Regional Arctic sea-ice prediction:
Potential versus operational seasonal forecast skill

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With contributions from:
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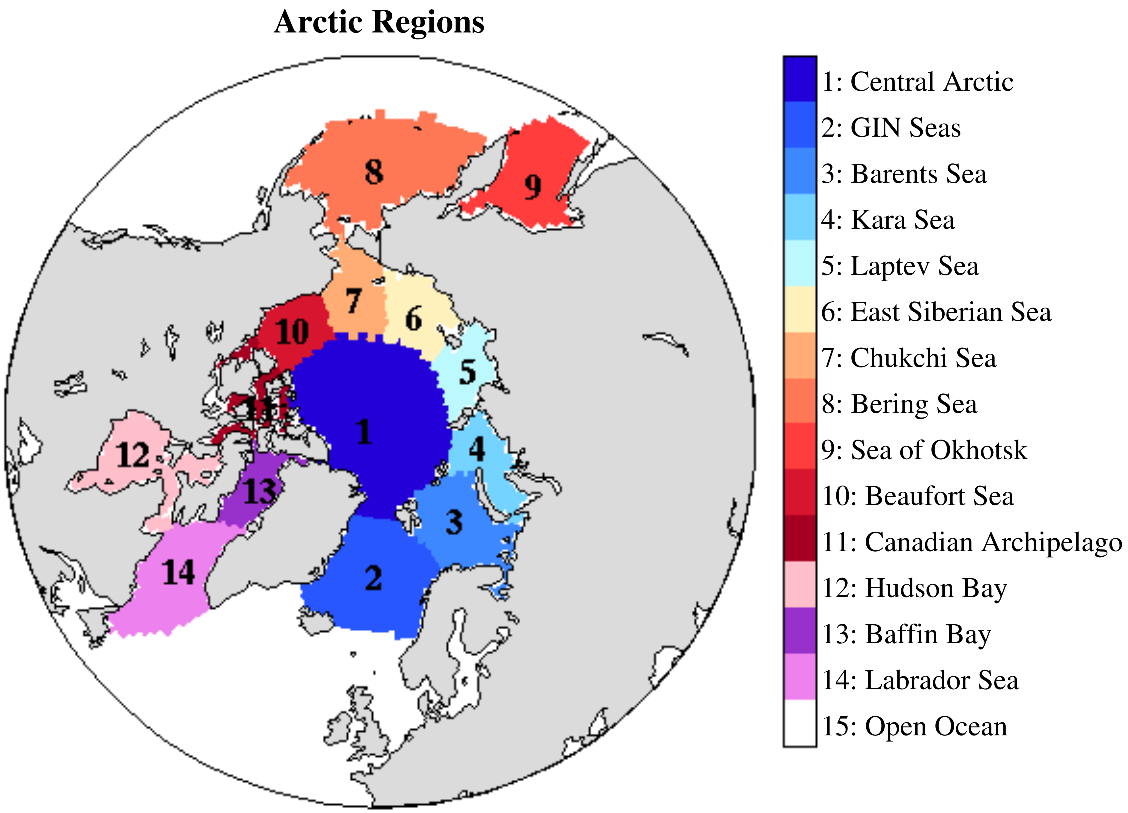
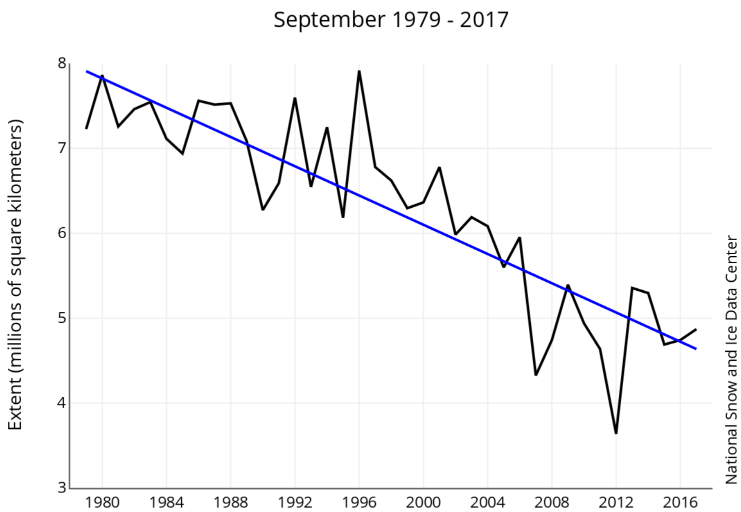
Xiaosong Yang, Rich Gudgel

Conference on Subseasonal to Decadal Prediction
S2D Session B6
Sept 20, 2018

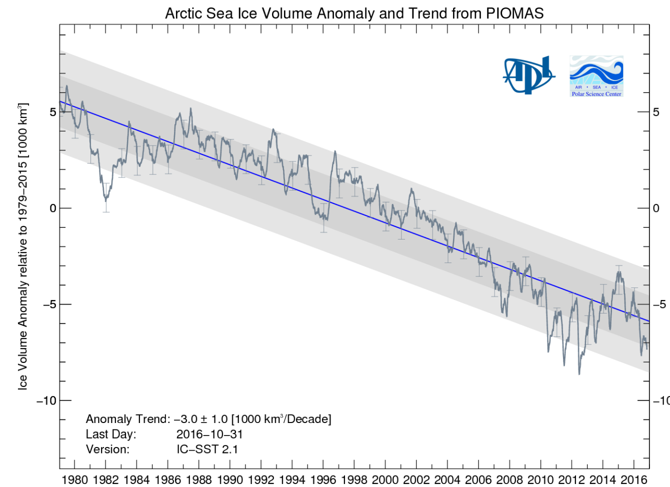


The Changing Arctic Sea-Ice Cover

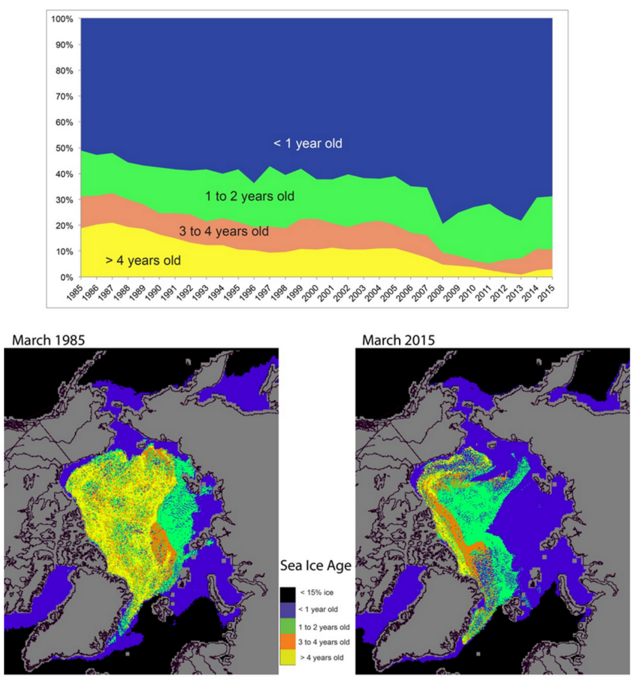
Negative extent trend



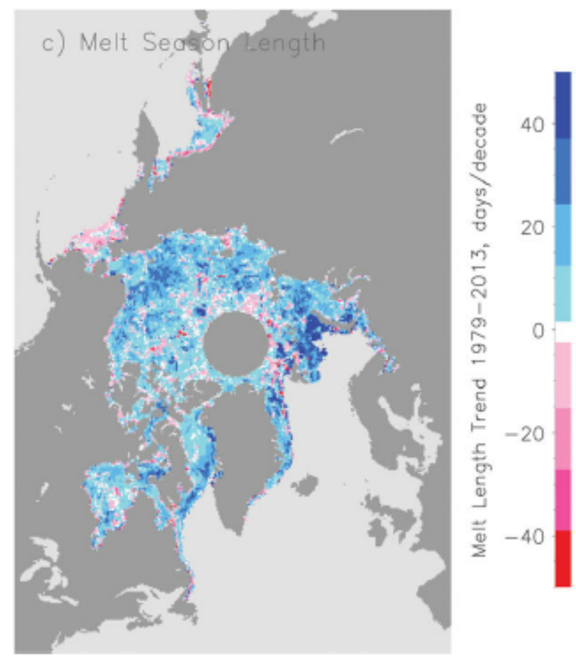
Negative volume trend



Younger and thinner ice cover

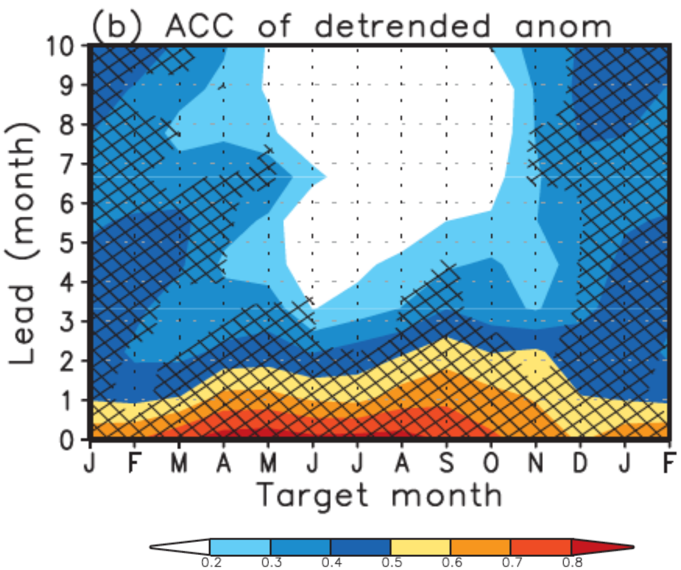


Longer melt seasons

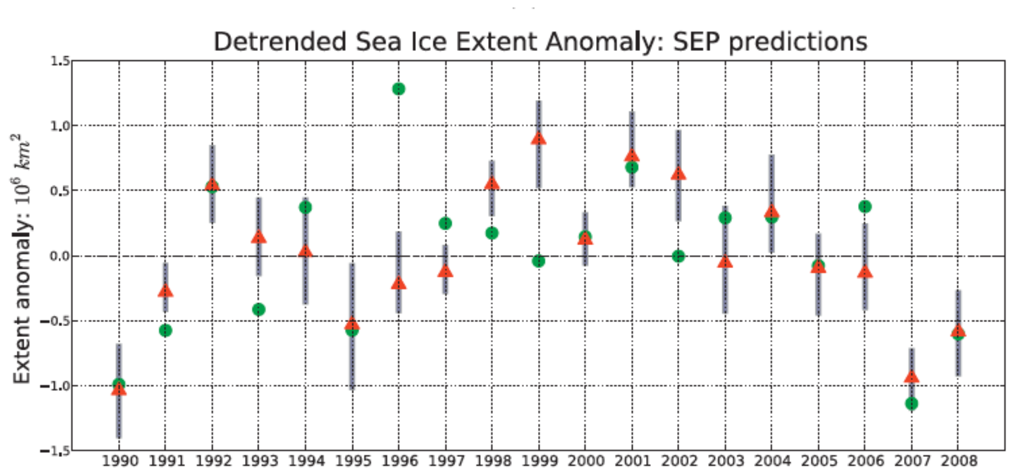


Operational Pan-Arctic Seasonal Sea Ice Predictions

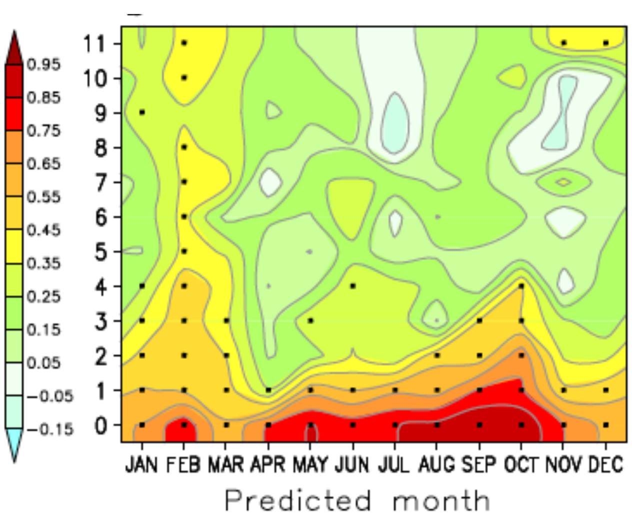
- **GCM-based hindcast skill for detrended SIE: 0-6 months**



