

The First Decade of Seasonal Sea Ice Predictions

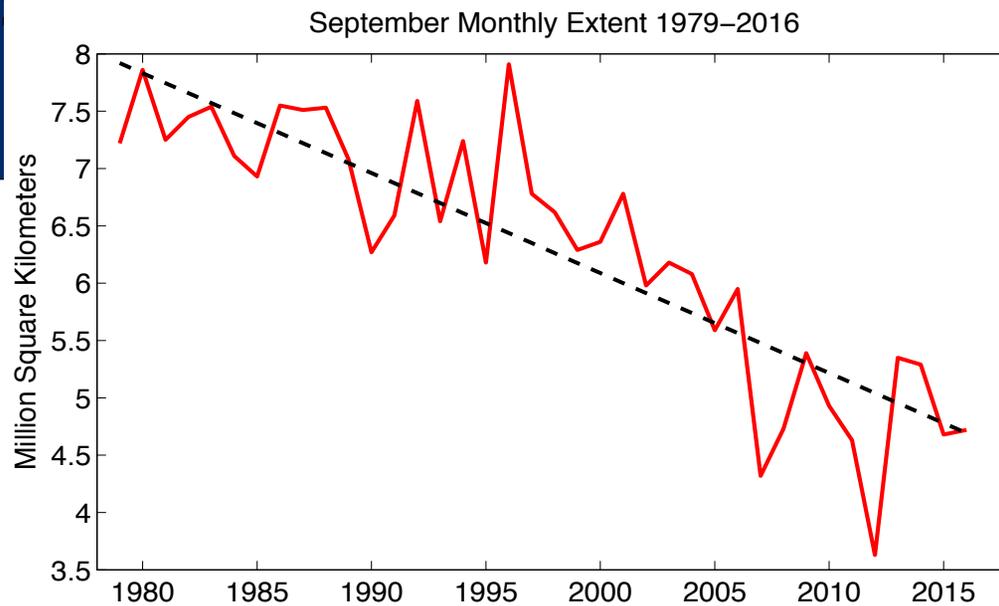
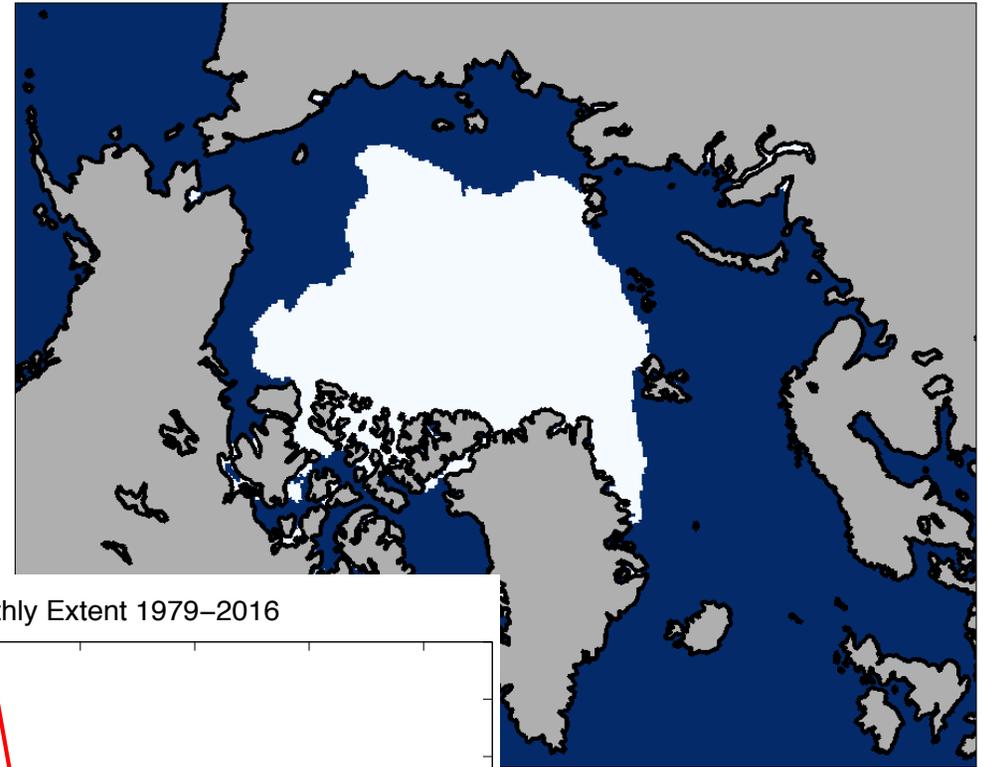
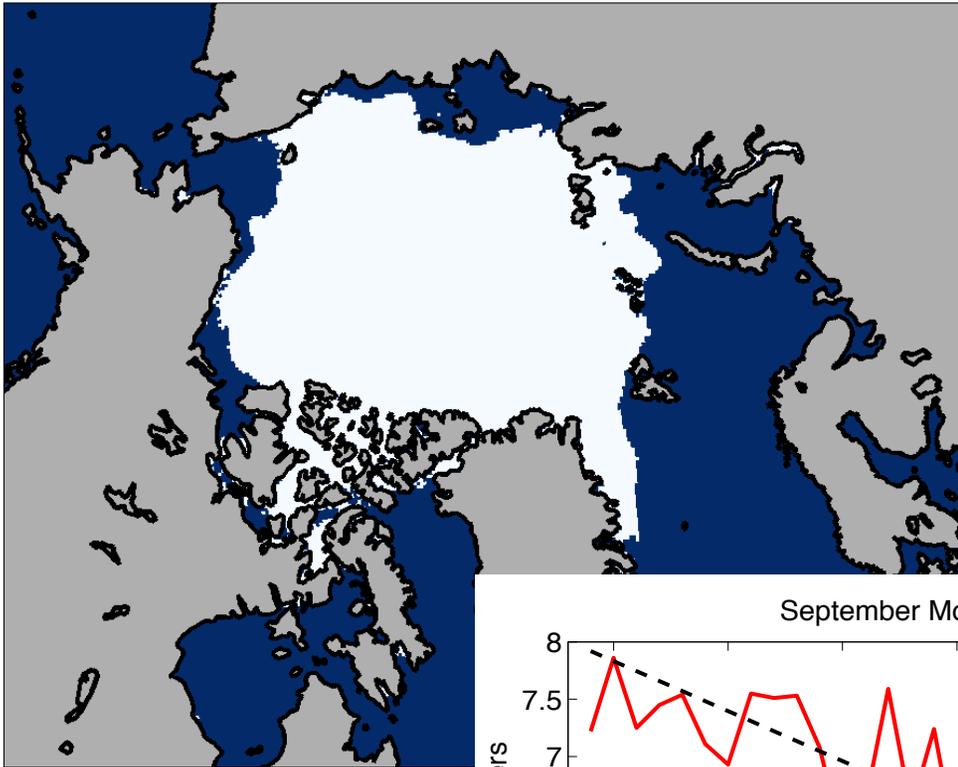
Cecilia Bitz,
Eduardo Blanchard-Wrigglesworth
and Yongfei Zhang
University of Washington
and the **Sea Ice Prediction Network**



September Arctic Sea Ice Extent

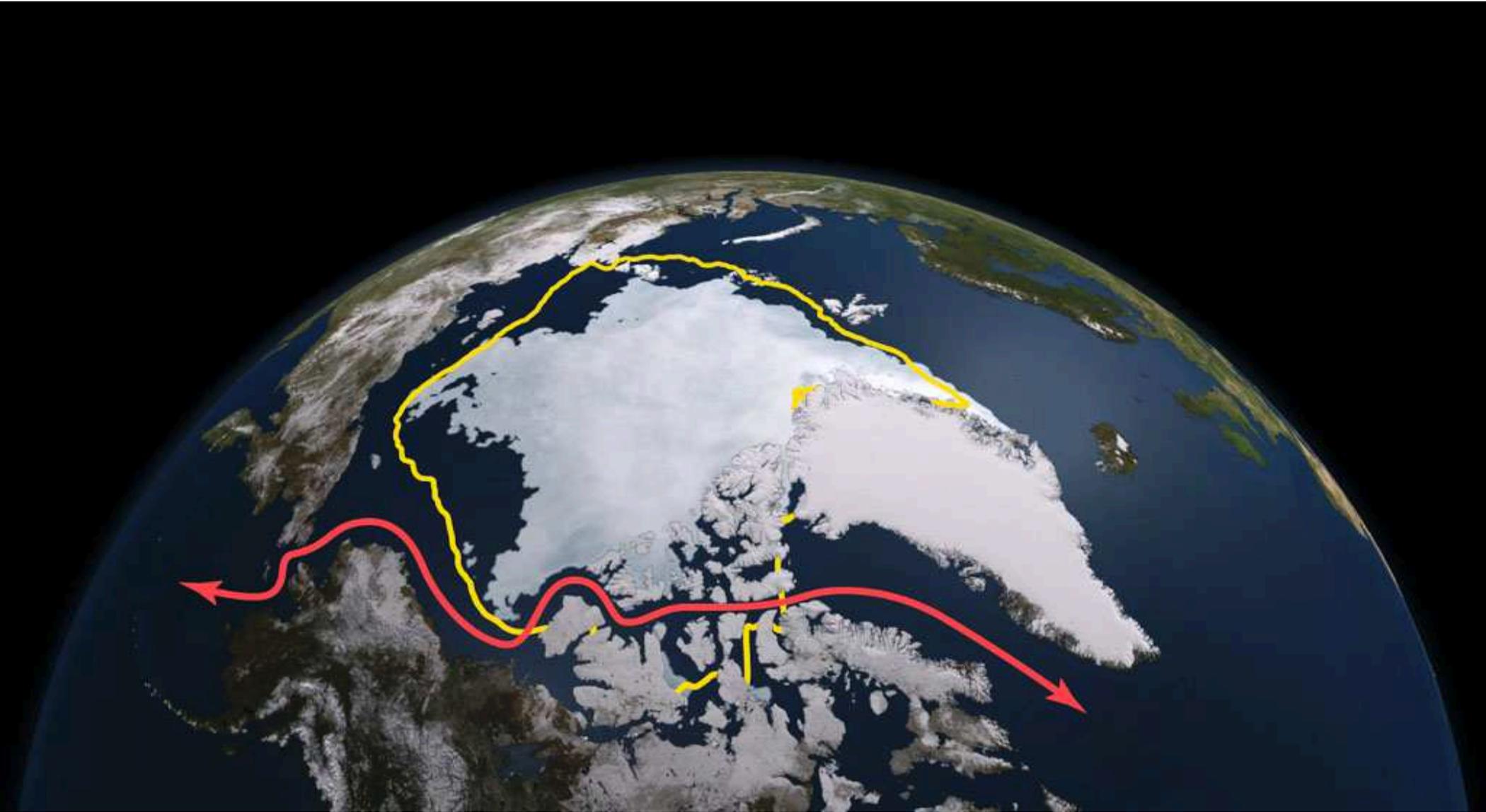
1979-1988

2005-2014



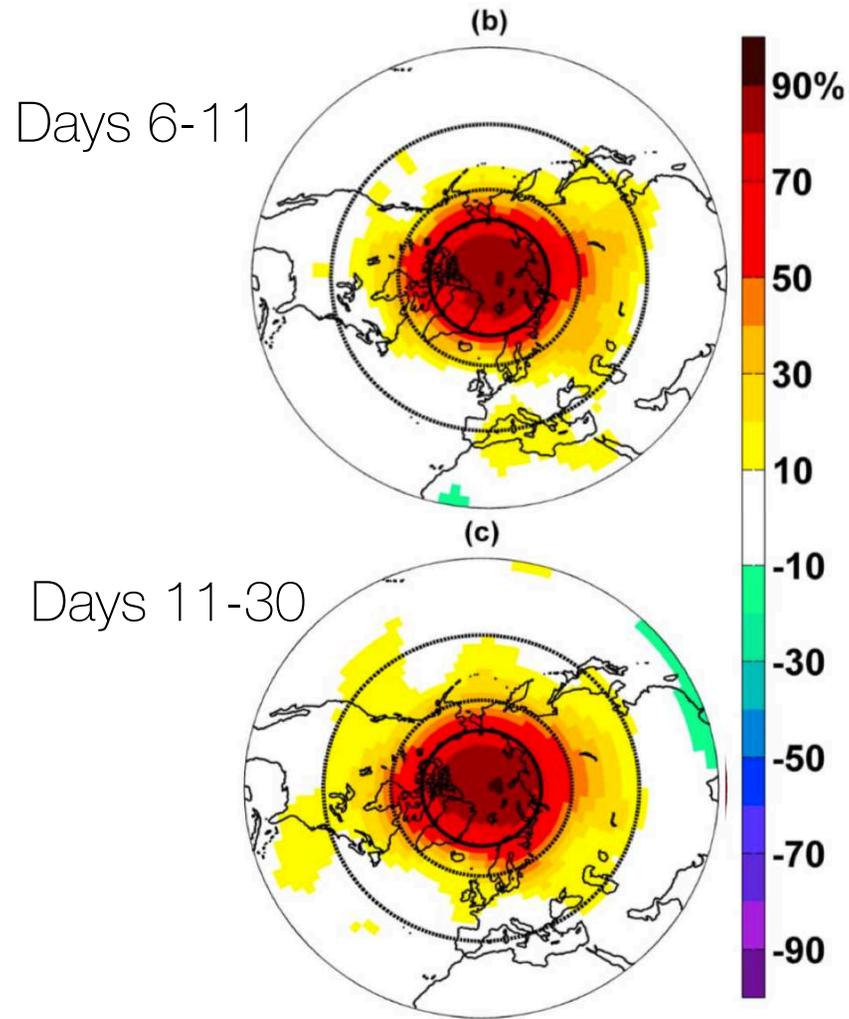
**~50%
reduction**

Forecasting for Sea Ice Use

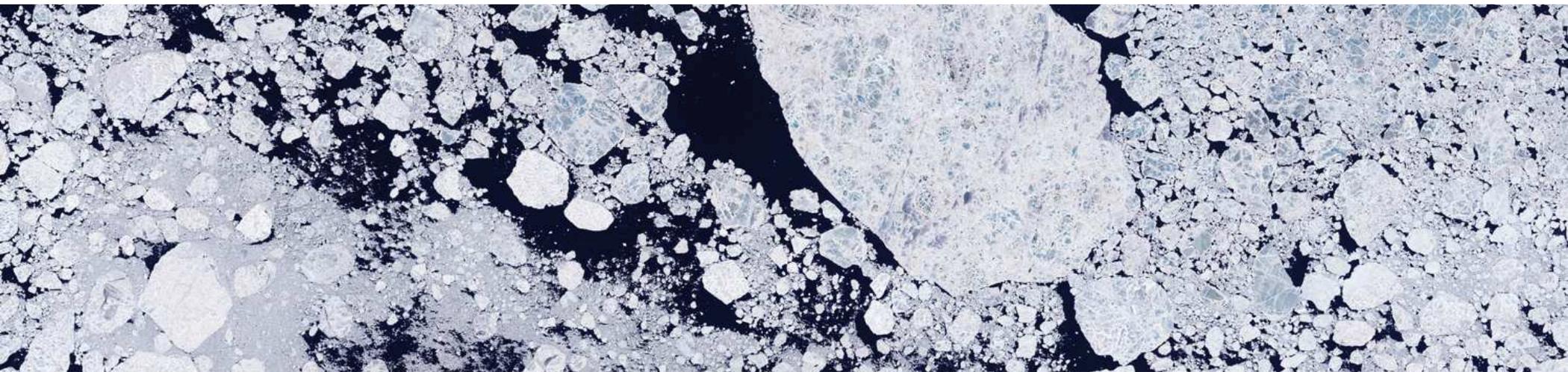


Forecasting the Arctic improves atmospheric forecast skill in lower latitudes

% reduction in
RMSE of Z500
forecast



Jung et al (2014)



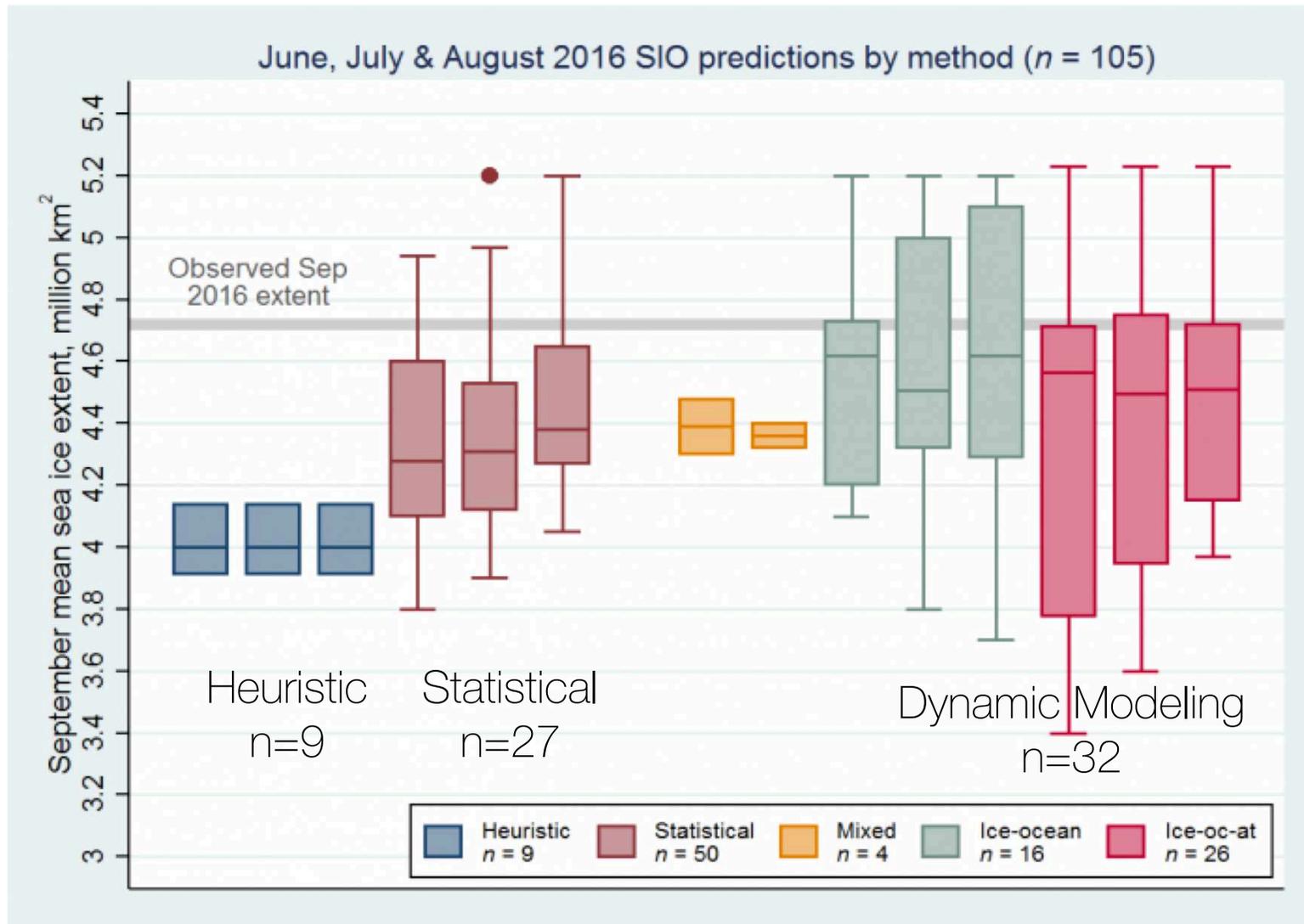
How does sea ice prediction effort compare to weather?

