Model skill and sensitivity to initial conditions in a sea ice prediction system

Eduardo Blanchard-Wrigglesworth,
University of Washington,

with Richard Cullather, Wanqiu Wang, Jinlun Zhang, CC Bitz

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(or how to be smart about winning ice cream)

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What is the Sea Ice Outlook (SIO)

Forecast of September sea ice extent

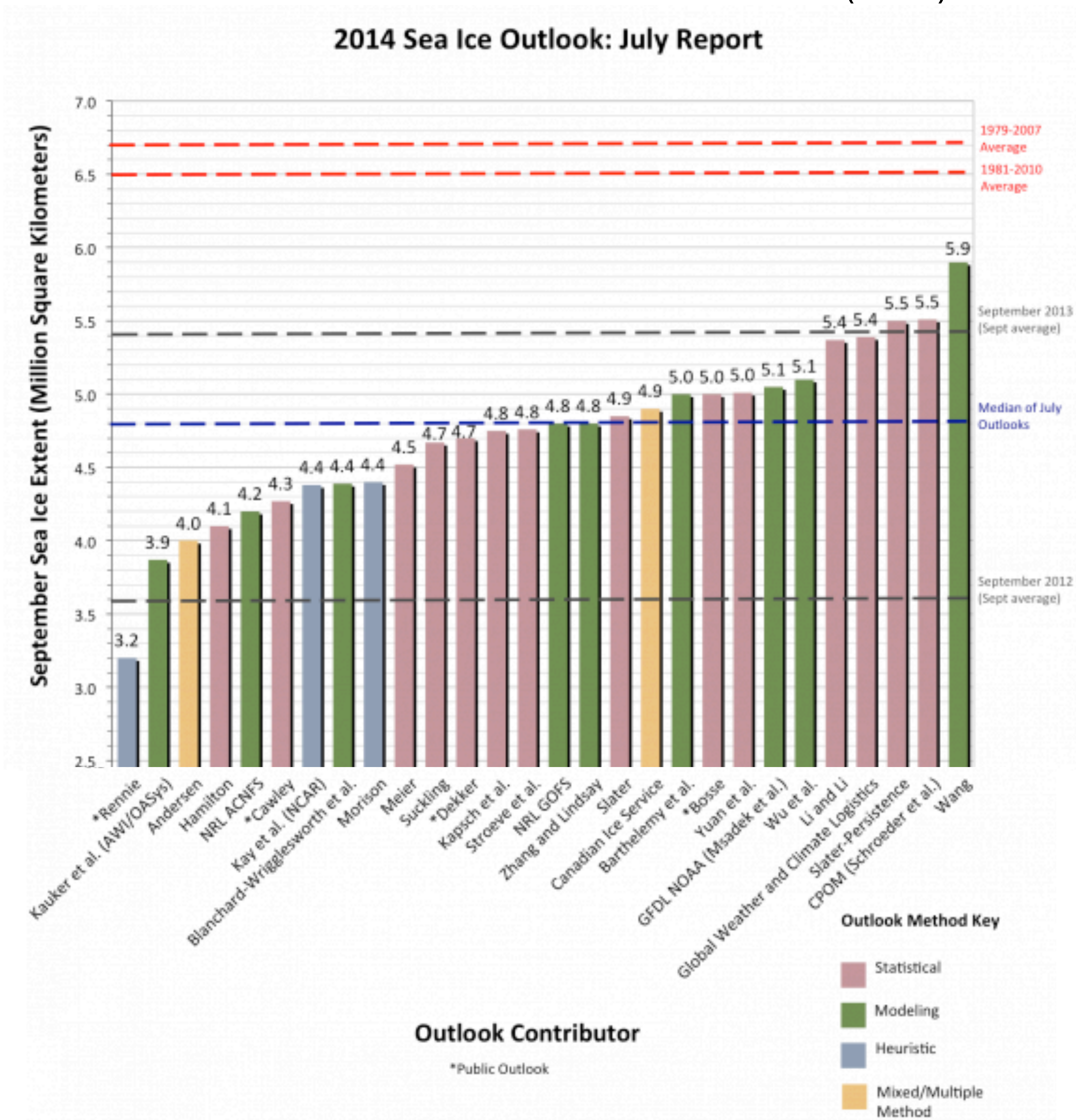
Organized by the Study of Environmental Arctic Change (SEARCH). Since 2013, hosted by the Sea Ice Prediction Network - SIPN. (arcus.org/sipn/sea-ice-outlook)

Initiated in 2008, triggered by 2007 summer record melt

Each summer, 3 submission calls - early June, early July, early August

All types of forecasting techniques welcome: dynamical models, statistical, heuristic, public polls.