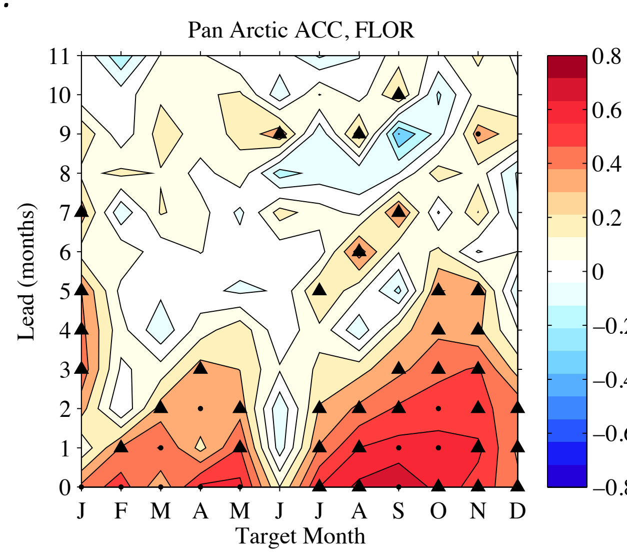
Wang et al. 2013, *Mon. Wea. Rev.*



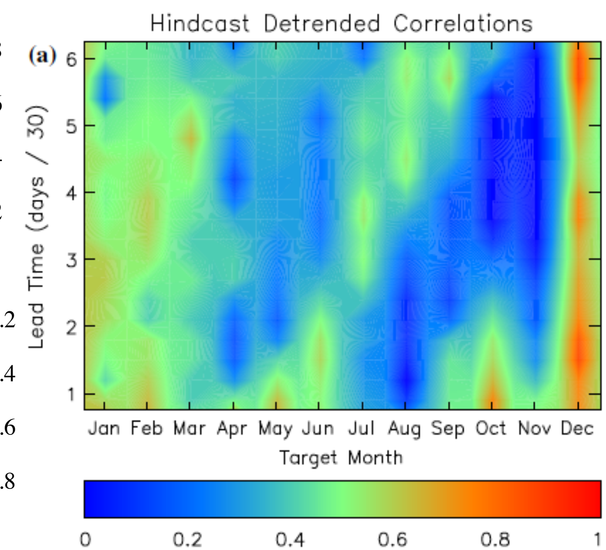
Chevallier et al. 2013, *J. Climate*



Merryfield et al. 2013, *GRL;*
Sigmond et al. 2013, *GRL*



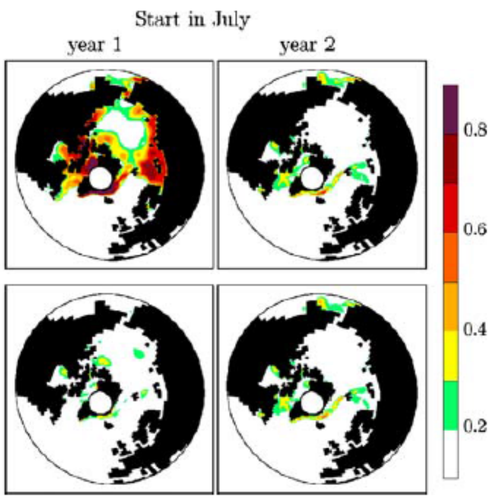
Msadek et al. 2014, *GRL;*
Bushuk et al. 2017, *GRL*



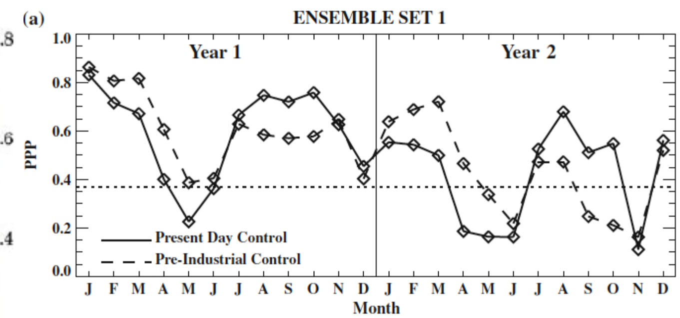
Peterson et al. 2015, *Clim. Dyn.*

Perfect Model Pan-Arctic Sea Ice Predictions

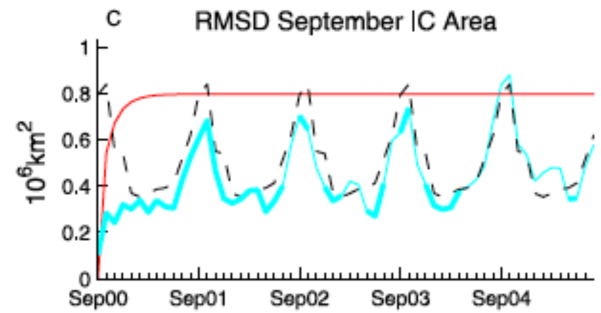
- **Perfect model skill: 12-24 months**



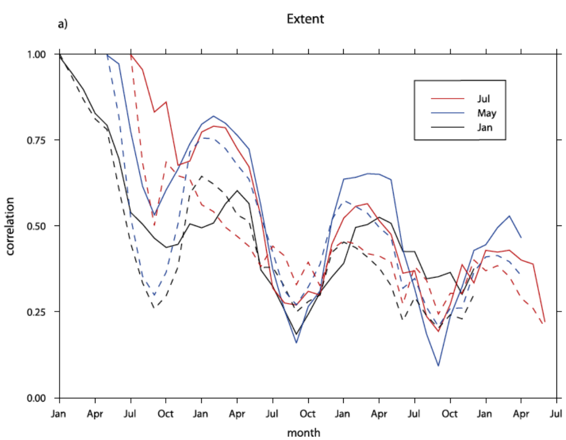
Koenigk and Mikolajewicz 2009, *Clim. Dyn.*



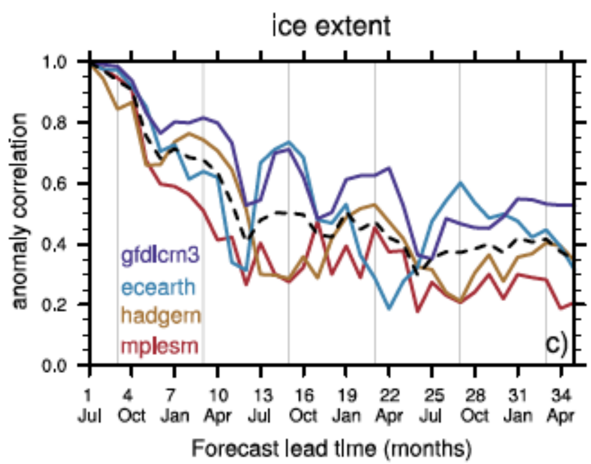
Holland et al. 2010, *Clim. Dyn.*



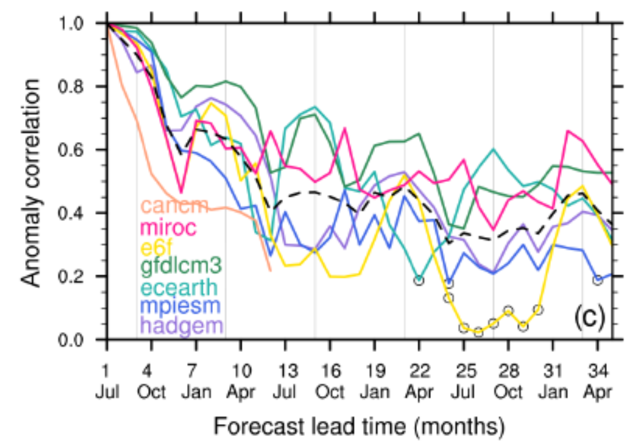
Blanchard-Wrigglesworth et al. 2011, *GRL*



Day et al. 2014, *J. Climate*



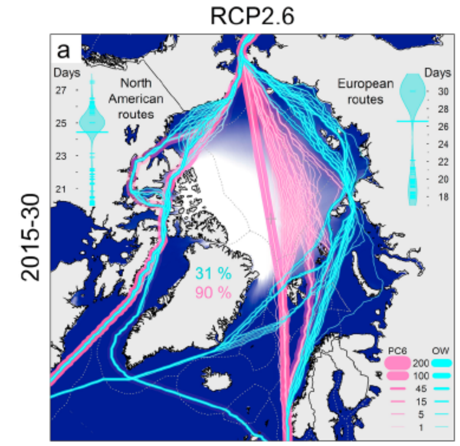
Tietsche et al. 2014, *GRL*



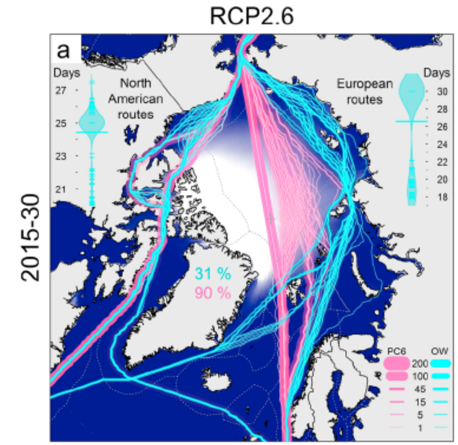
Day et al. 2016, *GMD*

Motivating questions/ideas for this work

(1) Regional Arctic sea ice predictability: How skillful are operational and perfect model regional predictions?



Motivating questions/ideas for this work



(1) Regional Arctic sea ice predictability: How skillful are operational and perfect model regional predictions?