Earliest sea ice forecasts from dynamic or statistical methods started about a decade ago

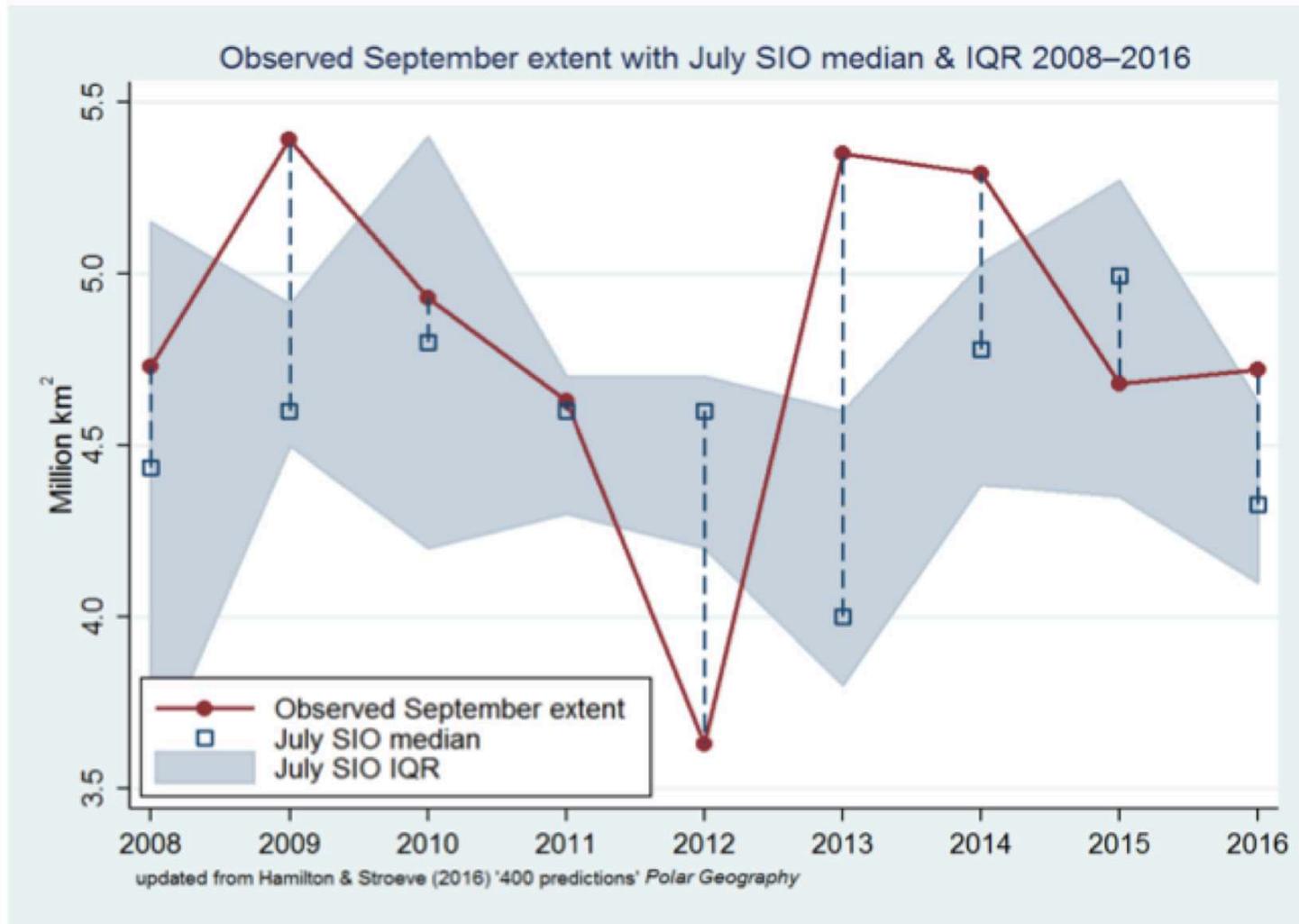
Ice charts have been around longer. Charting centers may consult a forecast model in a product they call an outlook, but most of the content is observational.

Yet sea ice modeling began much earlier. Norbert Untersteiner 1961 and William Hibler 1979. Used for climate prediction since Manabe and Stouffer 1980. Yet not used for sea ice forecasting until ~2008

The Sea Ice Outlook – Last Year

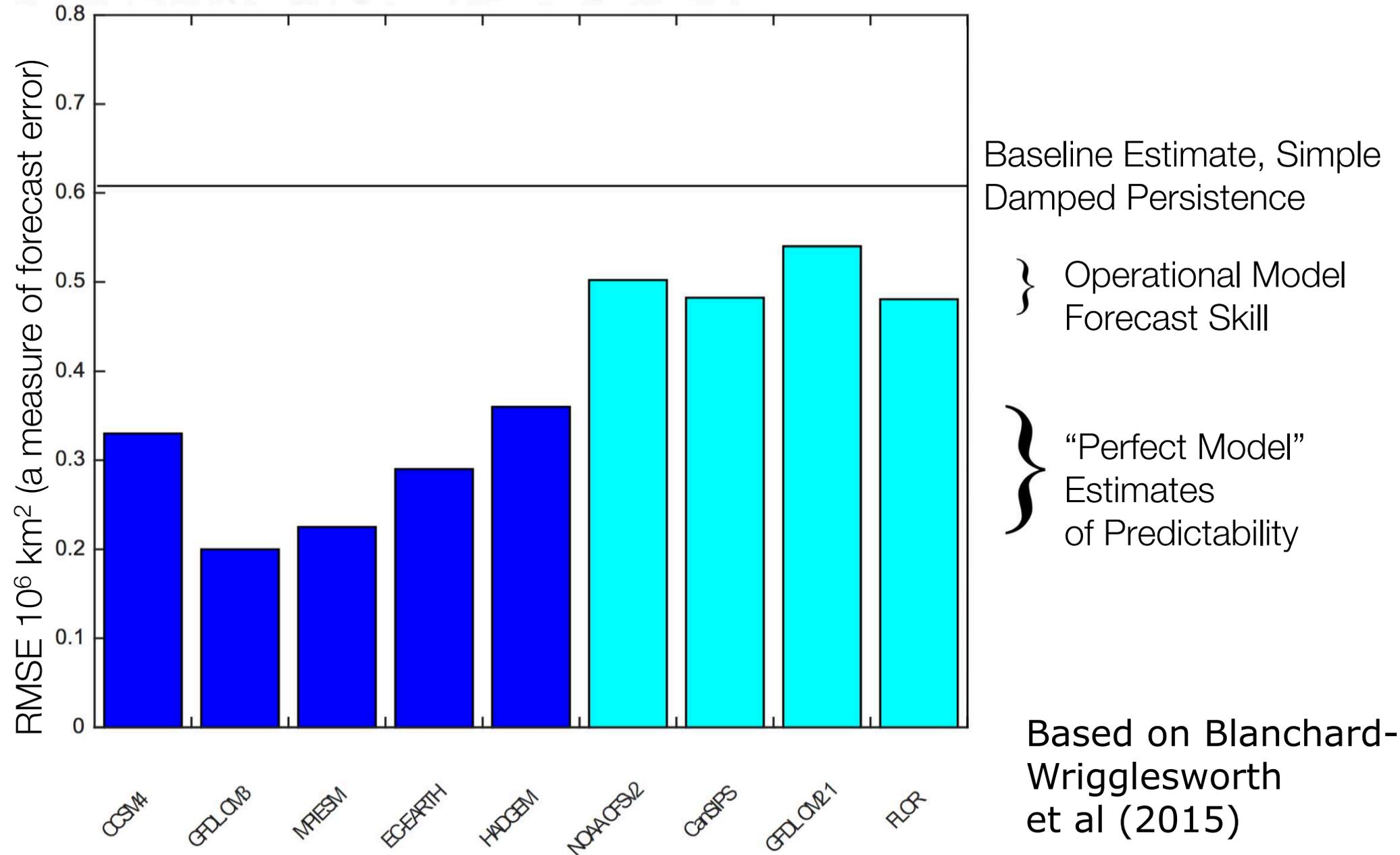


The Sea Ice Outlook - how well are we doing?



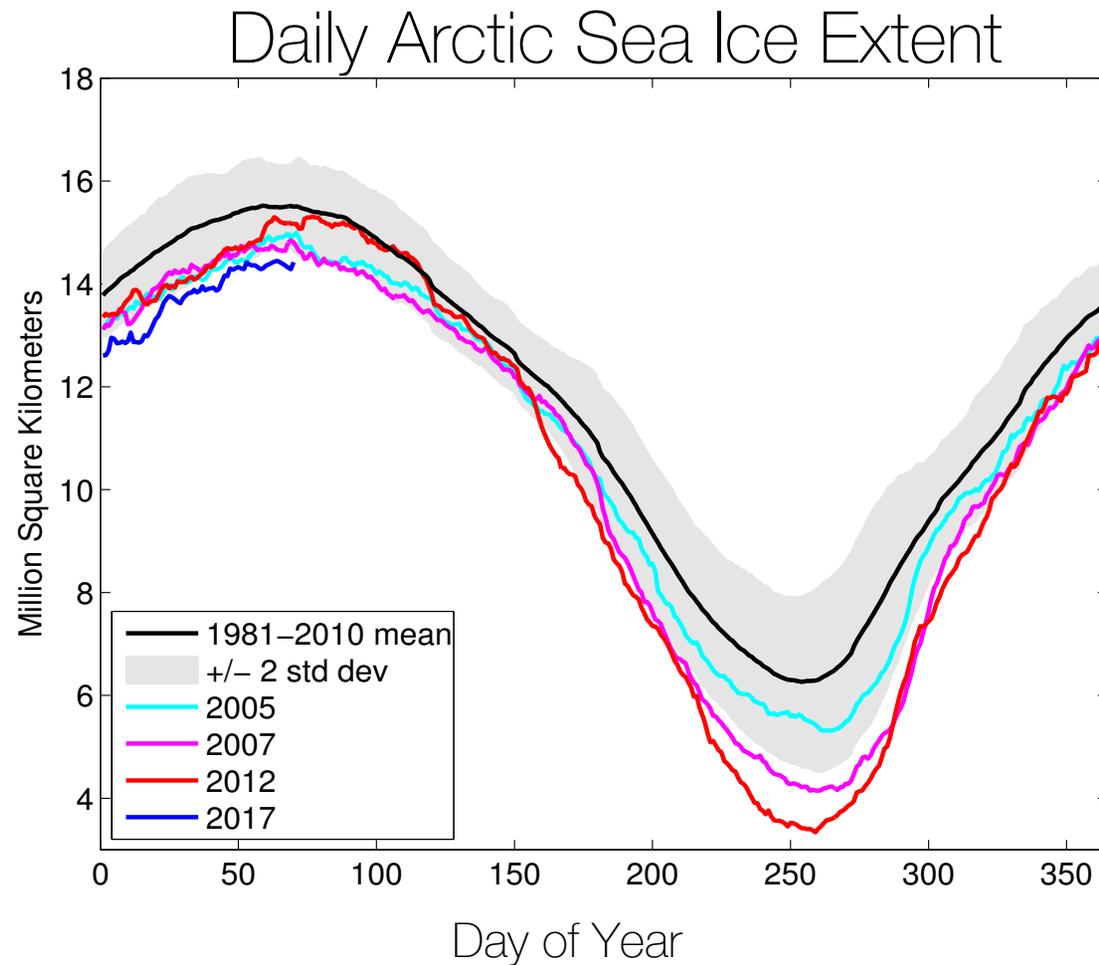
Updated Hamilton & Stroeve (2016)

Gap in Forecast Skill – For Arctic Extent Published in Literature (for this metric, higher values are low skill)



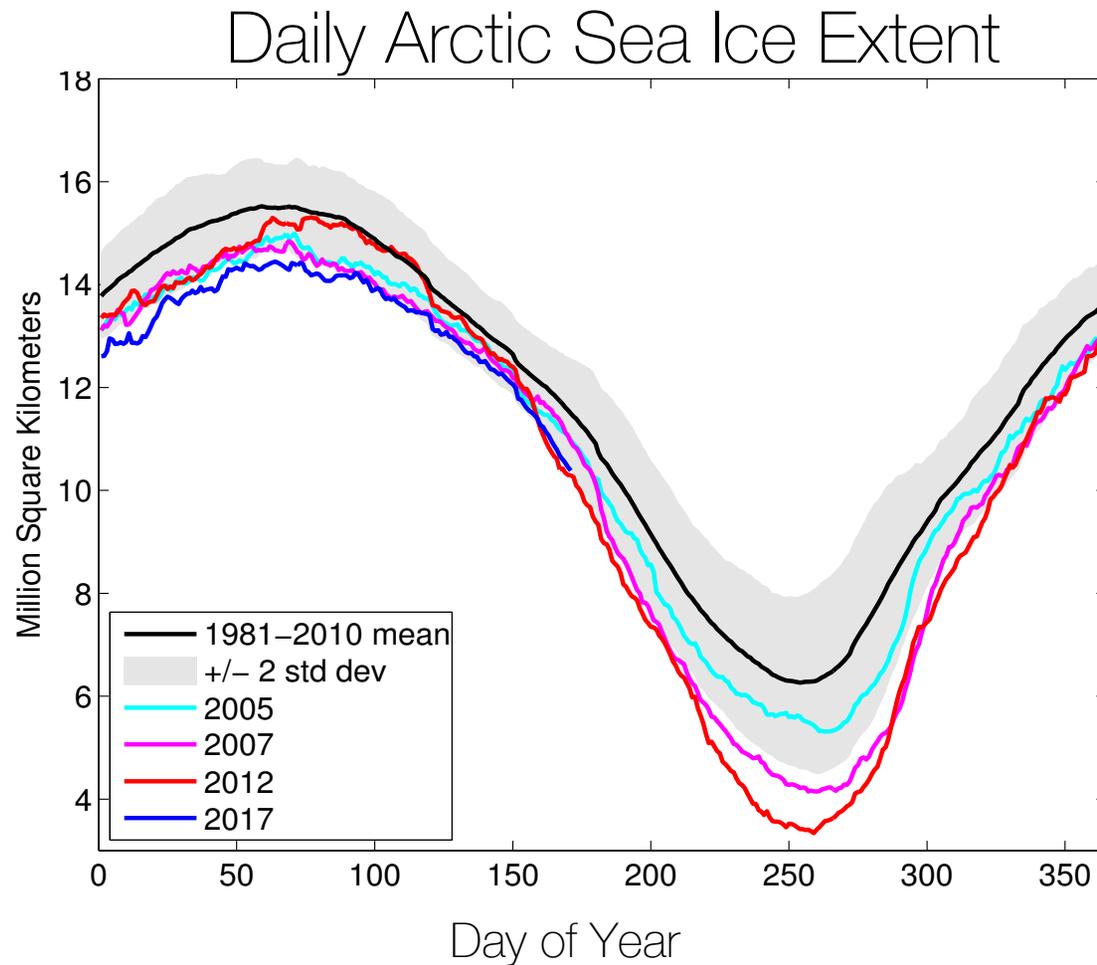
What makes sea ice predictable?

Initial extent is only moderately informative



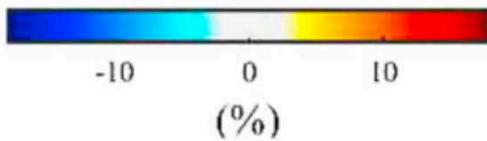
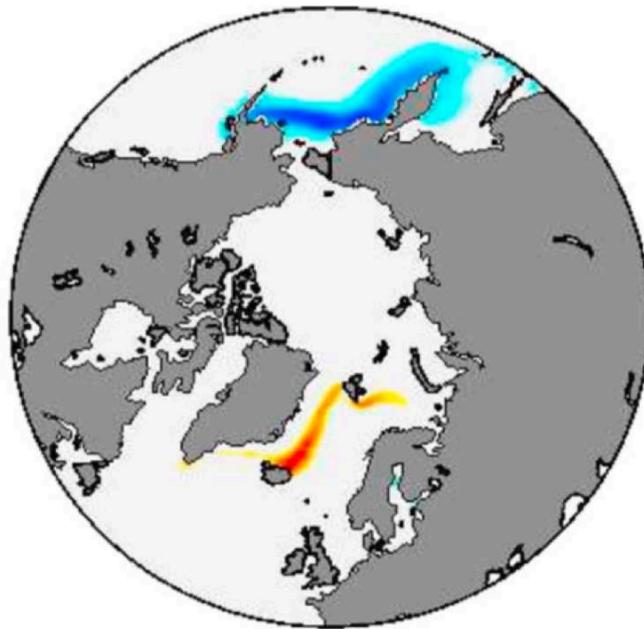
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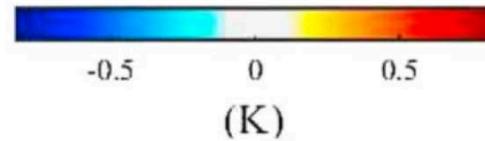
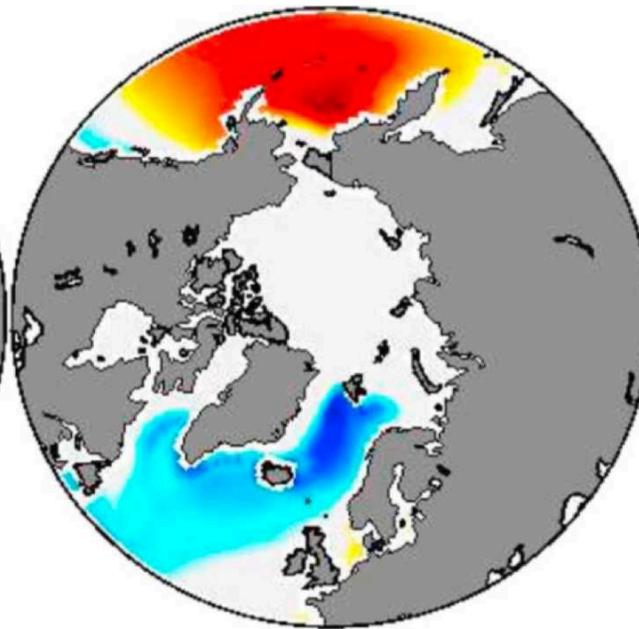