What is the Sea Ice Outlook (SIO)



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2008 - 2014: 7 years, 21 submission calls, 300+ submissions. 112 from dynamical models.

Skill first analysed for 2008-2013 in Stroeve et al 2014

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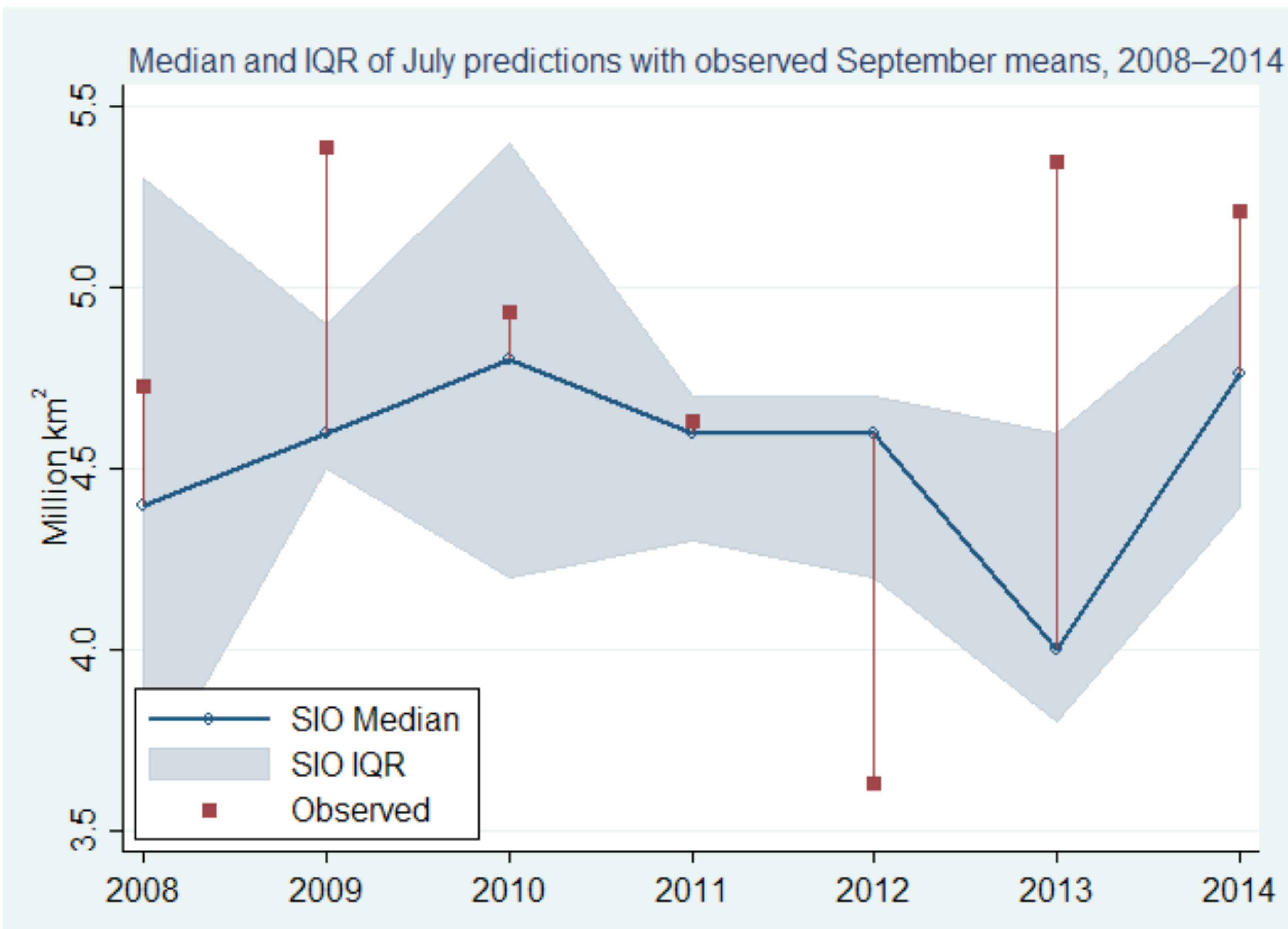

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Overall, little skill. Good when years are close to linear trend, bad when years depart from linear trend.

