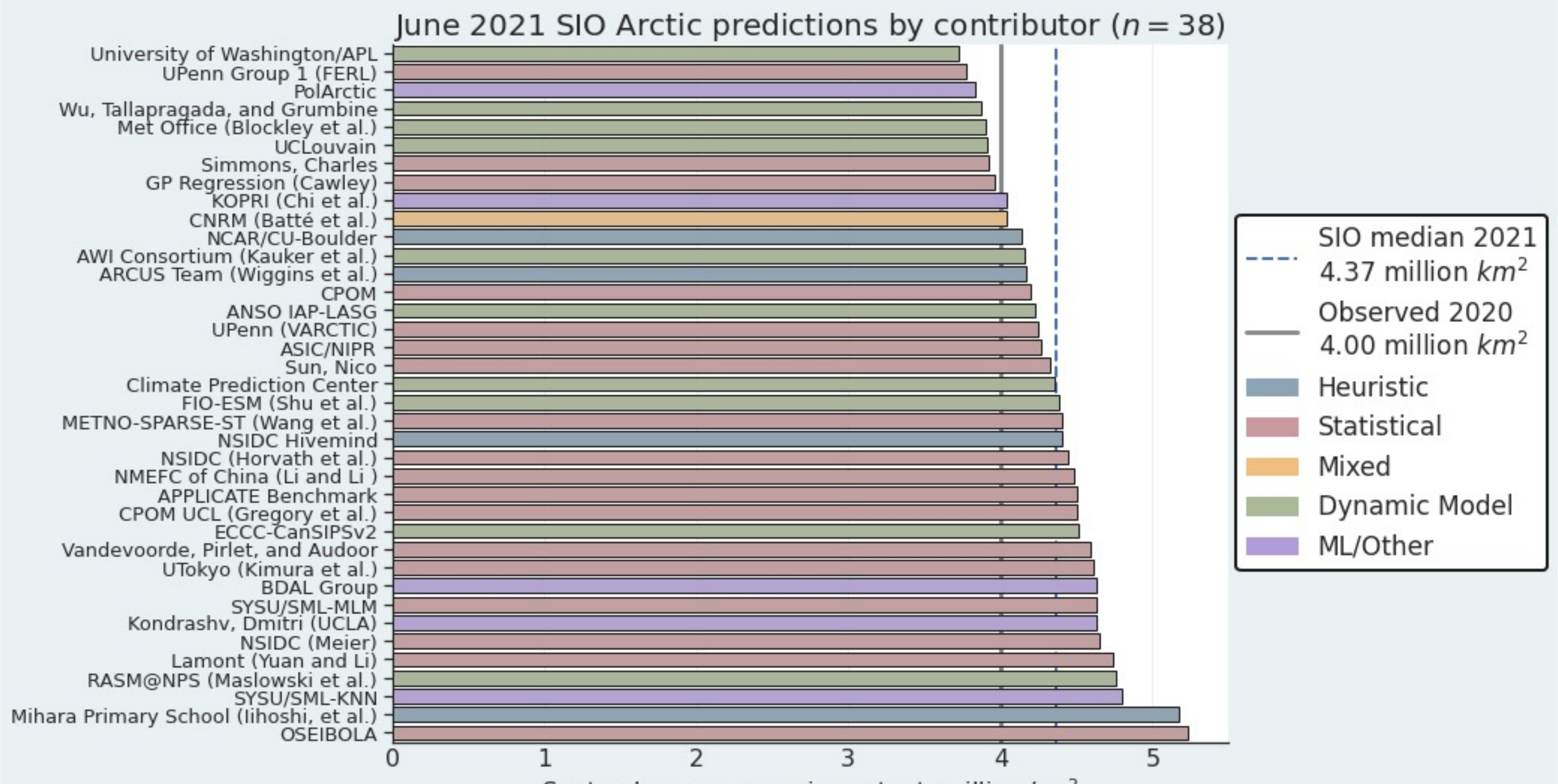
PRINCETON UNIVERSITY

Observed Decline of September Arctic Sea Ice Extent (SIE)



Sea Ice Outlook: Predictions of September 2021 SIE



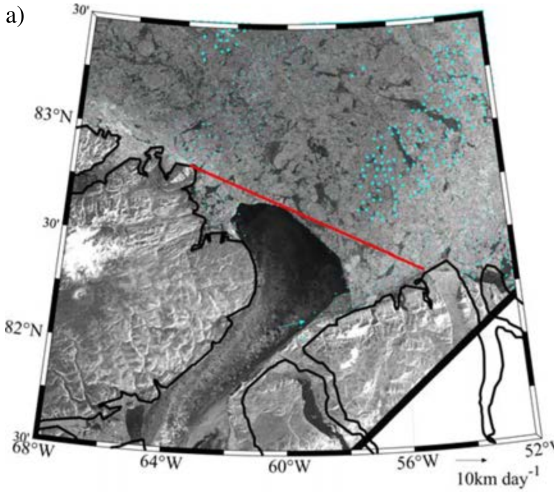
Wang et al. (2021), *Sea Ice Outlook June Report*

Moving Beyond Pan-Arctic SIE Predictions

Regional Predictions

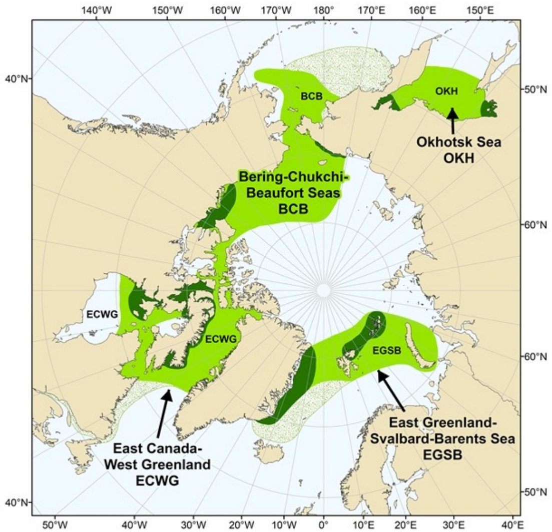
From Zack Labe

Lincoln Sea Ice Arches



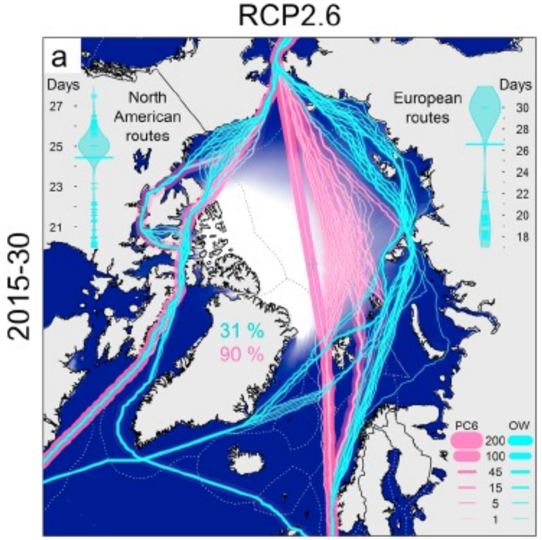
Moore et al. (2021), *Nat. Comms.*

Ecosystem Prediction



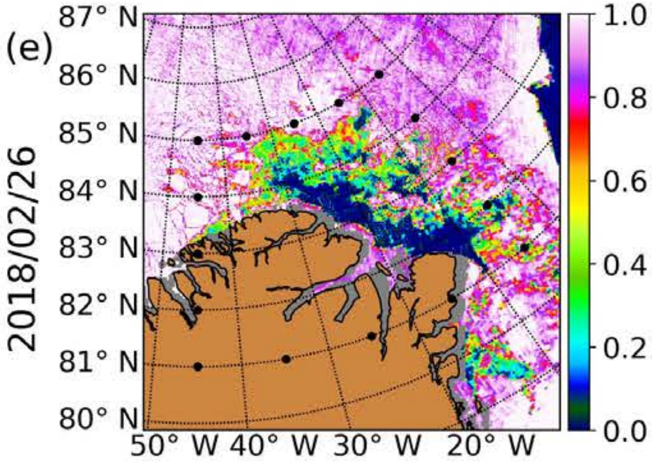
George et al. (2020), *Arctic Report Card*

Shipping Routes



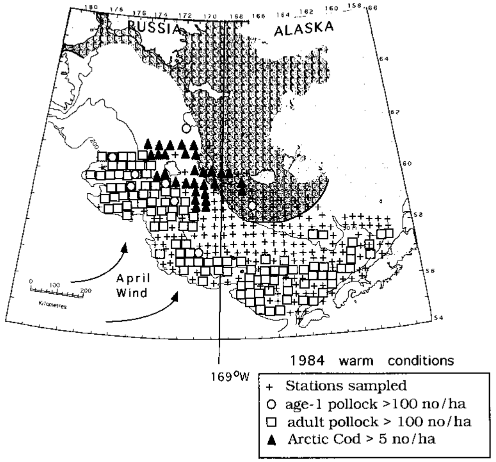
Melia et al. (2016), *GRL*

North Greenland Polynya



Ludwig et al. (2019), *Cryosphere*

Fisheries Management



Wyllie-Echeverria and Wooster (1998), *Fish. Oceanog.*

Outline for Today's Talk:

- Introduce the FLOR and SPEAR_MED dynamical prediction systems
- Evaluate regional SIE prediction skill of these systems
- Understand mechanisms of regional SIE predictability
- Improve forecasts with sea ice data assimilation
- Skillful predictions of Arctic shipping routes

GFDL Prediction Systems: Dynamical Models

	FLOR[1]	**SPEAR_MED**[2]
Atmosphere	AM2.5; 0.5°, 32 vertical levels	AM4; 0.5°, 33 vertical levels
Land	LM3; 0.5°	LM4; 0.5°
Ocean	MOM5; 1.0°, 50 vertical levels	MOM6; 1.0°, 75 vertical levels
Sea Ice	SIS1; 1.0°, 5 category ITD	SIS2; 1.0°, 5 category ITD

FLOR: **F**orecast-oriented **L**ow **O**cean **R**esolution
SPEAR: **S**eamless system for **P**rediction and **EA**rth system **R**esearch

1: Vecchi et al. 2014, *J. Climate;* 2: Delworth et al. 2020, *JAMES*

GFDL Prediction Systems: Initialization Methods

	FLOR[1]	SPEAR_MED[2]
Ocean Data	Satellite SST, Argo, XBT, Moored Buoys, CTD, Seal Data, other WOD profiles; daily	Satellite SST, Argo, XBT, Moored Buoys; daily
Atmospheric Data	3-D Temp from NCEP2 Reanalysis; 6 hourly	3-D Temp, Winds, Humidity from CFSR; 6 hourly
Sea Ice Data	None	SIC used to adjust under-ice SST; daily
Data assimilation method(s)	Ensemble Kalman Filter (EnKF)[1]	Ensemble Kalman Filter (ocean ICs); Nudged atmosphere/SST run (sea ice, atm, land ICs)[2]

Note: No direct sea ice DA in these systems; will present SPEAR w/ sea ice DA ahead

1: Zhang et al. 2007 *Mon. Wea. Rev.*; 2: Lu et al. 2020 *JAMES*

GFDL Prediction Systems: Retrospective Seasonal Predictions

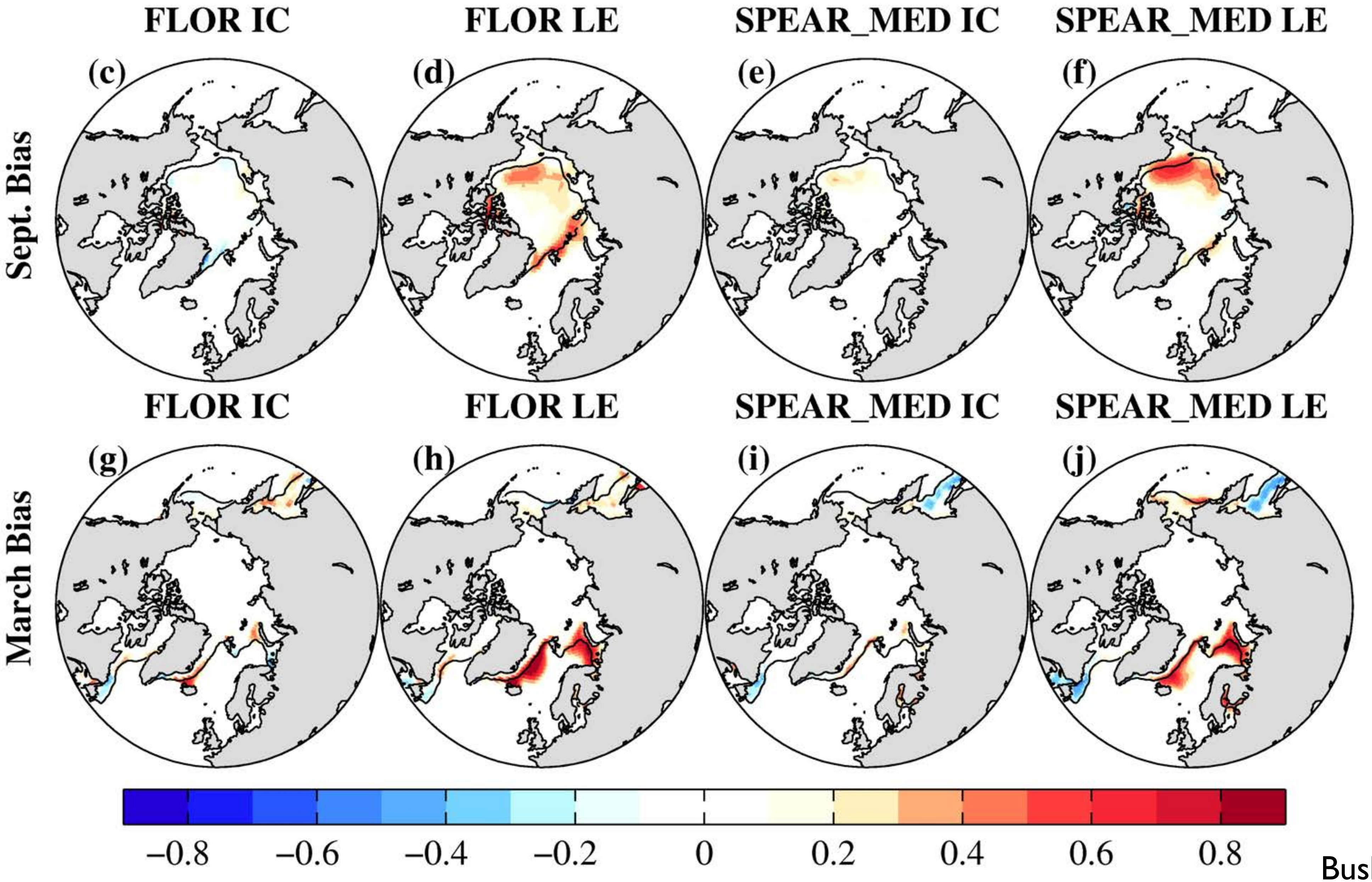
	FLOR[1]	**SPEAR_MED[2]**
Initialization Dates	First of the each month	First of the each month
Prediction Length	One year	One year
Ensemble Size	12	15
Time Period	1992-2020	1992-2020

FLOR: **F**orecast-oriented **L**ow **O**cean **R**esolution
SPEAR: **S**eamless system for **P**rediction and **EA**rth system **R**esearch

1: Vecchi et al. 2014, *J. Climate;* 2: Delworth et al. 2020, *JAMES*

A first question:
How good are the sea ice initial conditions?

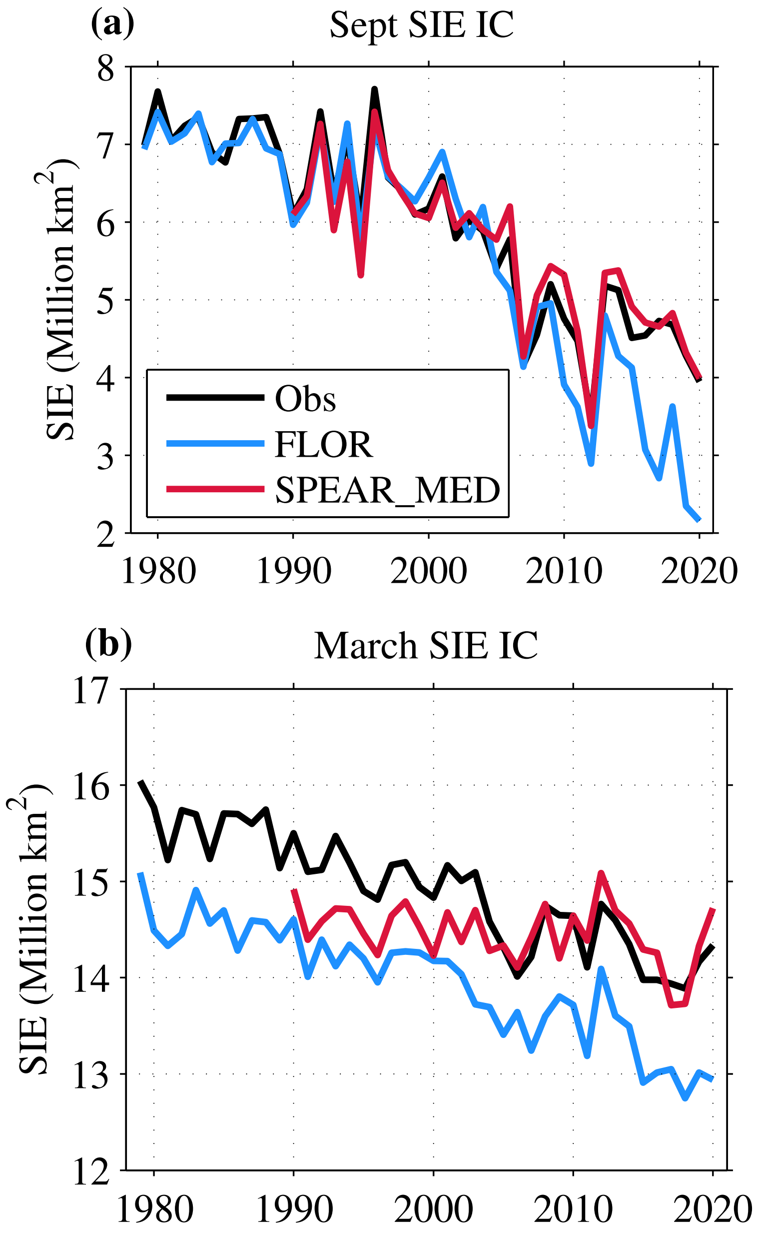
Sea Ice Concentration Climatological Biases (Model minus Obs)