SST and Sea Ice Covary

Concentration



SST

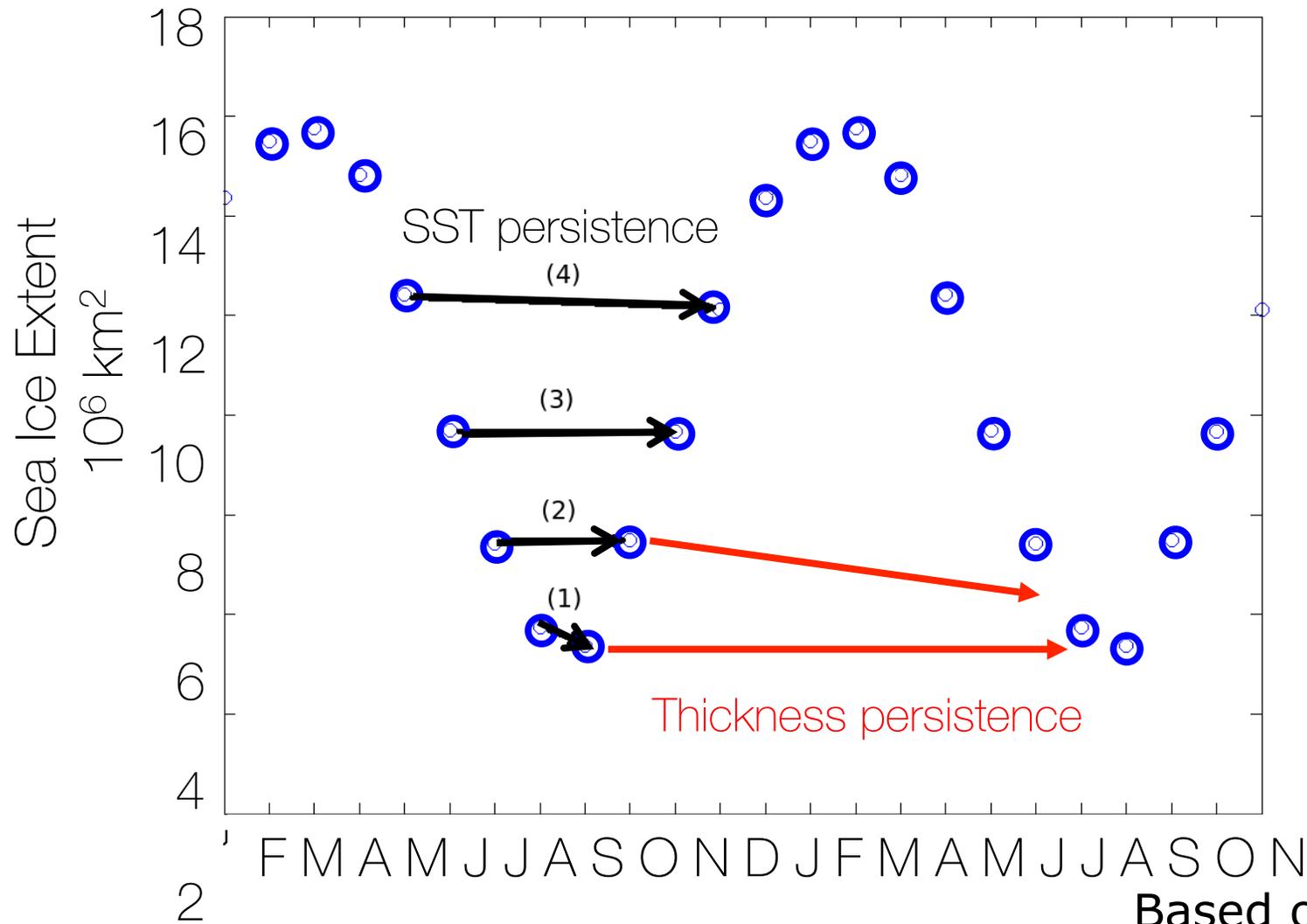


Sea ice anomalies leave behind SST in spring/summer as ice edge retreats into the Arctic. In fall ice edge encounters SST anomalies again.

Bushuk et al (2015), also found to covary with SLP

Sea ice persistence cartoon:

Persistence of SST and thickness anomalies enhance predictability of extent in certain seasons

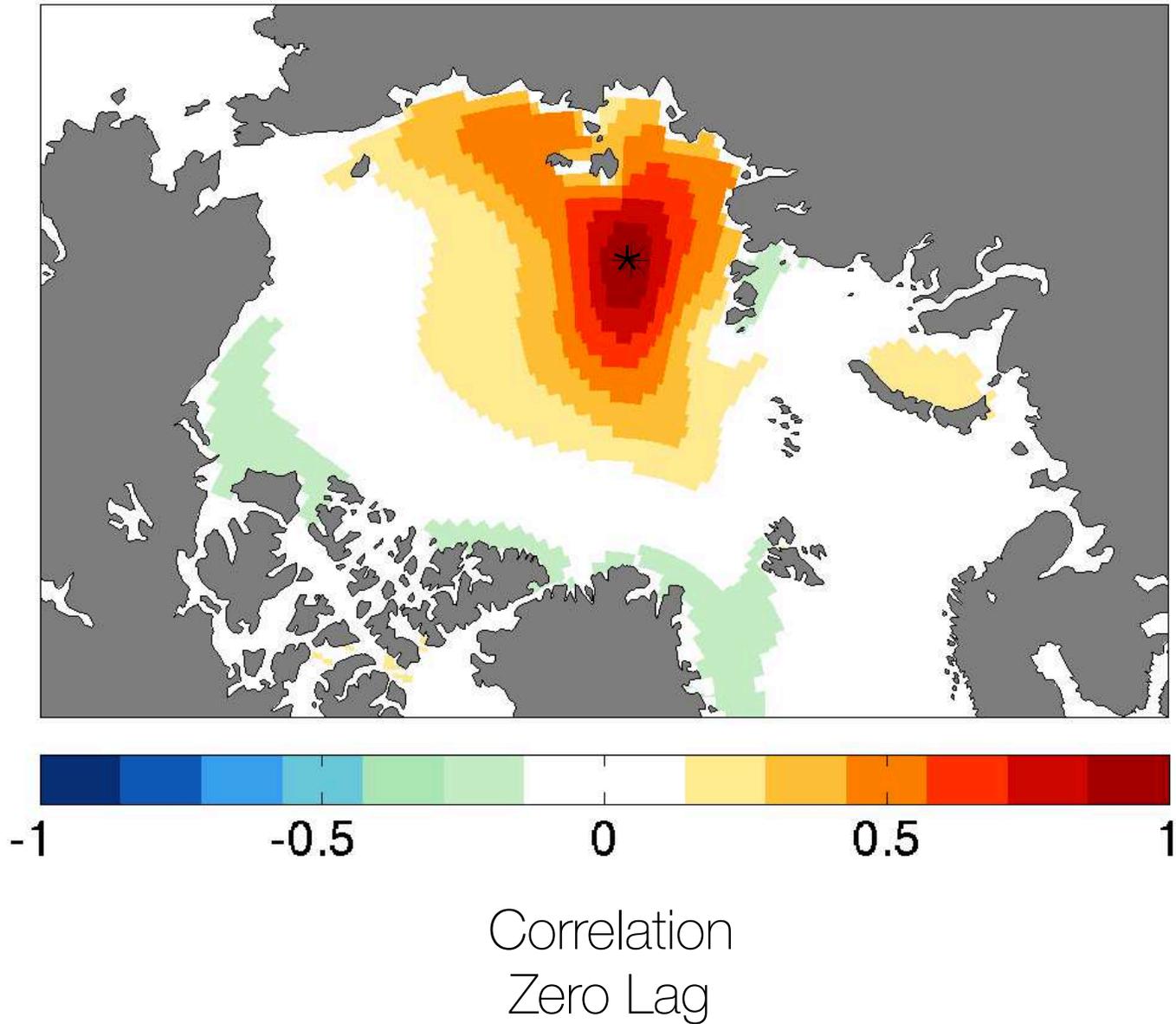


Based on Blanchard-Wrigglesworth et al (2011)

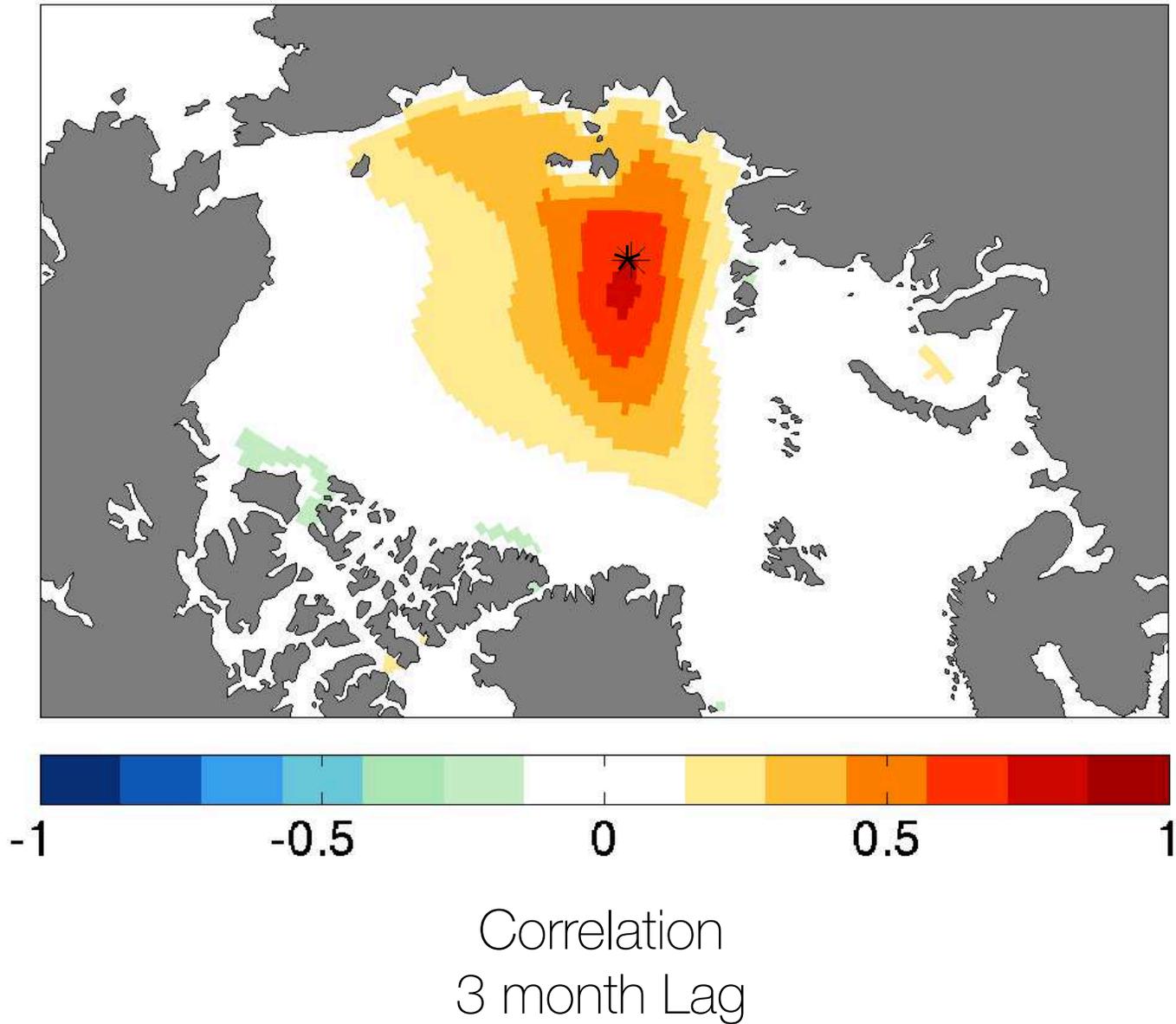


Sea ice thickness anomalies are long-lived
(up to years)
and strongly influence sea ice the extent/
concentration as the sea ice retreats in spring and
summer

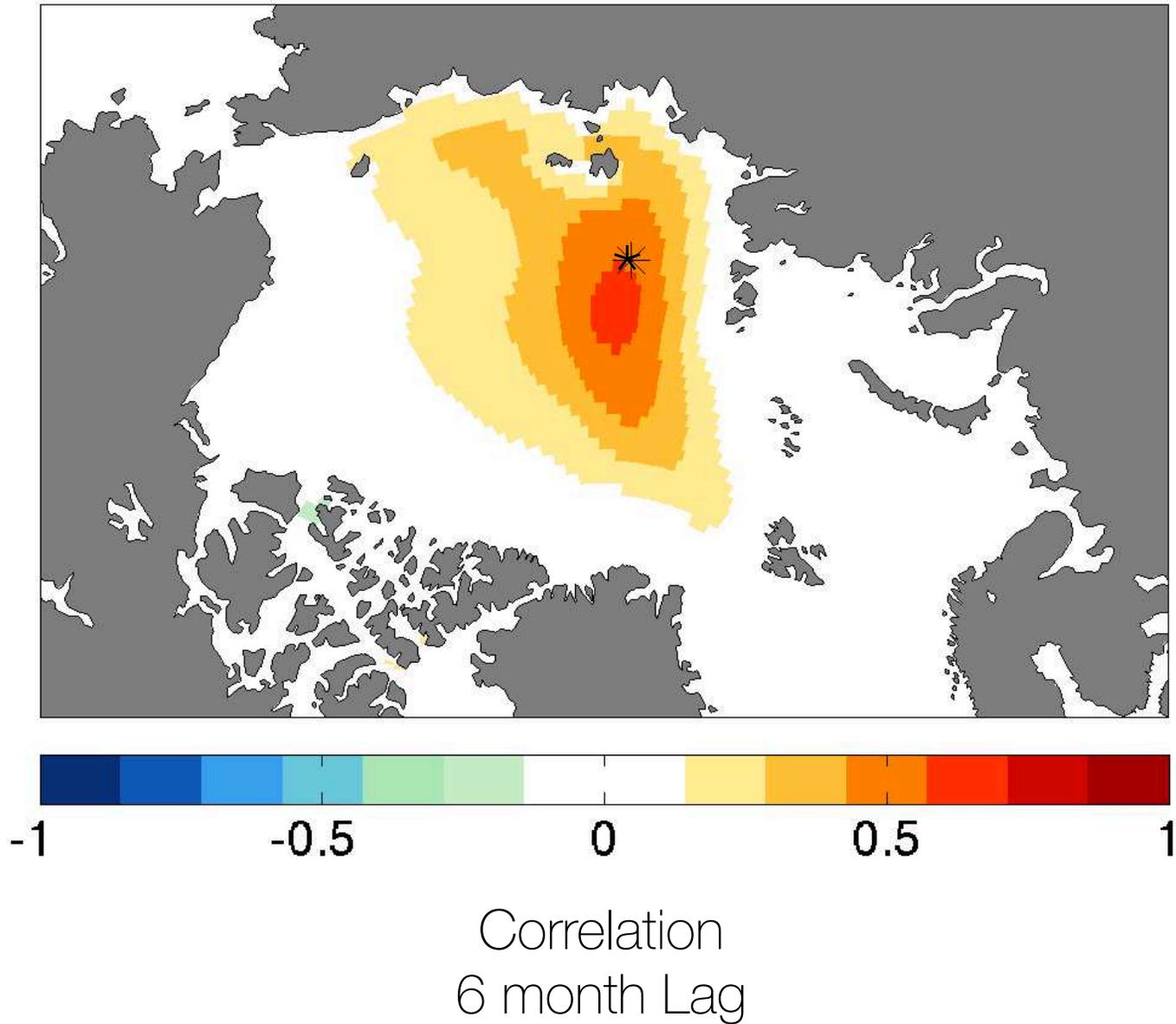
One-Point Correlation Map of Sea Ice Thickness in CCSM4 Control Run