(2) Assess operational and perfect model skill within a common dynamical prediction system

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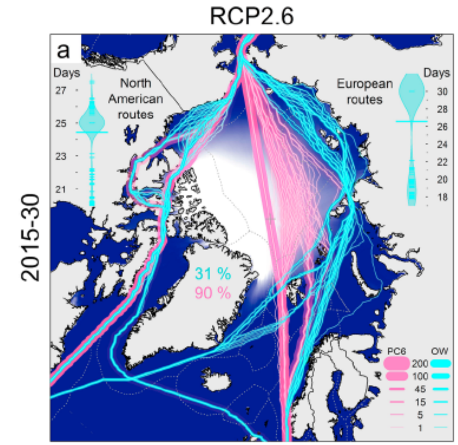
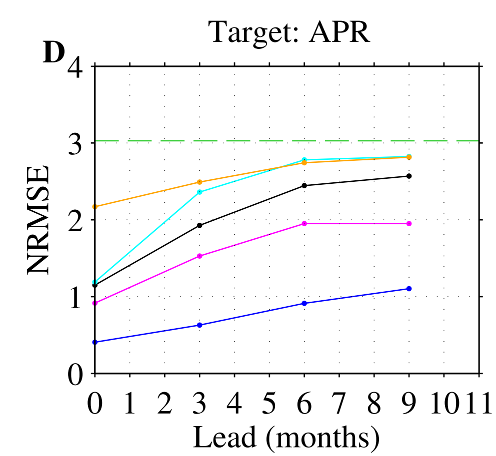
(1) Regional Arctic sea ice predictability: How skillful are operational and perfect model regional predictions?



(2) Assess operational and perfect model skill within a common dynamical prediction system

(3) How do we improve regional sea ice predictions?



The Dynamical Forecast Model

GFDL-FLOR[1]: **F**orecast-oriented **L**ow **O**cean **R**esolution

- Fully-coupled global model
- Atmosphere and Land (50km)
- Ocean and Sea Ice (1°)

Operational Predictions

Perfect Model Predictions

1: Vecchi et al. 2014, *J. Climate*

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Operational Predictions

Initialized from ECDA[2]:
Ensemble Kalman Filter **C**oupled **D**ata **A**ssimilation

- Ocean assimilates satellite SST, ARGO, CTD, XBT, other WOD profiles
- Atmosphere assimilates NCEP reanalysis
- No assimilation of sea ice data

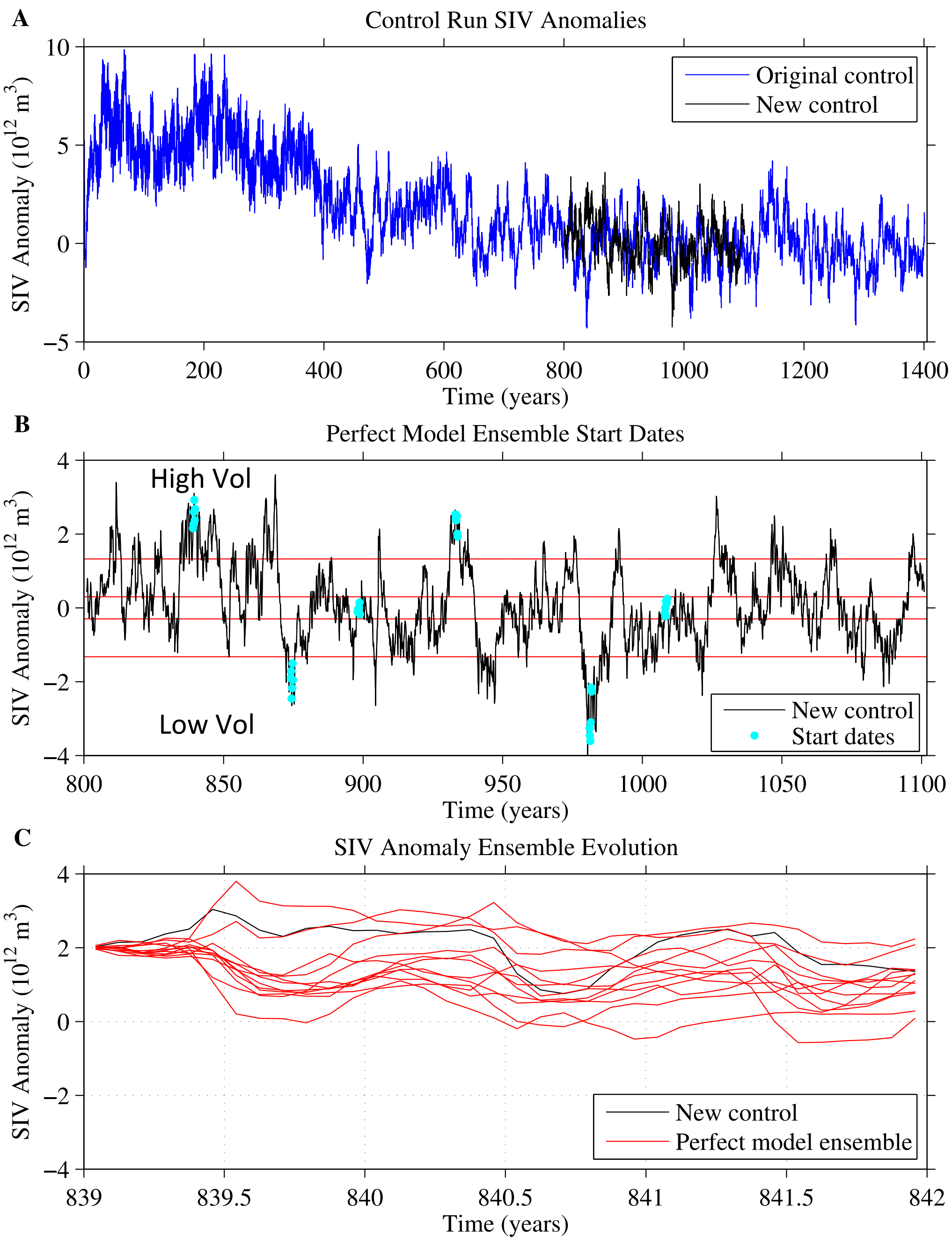
Retrospective Forecasts

- Forecasts initialized on the first of each month; run for one year
- 12-member ensemble
- Retrospective forecasts spanning 1980-2017

Perfect Model Predictions

1: Vecchi et al. 2014, *J. Climate*; 2: Zhang et al. 2007 *Mon. Wea. Rev.*

Perfect Model Predictions with GFDL-FLOR



- **Start Months**
  Jan, Mar, May, Jul, Sep, Nov
- **Start Years**
  839, 874, 898, 933, 981, 1008
- **Ensemble members**
  12
- **Integration time**
  3 years

Key Design Aspects

- Experiments run from well equilibrated climate of 1990 control run
- Seasonal coverage of start dates allows for study of skill at different lead times
- Performed with same model as seasonal forecast system. Allows for direct comparison of perfect model and operational skill

Bushuk et al. 2018, *Clim. Dyn.*

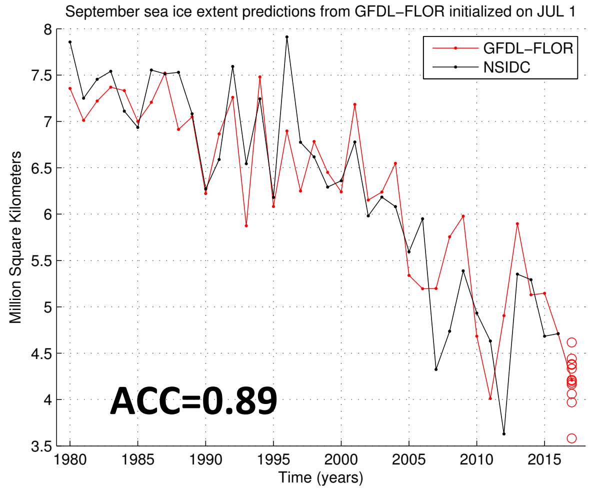
Operational Predictions of Pan-Arctic SIE

Target month: Month we are trying to predict

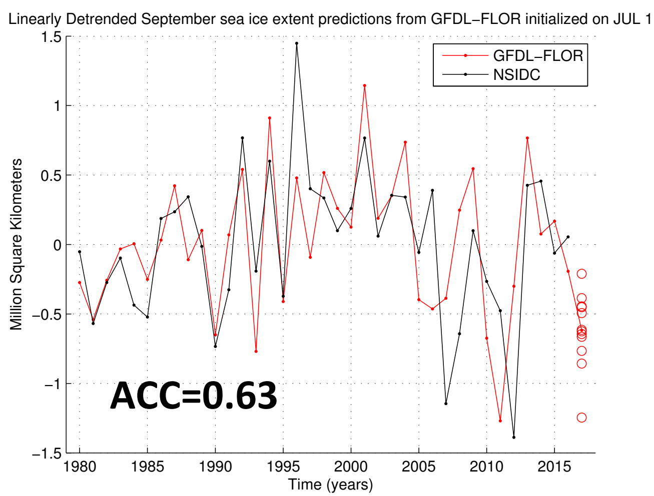
Lead time: Number of months prior to target month that forecast was initialized

Anomaly correlation coefficient (ACC): Correlation between observed and predicted SIE