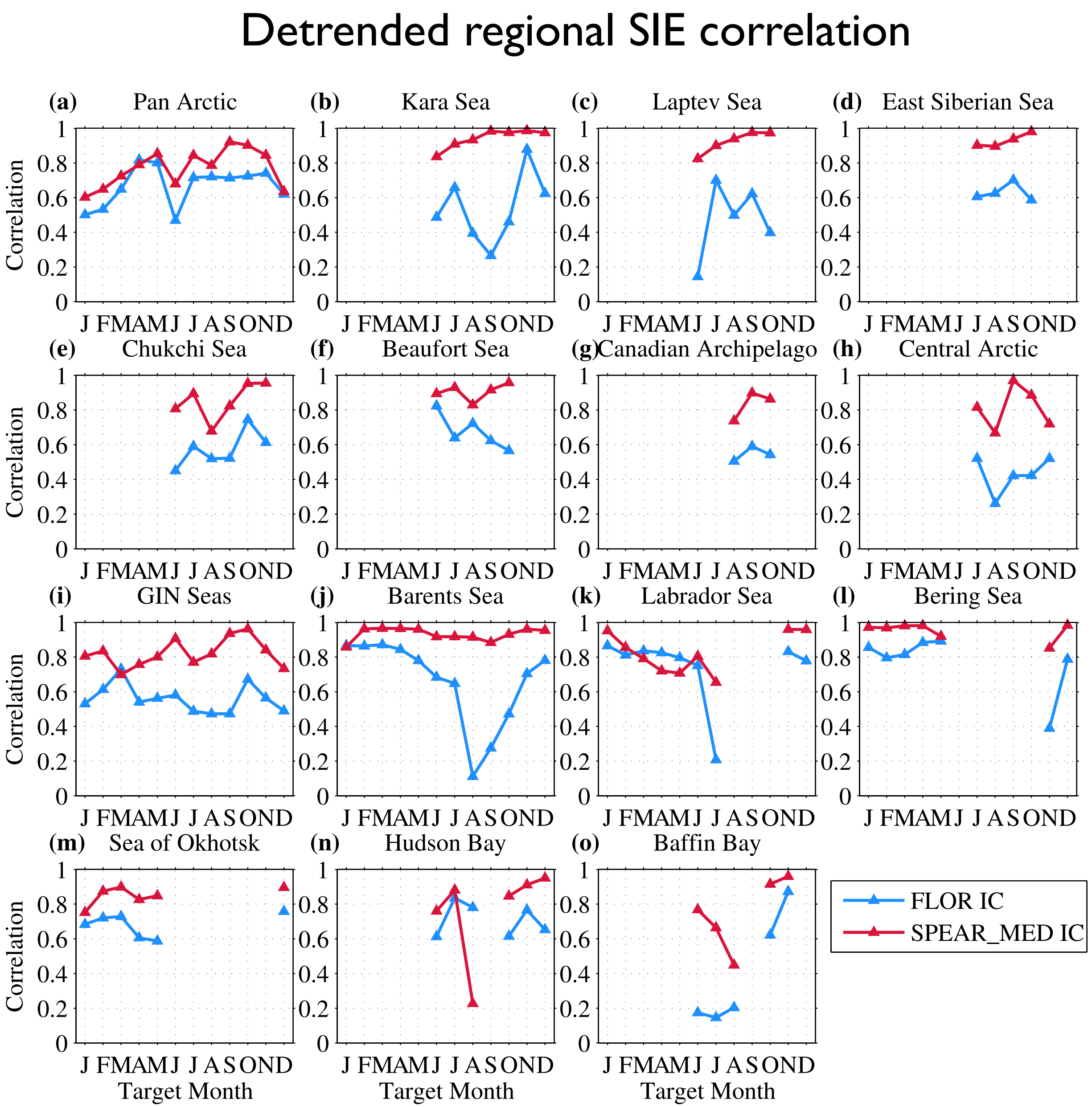


- FLOR and SPEAR initial conditions (ICs) improve upon the model SIC biases from historical simulations (LE)

Bushuk et al. 2021, *In prep.*

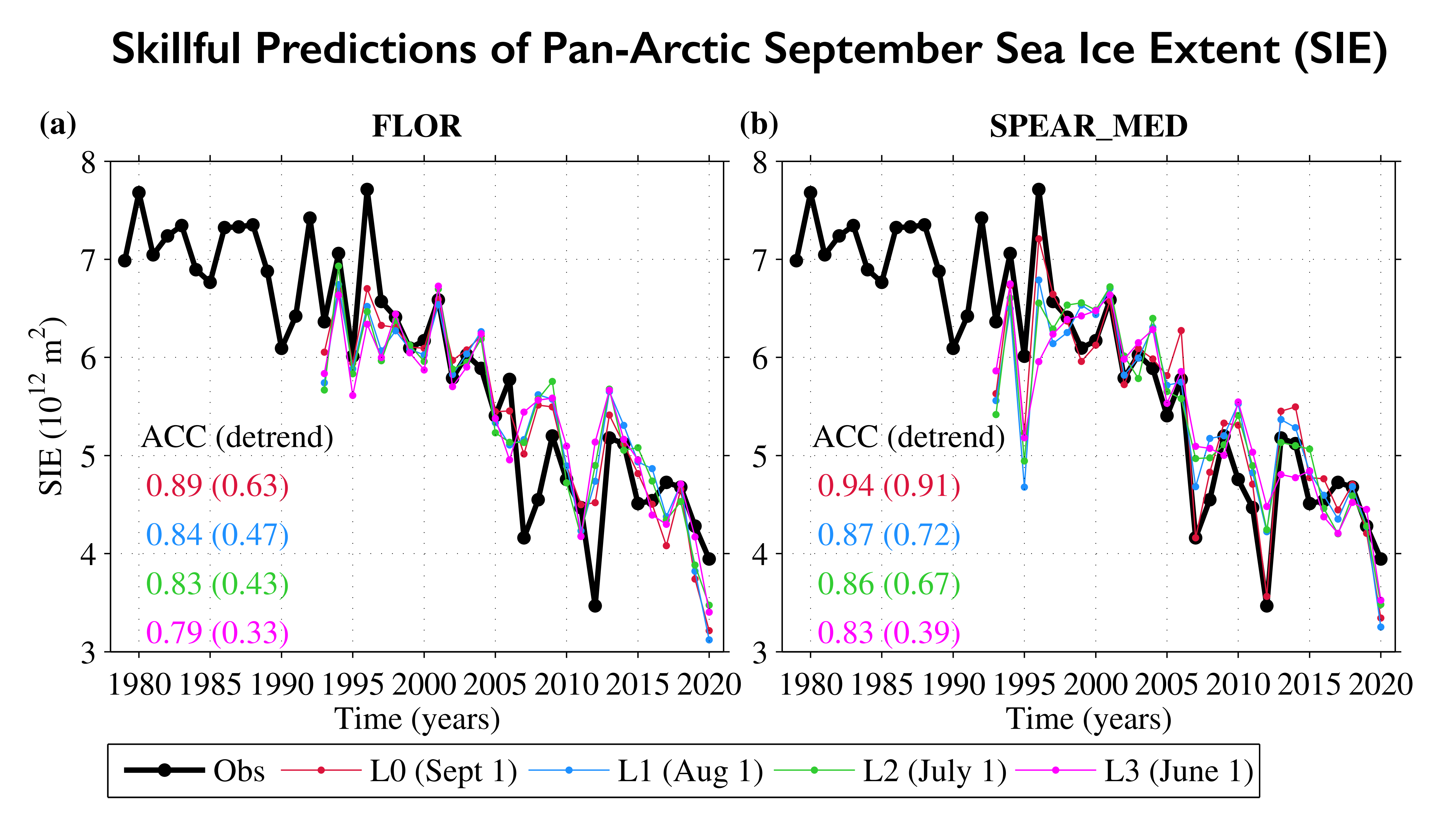
Sea Ice Extent (SIE) Initial Conditions Interannual Variability





- SPEAR_MED has improved SIE initial conditions over FLOR in nearly all Arctic regions
- Improvement is due to treatment of SST under sea ice, which provides a strong constraint on SIE

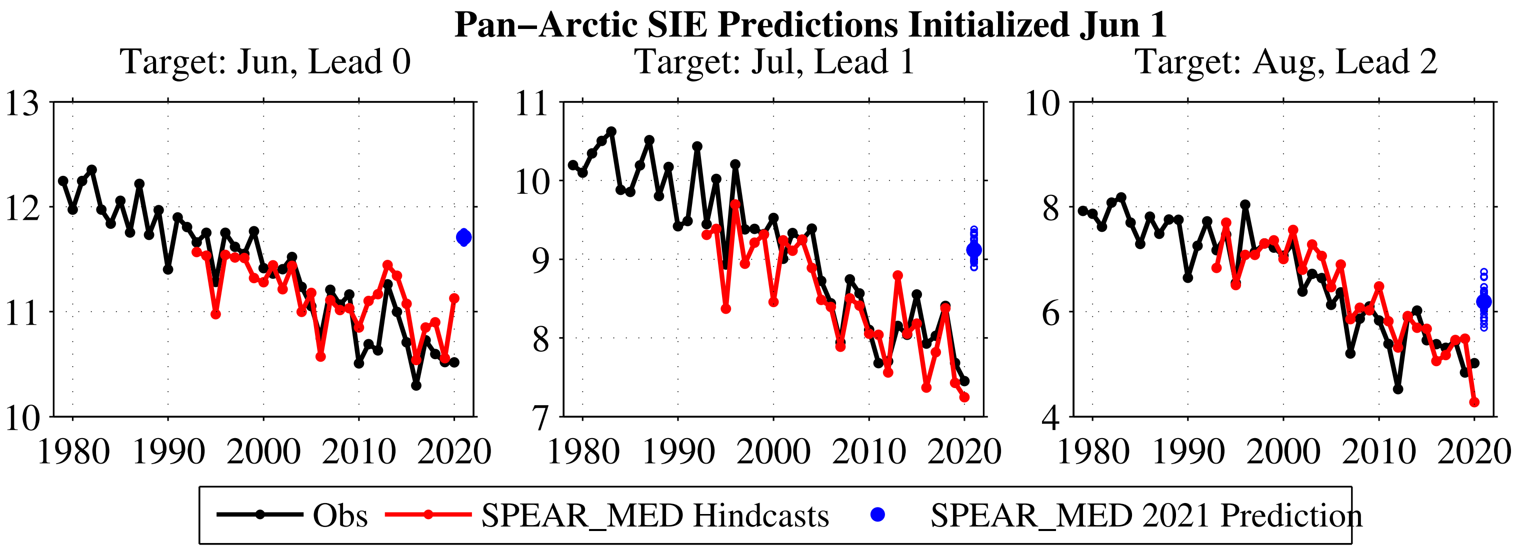
Do FLOR and SPEAR have SIE prediction skill?



Skillful Predictions of Pan-Arctic September Sea Ice Extent (SIE)
(a)
FLOR
(b)
SPEAR_MED
SIE (10^{12} m^2)
ACC (detrend)
0.89 (0.63)
0.84 (0.47)
0.83 (0.43)
0.79 (0.33)
ACC (detrend)
0.94 (0.91)
0.87 (0.72)
0.86 (0.67)
0.83 (0.39)
Time (years)
Time (years)
Obs
L0 (Sept 1)
L1 (Aug 1)
L2 (July 1)
L3 (June 1)

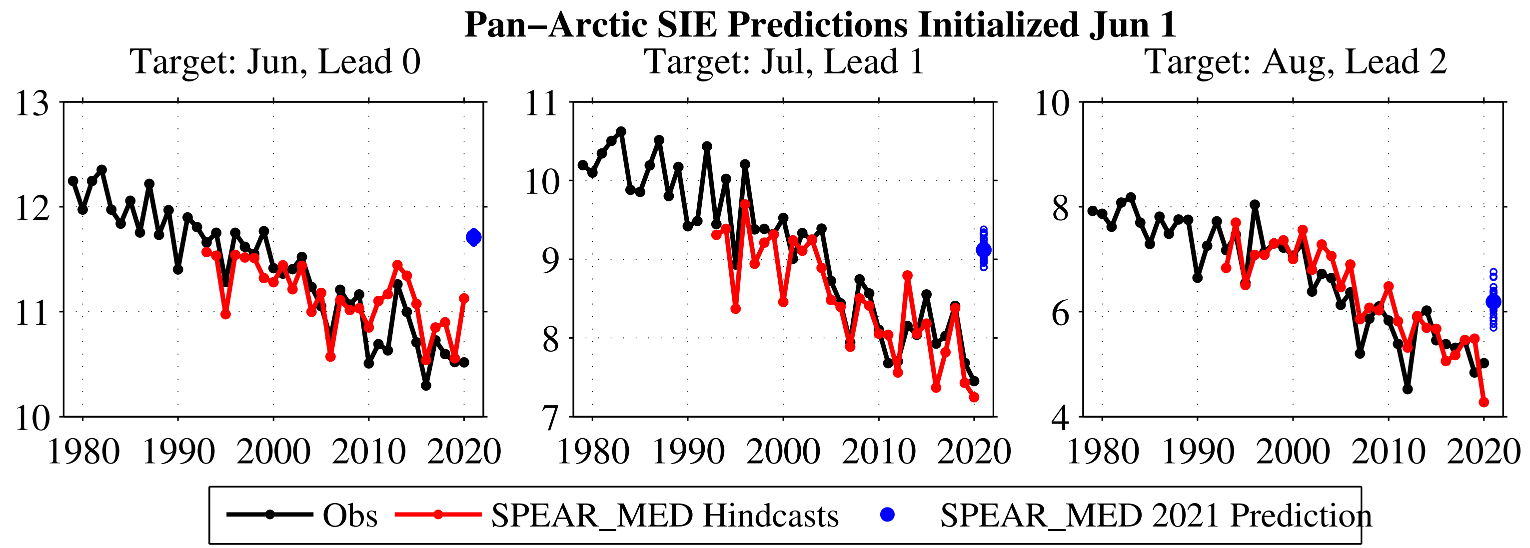
A Cautionary Note: Systematic errors for real-time forecasts