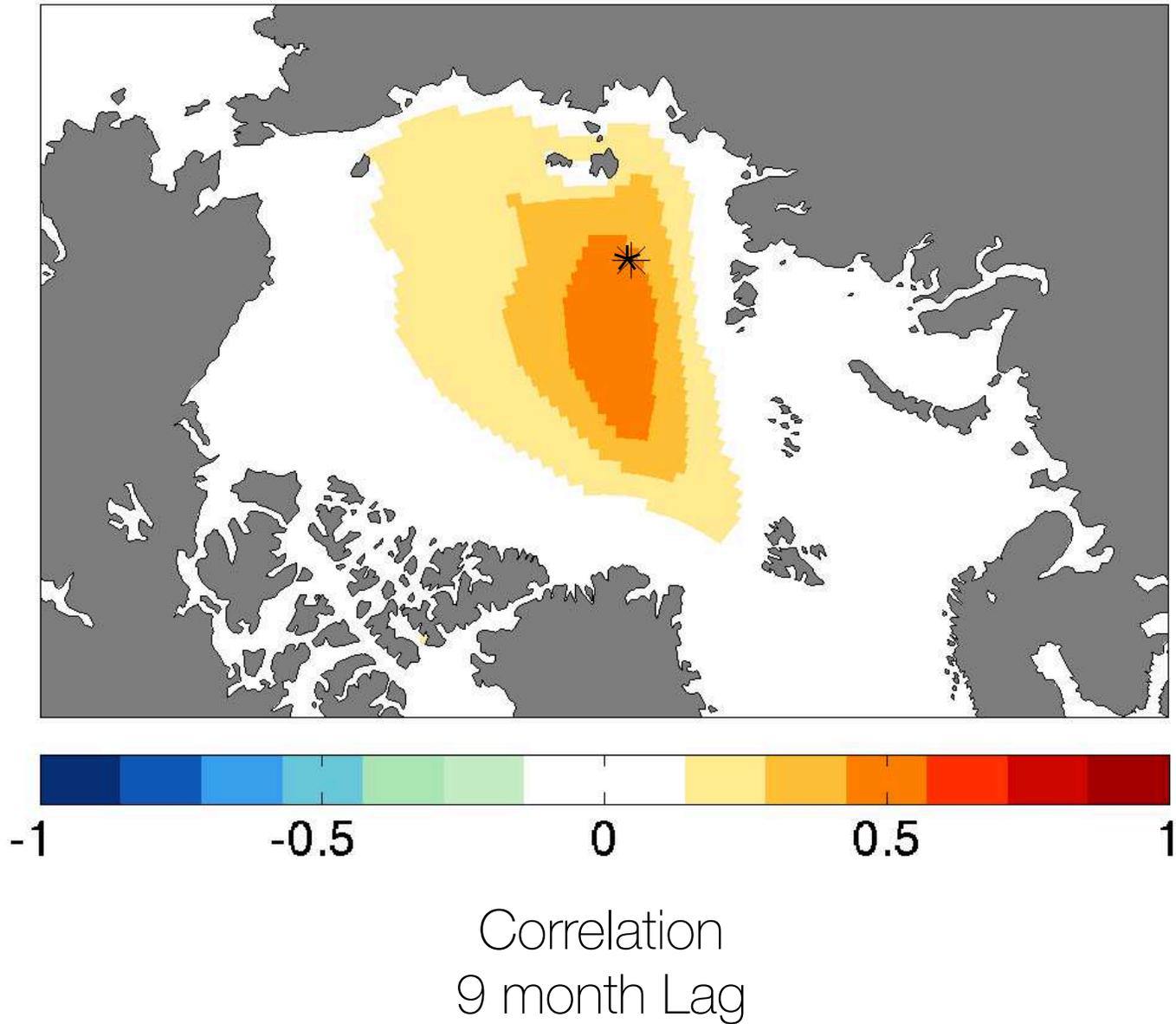
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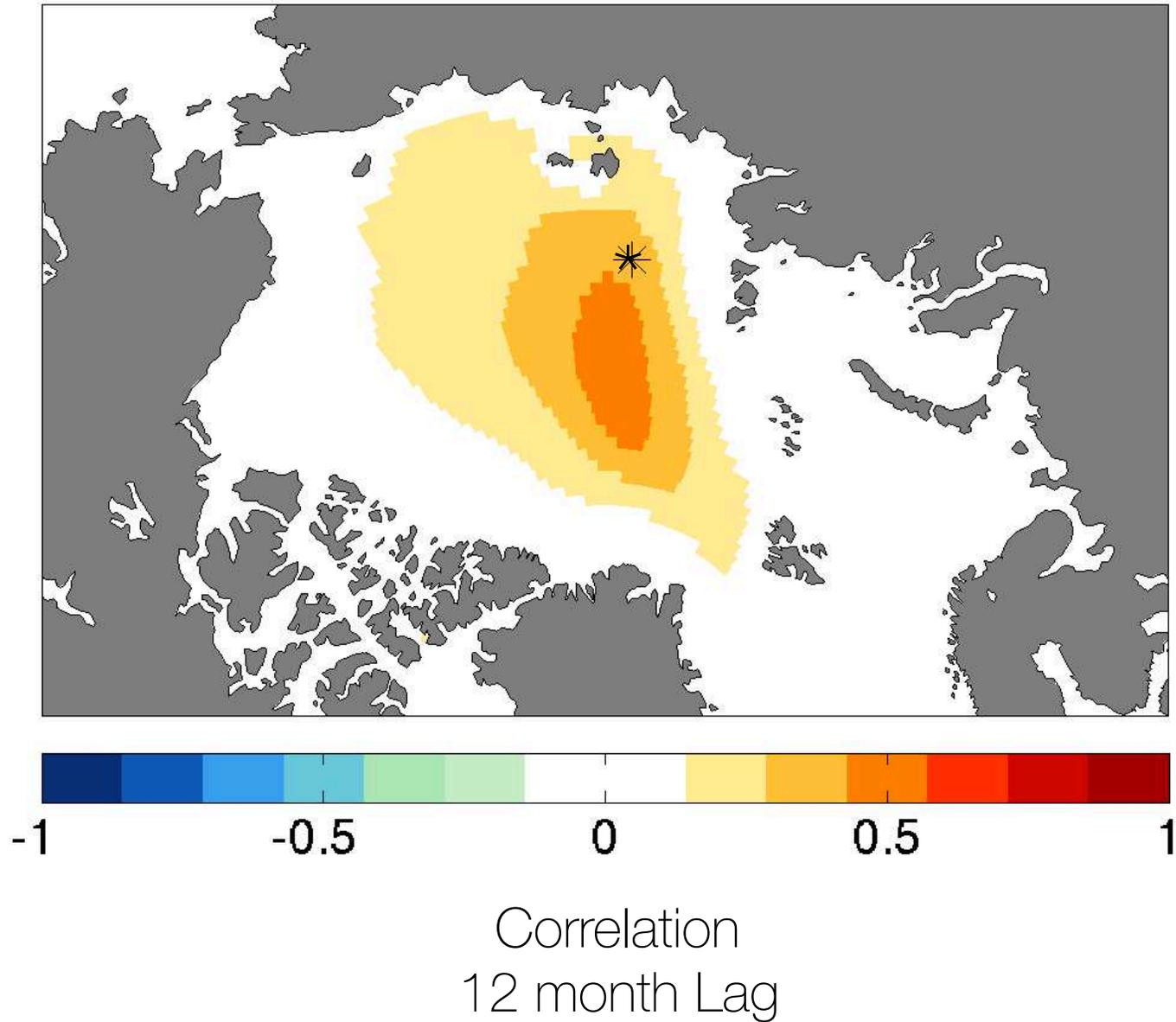
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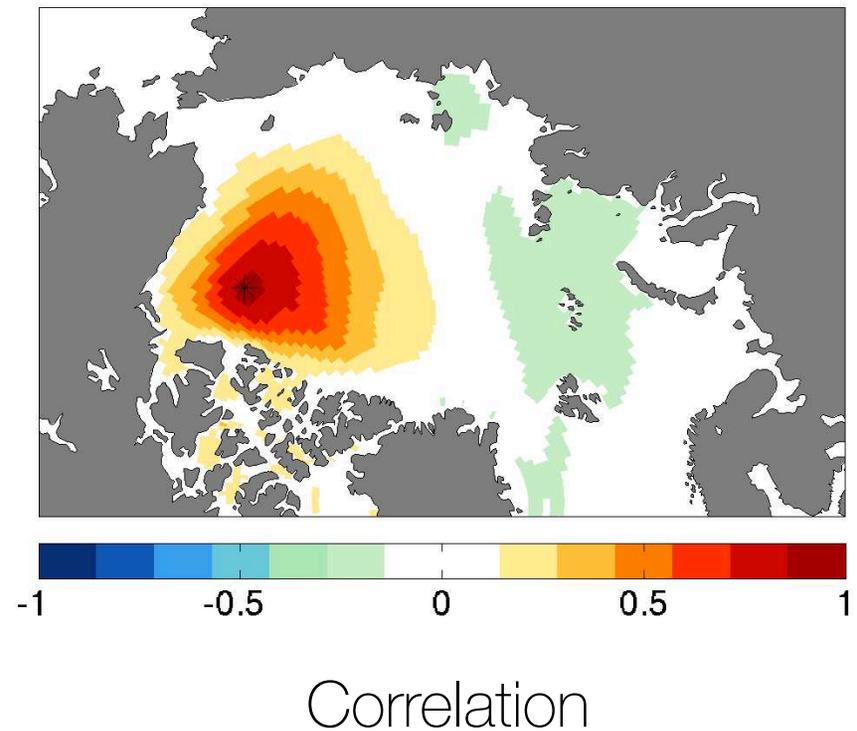
Using one-point correlation map of monthly thickness anomalies

Area of $1/e$ contour at zero lag

Divide by area of Arctic to estimate number of observations needed, we find 5 to 10^* .

Estimate time for autocorrelation at each point to decrease to $1/e$
It is ~ 9 months

If we take transport into account the time increases by 50-100%



Blanchard-Wrigglesworth
and Bitz (2014)

*Lindsay et al (2006) found this number to be 3



“Known” sources of sea ice predictability

predictability of extent (or concentration) –

extent

thickness

SST

transport

melt ponds

predictability of volume (or thickness) –

thickness & transport



Furthermore sea ice prediction depends strongly on
coupled interactions with the atmosphere and
ocean

We should do our best to initialize sea ice and ocean quantities faithfully, with correct relationships, and then simulate them with our best modeling methods.

Measurements are sparse and inaccurate and models have biases and missing processes

Initial Conditions for the June 2017 Sea Ice Outlook used by 4 different participants

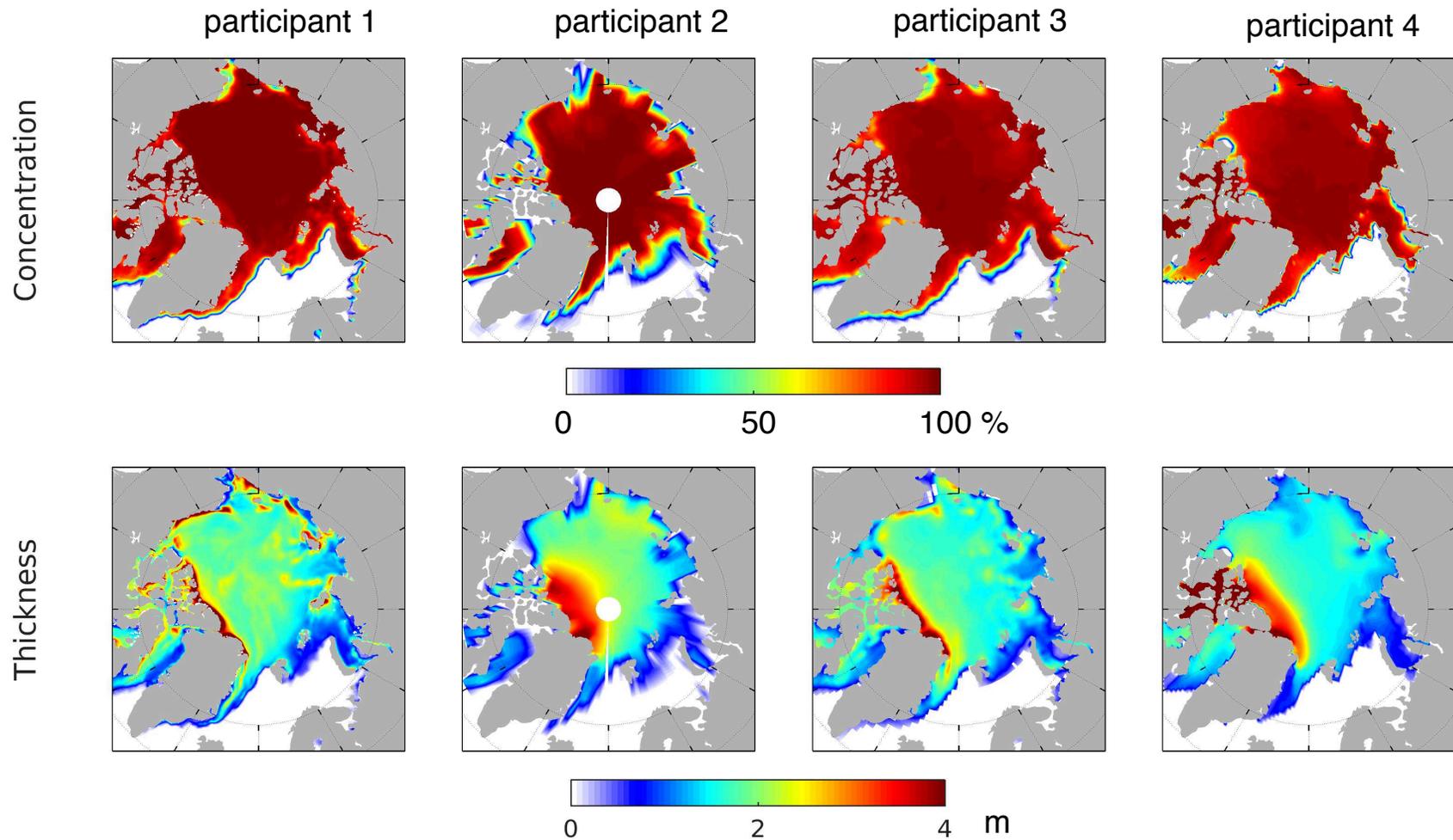
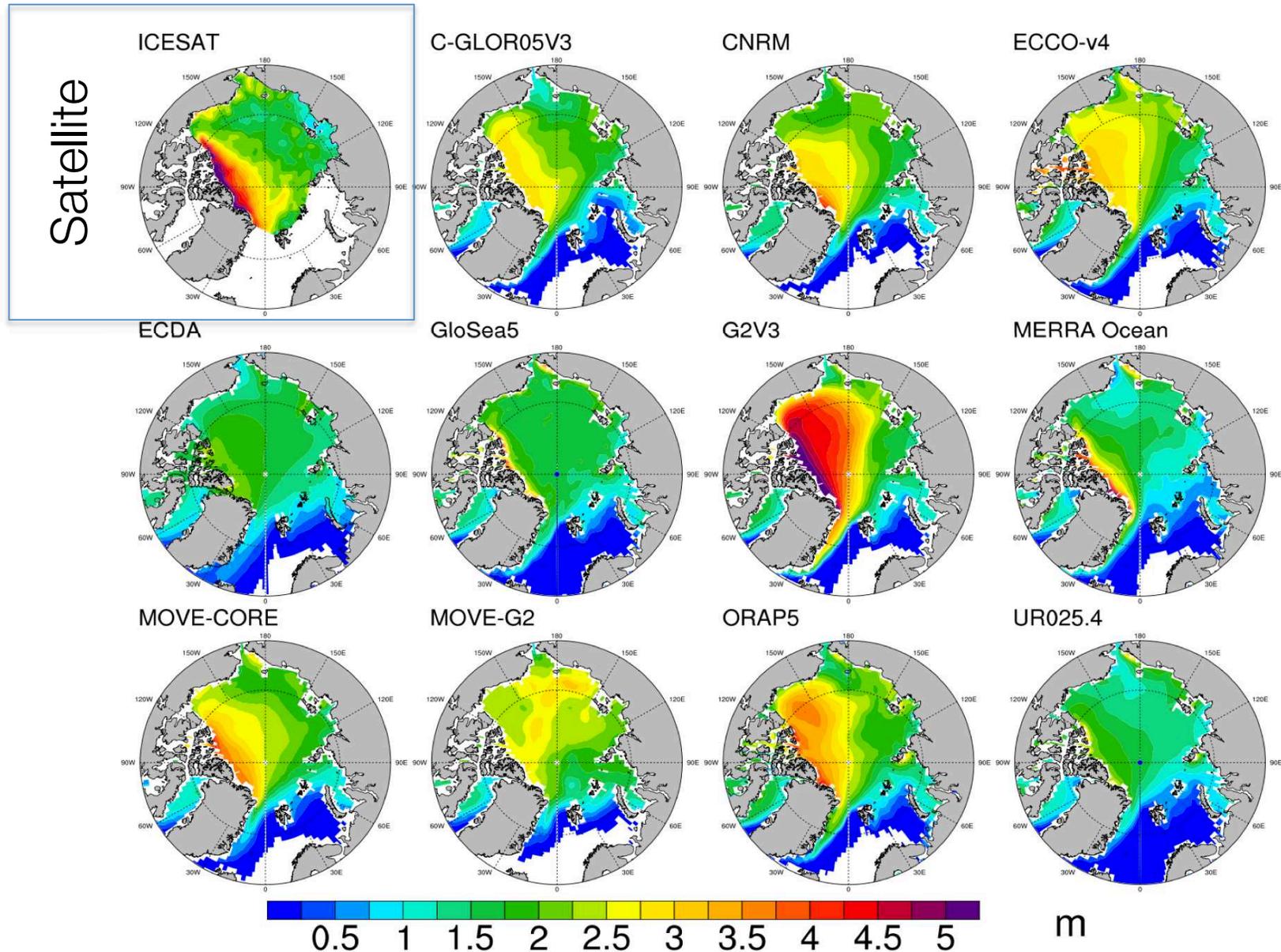


Figure by Blanchard-
Wrigglesworth

sea ice thickness from reanalysis/reconstruction (from which initial conditions are taken)

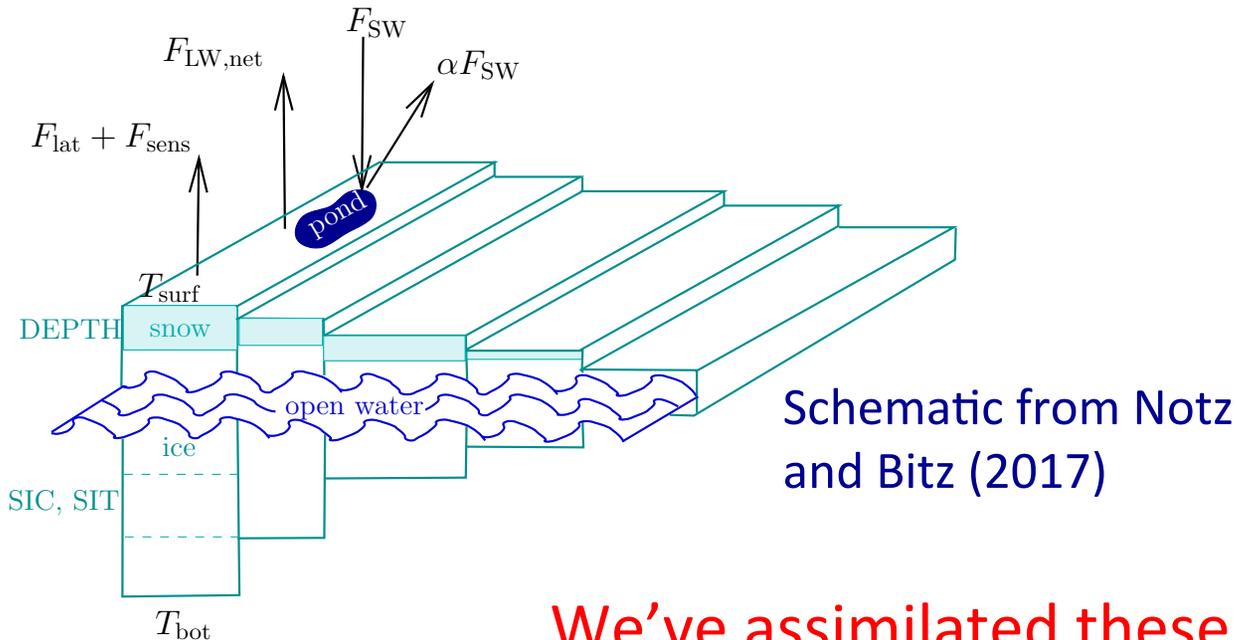


Mean March 2003-2007 Sea Ice Thickness (m) in global ocean-sea ice reanalyses with assimilation of sea ice concentration

Chevallier et al (2016)

Data Assimilation in CICE5 within CESM2 using DART Kalman Filter

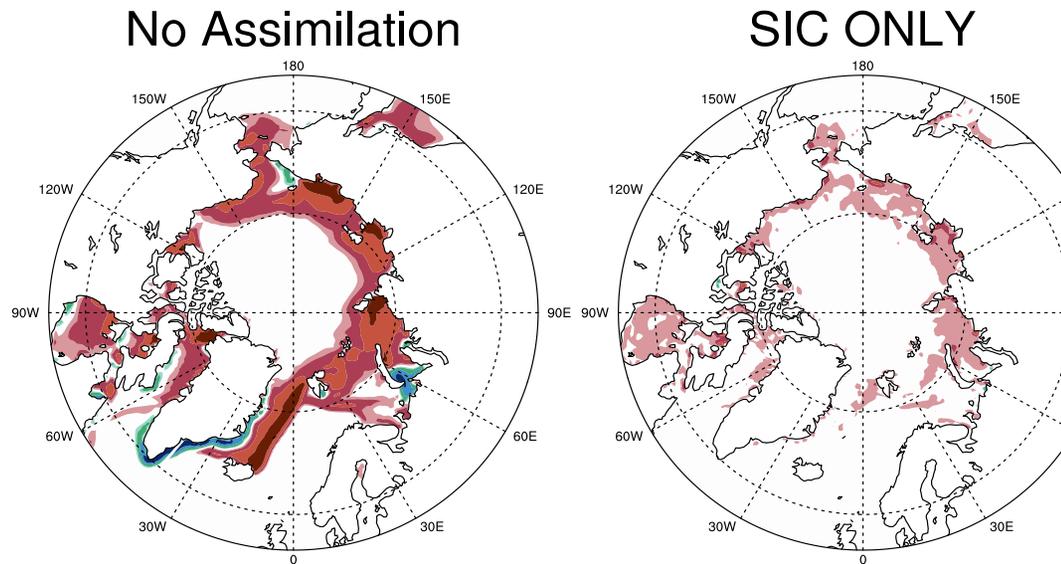
A grid cell has these variables in **each** thickness category



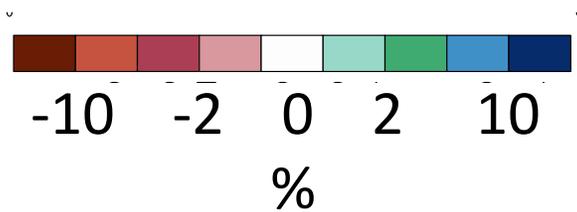
We've assimilated these variables successively

1. "Aggregate" sea ice concentration (SIC)
2. "Aggregate" sea ice thickness (SIT)
3. "Aggregate" first-year ice concentration (AGE)