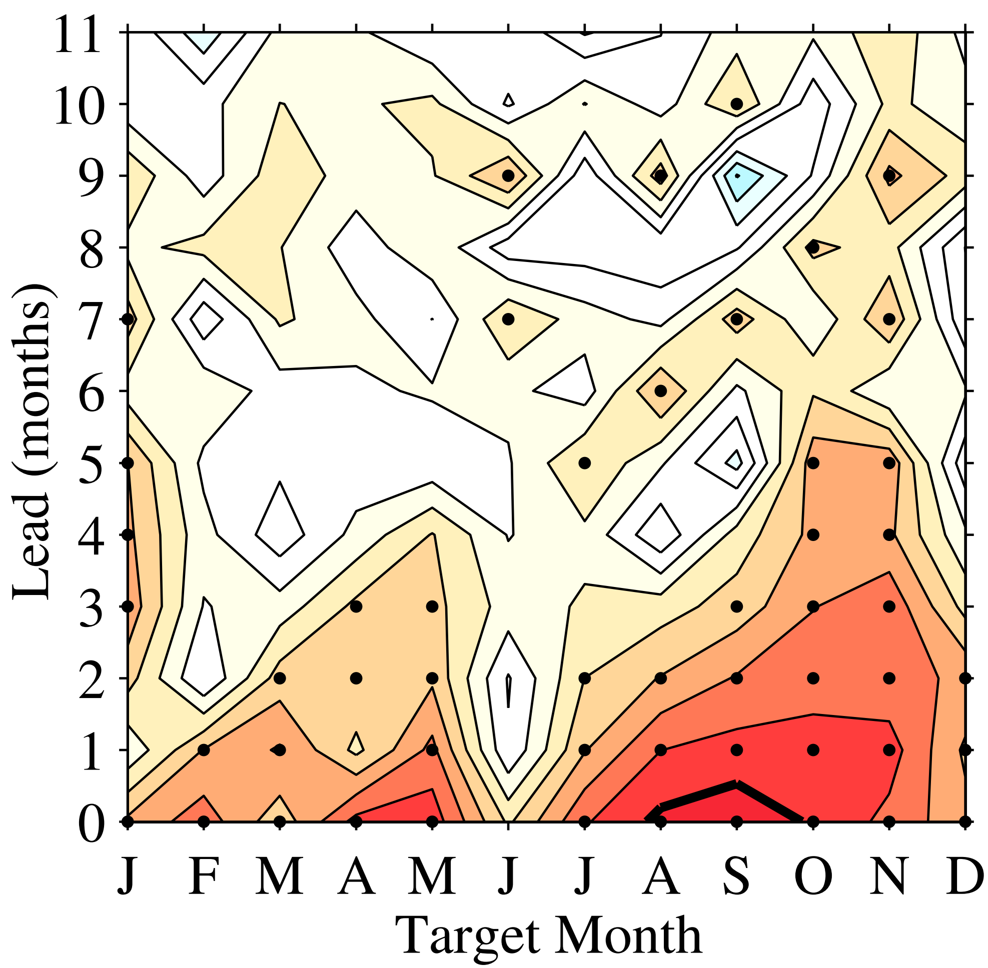
Target: September; Lead: 2



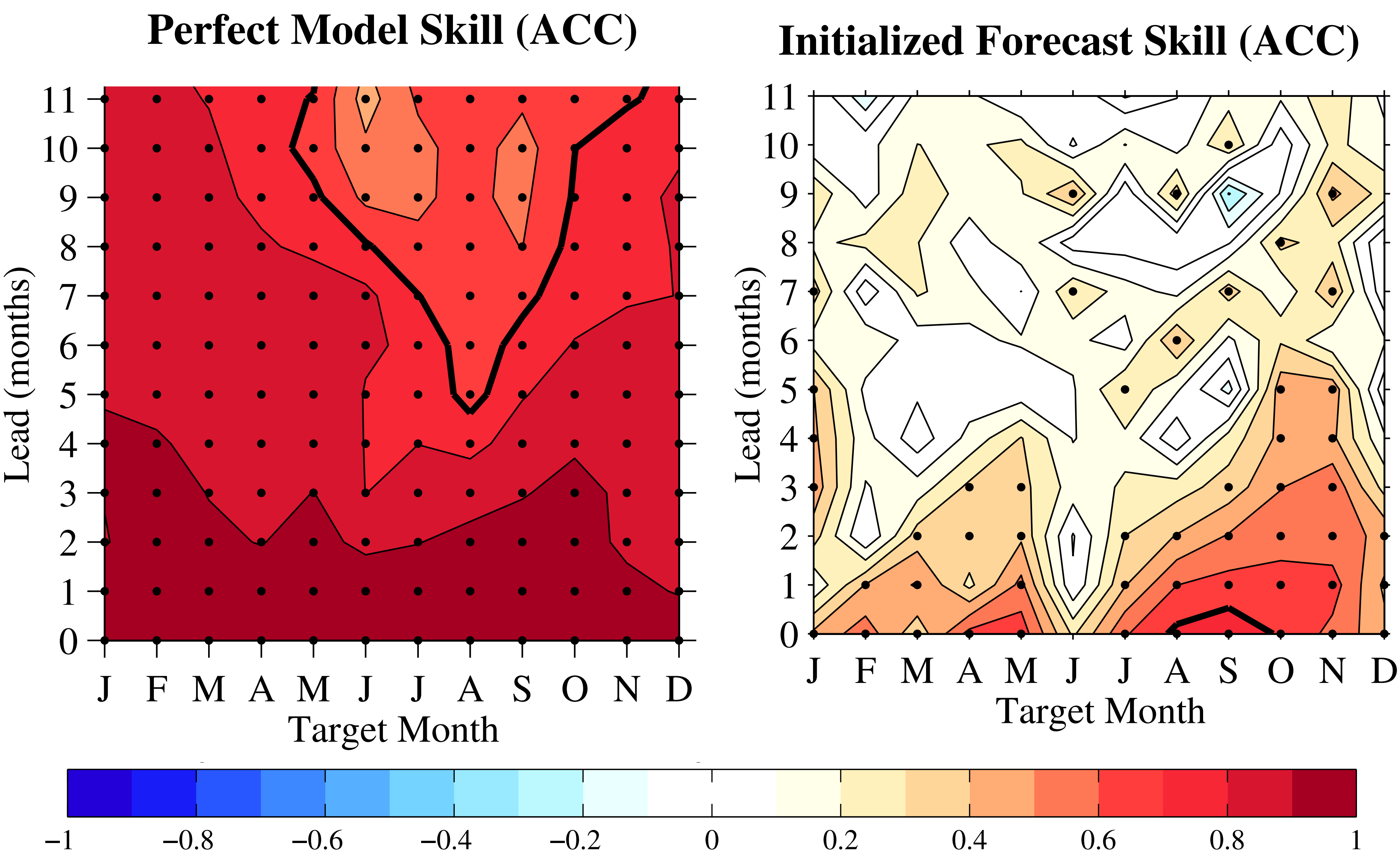
Detrended



Initialized Forecast Skill (ACC)



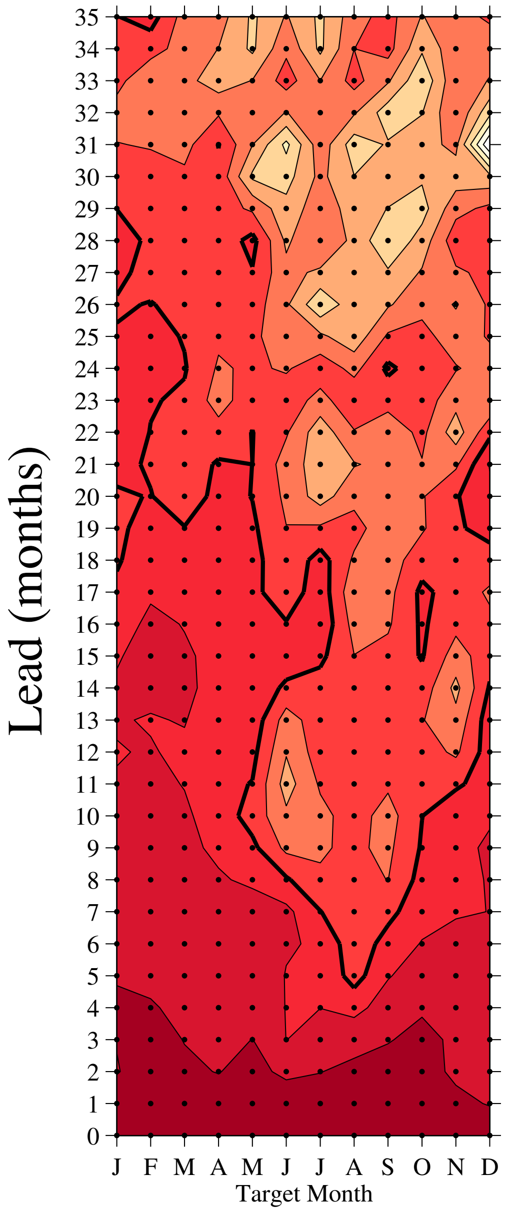
Comparison of Perfect Model and Operational Skill: Pan-Arctic SIE



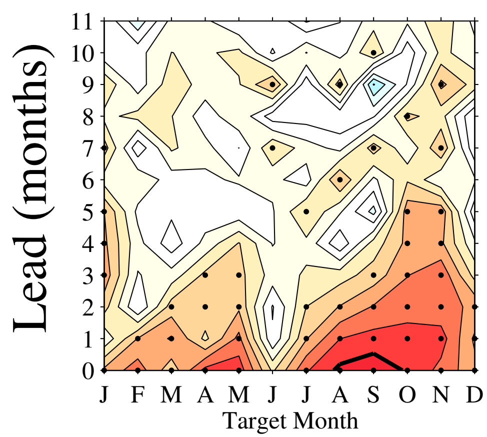
●: Statisically significant prediction skill

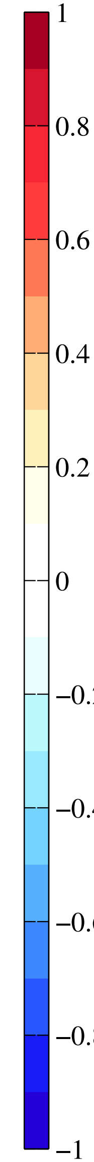
The Prediction Skill Gap: Pan-Arctic SIE

Perfect Model Skill (ACC)



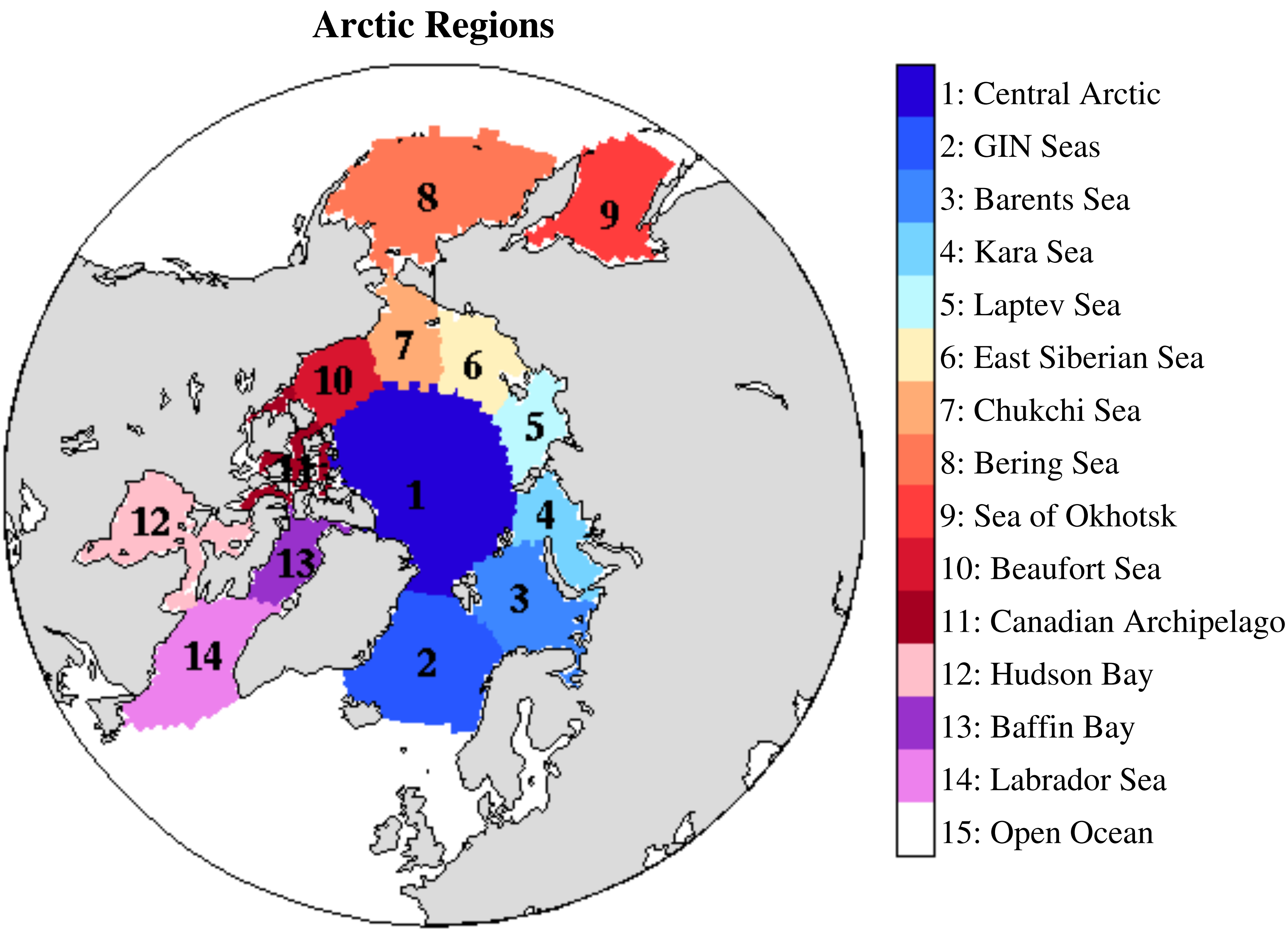
Initialized Forecast Skill (ACC)