Prediction made June 1, 2021

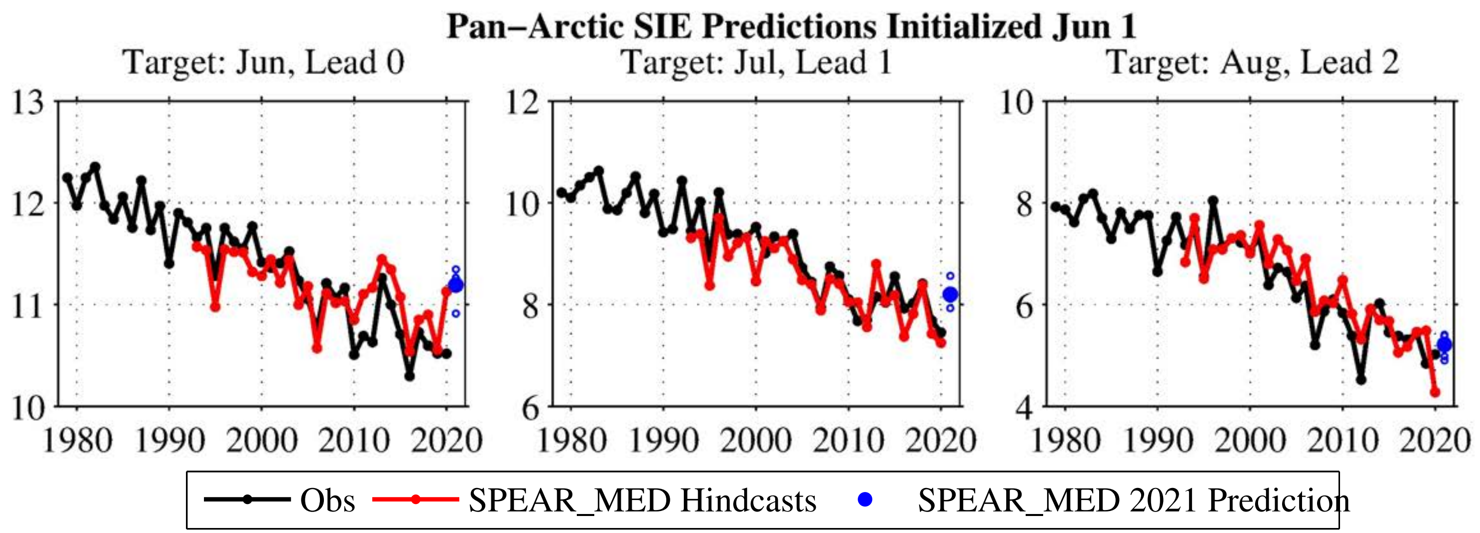


A Cautionary Note: Systematic errors for real-time forecasts

Prediction made June 1, 2021

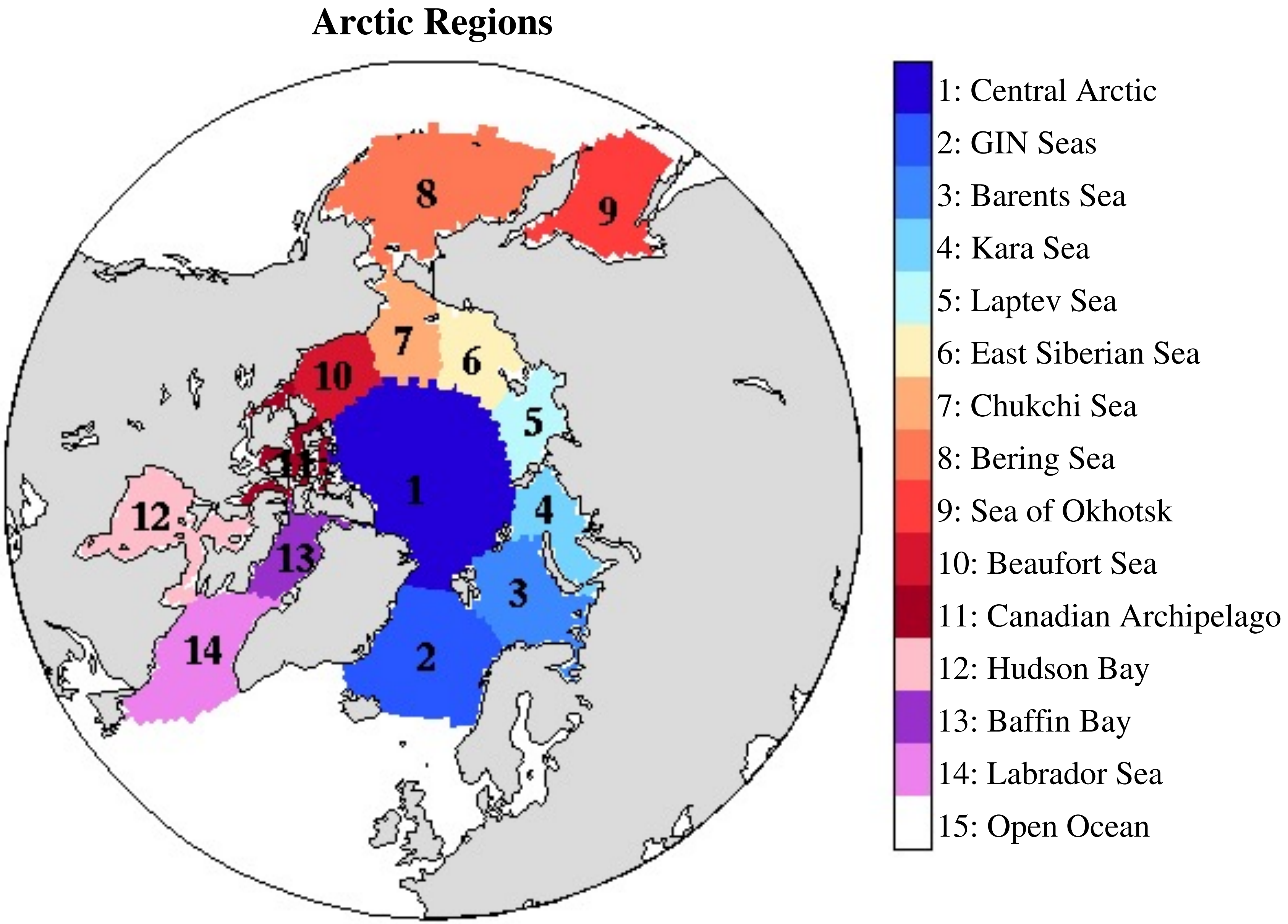


Rerun June 1, 2021 prediction using "final" OISST data

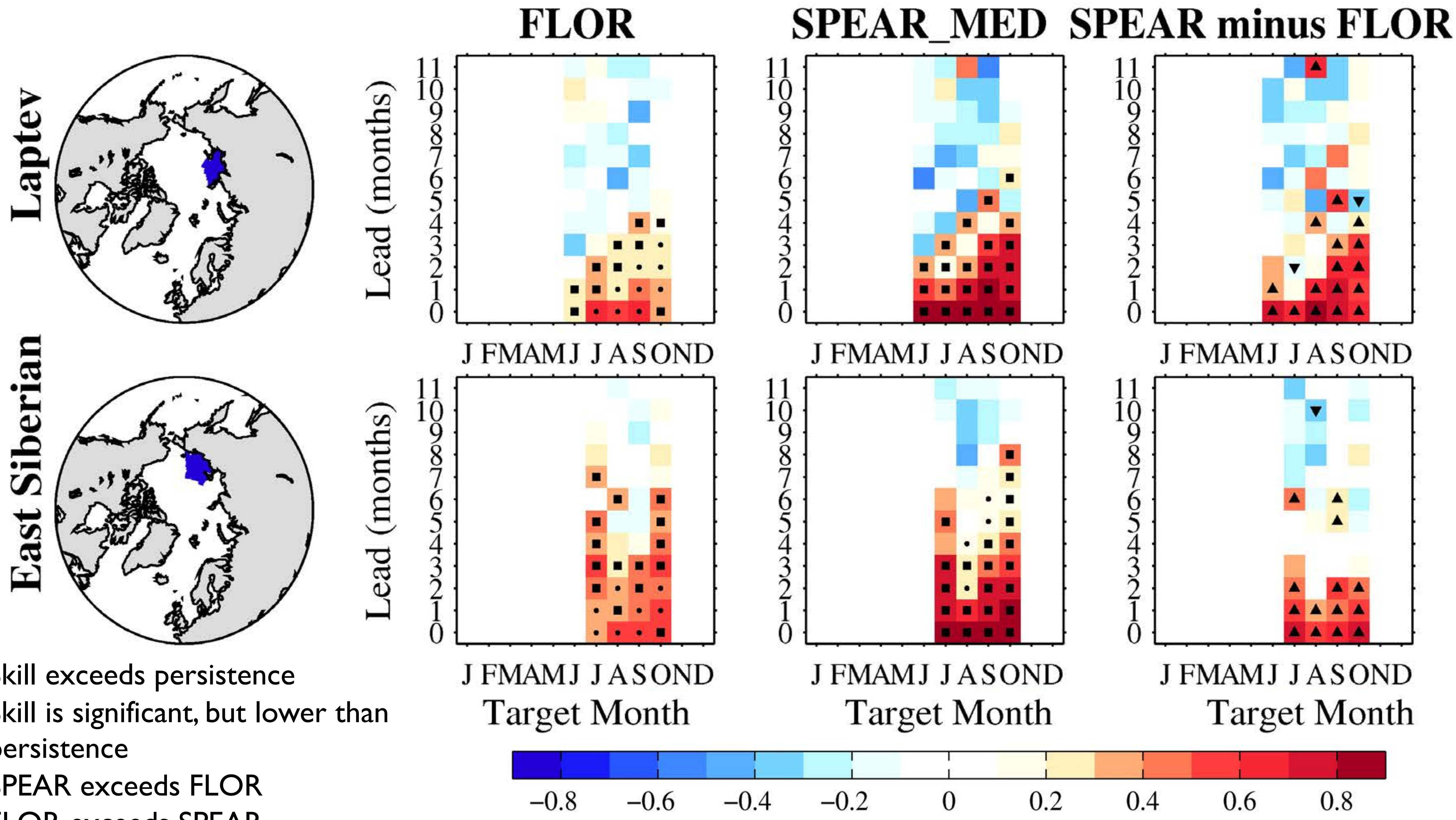


- Real time forecasting necessitates the use of "preliminary" OISST data for the most recent two weeks
- Real-time SPEAR SIE forecasts at short leads currently have systematic high biases associated with these data.

Regional SIE Prediction Skill

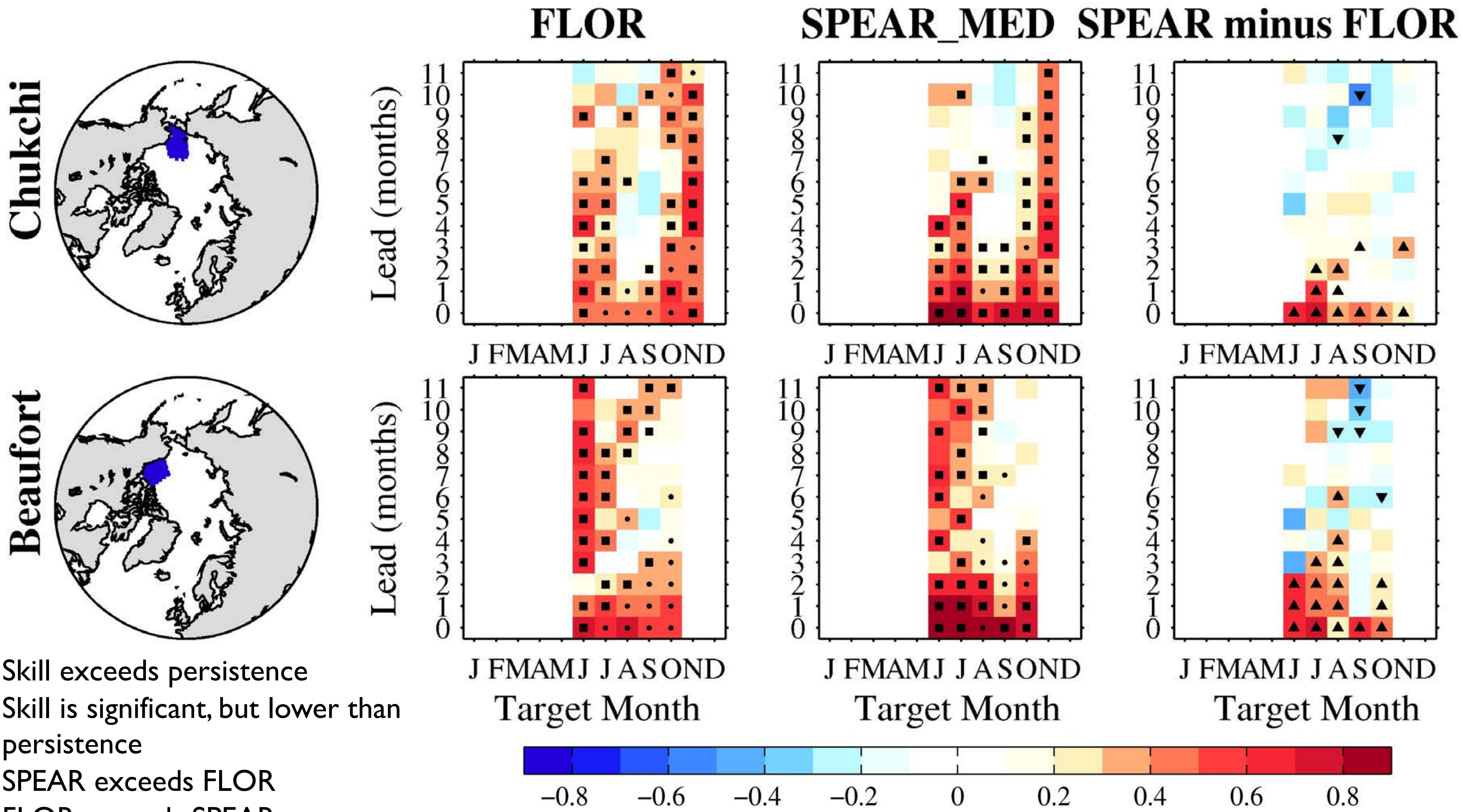


Summer Regional Prediction Skill (Detrended ACC): Laptev and East Siberian



■ Skill exceeds persistence
● Skill is significant, but lower than persistence
▲ SPEAR exceeds FLOR
▼ FLOR exceeds SPEAR

Summer Regional Prediction Skill (Detrended ACC): Beaufort and Chukchi



■ Skill exceeds persistence

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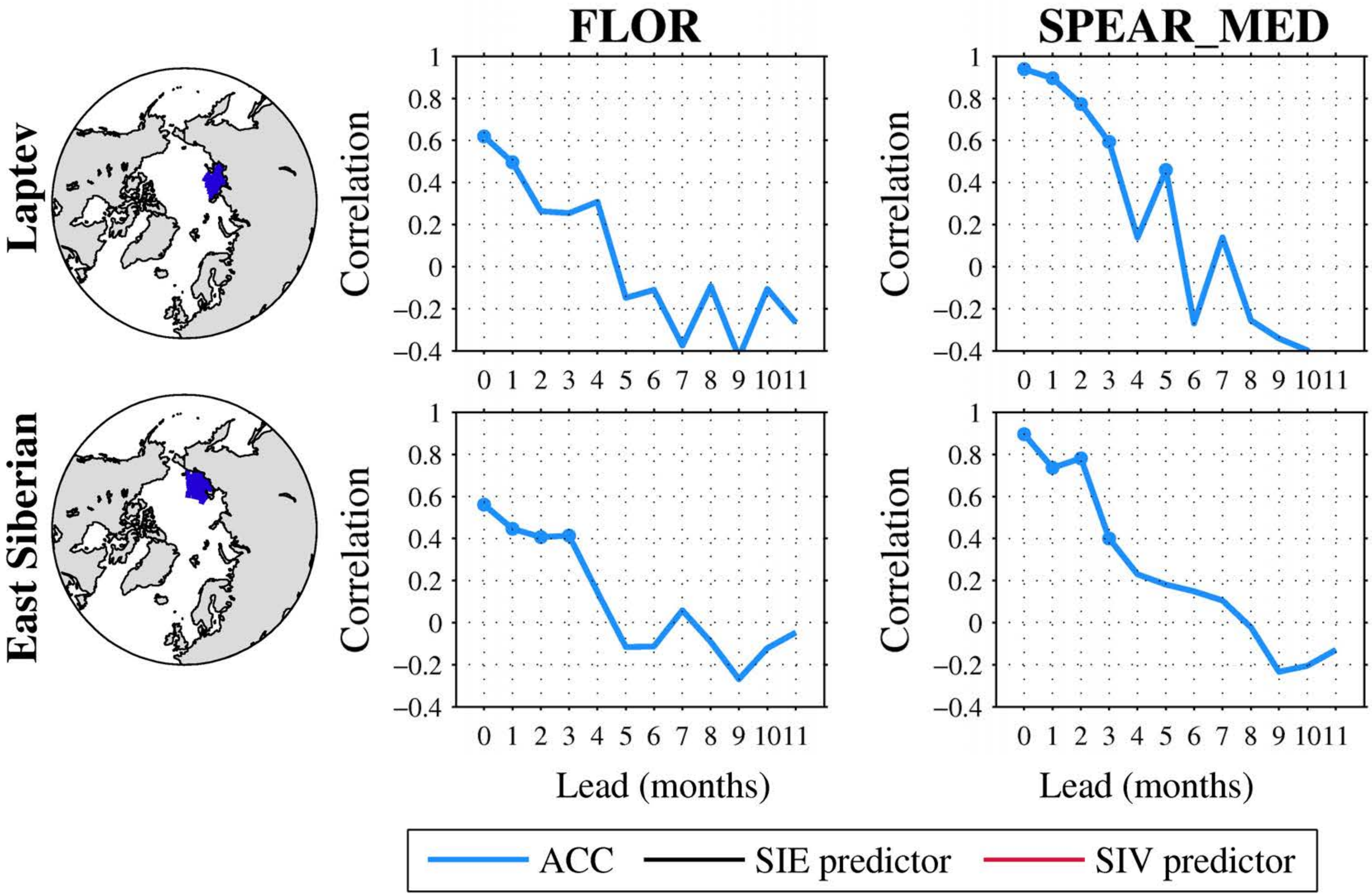
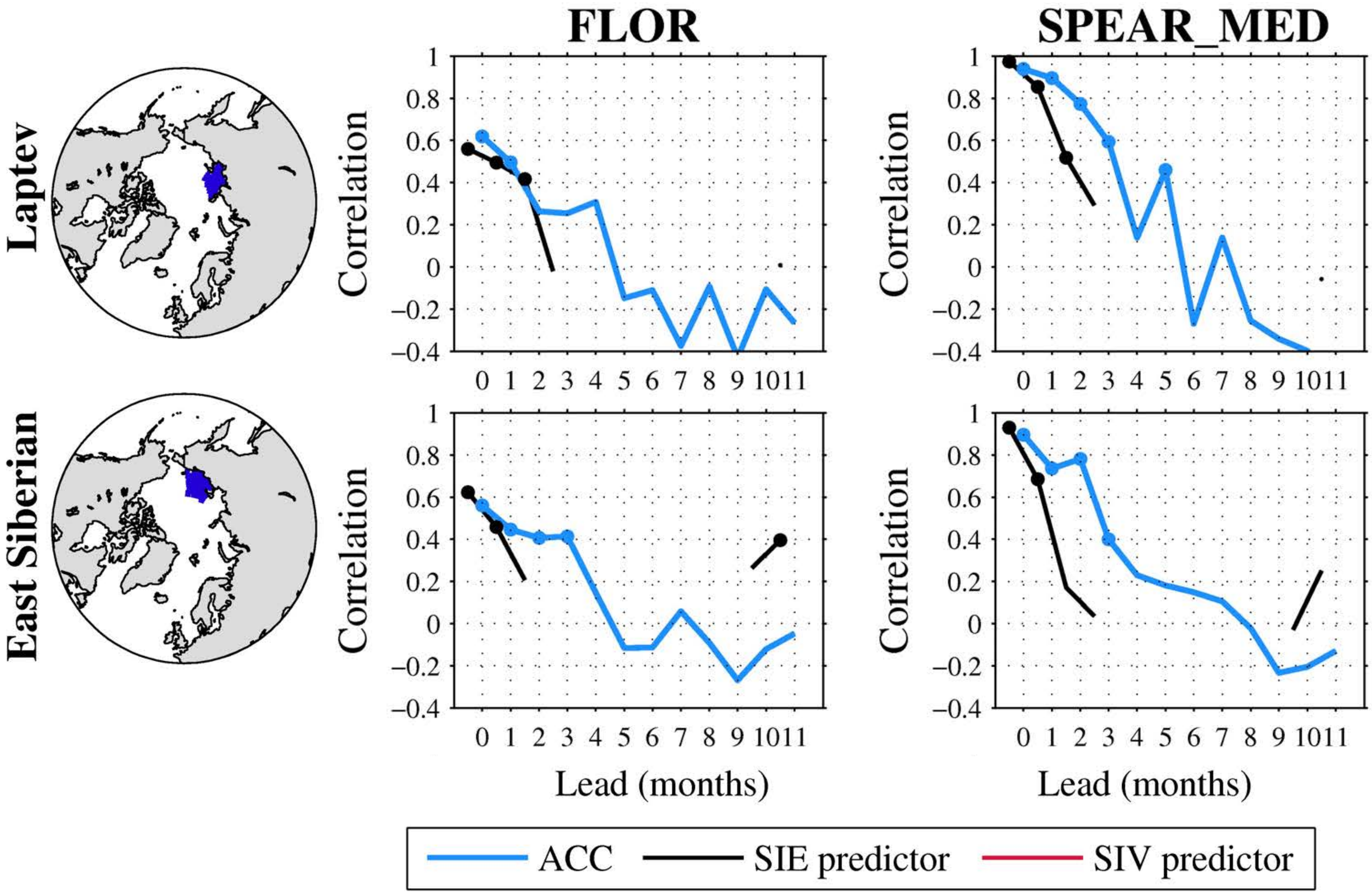
What are the key sources of predictability for summer SIE in these systems?

Sources of Summer (September) SIE Prediction Skill



- SIE/SIV predictors based on initial conditions used for forecasts

Sources of Summer (September) SIE Prediction Skill



- SIE/SIV predictors based on initial conditions used for forecasts
- Regional SIE persistence is the key source of summer prediction skill at short lead times (0-1 months)

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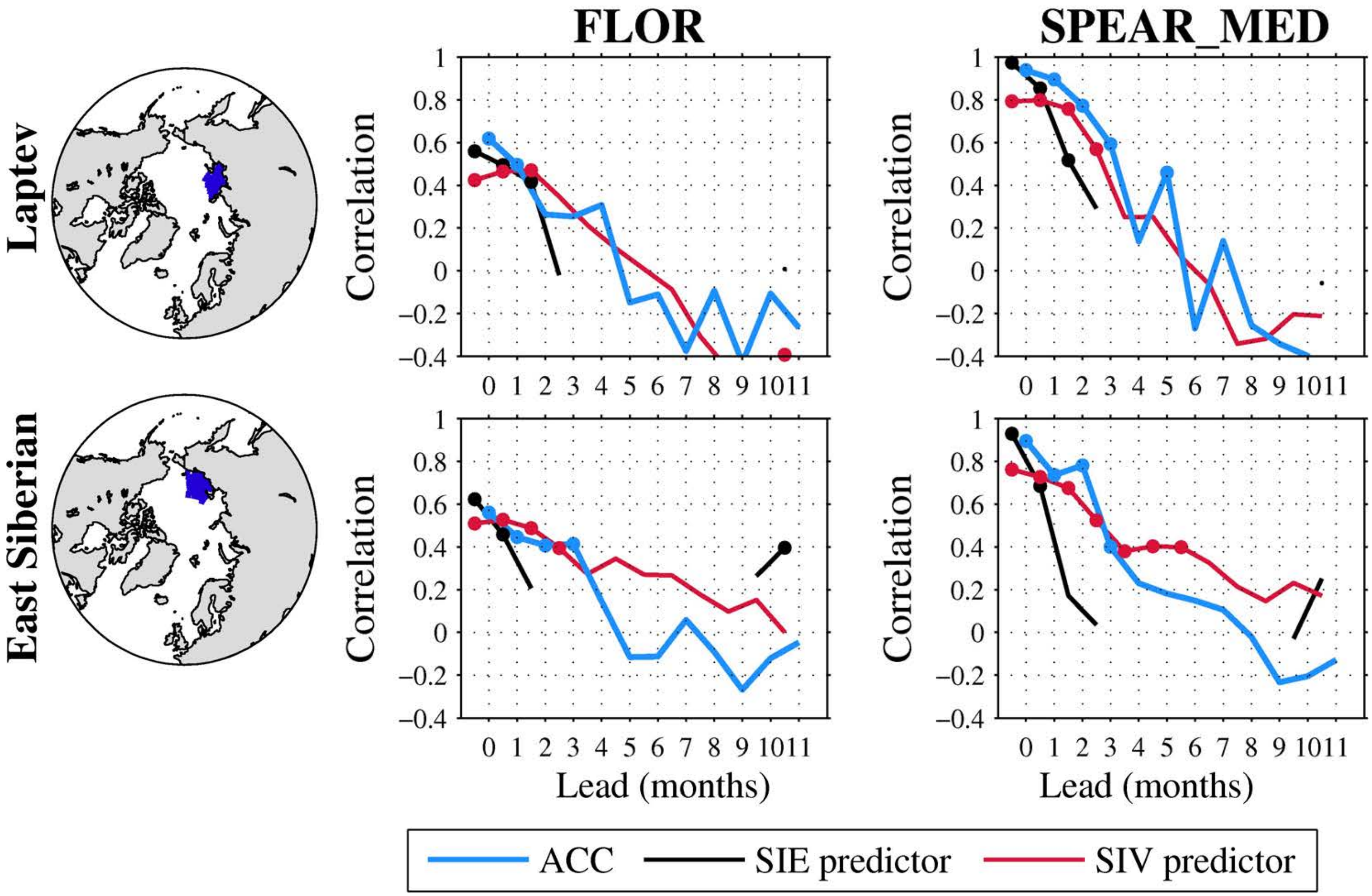