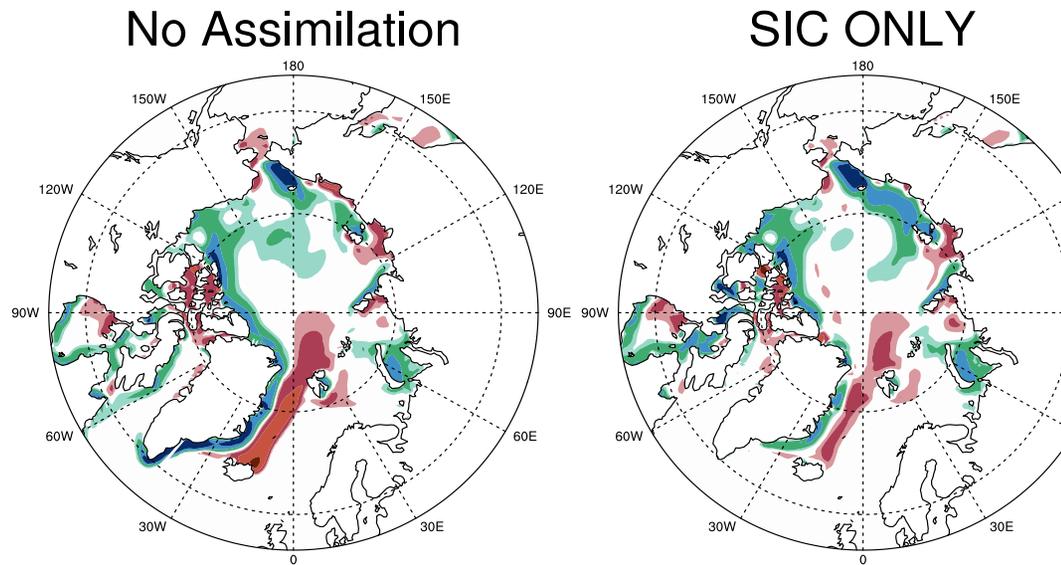
Sea Ice Concentration (SIC) Bias – All Months



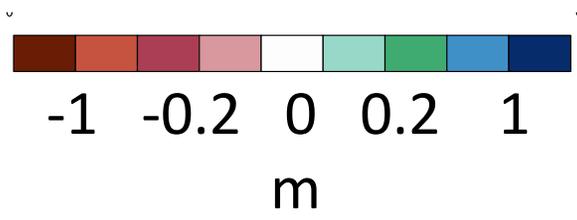
Assimilating SIC alone successfully reduces the bias



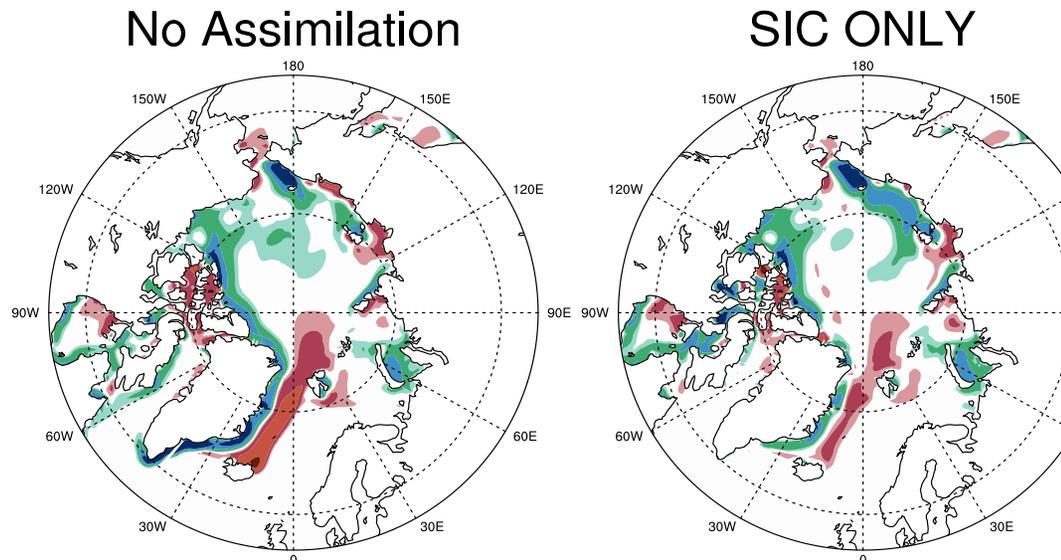
Sea Ice Thickness (SIT) Bias – April-May



Assimilating SIC alone does LITTLE to reduce the bias

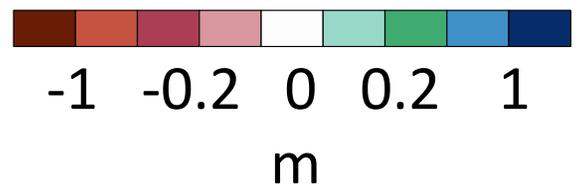
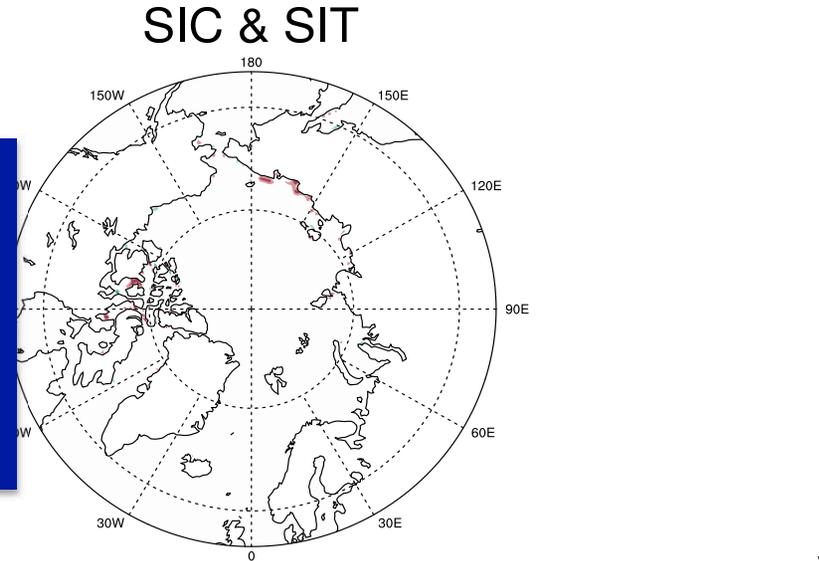


Sea Ice Thickness (SIT) Bias – April-May

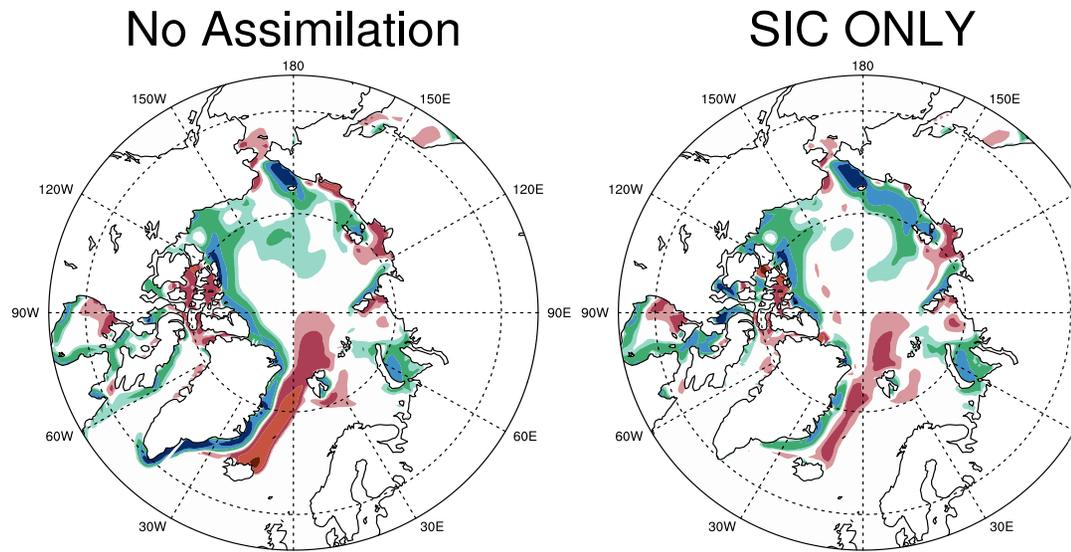


Assimilating SIC alone does LITTLE to reduce the bias

Assimilating thickness (SIT) yields major reduction of the bias

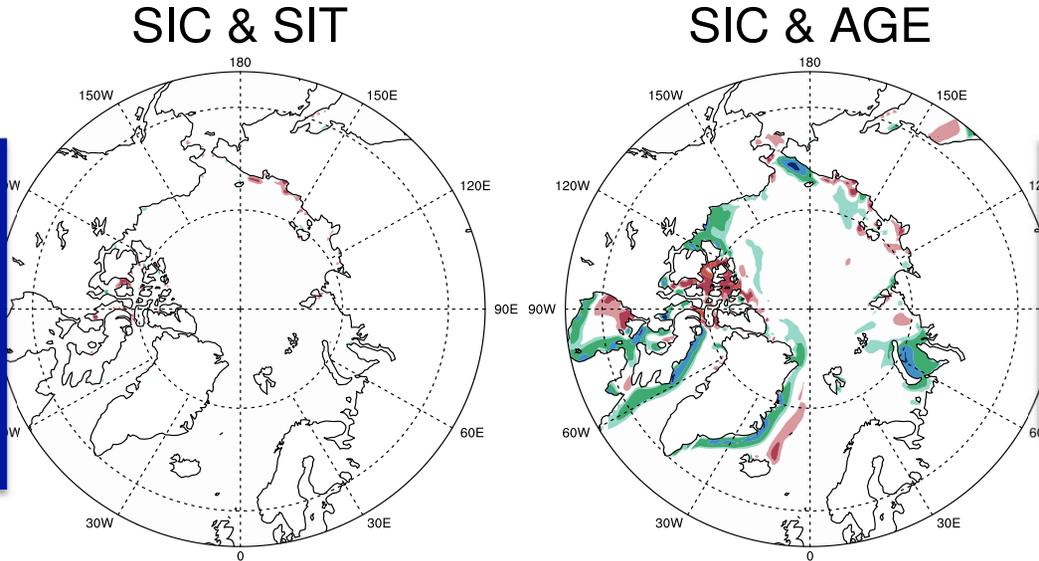


Sea Ice Thickness (SIT) Bias – April-May

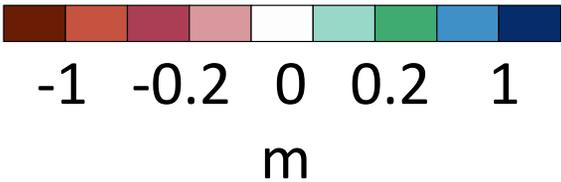


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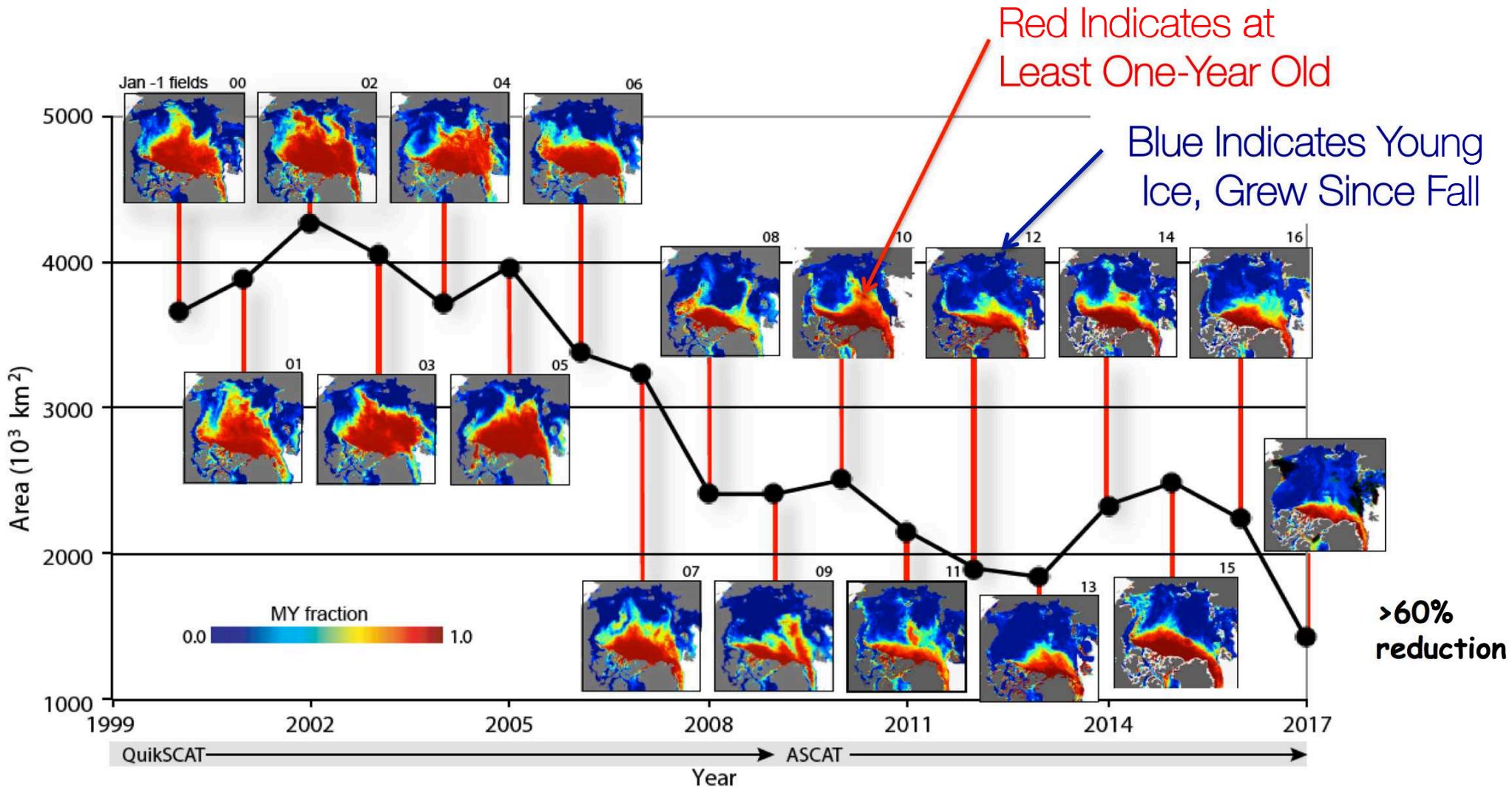


Assimilating AGE instead of SIT is reasonably successful too





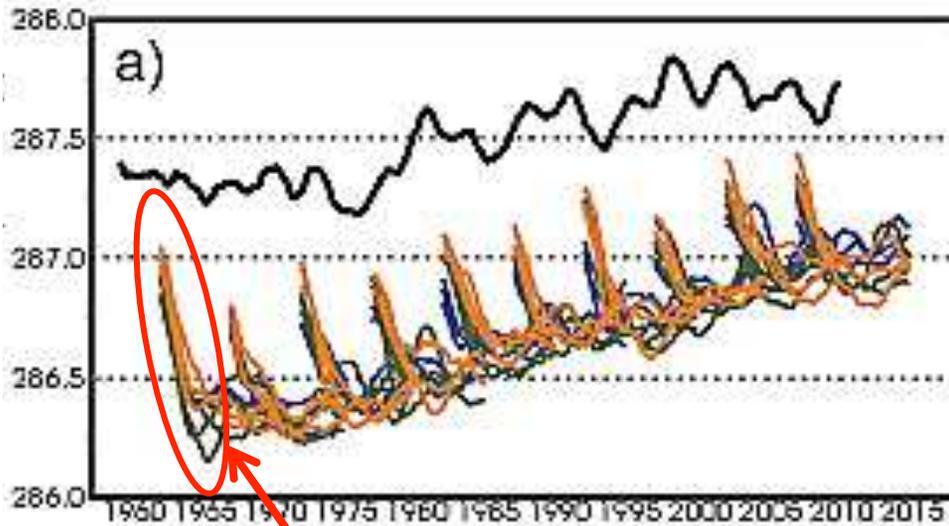
Loss of Multiyear Sea Ice (from Satellite Scatterometers)