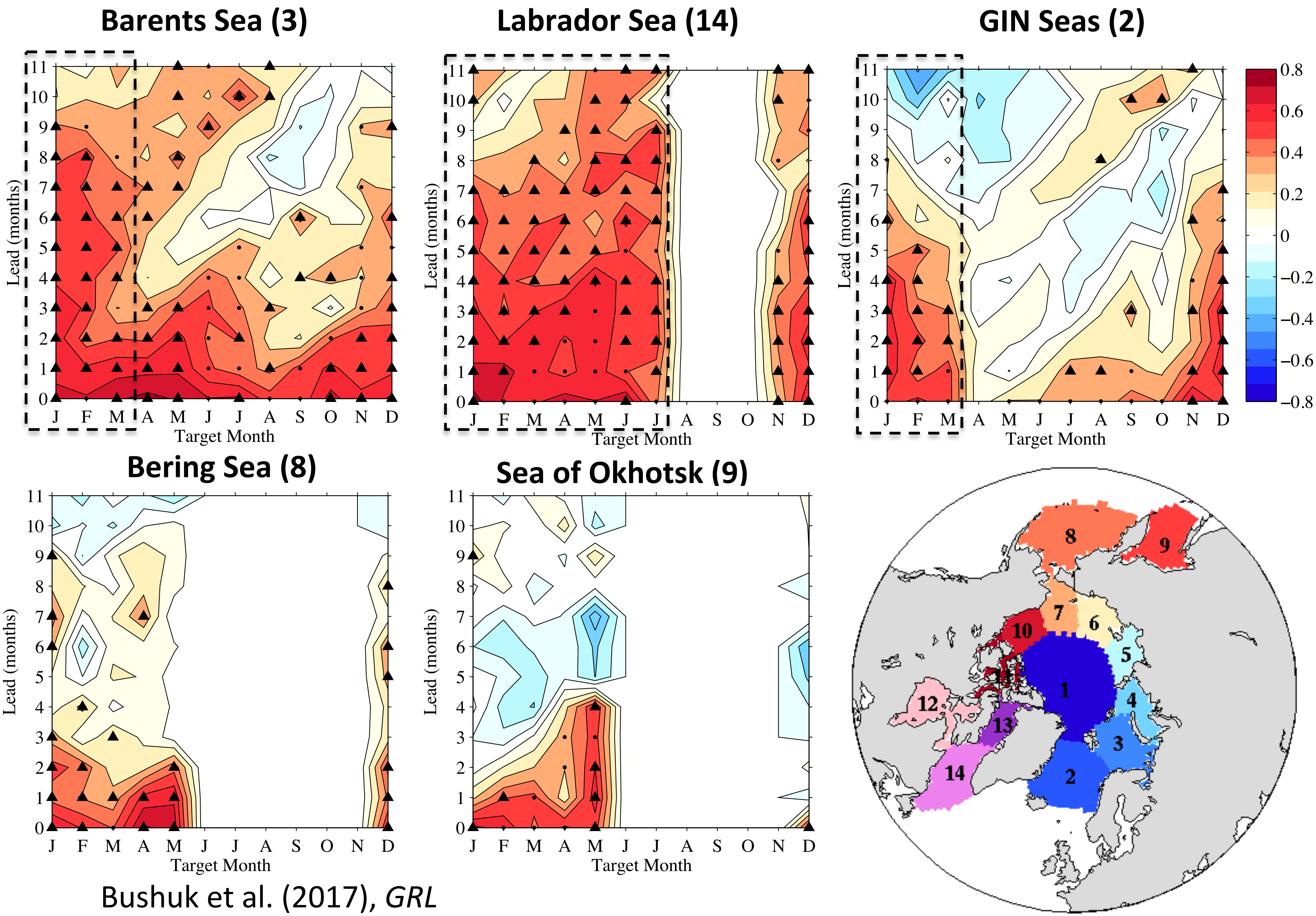


Black contour:
ACC=0.7

Regional Prediction Skill

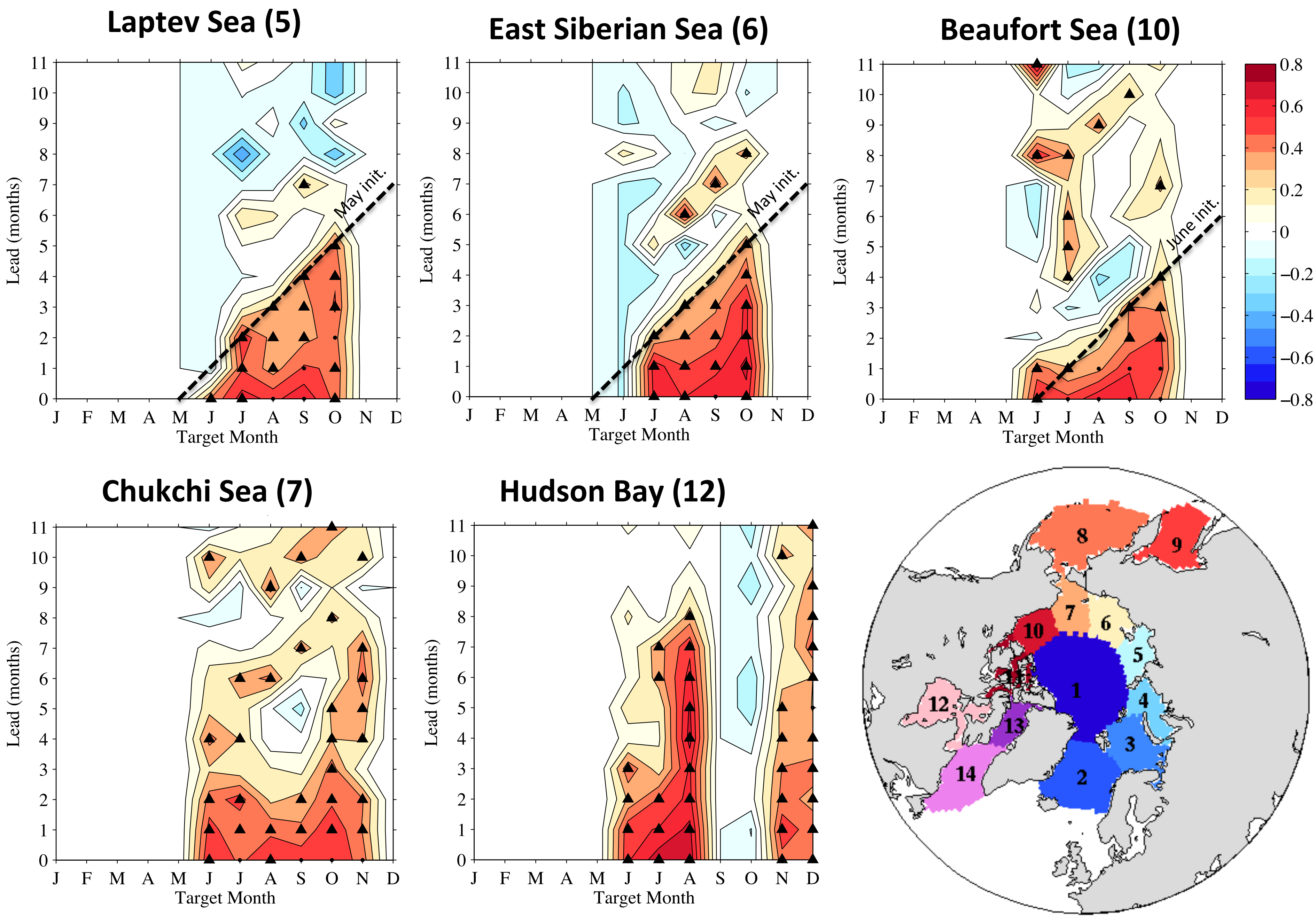


Operational Prediction Skill For Winter Ice Regions (Region # in parentheses)