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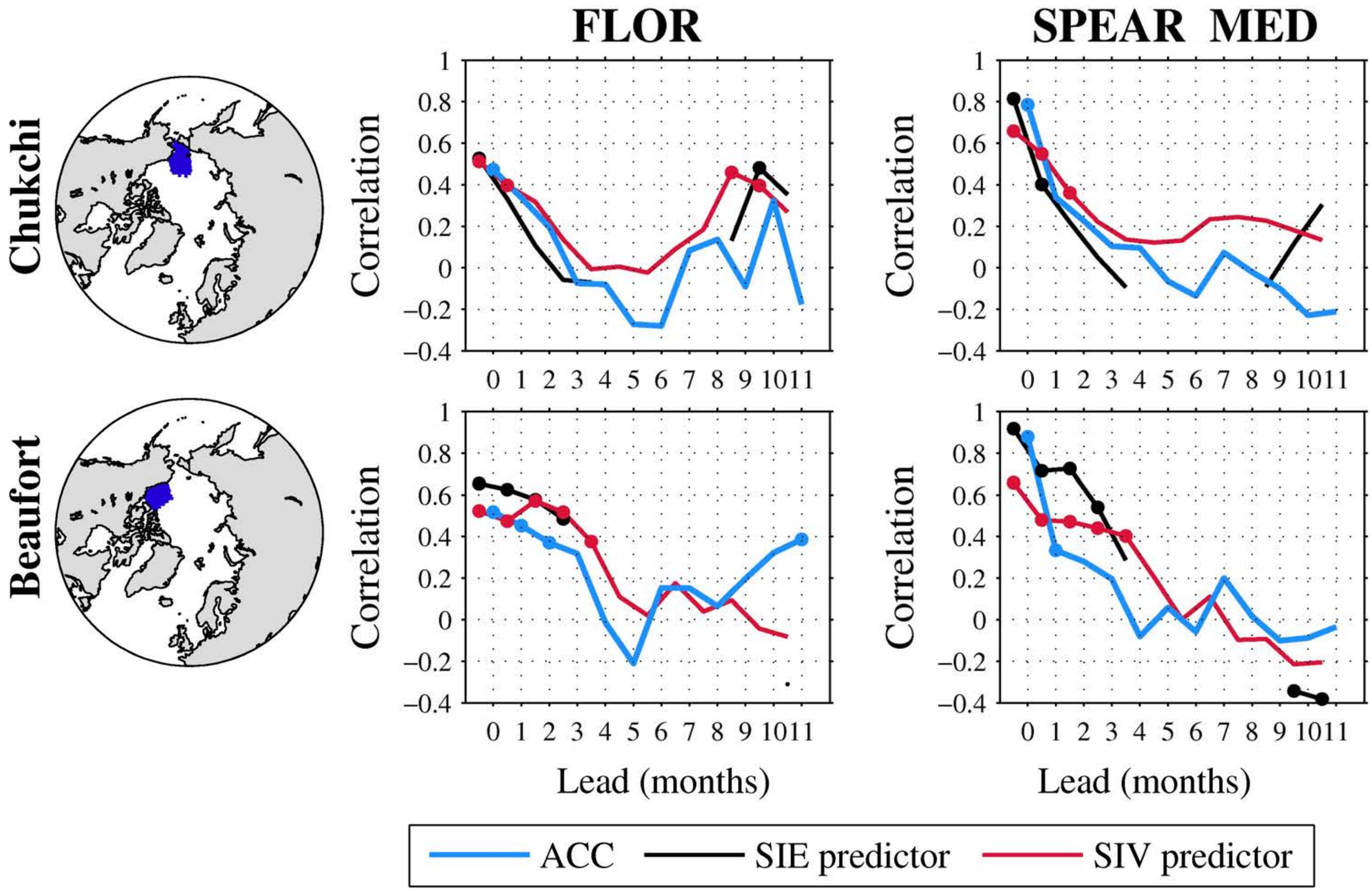
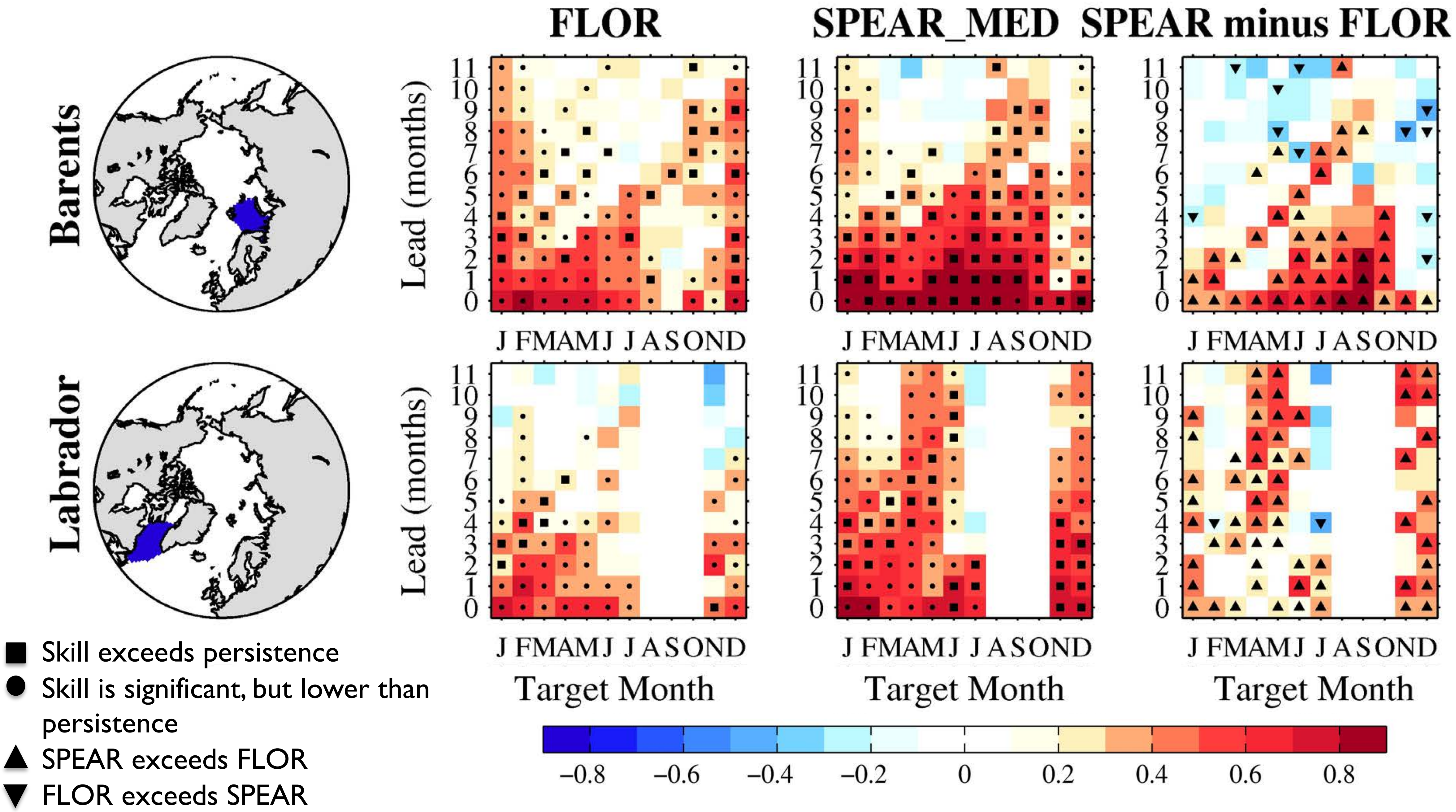
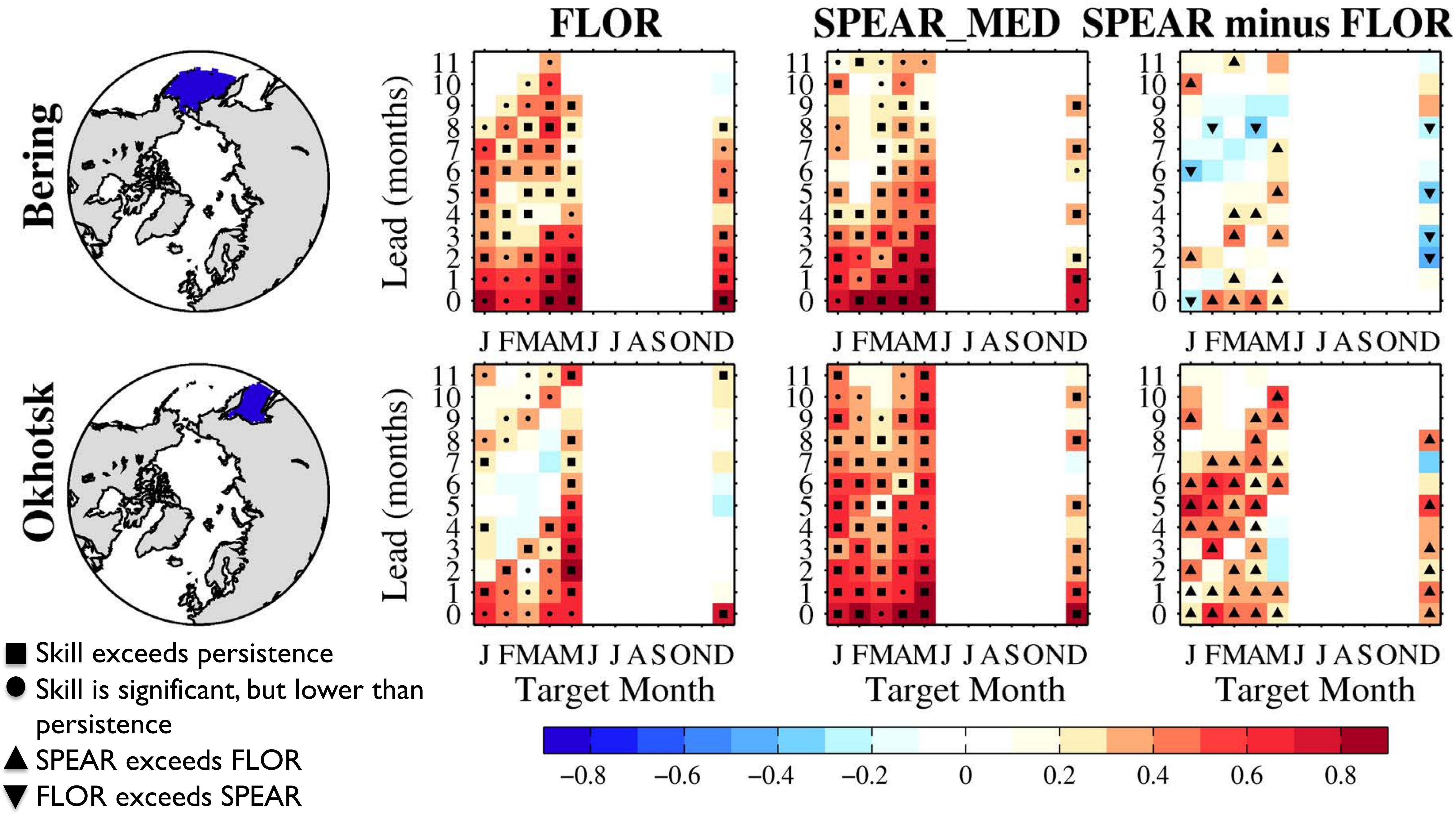


- Regional SIE/SIV predictors based on initial conditions used for forecasts
- Regional SIE persistence is the key source of summer prediction skill at short lead times (0-1 months)
- Regional SIV persistence is the key source of summer prediction skill at longer lead times (2-4 months)
- Combination of SIE and SIV predictors provide a challenging skill benchmark for models to beat

Winter Regional Prediction Skill (Detrended ACC): Barents and Labrador Seas

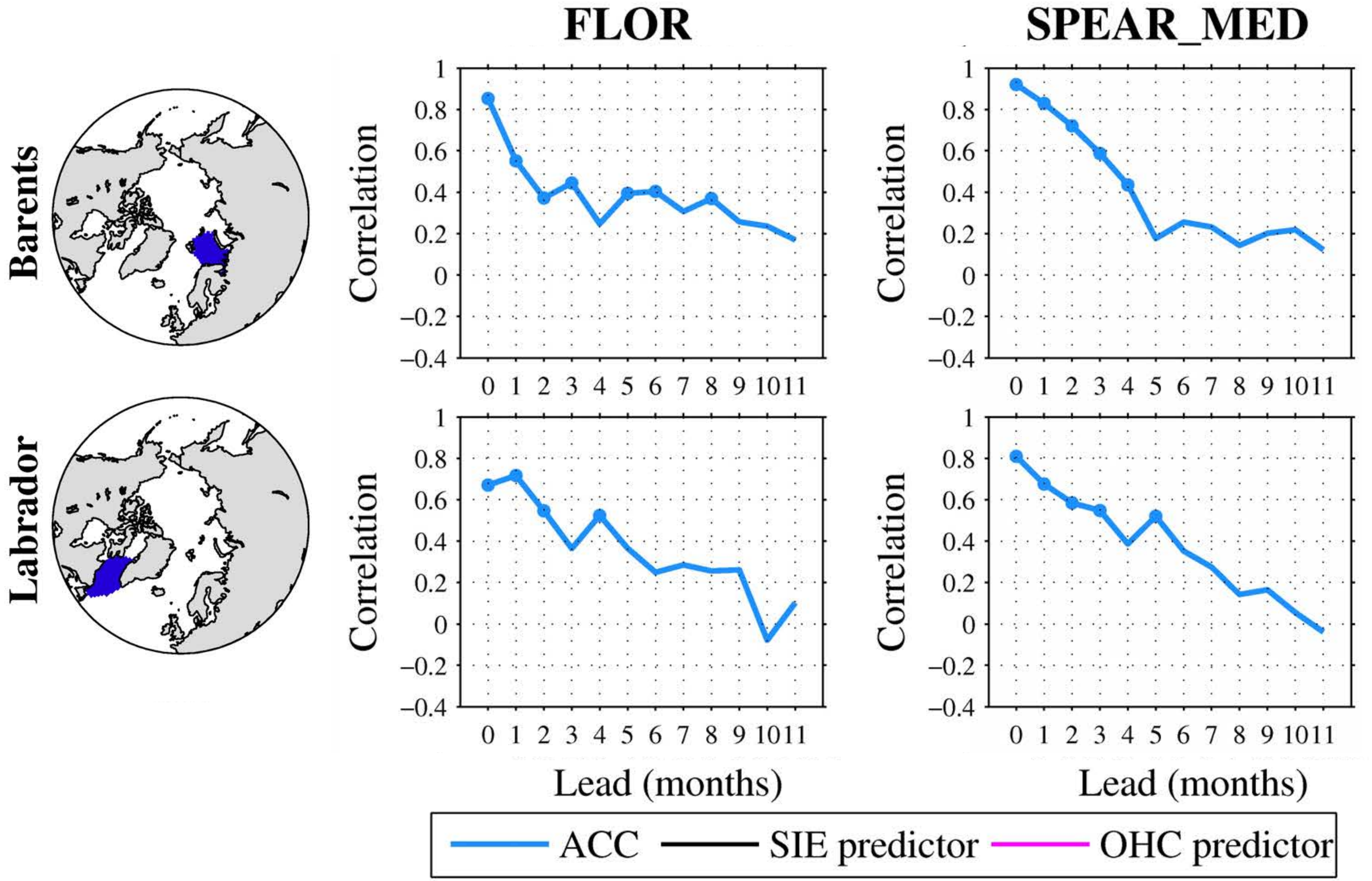


Winter Regional Prediction Skill (Detrended ACC): Bering and Okhotsk



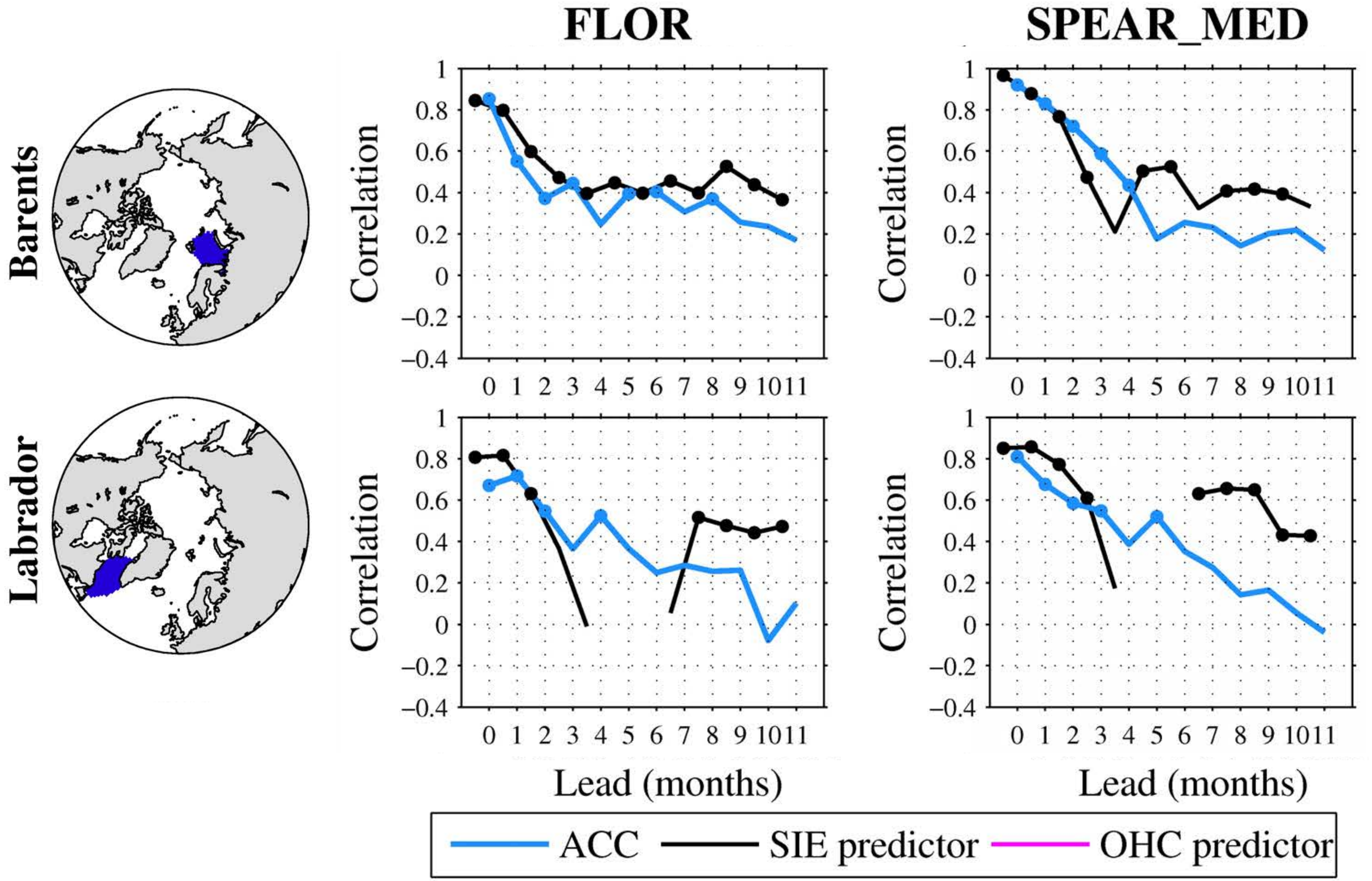
What are the key sources of predictability for winter SIE in these systems?