Courtesy of Ron Kwok

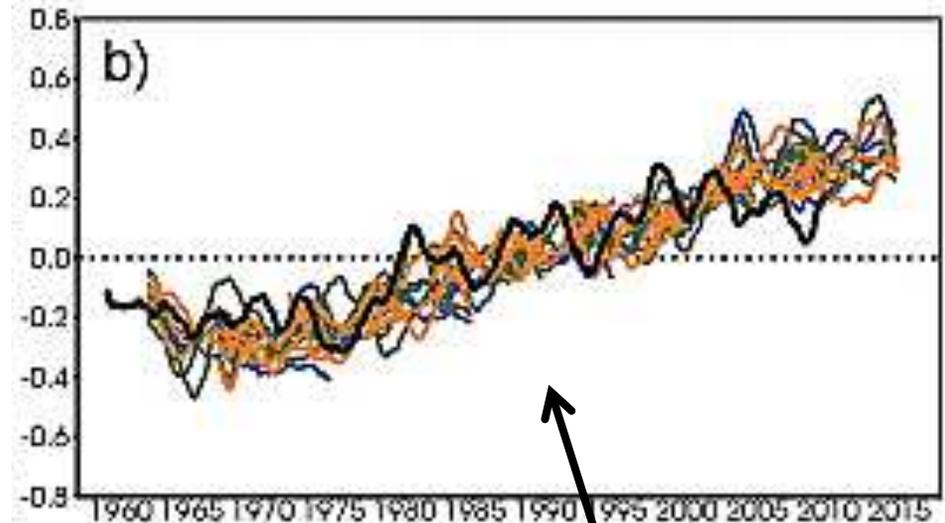
Real Forecasts Have Biases

Surface Temperature



A forecast ensemble diverging from initial condition due to systematic error

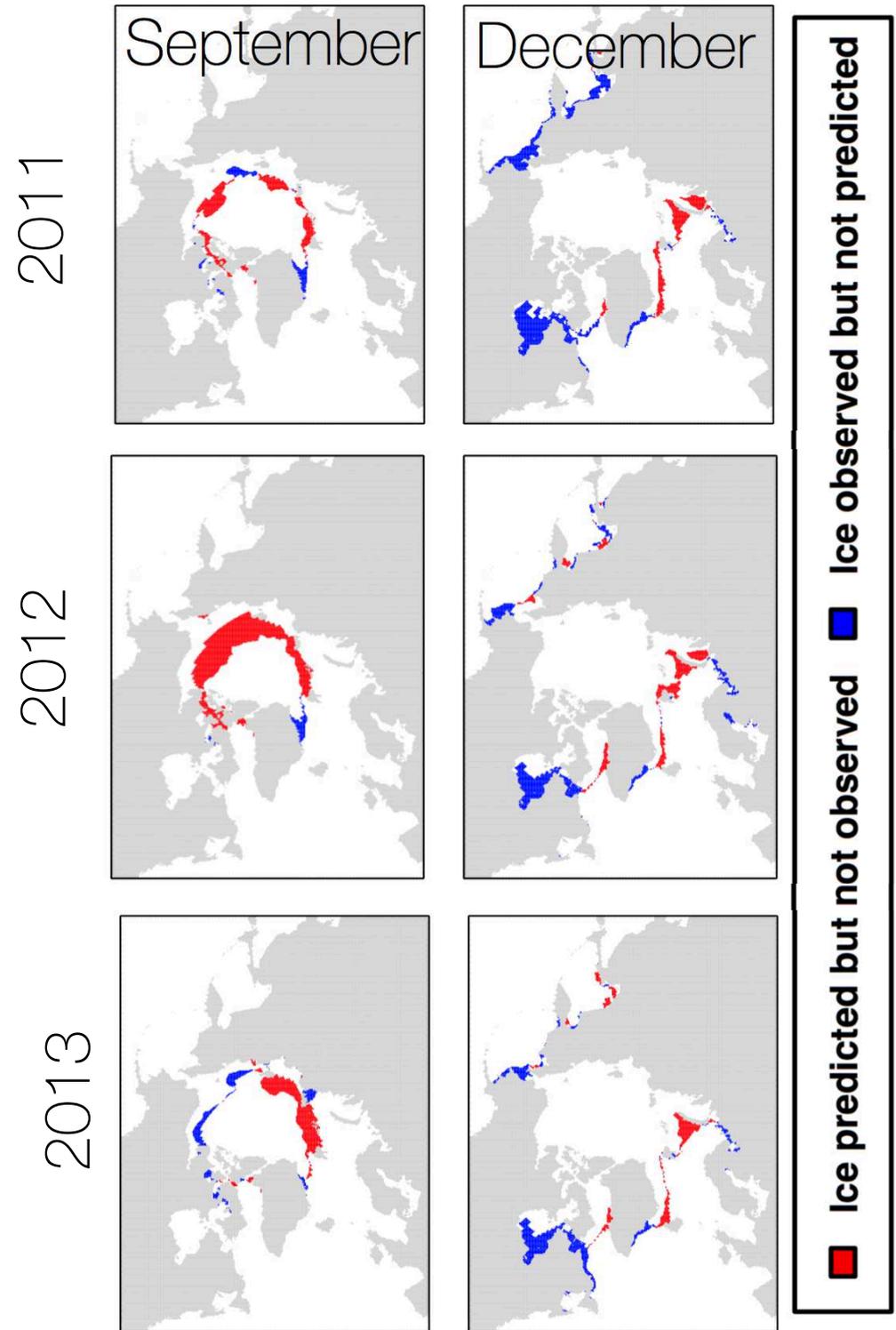
Surface Temperature Anomaly



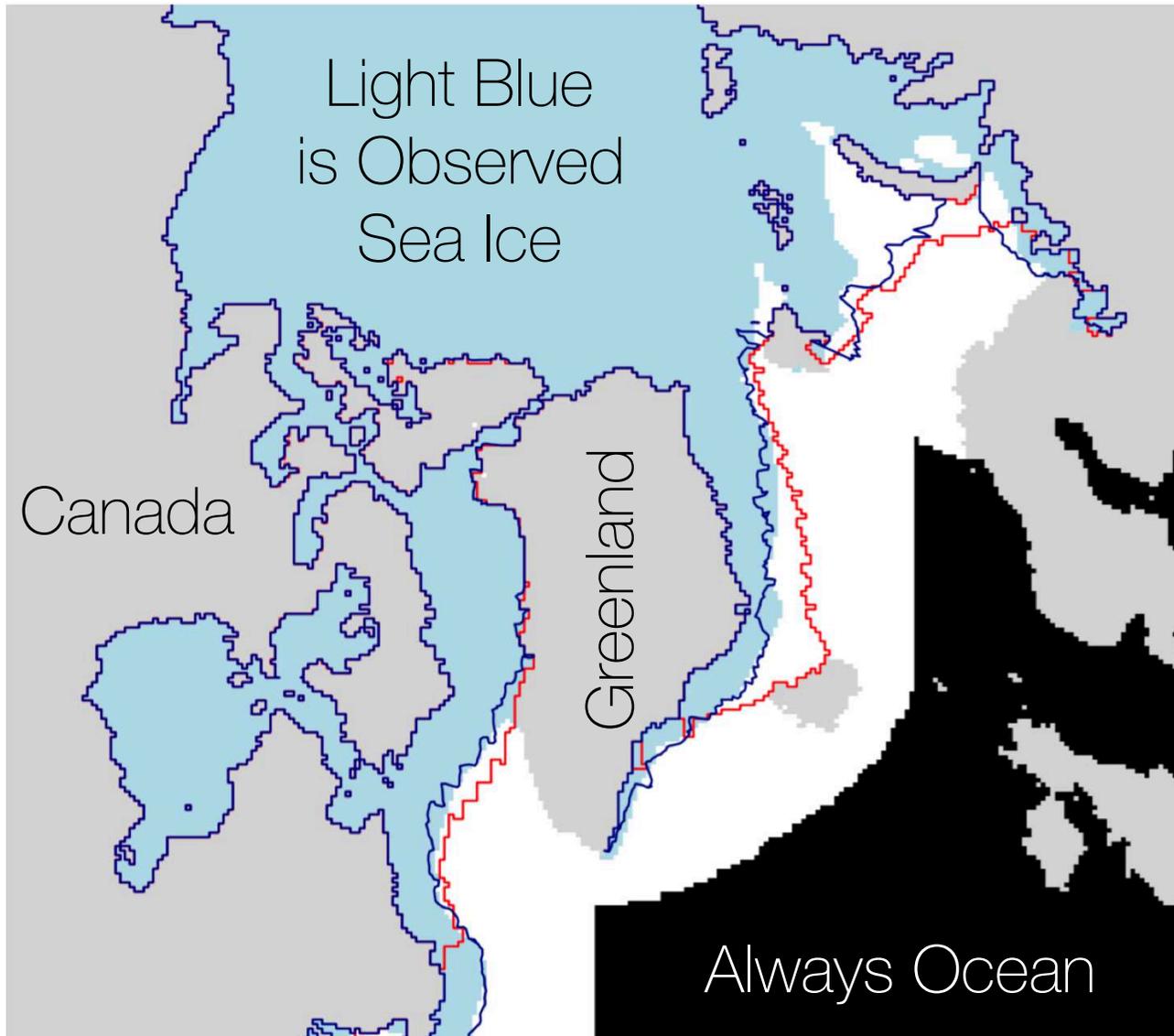
Easy to remove for scalar, such as temperature

How should we bias correct the ice edge?

Forecasts initialized the previous May have clear **systematic biases**



Demonstrating Our Contour Shifting Method



Dark blue is our corrected forecasted sea ice edge

Red is the uncorrected forecast

A bias-corrected forecast issued 11.5 months in advance is more accurate than an unadjusted forecast issued 1.5 months in advance at some times of the year.



Summary

Predictability of sea ice is due to persistence and transport of thickness and SST.

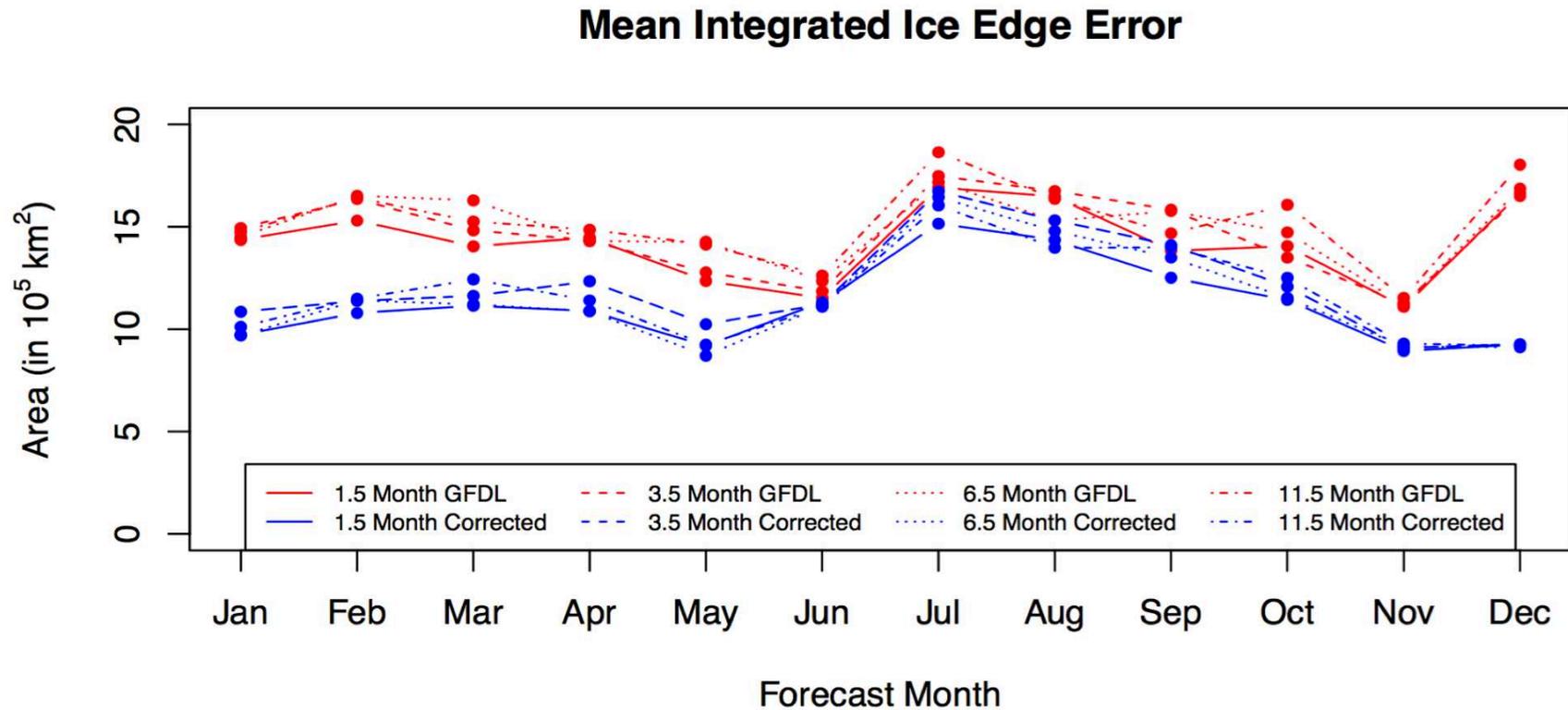
Large gap between predictability estimates and actual predictions.

Forecast skill varies regionally. Often poor along coastlines, where skill may be most useful to stakeholders.

Need for better Data Assimilation, much improved from multivariate methods that include thickness or ice age

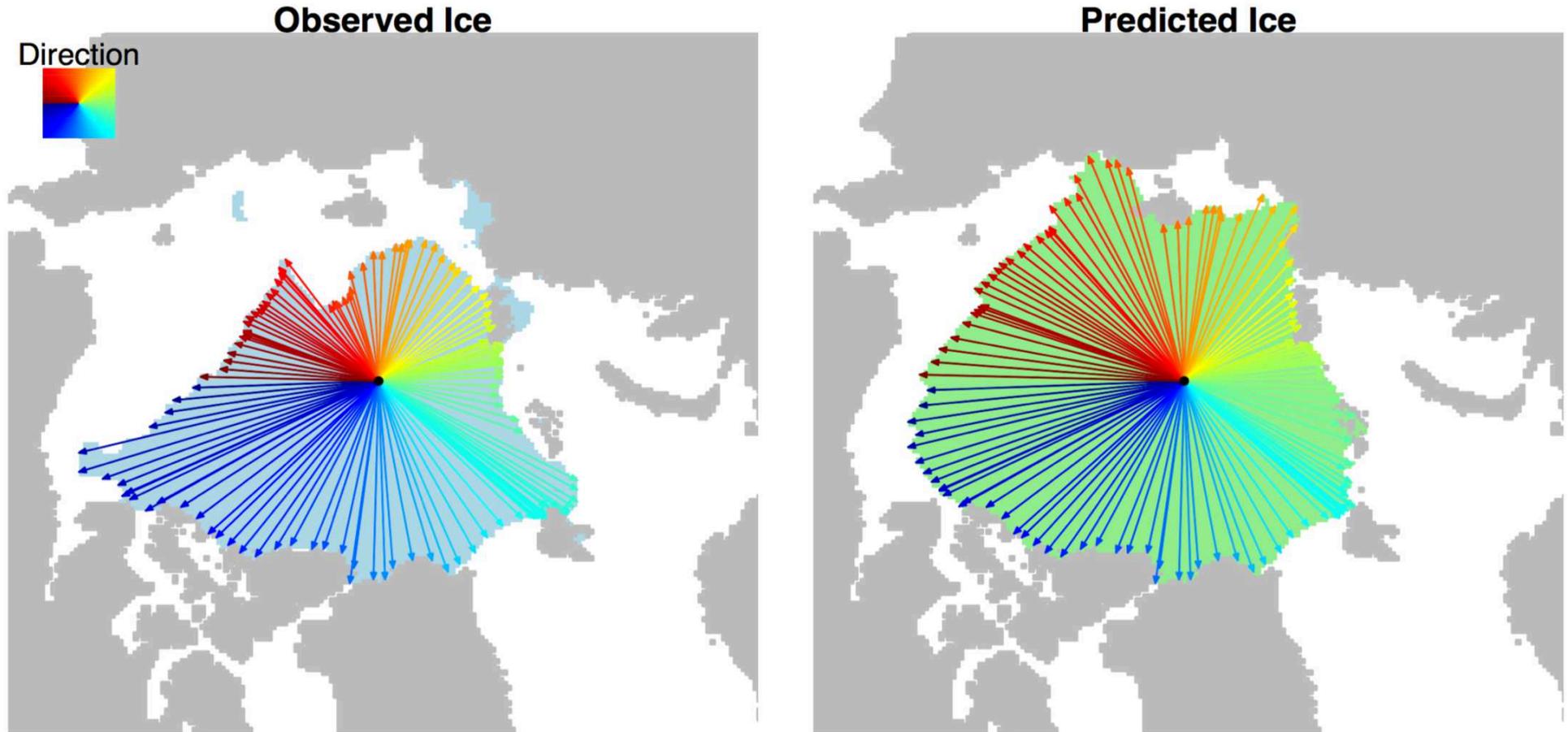
High need for post-processing, including correcting bias in sea ice edge

Average 20% reducing in mean integrated ice edge error (proposed by Goessling et al, 2016)



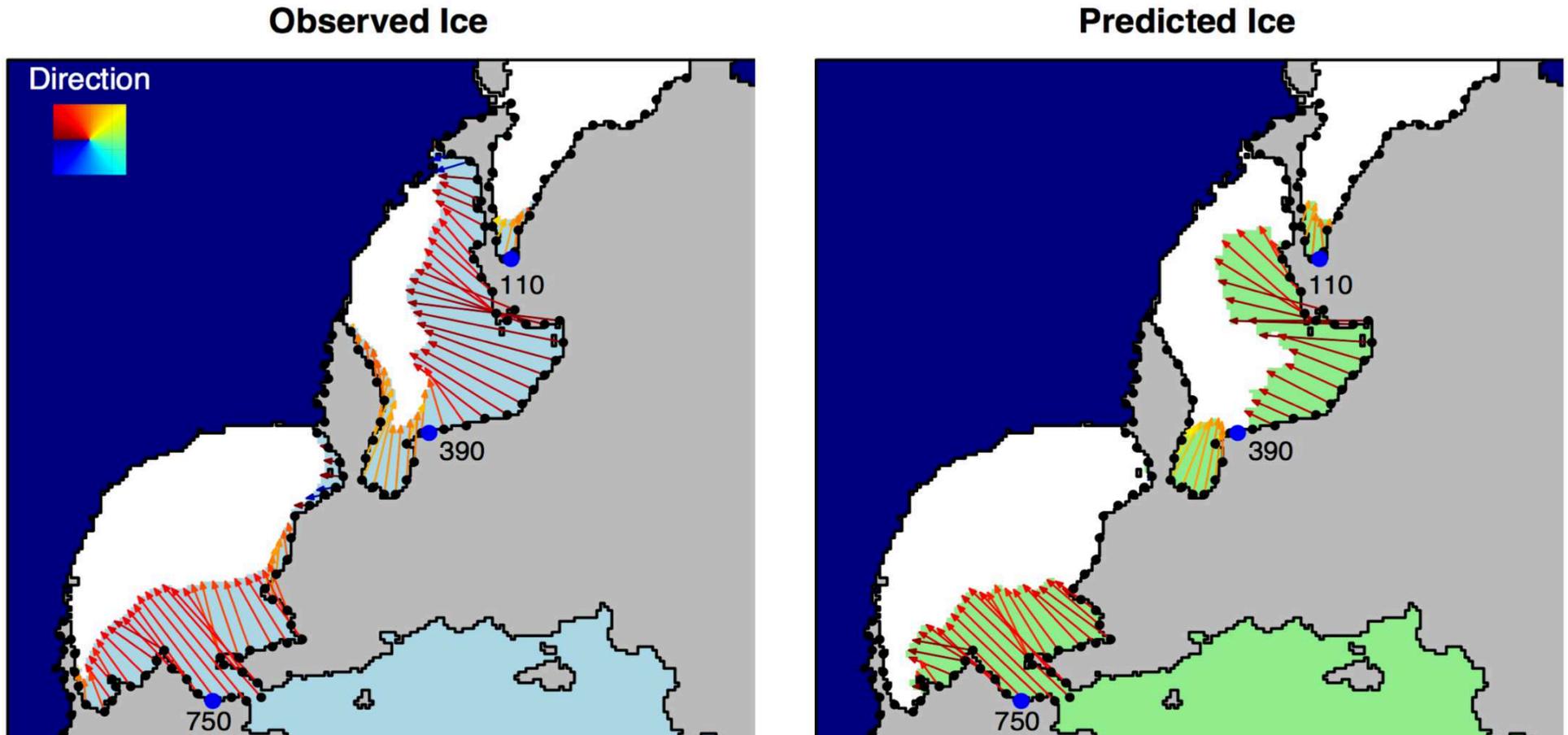
Often a bias-corrected forecast issued 11.5 months in advance is more accurate than an unadjusted forecast issued 1.5 months in advance.

Our Contour Shifting Method



We identify systematic differences between the length of a series of vectors that define the ice edge.

Our Contour Shifting Method



In some regions the vector tail starts at land. Additional special cases need correcting too.

What is predictability?

‘Predictability is the degree to which a correct prediction or forecast of a system's state can be made either qualitatively or quantitatively.’