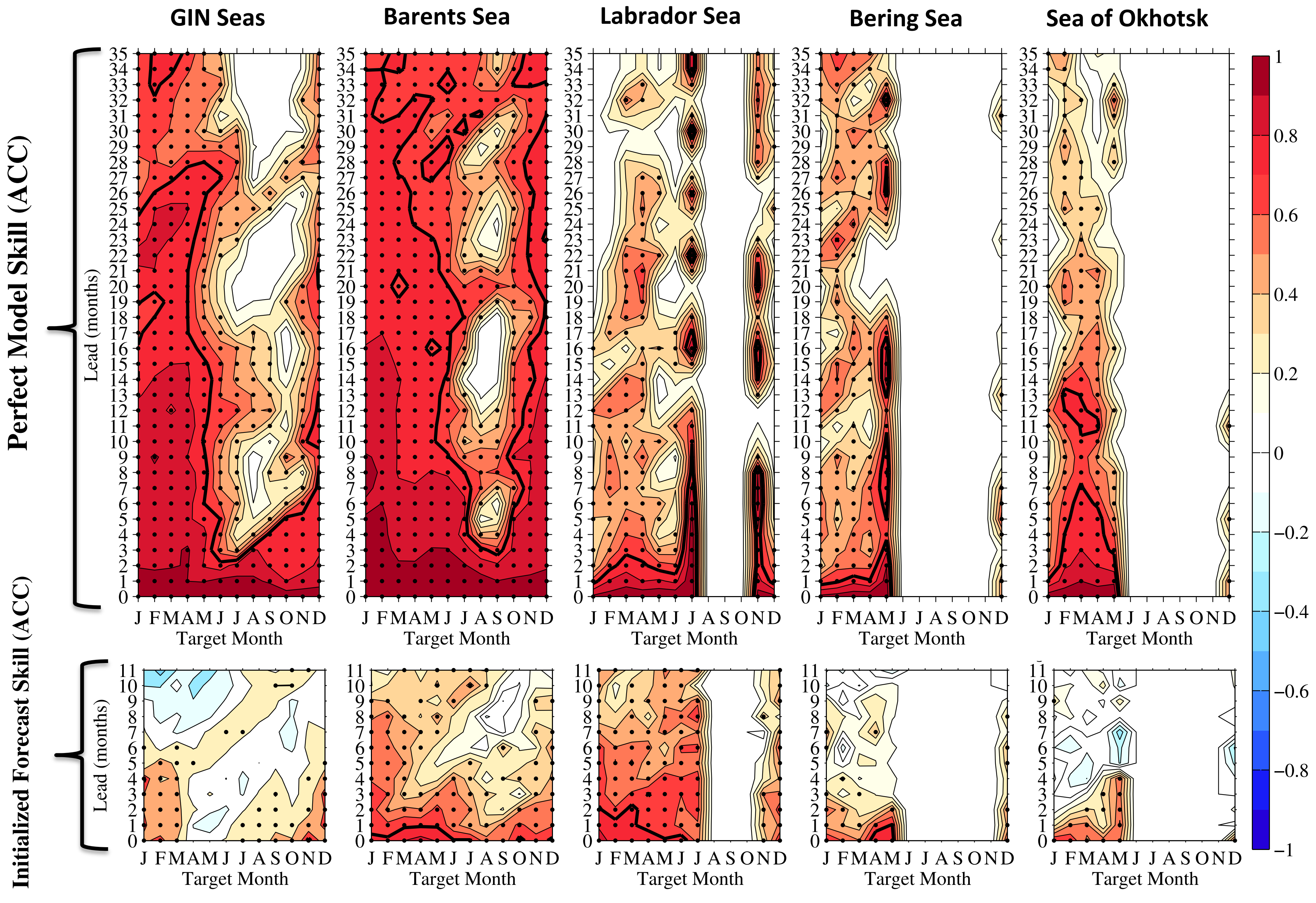


Bushuk et al. (2017), *GRL*

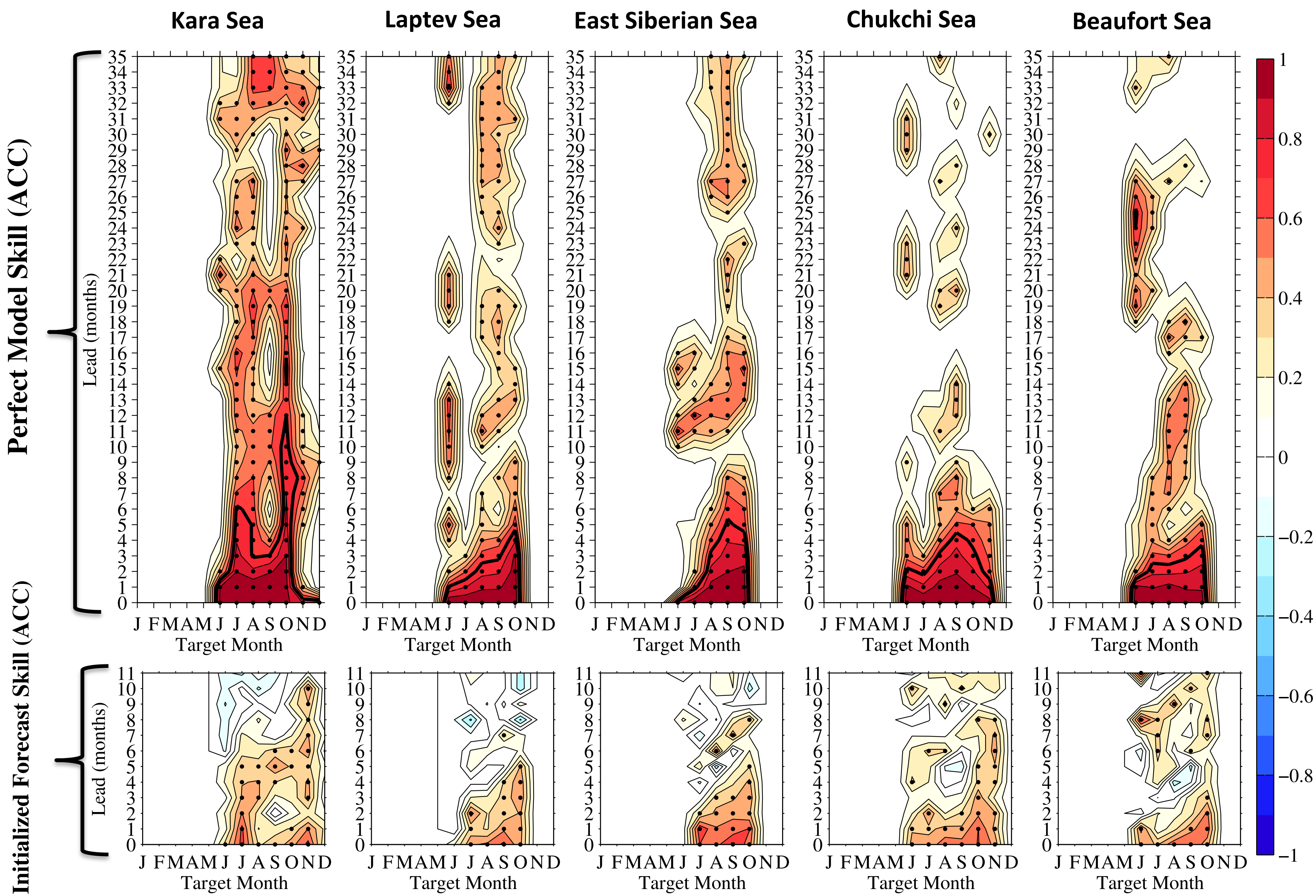
Operational Prediction Skill For Summer Ice Regions (Region # in parentheses)



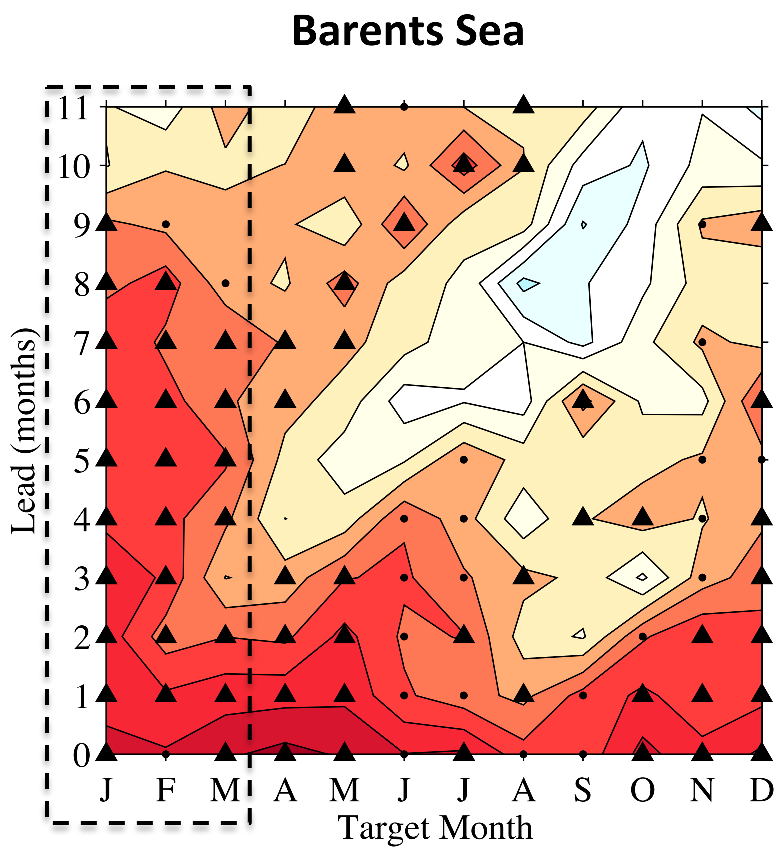
The Prediction Skill Gap: Regional Winter SIE

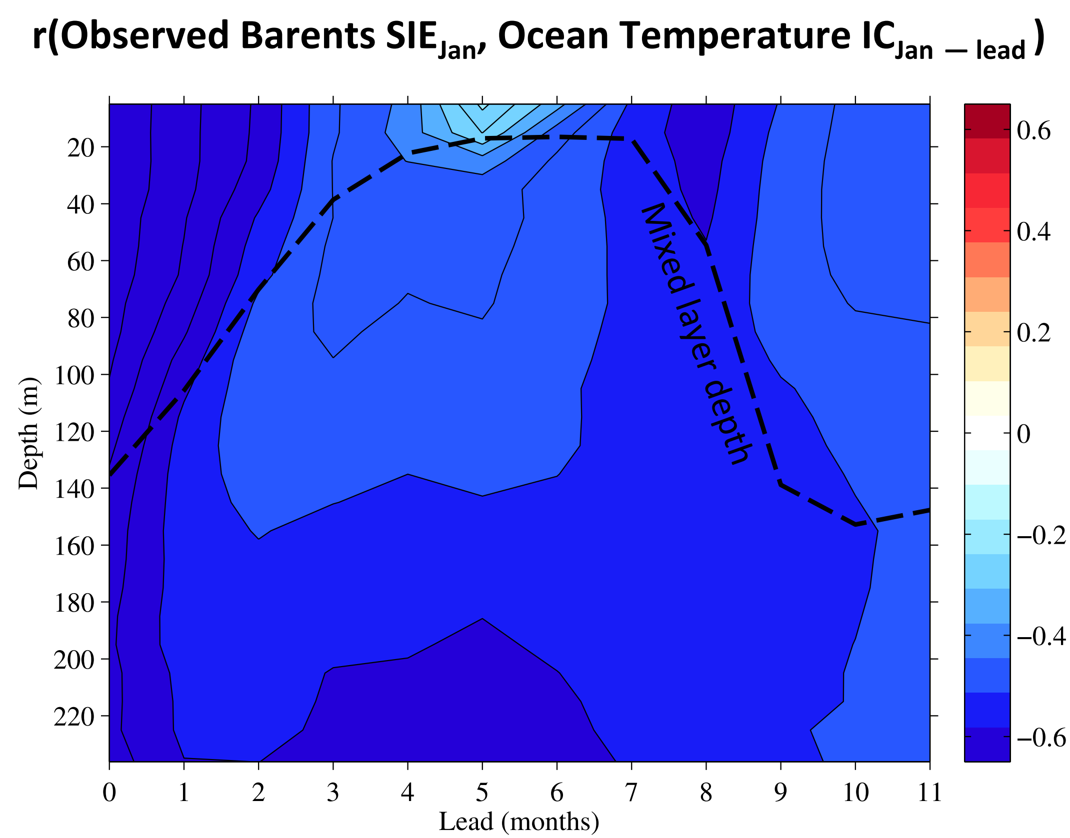


The Prediction Skill Gap: Regional Summer SIE



Sources of Winter Prediction Skill: Ocean Temperature Initialization





- Subsurface ocean temperature initialization provides key source of winter prediction skill
- Important skill improvements associated with assimilation of CTD and SST data