Sources of Winter SIE Prediction Skill



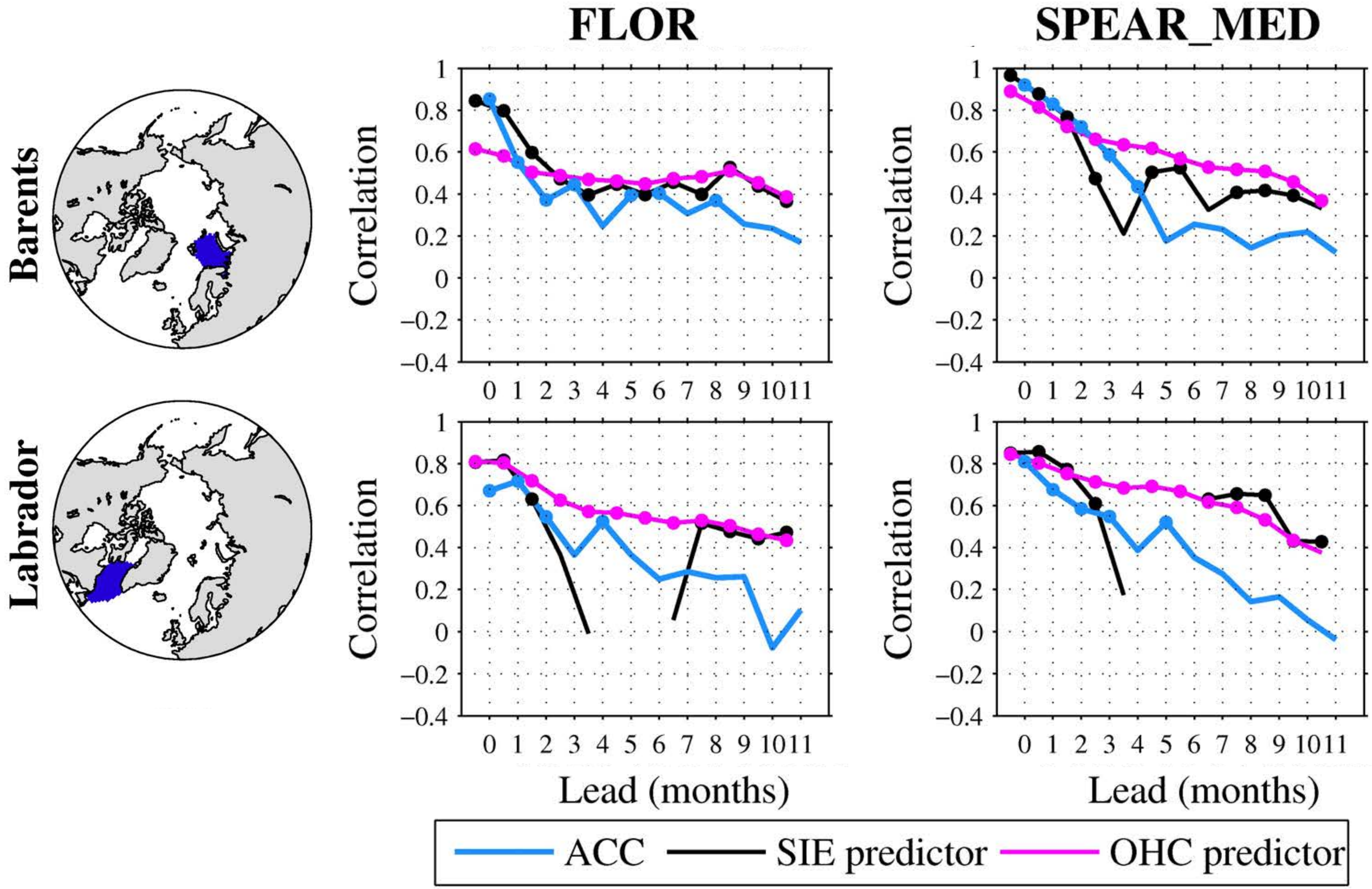
- Regional SIE/OHC predictors based on initial conditions used for forecasts

Sources of Winter SIE Prediction Skill



- Regional SIE/OHC predictors based on initial conditions used for forecasts
- Regional SIE persistence is the key source of winter prediction skill at short lead times (0-2 months)
- Regional SIE shows a winter-to-winter reemergence of prediction skill

Sources of Winter SIE Prediction Skill



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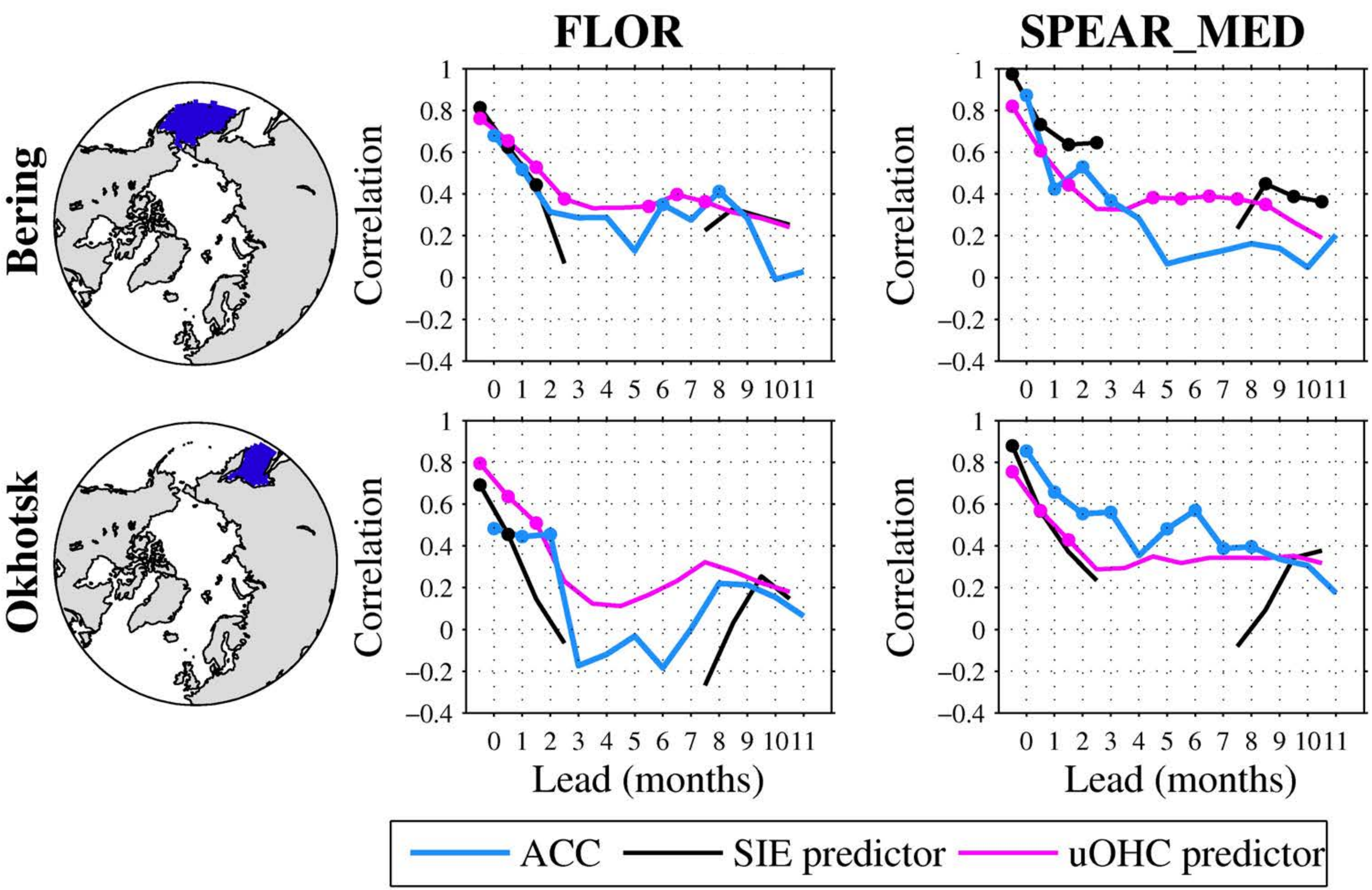
- Regional OHC persistence is the key source of summer prediction skill at longer lead times (3-11 months)

Sources of Winter SIE Prediction Skill



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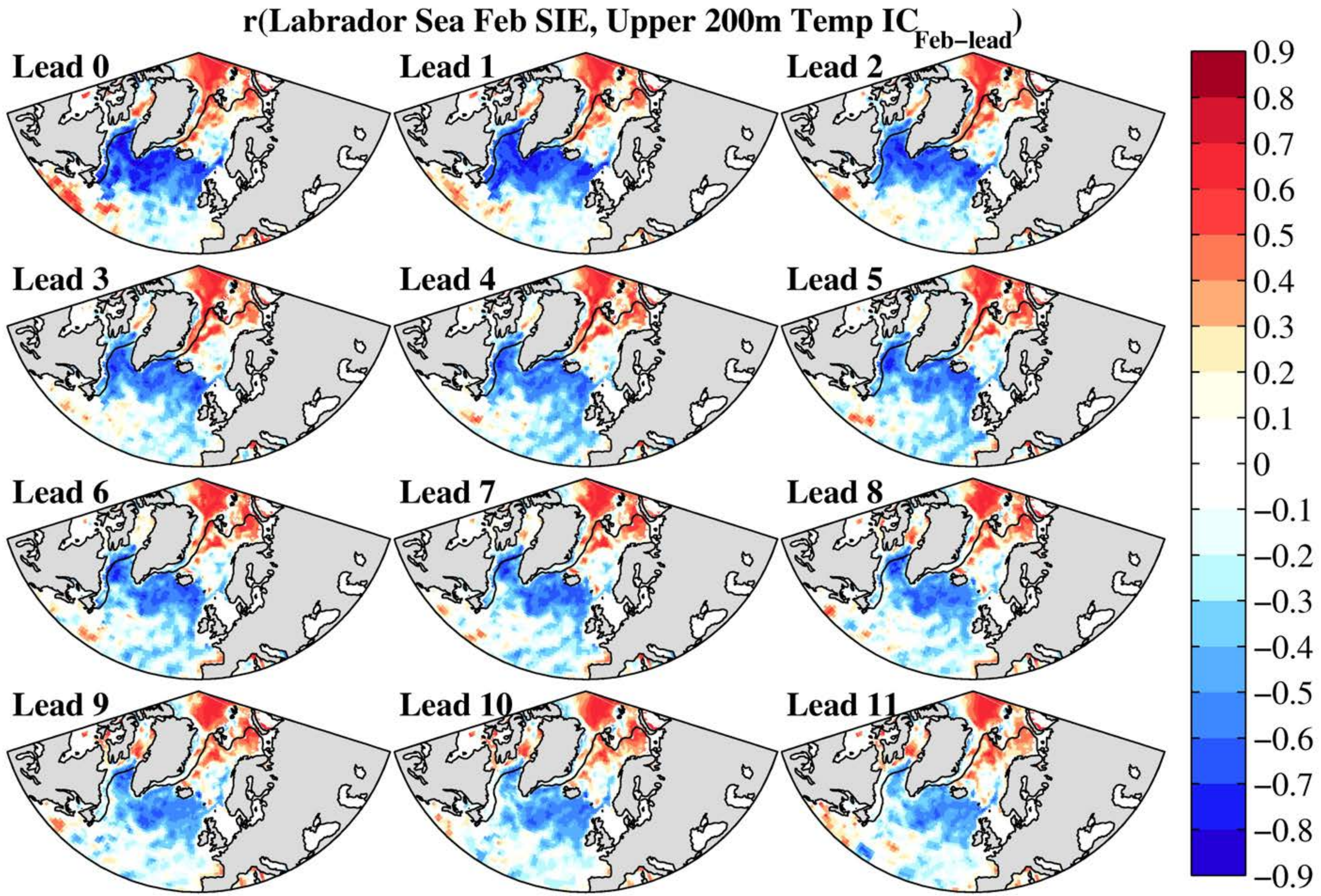
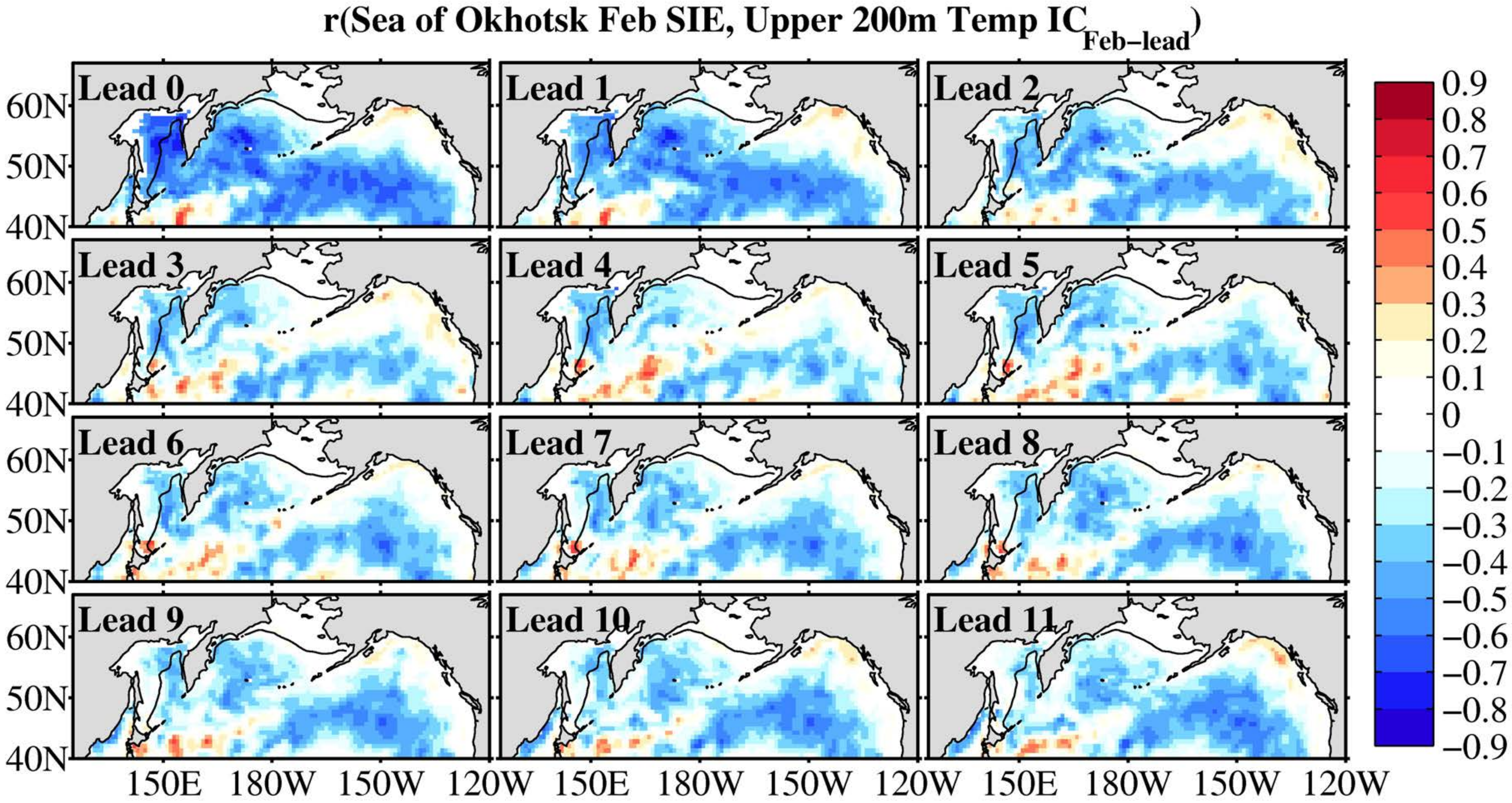
- Regional OHC persistence is the key source of summer prediction skill at longer lead times (3-11 months)
- Combination of SIE and OHC predictors provides a challenging skill benchmark

Connection to Large-Scale Modes of Variability: Labrador SIE - NAO

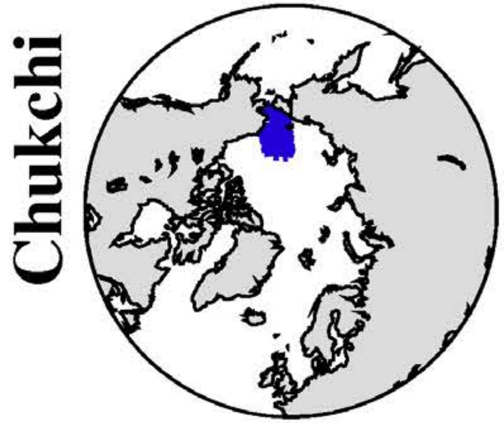


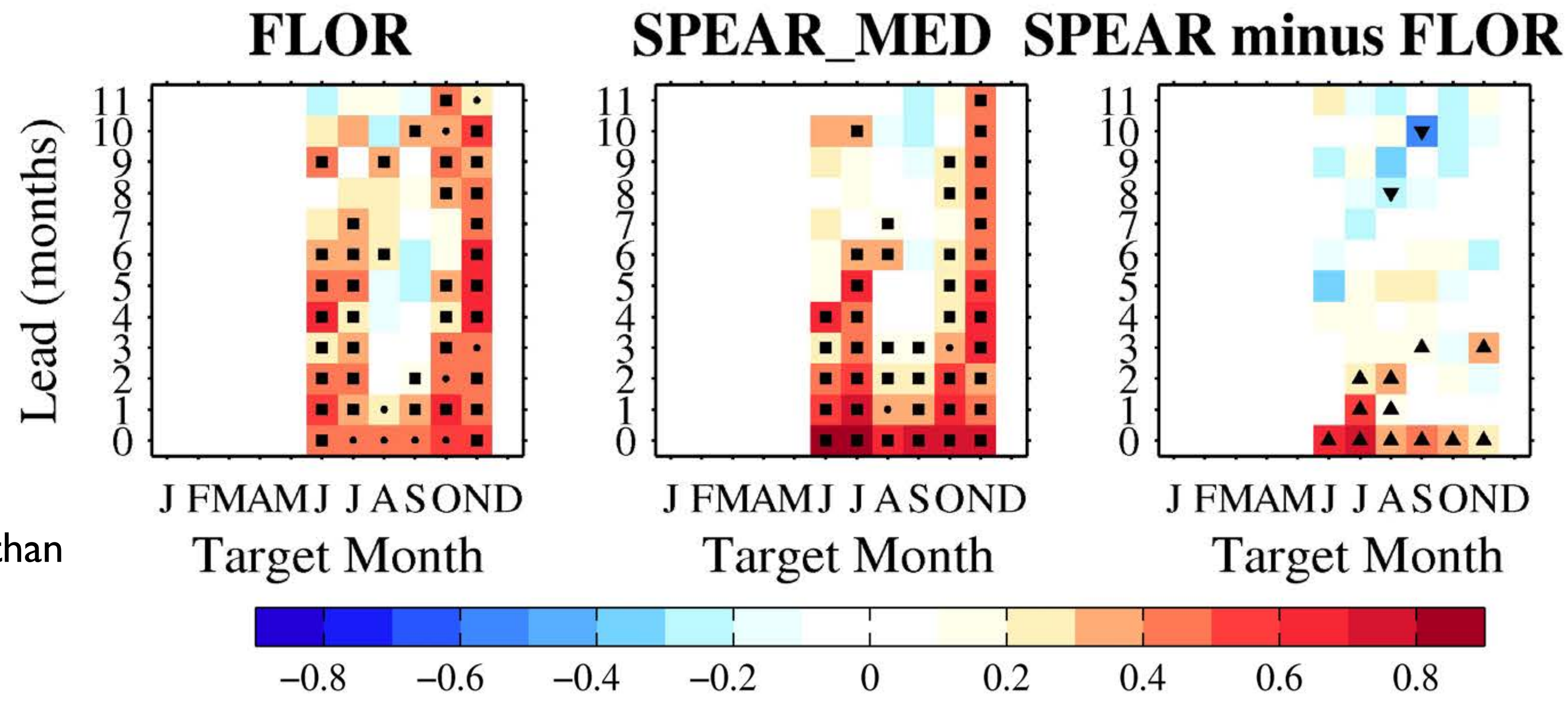
- Persistent correlations between winter Labrador SIE and earlier upper ocean temperature anomalies
- Spatial pattern is very similar to the NAO regression pattern
- Suggests that skillfully predicting the NAO could further improve Atlantic winter SIE predictions