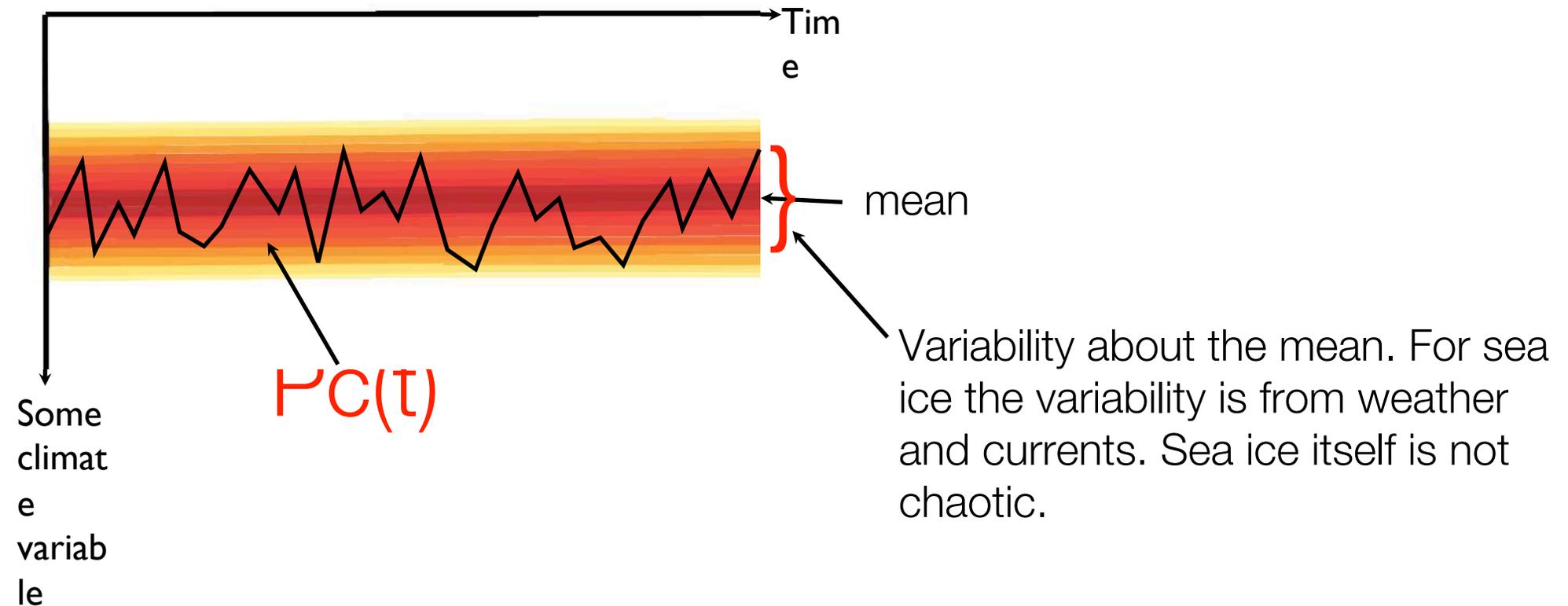
wikipedia

‘A limit to the accuracy with which forecasting is possible’

Lorenz (1969)

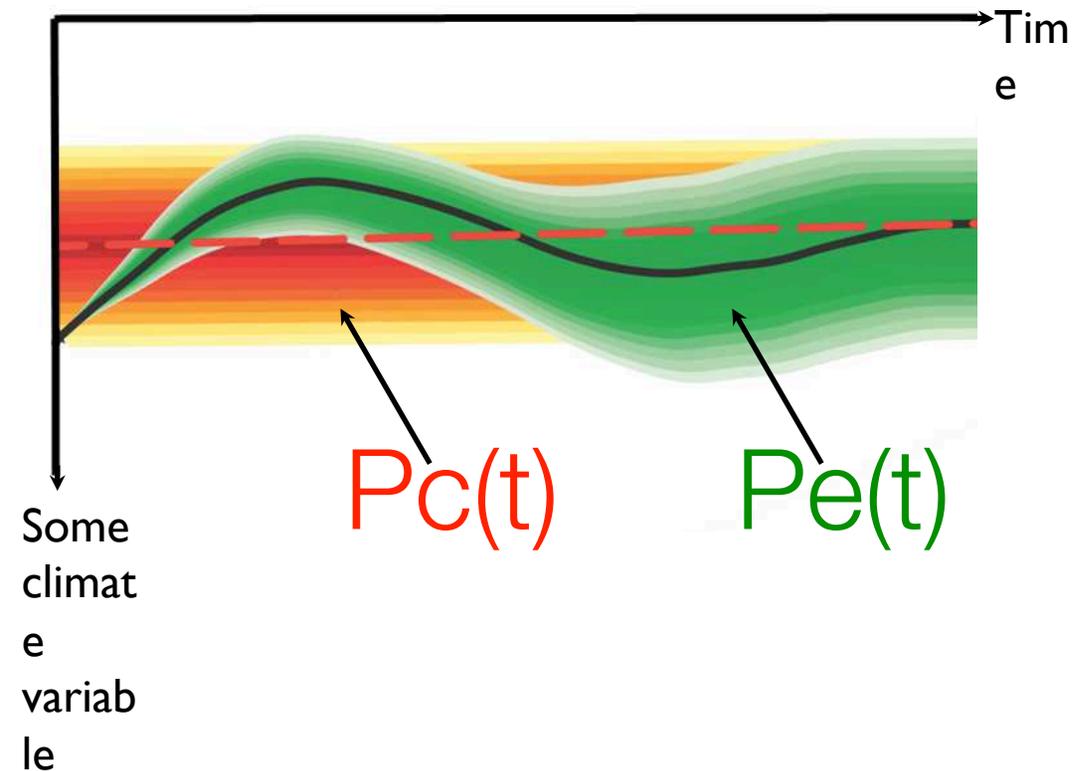
Predictability in Theory

$P_c(t)$ the control distribution (ensemble) evolves independent of any particular initial state.



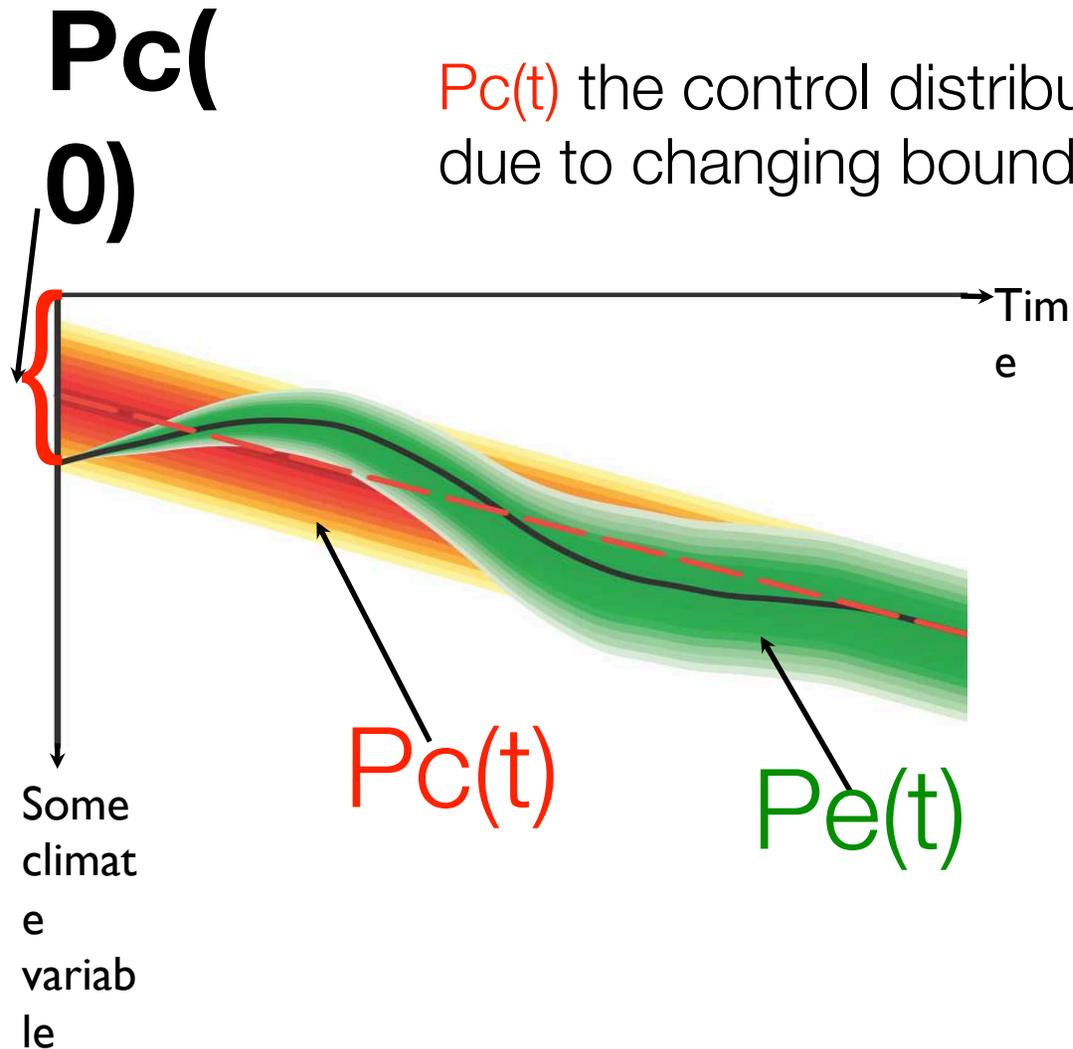
Predictability in Theory

$Pe(t)$ is an ensemble of predicted states evolving from a specific tight cluster of initial conditions.



$Pe(t)$ versus $Pc(t)$ represents “initial-value predictability” (Lorenz 1975). Like a weather forecast.

Predictability in Theory

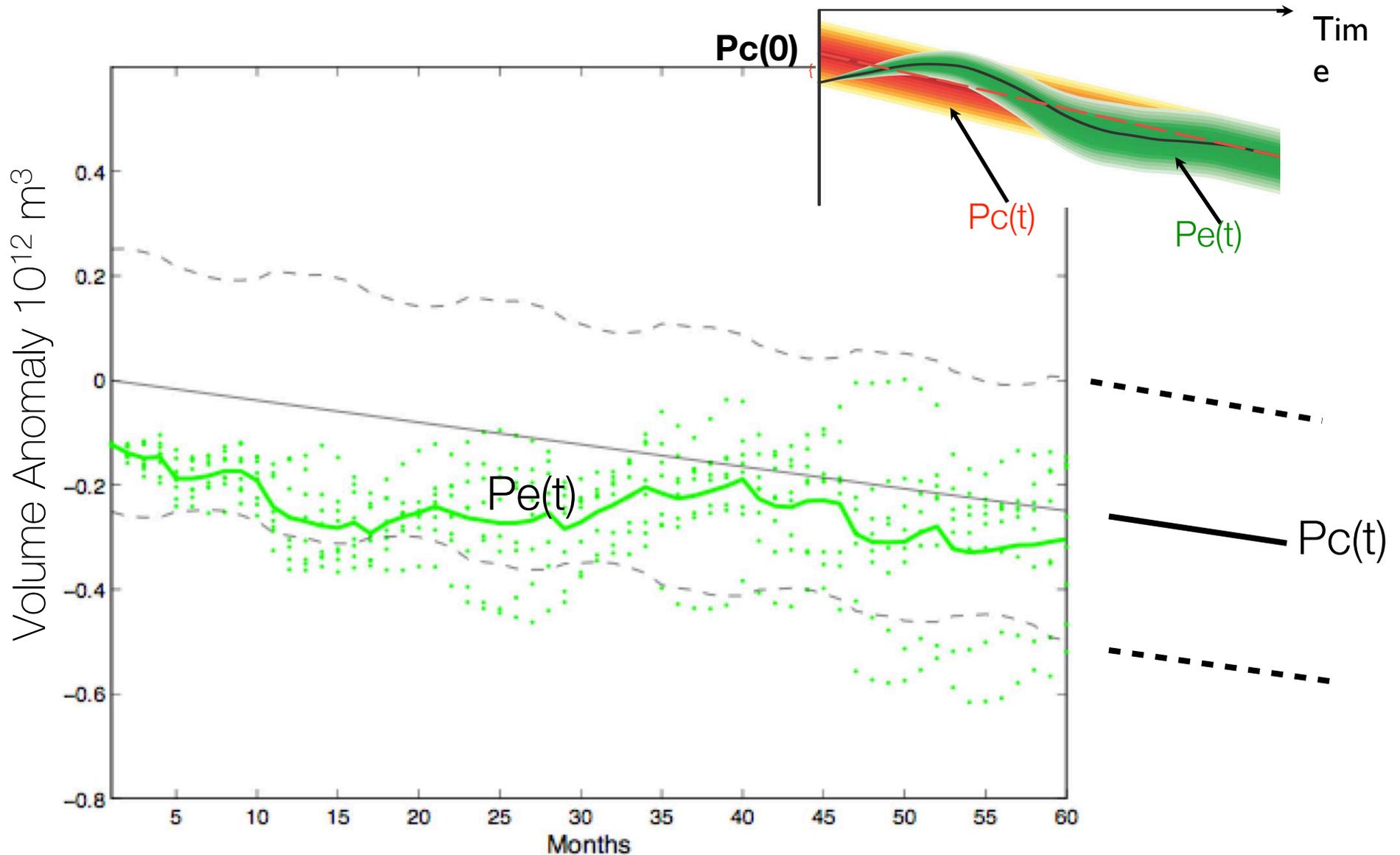


$P_c(t)$ versus $P_c(0)$ represents “forced predictability” (Lorenz 1975). This is climate change prediction.

Both kinds of predictability are important for sea ice

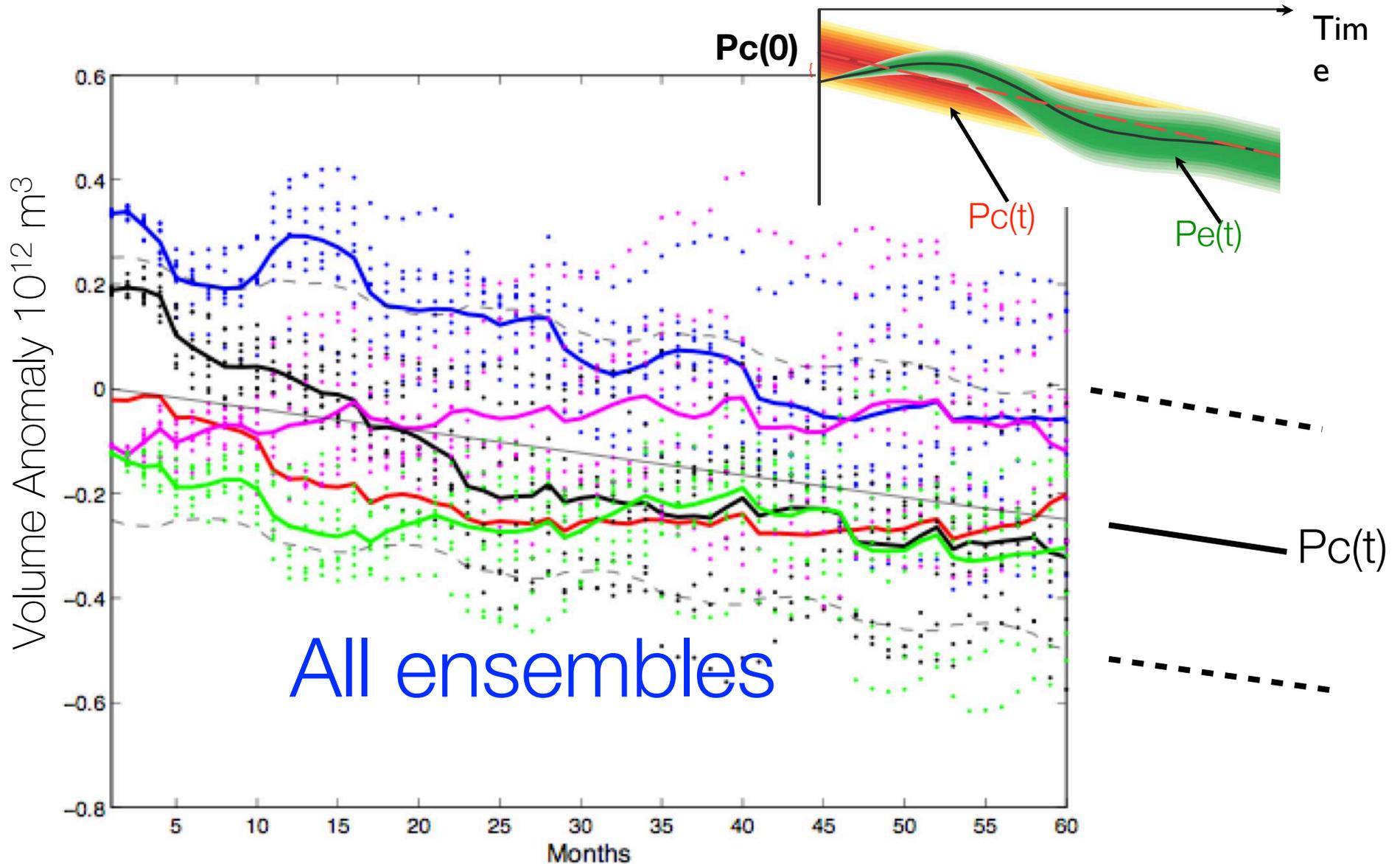
'Perfect model' predictability studies with a GCM

Forecast is compared with its own control



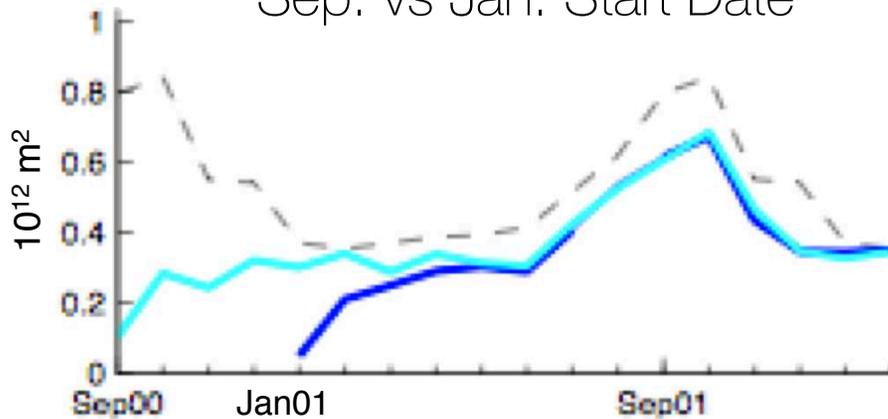
'Perfect model' predictability studies with a GCM

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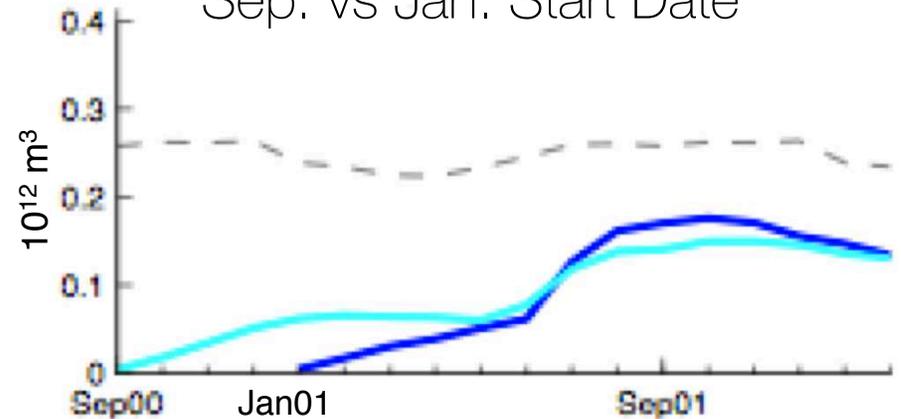


“Perfect” Model Predictability studies with CCSM4

“Spread” of $P_e(t)$ vs $P_c(t)$
RMSD of pan-Arctic Area
Sep. vs Jan. Start Date

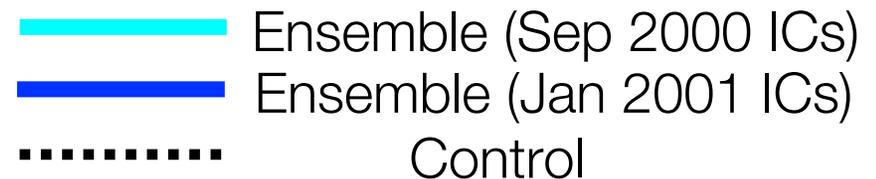


“Spread” of $P_e(t)$ vs $P_c(t)$
RMSD of pan-Arctic Volume
Sep. vs Jan. Start Date



- Beyond spring of the first year, model predictions are equally good whether initialized in September or January.