Conclusions

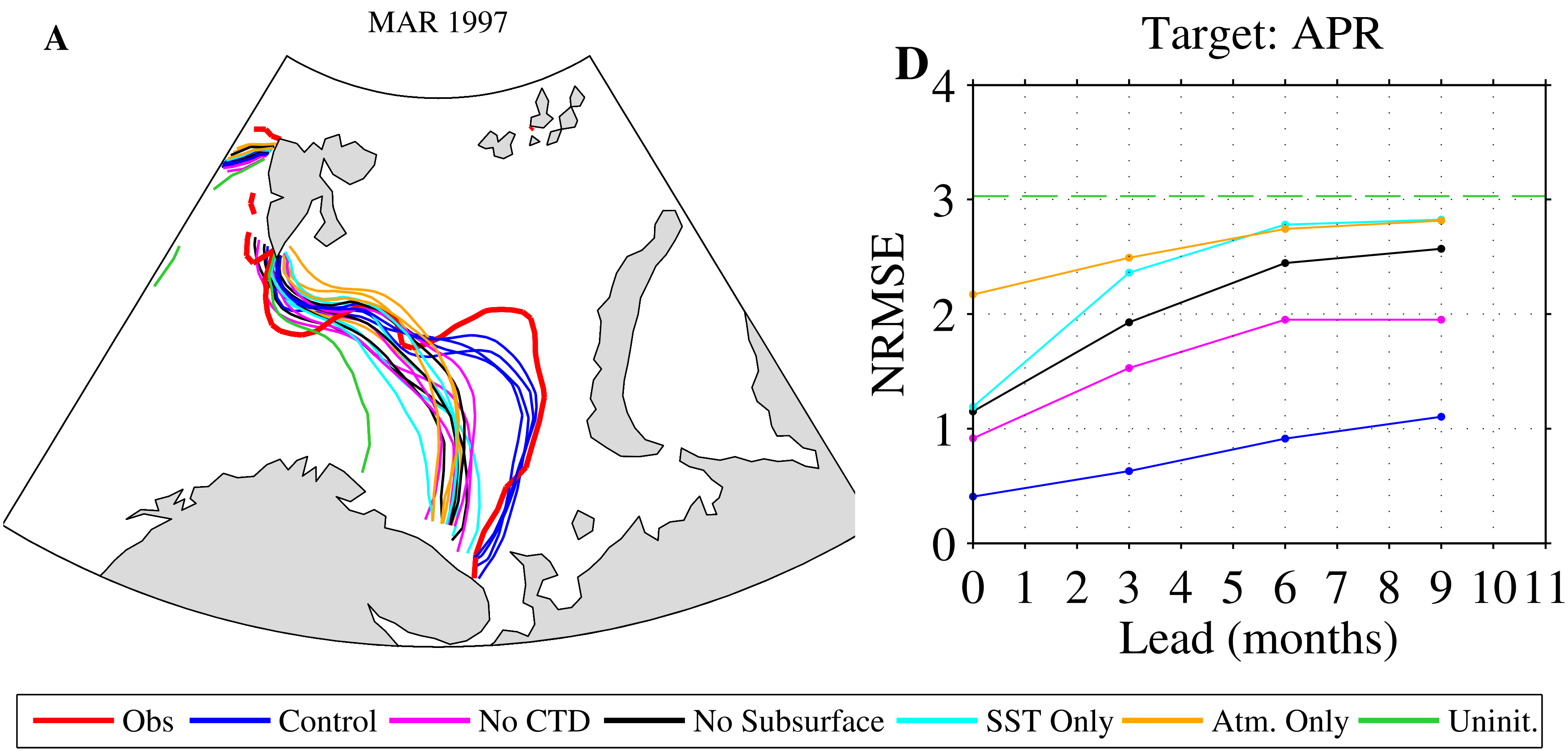
1. In nearly all Arctic regions, there is a large skill gap between perfect model and operational prediction skill
2. Highest regional SIE skill is found for North Atlantic regions; attributable to persistence of subsurface ocean temperatures
3. Summer SIE skill generally lower than winter SIE skill; some summer regions display May prediction skill barrier
4. Skill improvements are possible with improved subsurface ocean initialization and satellite-based sea-ice thickness initialization

Thank you!
Questions?

Contact me at: Mitchell.Bushuk@noaa.gov

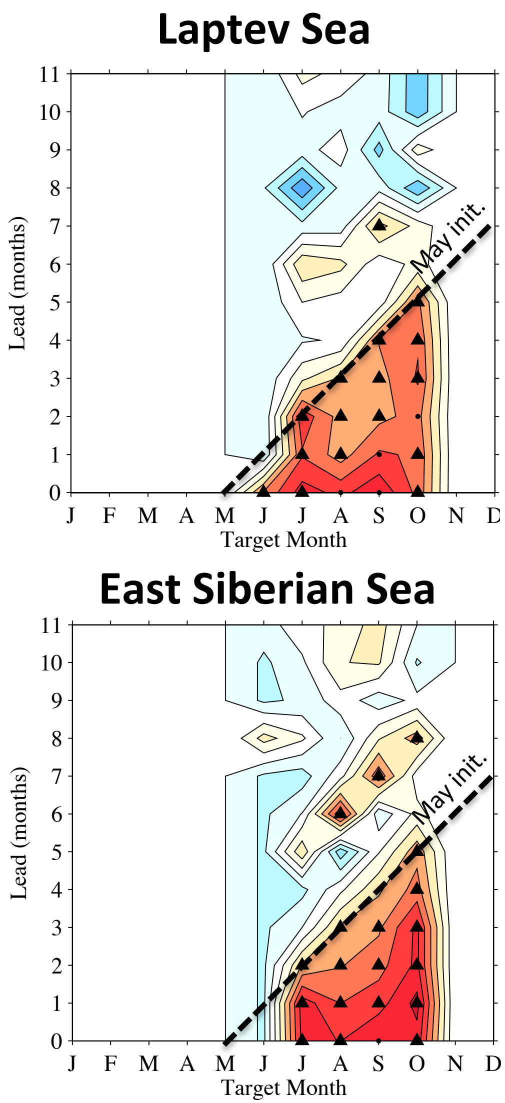
Appendix Slides

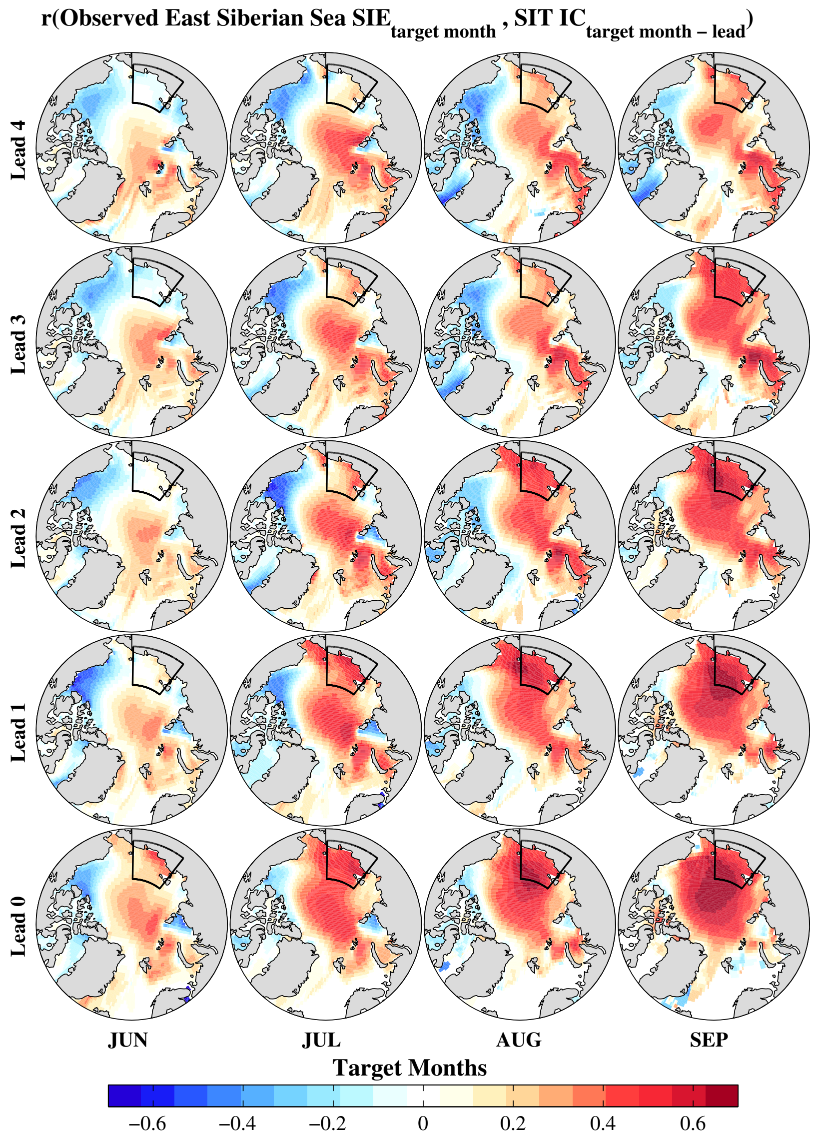
Barents Sea Prediction Skill: Surface vs Subsurface Data



- Observing System Experiments performed over 1995-2016
- Important skill improvements associated with assimilation of CTD and SST data

Sources of Summer Prediction Skill: Sea Ice Thickness Initialization



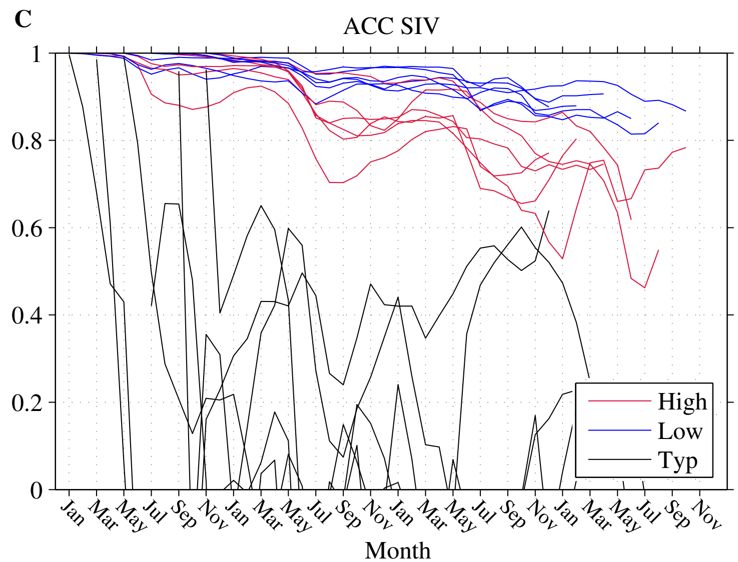


- Laptev and East Siberian Seas have spring prediction skill barrier: Predictions initialized May 1 and later are skillful; those initialized prior to May 1 are not
- Sea ice thickness initialization provides key source of summer prediction skill

Perfect model skill metrics

- Perfect model ACC is state dependent; can be biased by start date sampling

$$ACC(\tau) = \frac{\sum_{j=1}^{M}\sum_{i=1}^{N}\Big(\langle \mathbf{x}_{\hat{i}j}(\tau)\rangle - \mu(\tau)\Big)\Big(x_{ij}(\tau) - \mu(\tau)\Big)}{\sqrt{\sum_{j=1}^{M}\sum_{i=1}^{N}\Big(\langle \mathbf{x}_{\hat{i}j}(\tau)\rangle - \mu(\tau)\Big)^2}\sqrt{\sum_{j=1}^{M}\sum_{i=1}^{N}\Big(x_{ij}(\tau) - \mu(\tau)\Big)^2}}.$$