Connection to Large-Scale Modes of Variability: Okhotsk SIE - NPGO



Revisiting Chukchi Sea Prediction Skill





■ Skill exceeds persistence
● Skill is significant, but lower than persistence
▲ SPEAR exceeds FLOR
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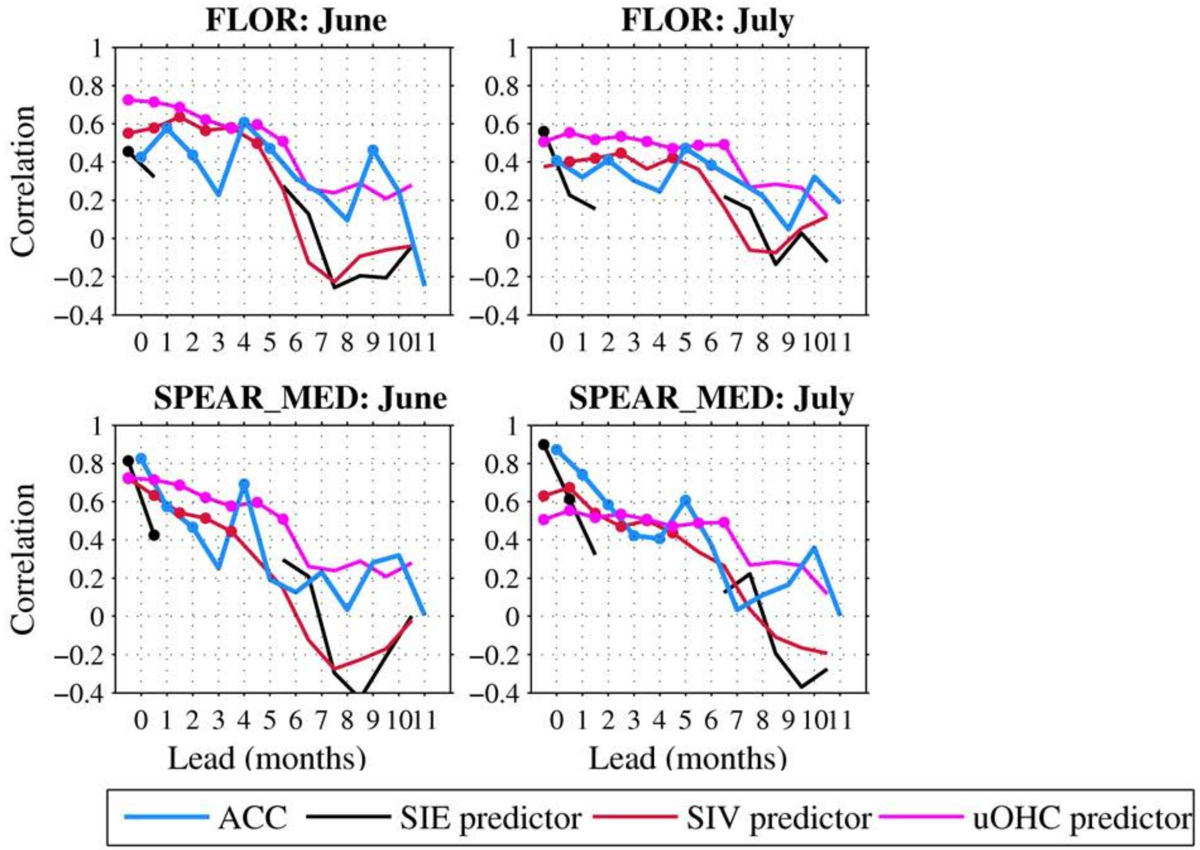
- High skill for target months June, July, November
- Lower skill in intervening summer months
- Suggestive of a combination of different predictability regimes in this region.

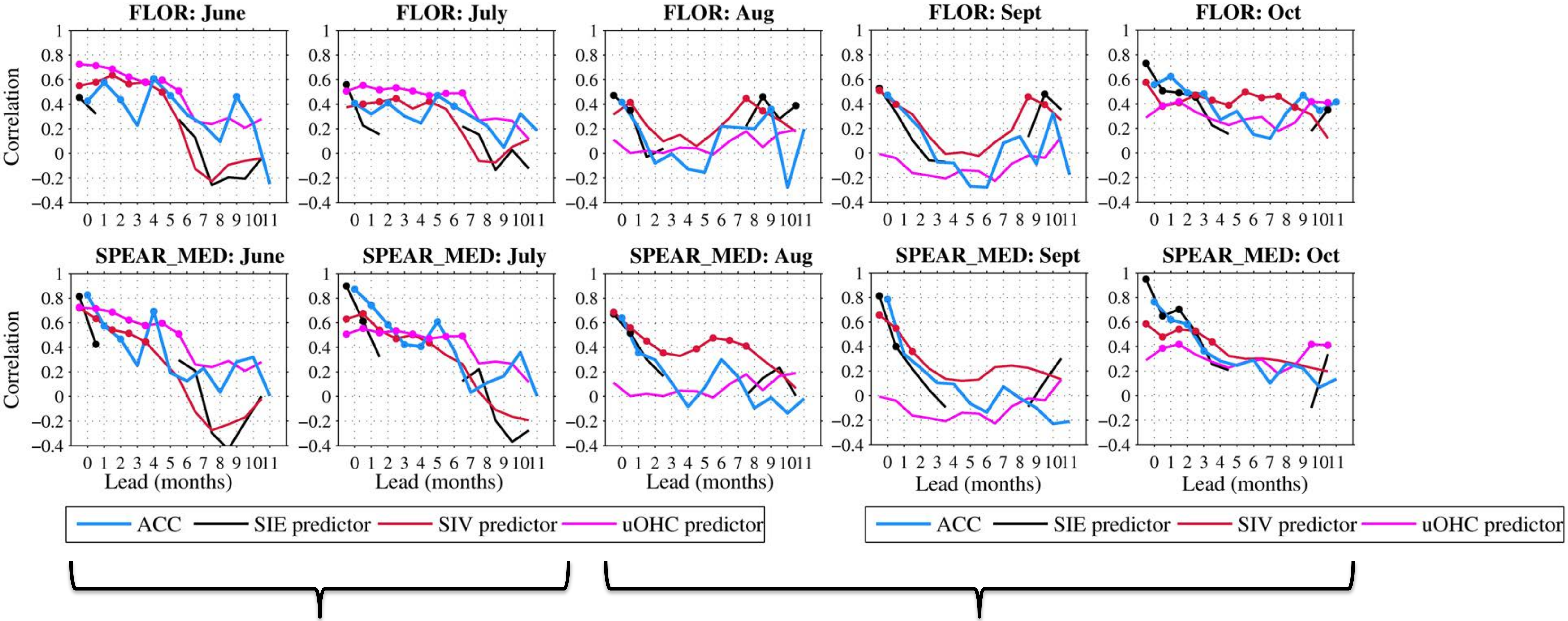
Sources of Chukchi SIE Prediction Skill



Ocean-based predictability regime

- OHC predictor based on Chukchi and Bering Seas

Sources of Chukchi SIE Prediction Skill

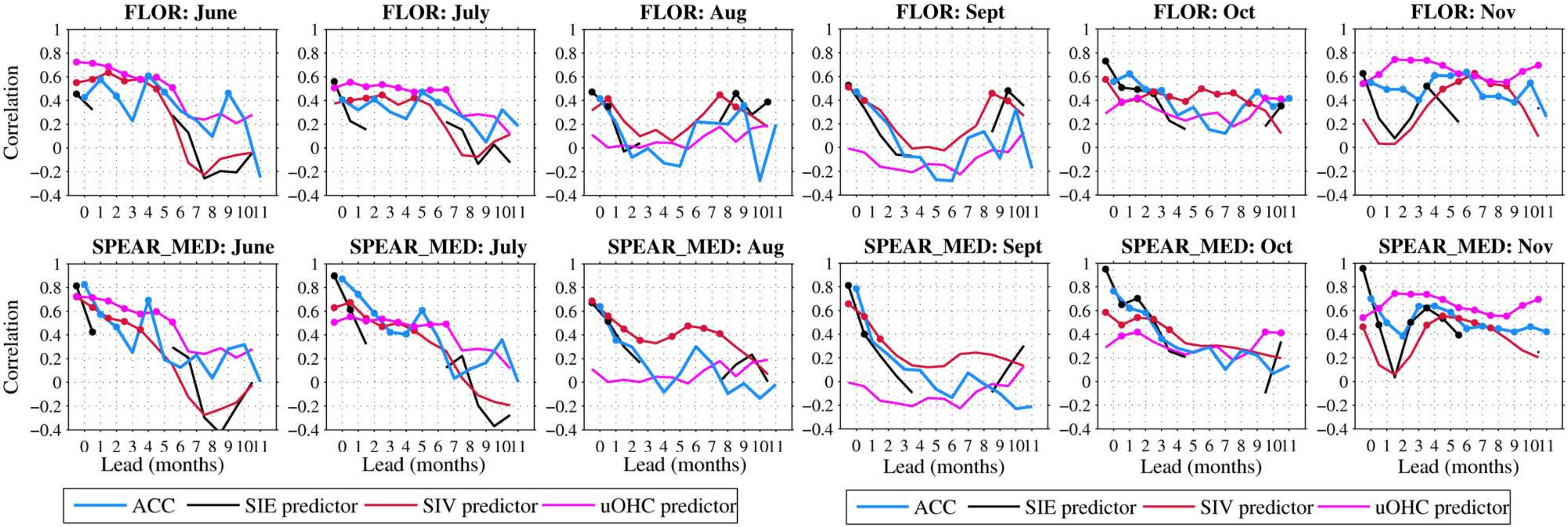


Ocean-based predictability regime

Ice thickness-based predictability regime

- OHC predictor based on Chukchi and Bering Seas

Sources of Chukchi SIE Prediction Skill



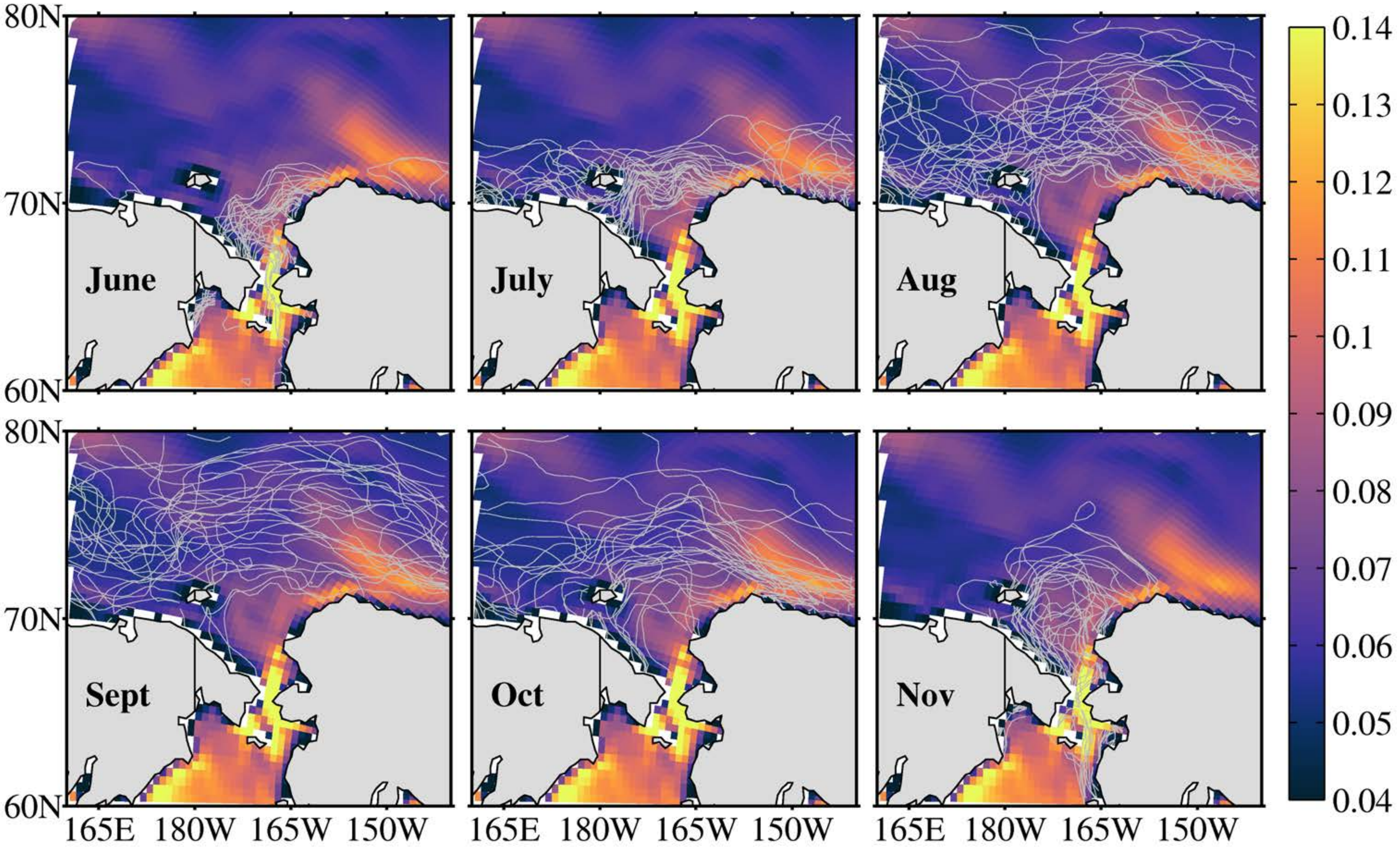
Ocean-based predictability regime

Ice thickness-based predictability regime

Ocean-based predictability regime

- OHC predictor based on Chukchi and Bering Seas
- Findings consistent with Lenetsky et al. (2021), *J. Clim*., who found that Bering Strait OHT skillfully predict Chukchi SIA in June, July, and November, but not the intervening summer months.

Why is there a trade off between ocean and thickness based predictability regimes?



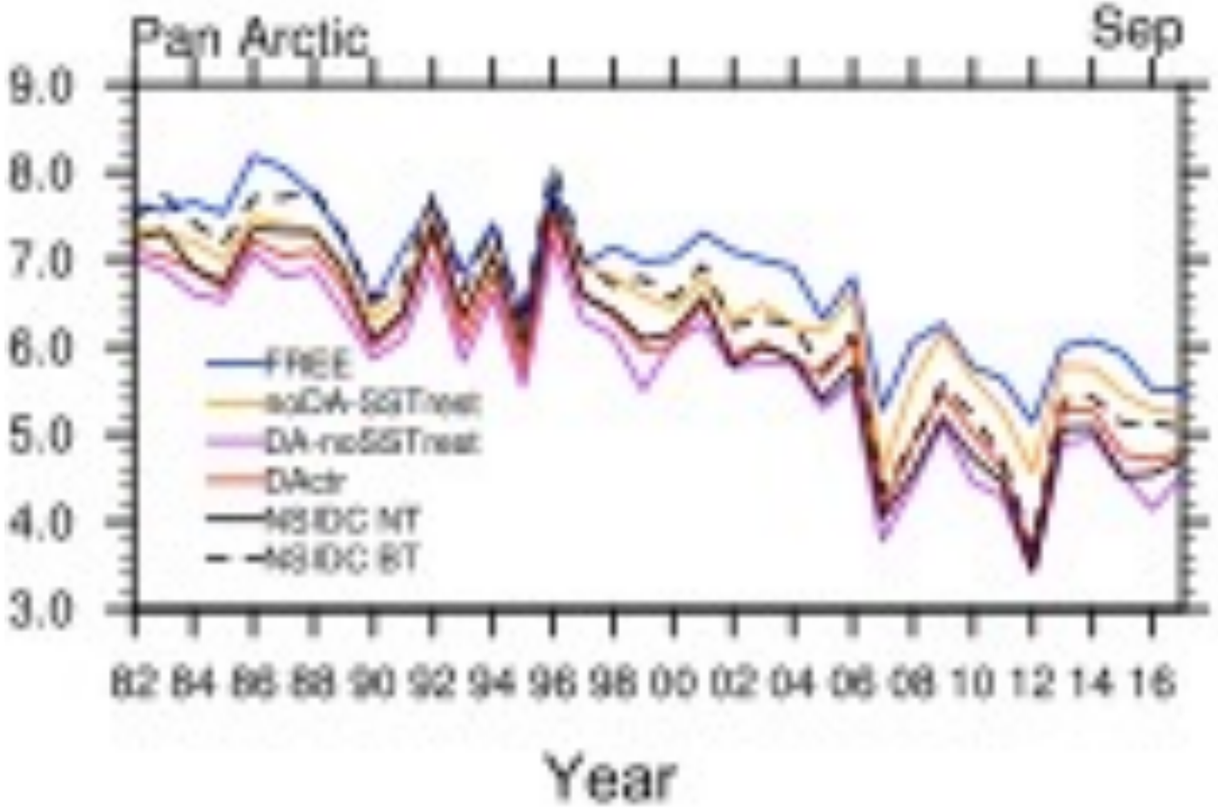
- Ocean surface current speed (m/s) plotted in color
- Observed sea ice edges plotted in gray contours
- Inflowing ocean waters interact strongly with the sea ice edge in June and July.
- Interaction with inflowing ocean waters is lost in August, when the ice edge retreats.
- Ocean-based predictability returns in November when ice edge returns to inflow location

Can sea ice data assimilation improve prediction skill?