- Predictability for over a year in pan-Arctic Area due to persistence in thickness and SST anomalies



Blanchard-Wrigglesworth
et al (2011)

Processes Considered in Sea Ice Models

When & where do openings (leads) form?



What is the distribution of snow?



When does melt start?



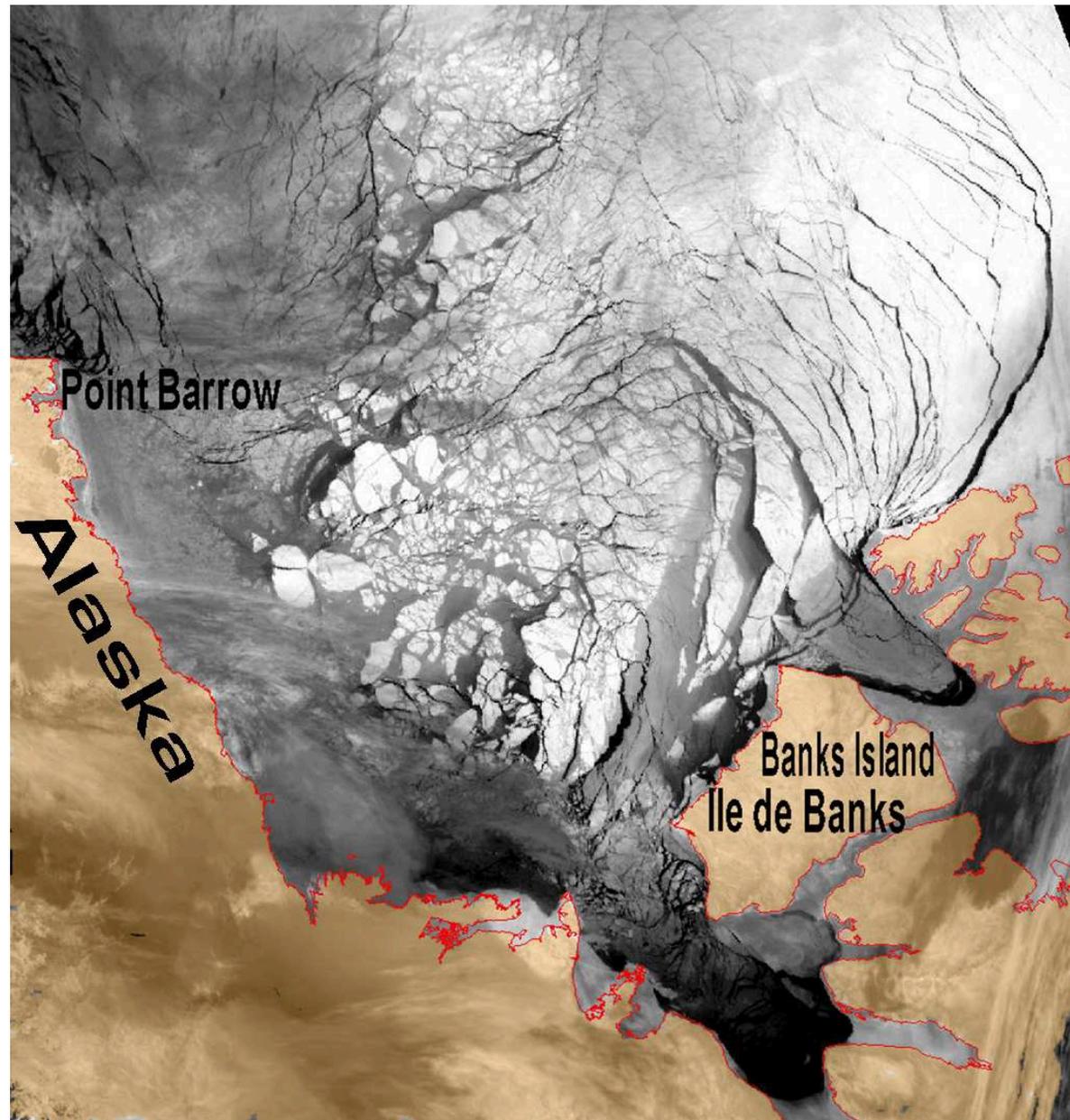
- Conditions are strongly forced by atmosphere and ocean
- Seasonal prediction is inherently probabilistic

When do ponds form?

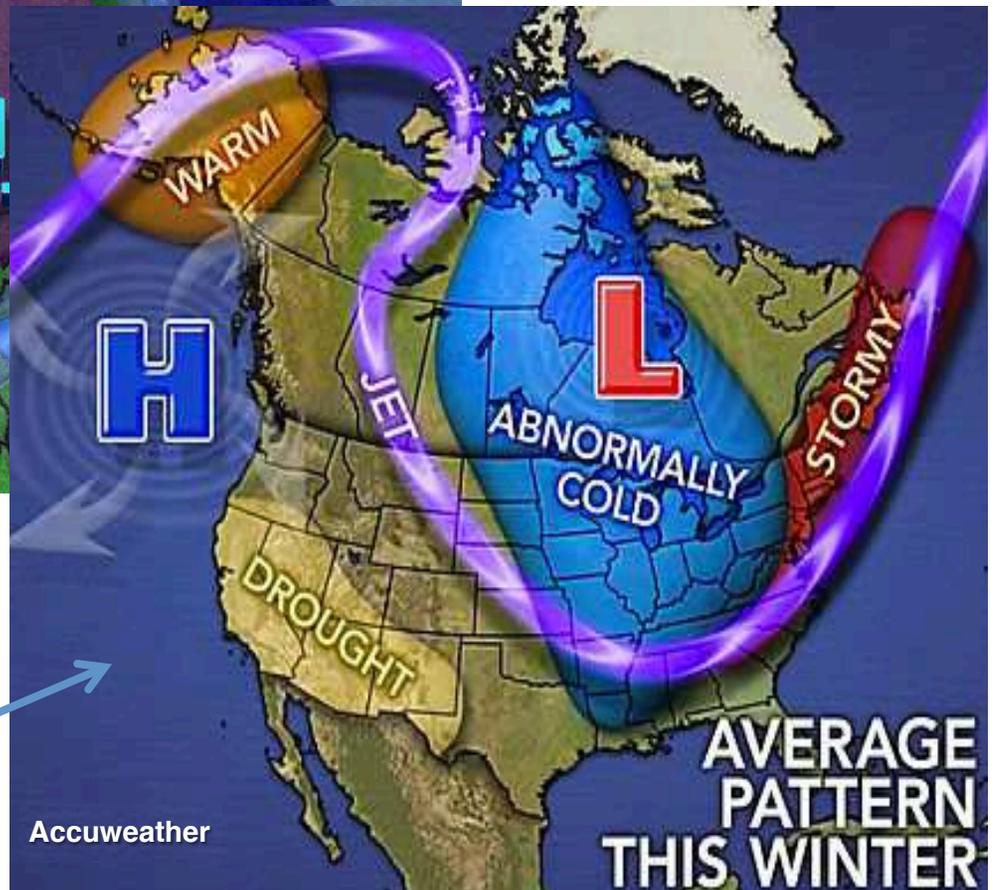


slide from D. Perovich

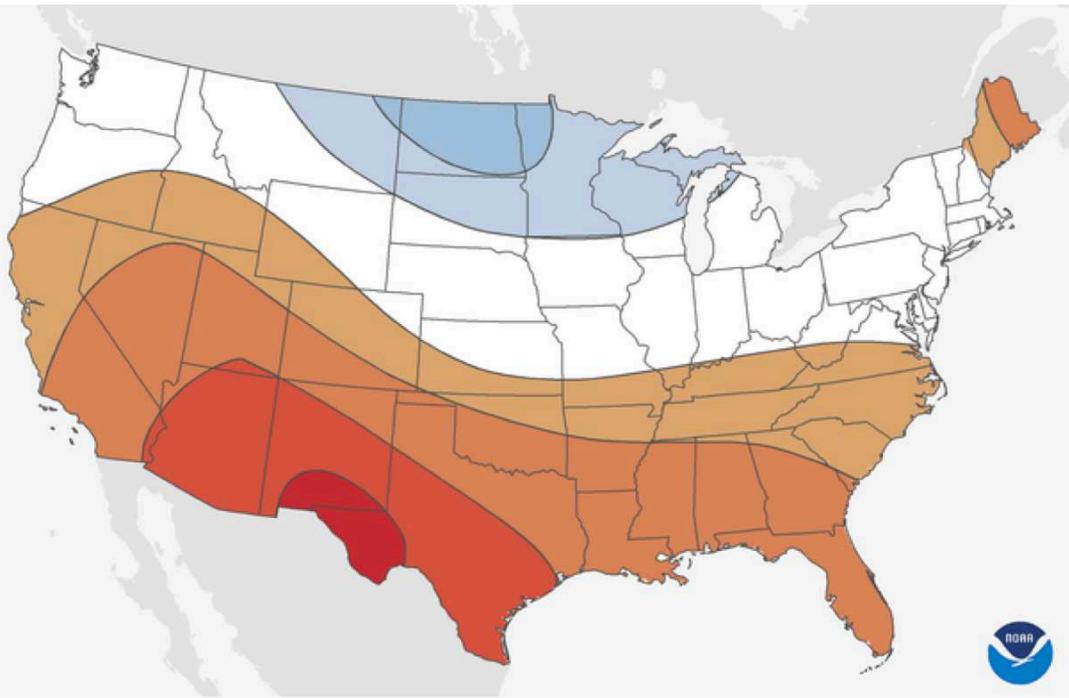
Simulated sea ice is motion, modeled as a viscous-plastic material



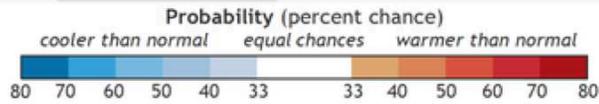
ARCTIC BLAST JANUARY 2014



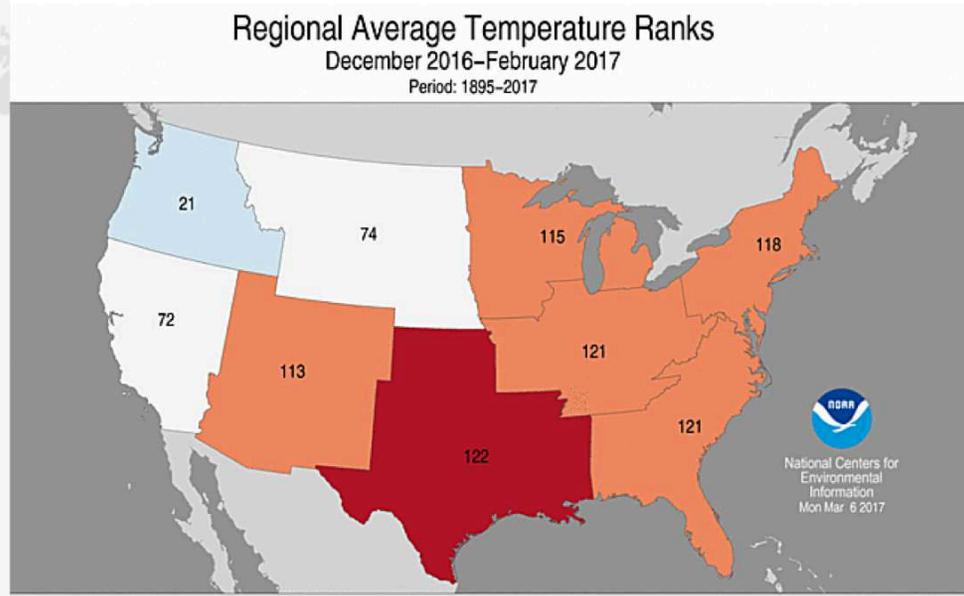
Predicted in December
this year by Accuweather



Temperature Outlook for December - February Issued 20 Oct 2016



Climate.gov Data: CPC



Predicted in October this year by NOAA

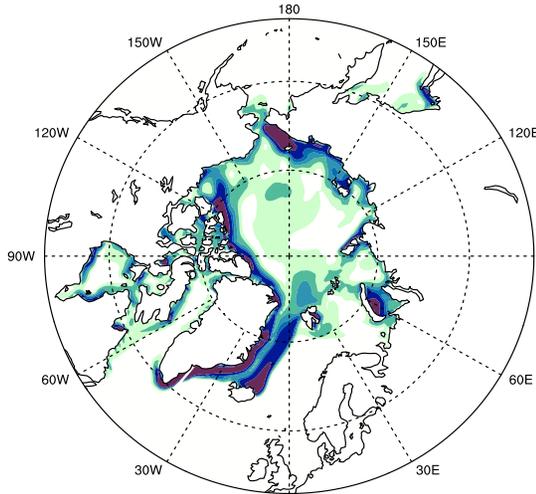


Predicted in December this year by Accuweather

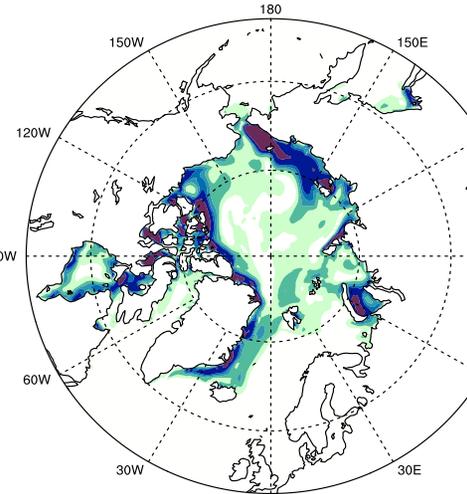


Sea Ice Thickness (SIT) RMSE – April-May

No Assimilation

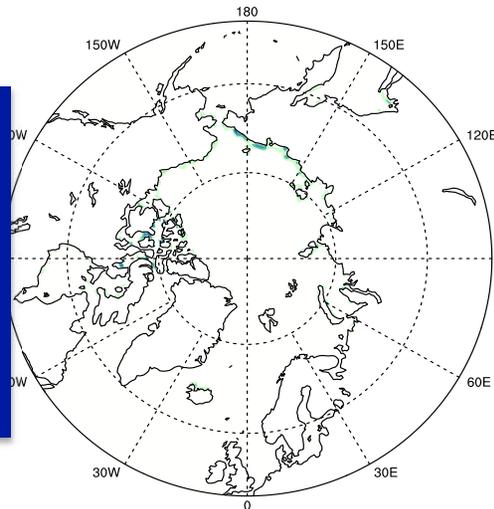


SIC ONLY



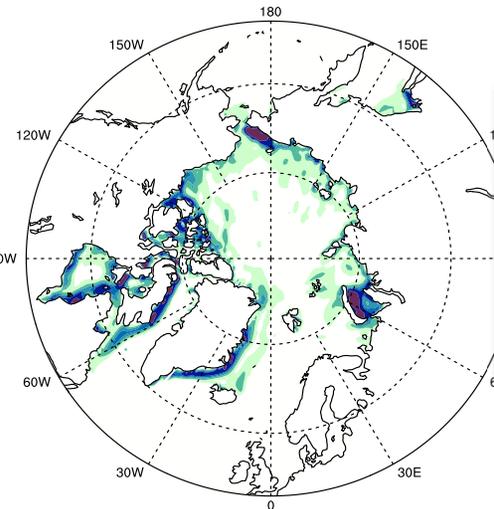
Assimilating SIC alone does LITTLE to reduce the bias

SIC & SIT



Assimilating thickness (SIT) yields major reduction of the bias

SIC & AGE



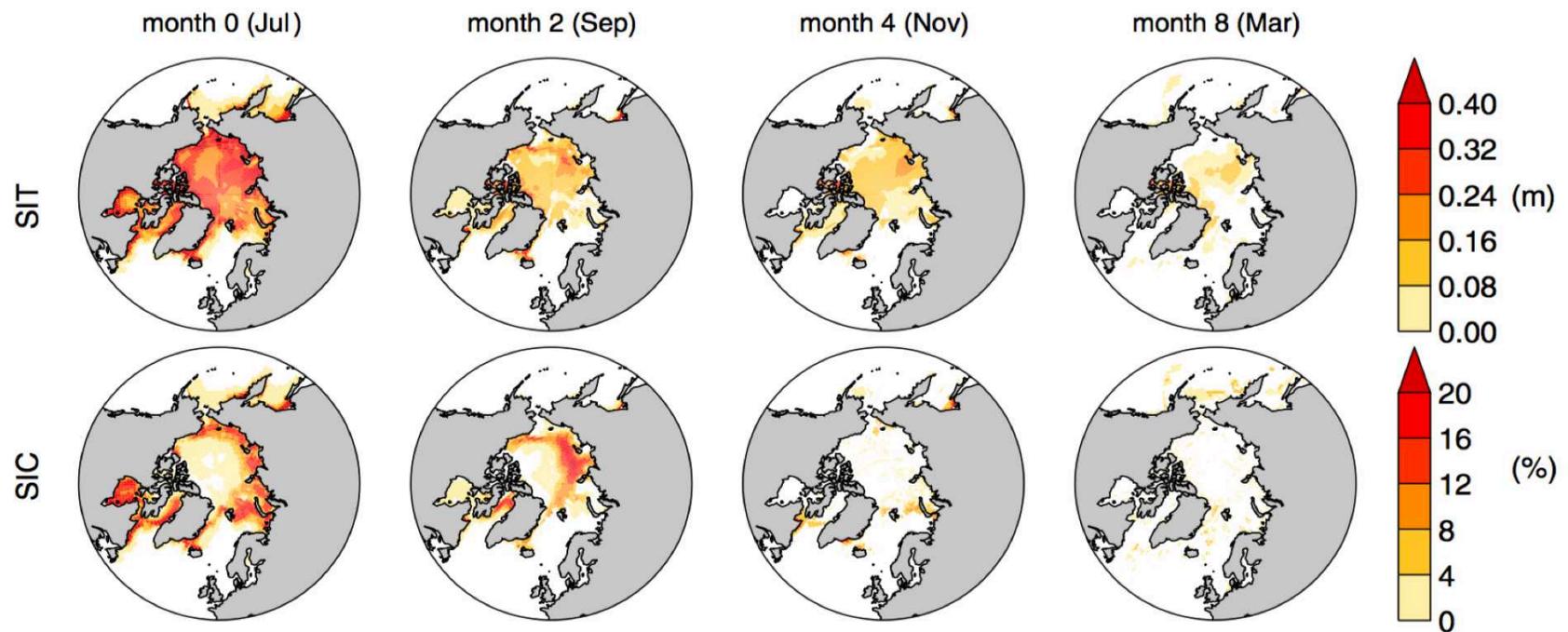
Assimilating AGE instead of SIT is reasonably successful too



0.1 0.3 0.5 0.8

m

Influence of initializing sea ice thickness in perfect model forecast, especially in summer



Response to July initializing with thickness of a given year compared to climatological thickness,