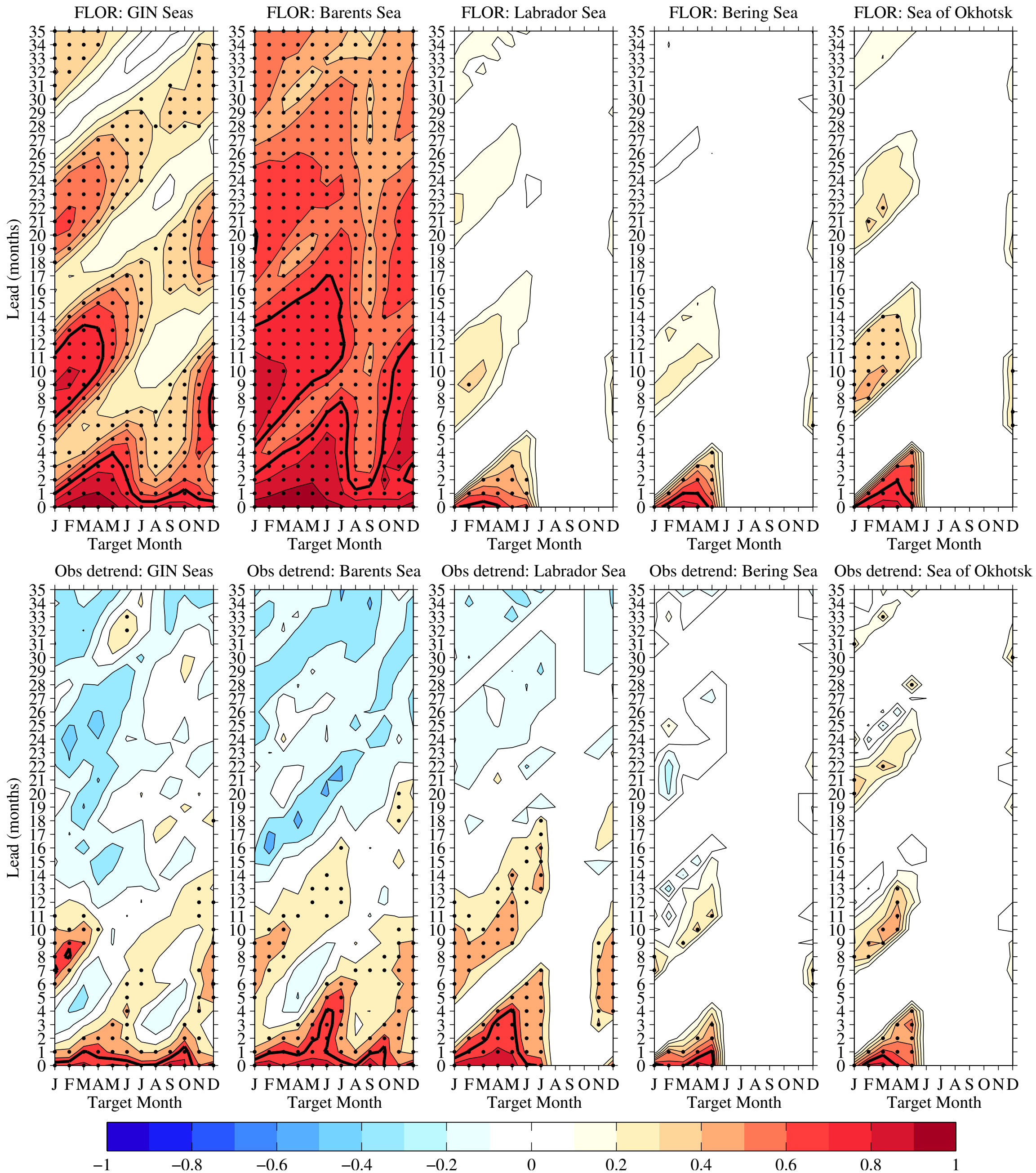
- Perfect model RMSE of Collins et al. (2002) not directly comparable to operational RMSE

$$RMSE_{PM} = \sqrt{2}RMSE_{OP}$$

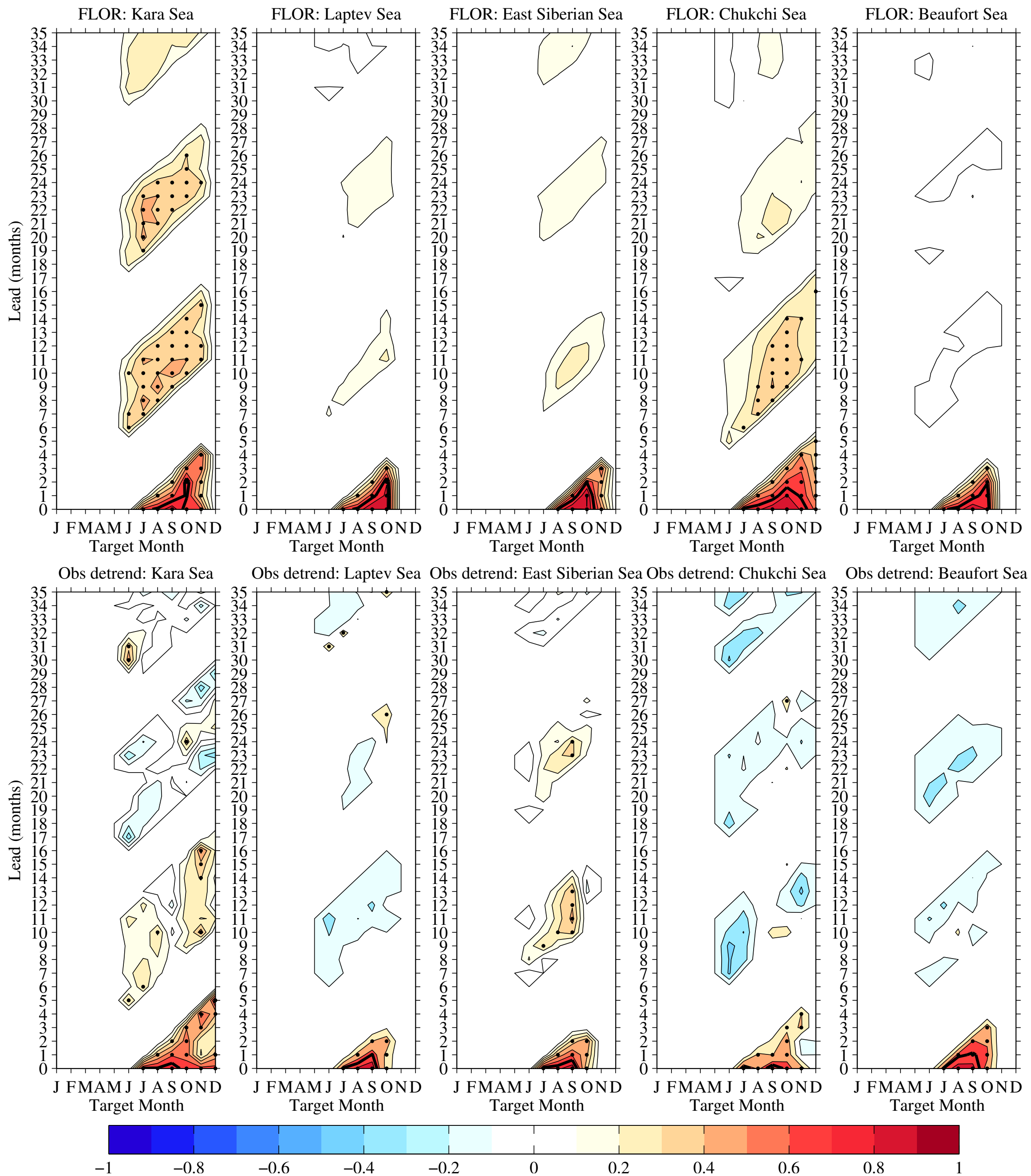
- We define RMSE and an "unbiased ACC" which can be directly compared to operational RMSE and ACC.

$$ACC_U = \sqrt{MSSS}.$$

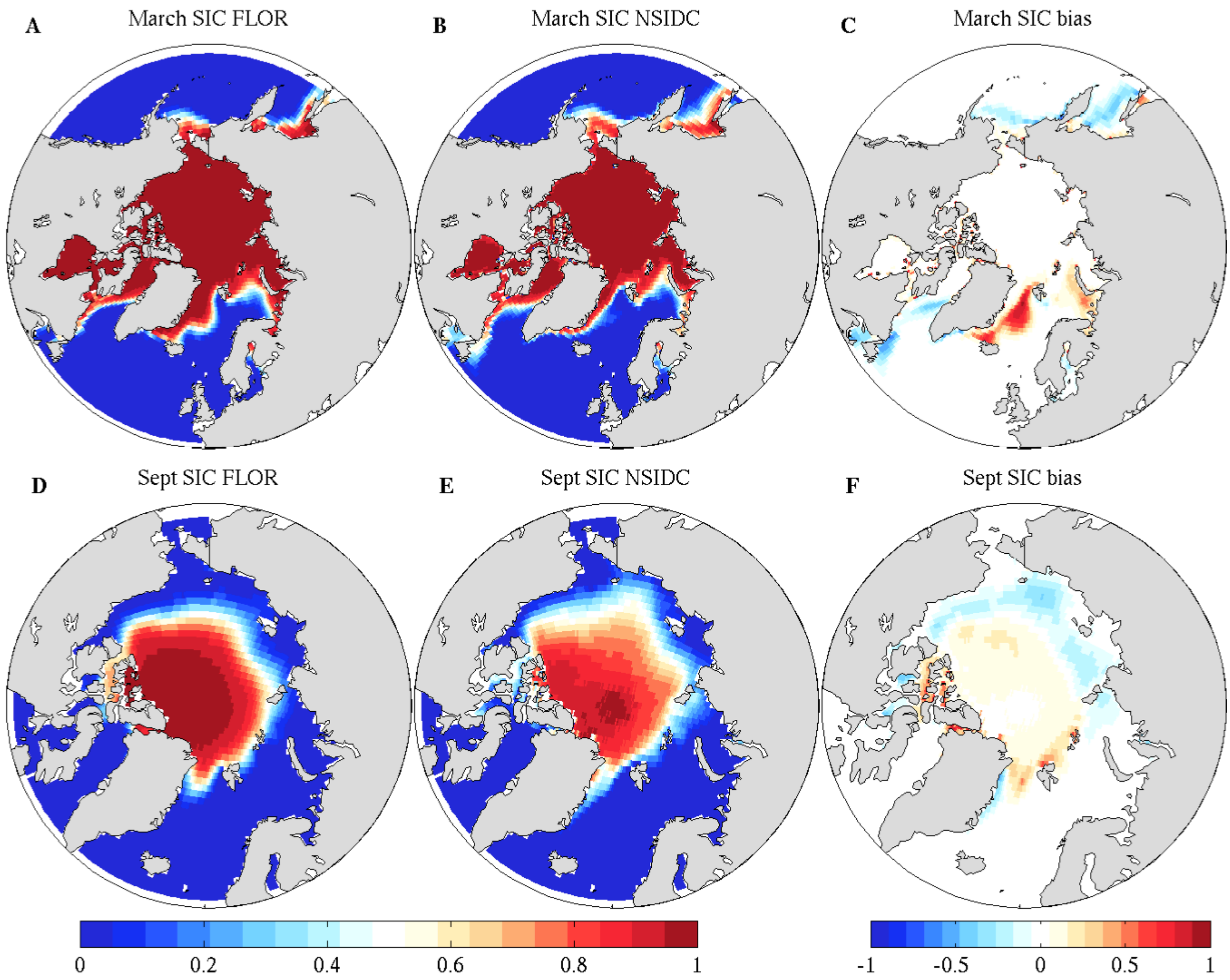
Comparison of SIE Autocorrelation: Winter SIE regions



Comparison of SIE Autocorrelation: Summer SIE regions



FLOR SIC Climatological Biases



FLOR SIC Variability Biases