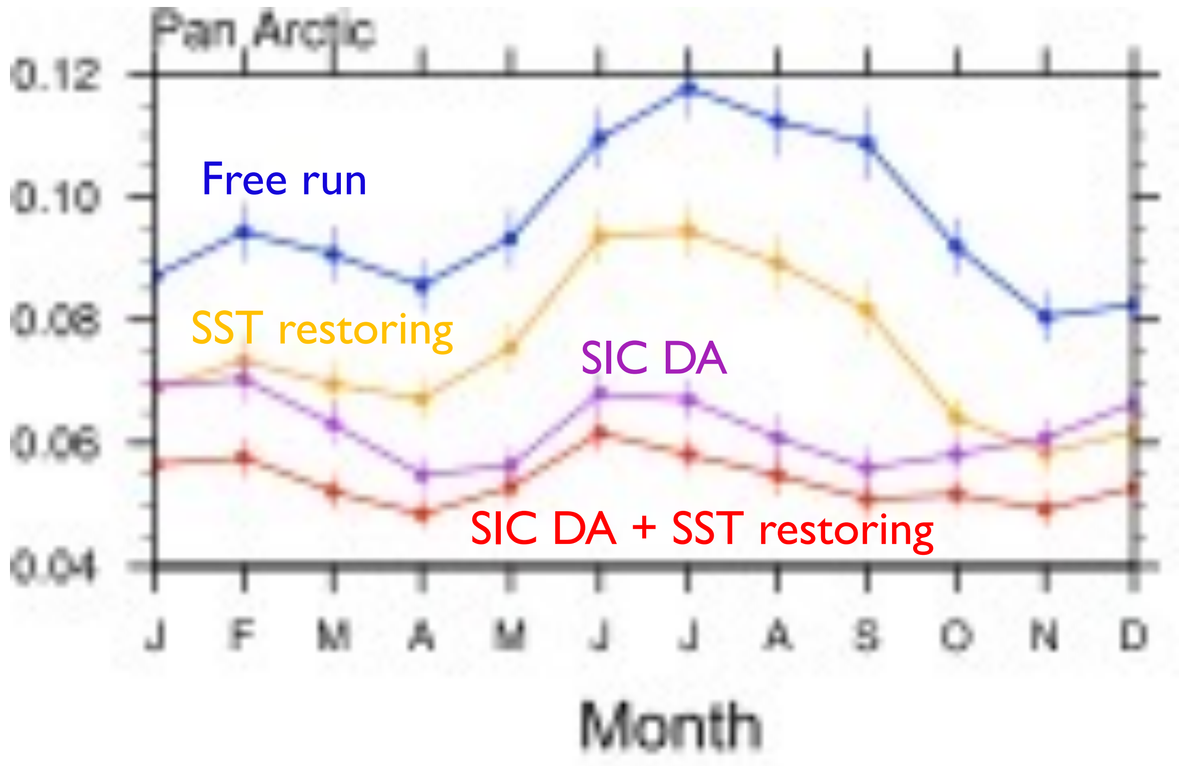
Work led by Yongfei Zhang

SIS2/MOM6 Sea Ice Data Assimilation System[1]

- MOM6/SIS2 (SPEAR ice-ocean components) forced by the JRA-55do atmospheric reanalysis from 1982–2017
- SST is nudged to OISST (SST under sea ice is set to salinity-based freezing point)
- Perturbed physics ensemble (albedo and ice strength parameters)
- Sea ice concentration NSIDC Nasa Team observations assimilated using Data Assimilation Research Testbed (DART) and the Ensemble Adjustment Kalman Filter (EAKF)

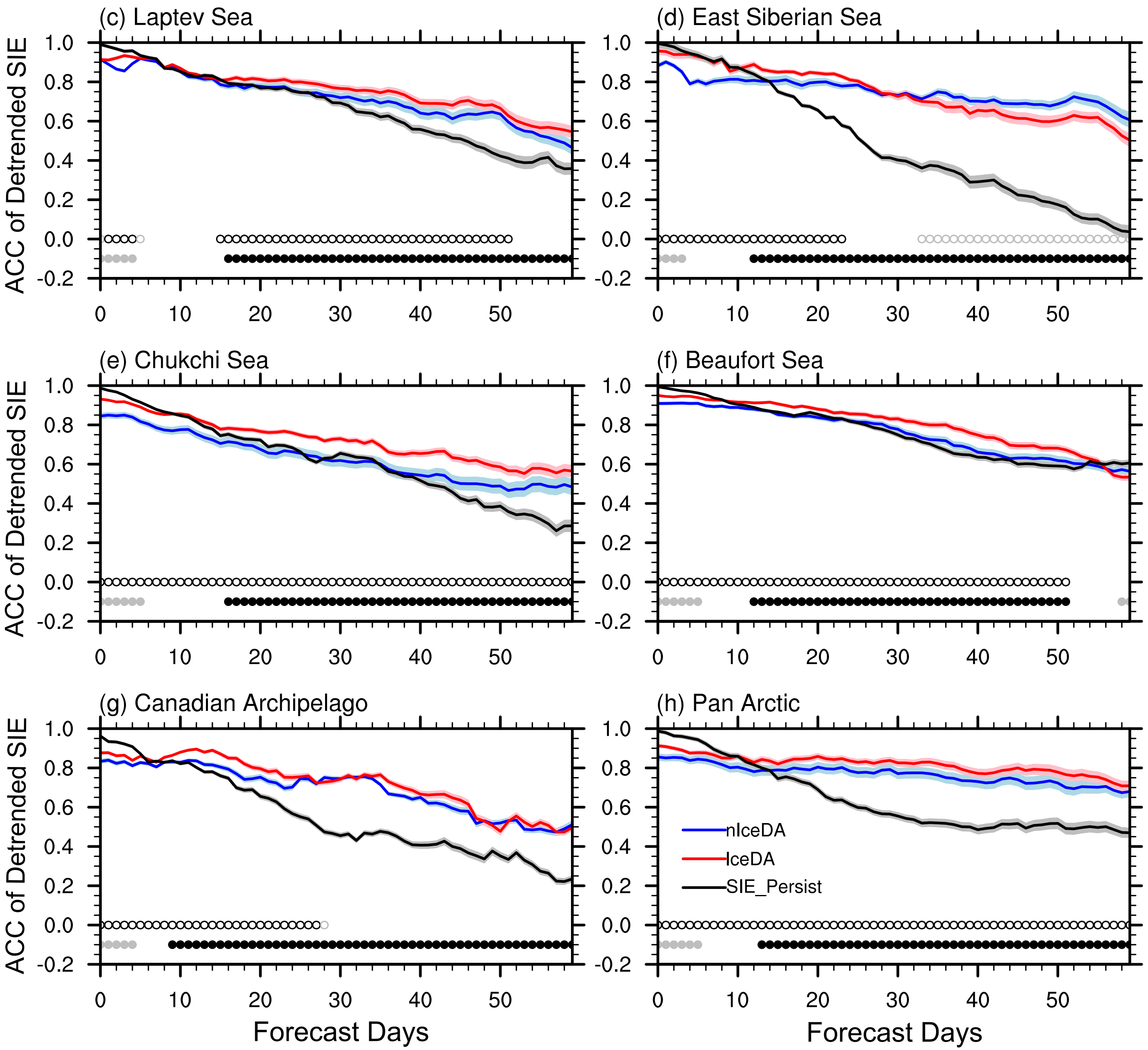


SIC RMSE



1: Zhang et al. 2021, *J. Clim.*

SIC DA Improves Subseasonal (0-8 week) SIE Prediction Skill



SPEAR w/ SIC DA

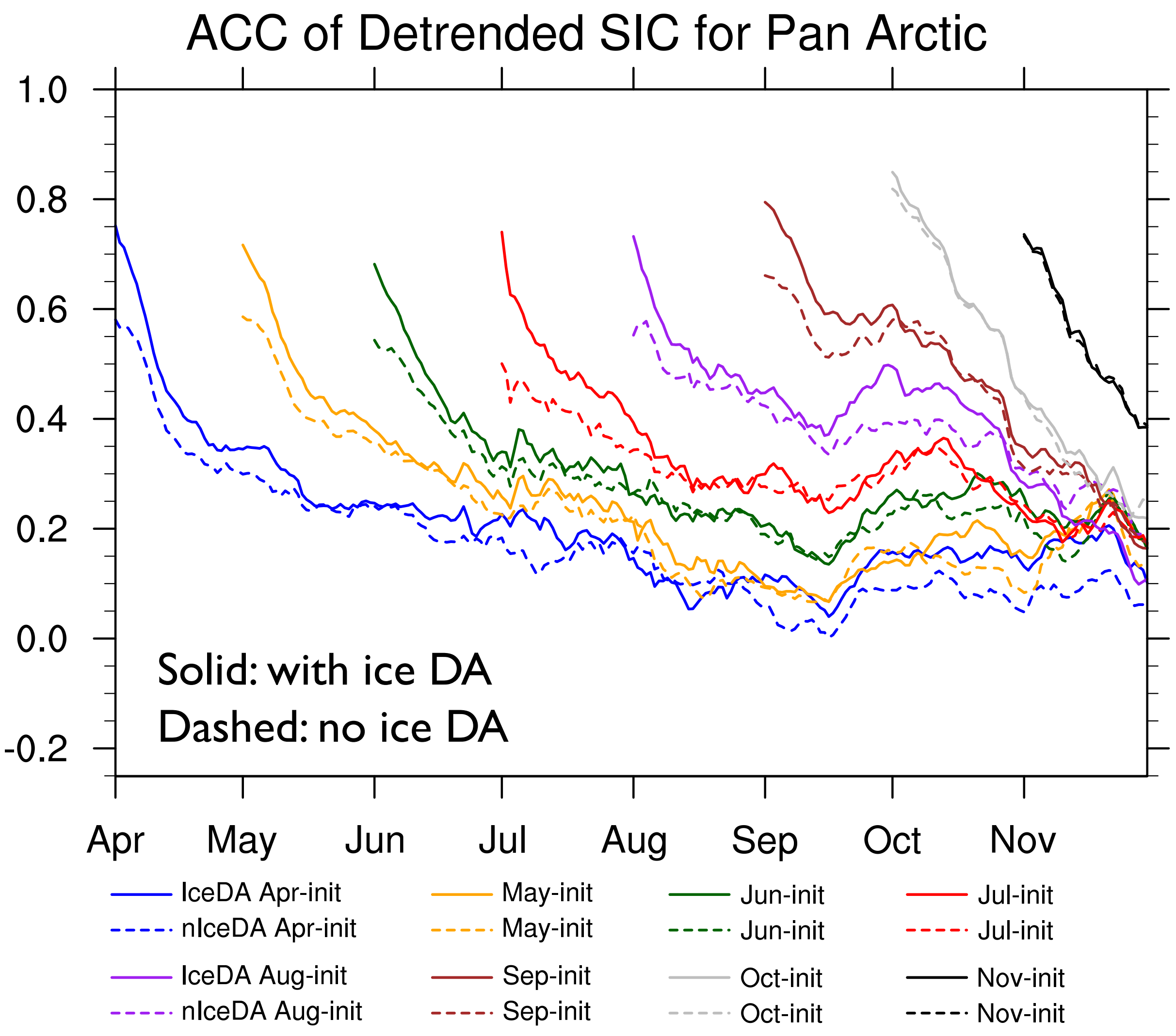
SPEAR

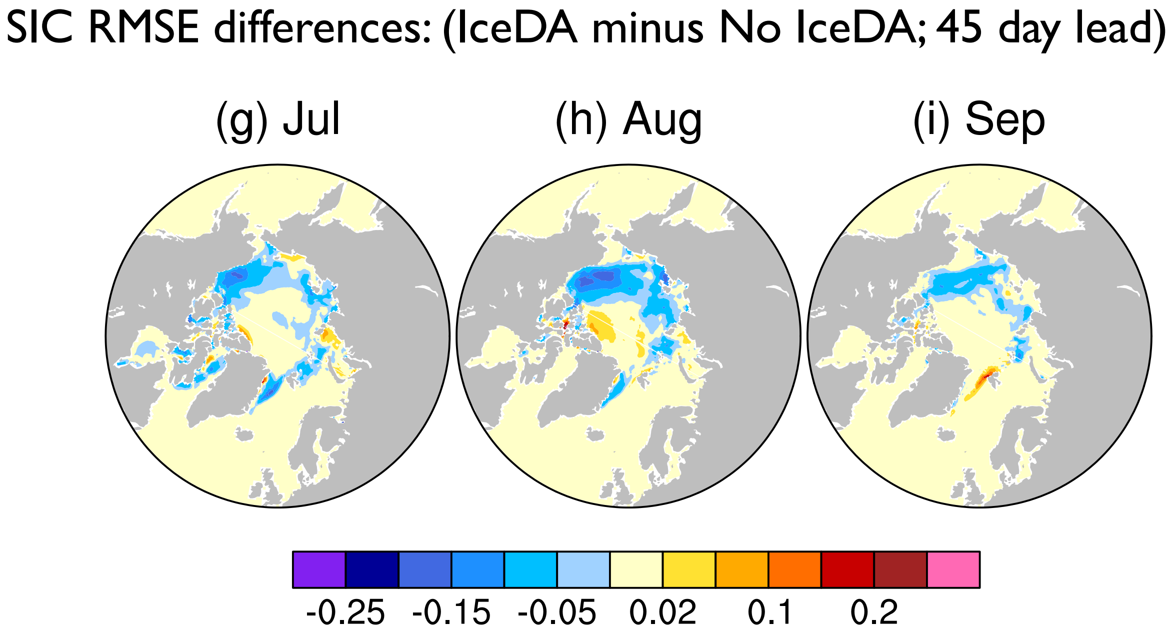
SIE persistence

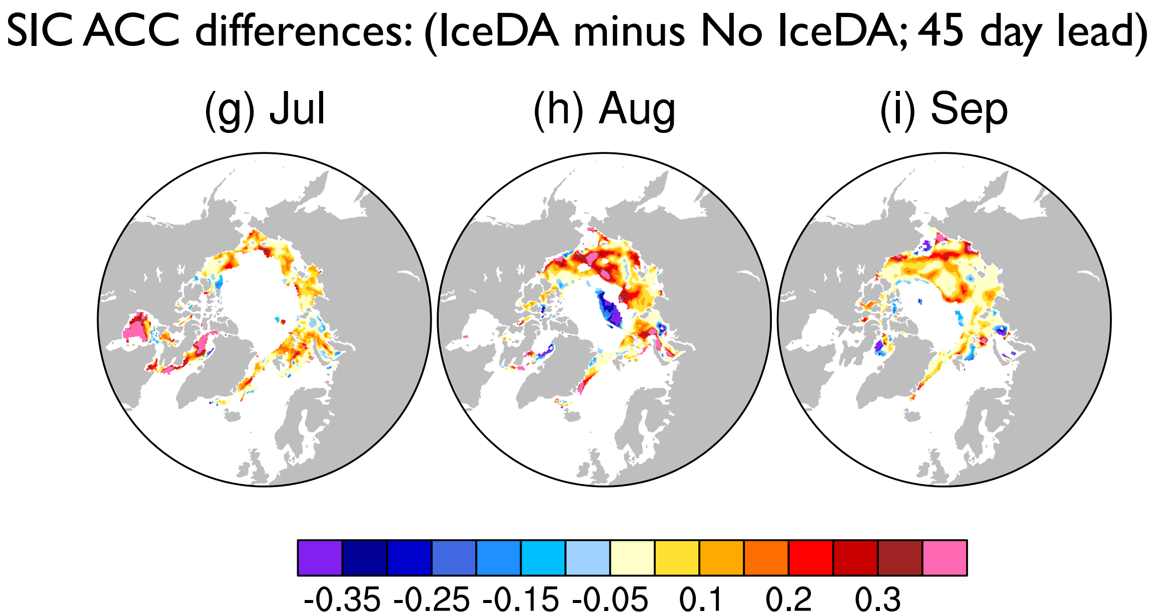
- Statistically significant, but relatively modest, improvements in regional SIE skill associated with SIC DA.
- Subseasonal predictions lose to persistence for first ~10 days, generally beat persistence beyond 10 days.

Zhang et al. 2021, *In Prep.*

SIC DA Improves Subseasonal Predictions of SIC





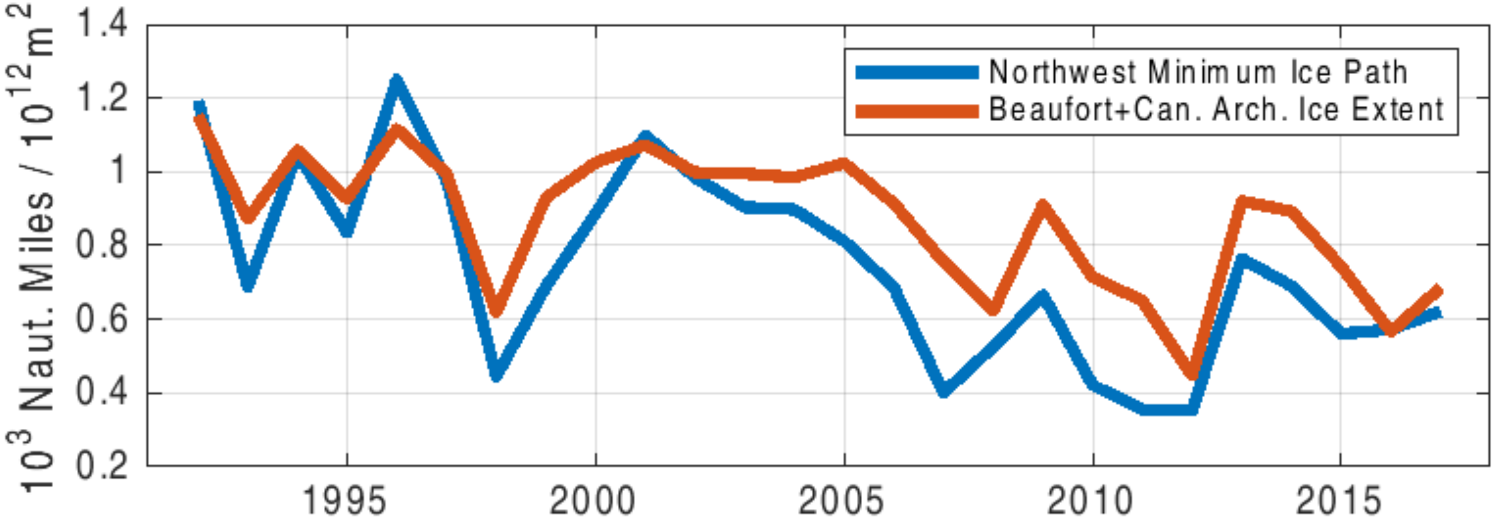


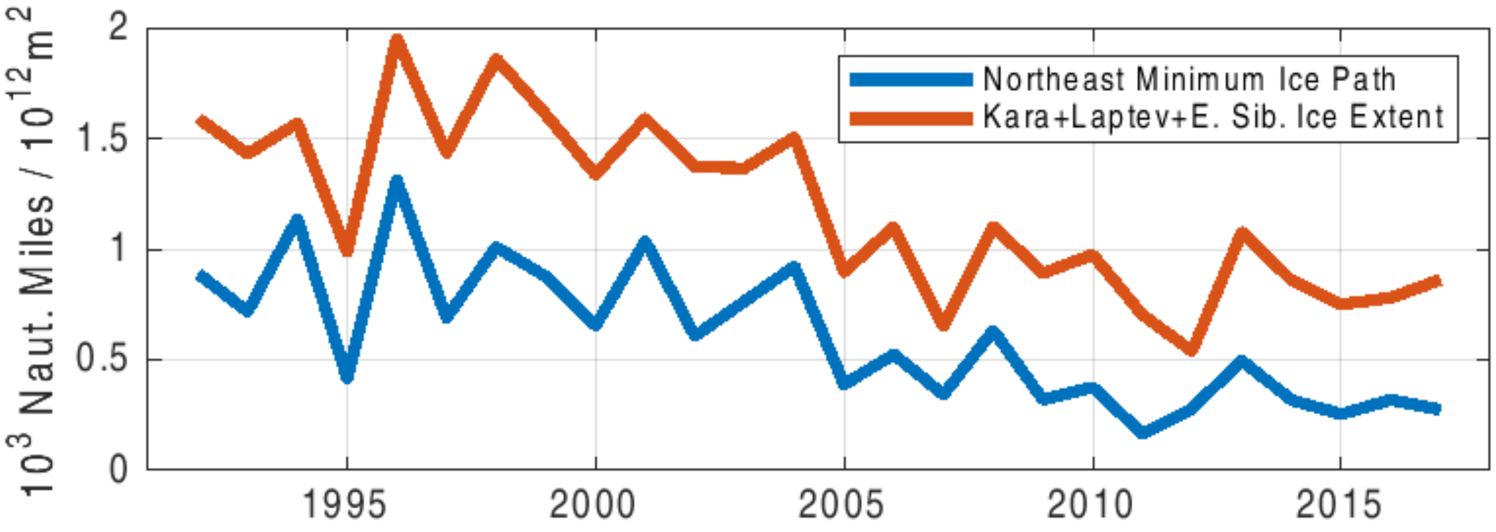
Zhang et al. 2021, *In Prep.*

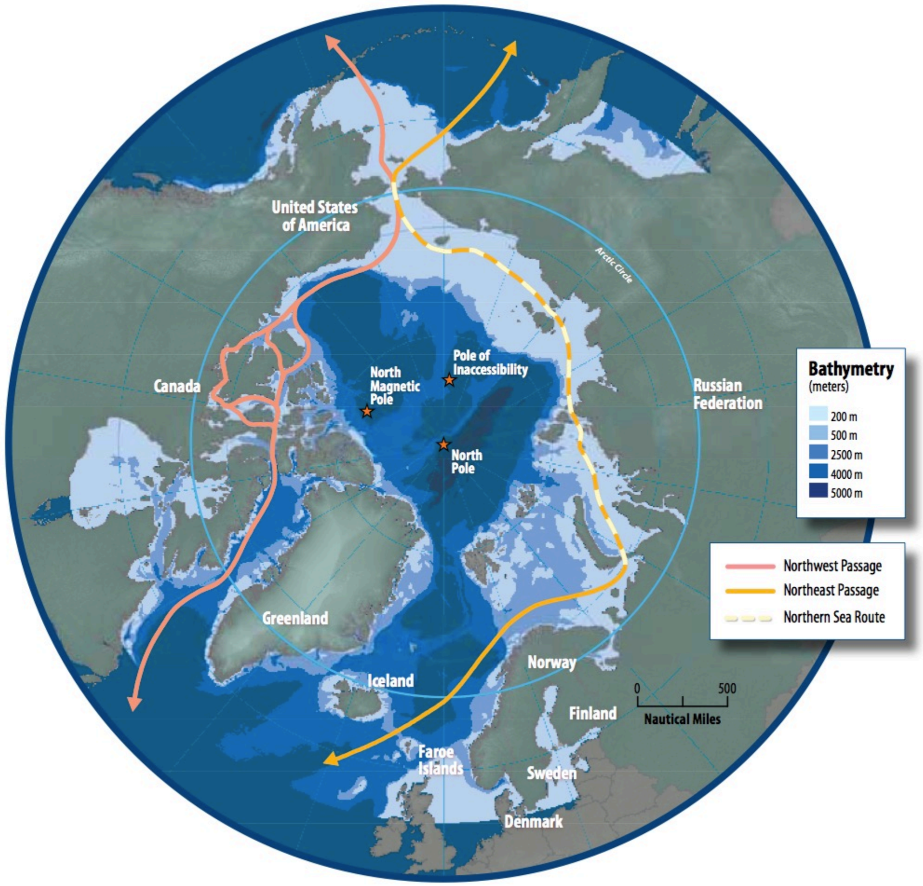
Can shipping routes be skillfully predicted?

Work led by Mike Winton

Observed Minimum Ice Path is Highly Correlated with Regional SIE

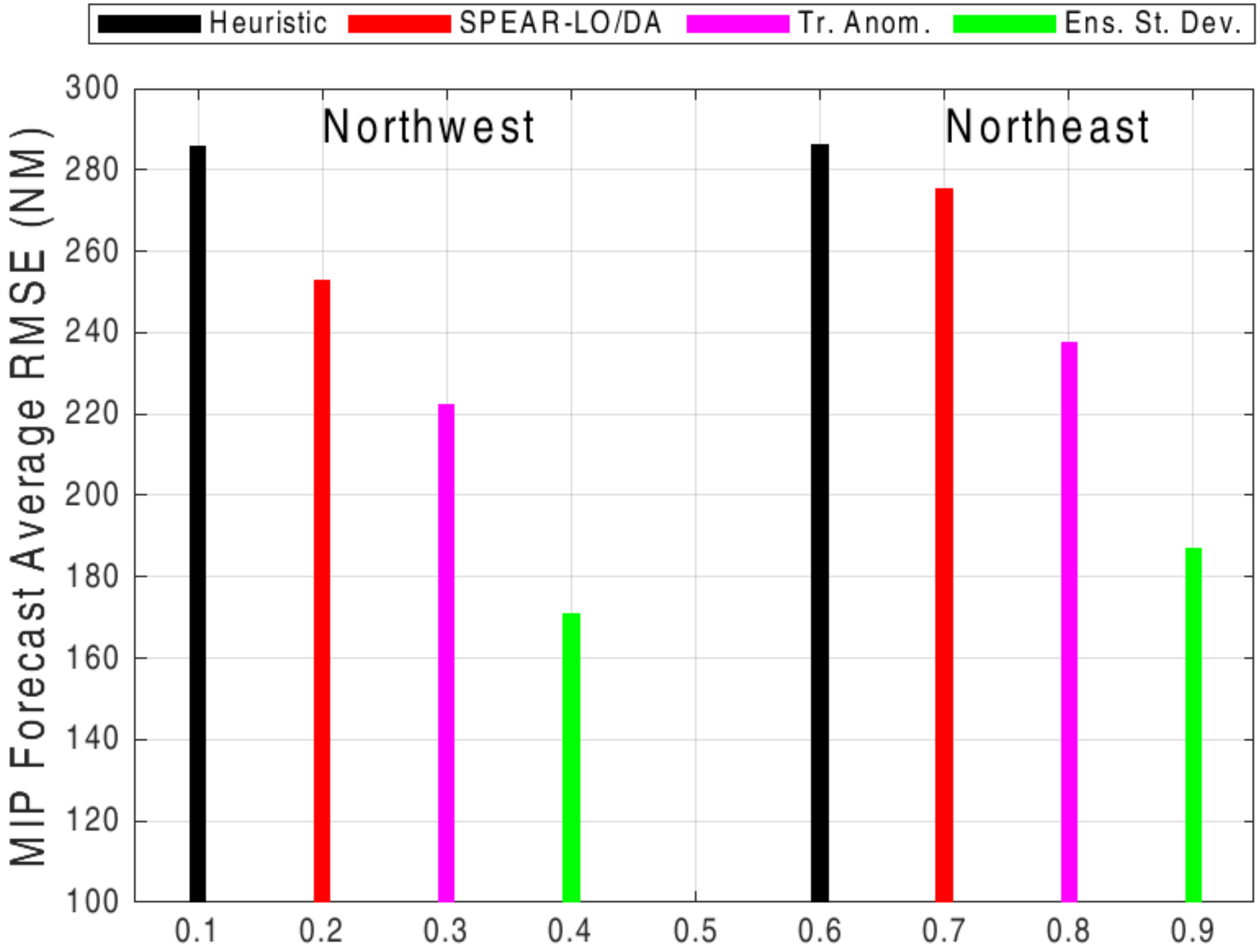






Winton et al. 2021, *In Prep.*

Skillful Predictions of Minimum Ice Path (MIP)



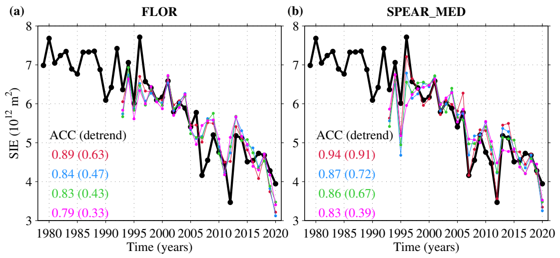
5-year climatology plus anomaly persistence
SPEAR w/ SIC DA
SPEAR w/ SIC DA + trend bias correction
SPEAR ensemble standard deviation (upper limit of predictability)

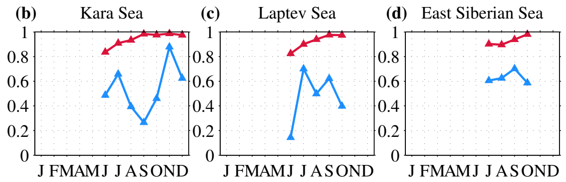
- MIP predictions are slightly more skillful than persistence forecast.
- There is substantial room for improvement via bias correction (red vs magenta) and model/initialization improvement (red vs green)

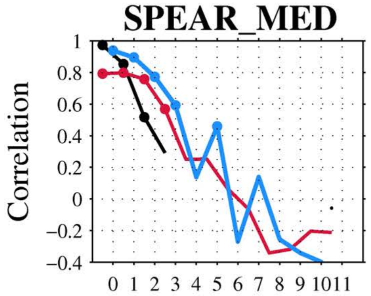
Winton et al. 2021, *In Prep.*

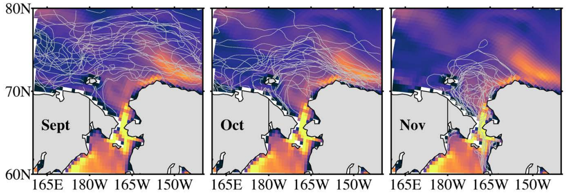
Conclusions

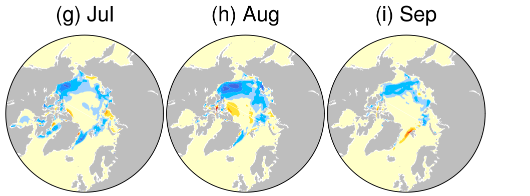
- SPEAR and FLOR prediction systems skillfully predict Pan-Arctic and regional sea ice extent (SIE)
- SPEAR skill generally higher than FLOR due to improved SIE and sea ice volume (SIV) initial conditions
- A combination of regional predictors (SIE, SIV, and upper ocean heat content) can match, or in some cases exceed, the skill of the dynamical models. We advocate using these three simple predictors as benchmark tests of Arctic seasonal prediction systems.
- Chukchi Sea exhibits a combined predictability regime, associated with interactions between the ice edge and inflowing ocean waters through Bering Strait.
- Sea ice concentration (SIC) data assimilation improves subseasonal predictions of SIE, SIC, ice free probability, and ice retreat date.
- SPEAR can skillfully predict "minimum ice path" through the Northeast and Northwest passages, and shows "room for improvement."

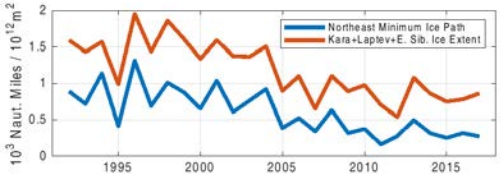












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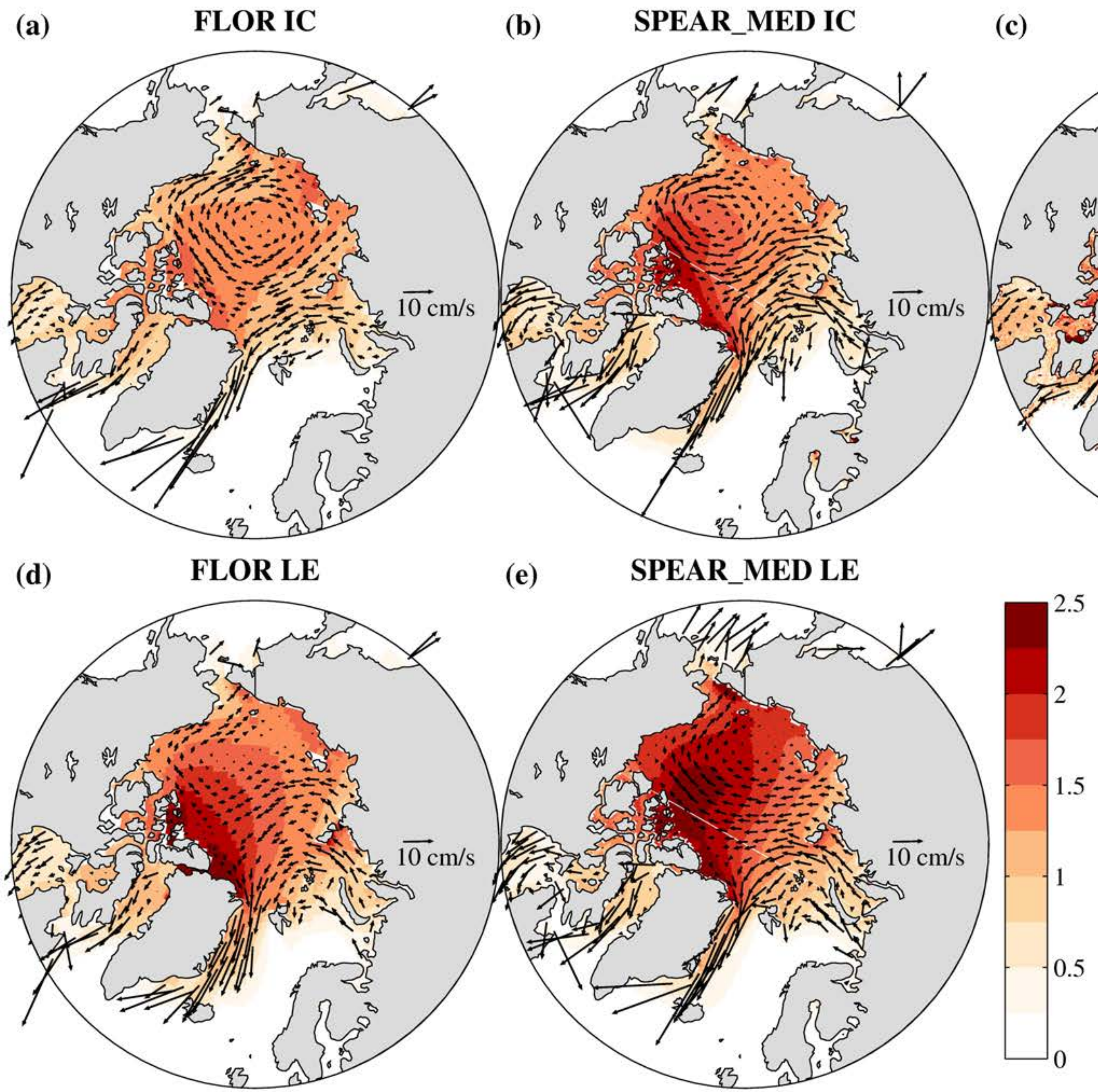
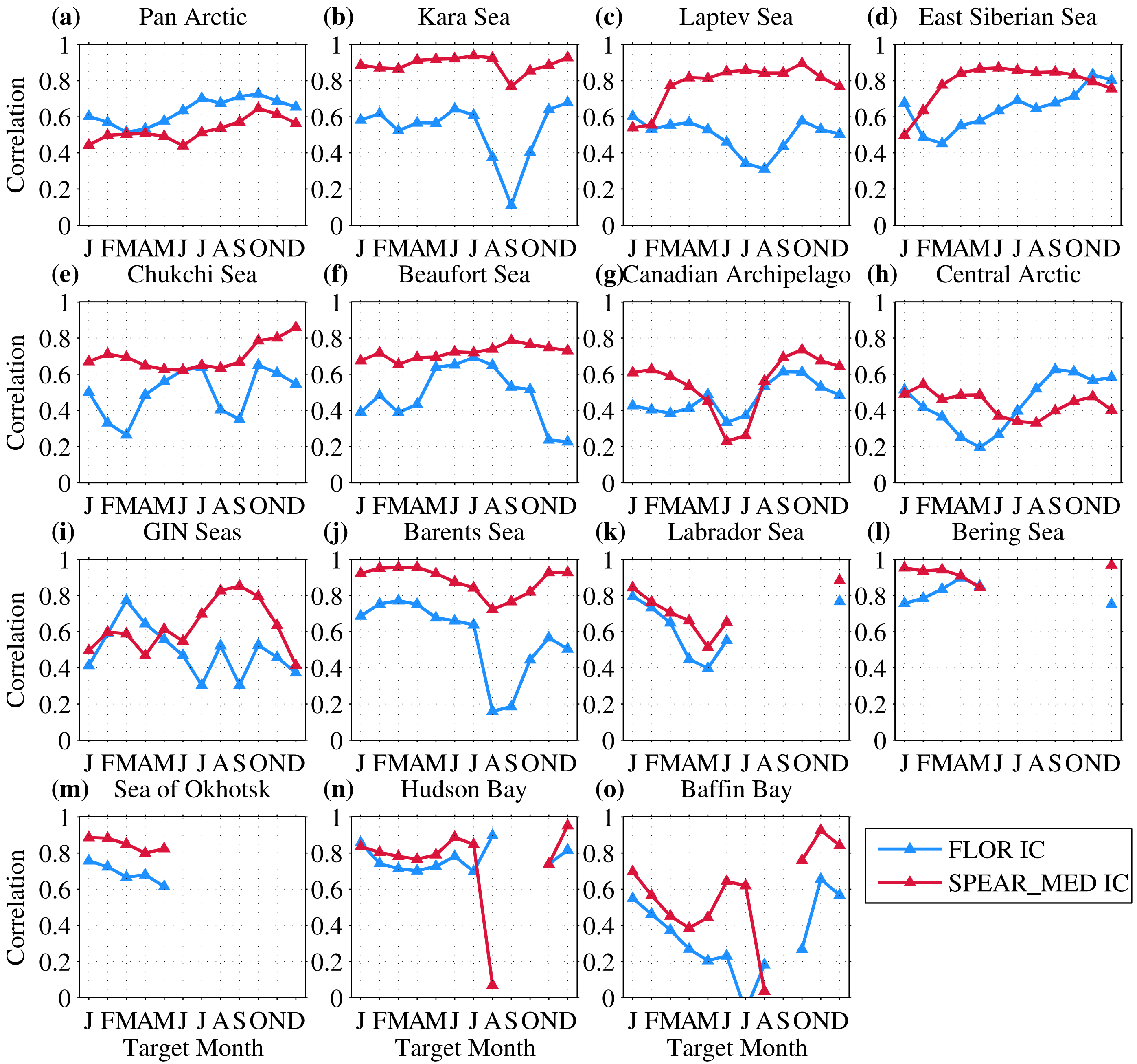
Please contact me at Mitchell.Bushuk@noaa.gov for pdfs or preprints, and for questions!

Appendix Slides

Sea Ice Thickness and Drift Climatology



Sea Ice Volume (SIV) Initial Conditions Interannual Variability



- Detrended regional SIV correlations with PIOMAS