Statistical slightly better than dynamical models.

Not much improvement as season progresses (lead 4 month to lead 2 month forecasts)

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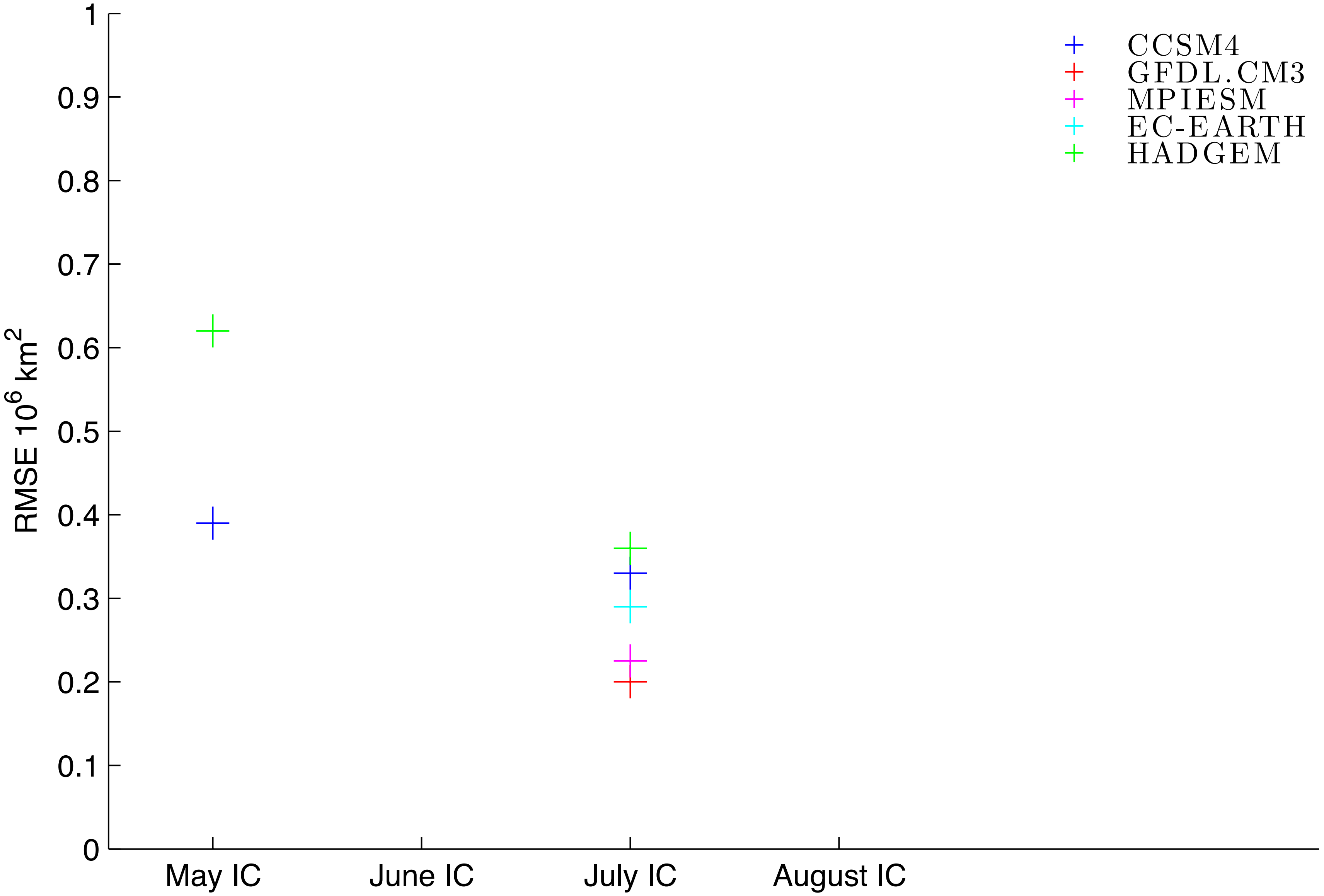
In this talk...

Analyze SIO dynamical models. Is there skill? Should one expect skill? If there’s no skill, why? What can one do to improve skill?

Analyse dynamical models 2009-2014

115 total submissions - 35 June, 43 July, 37 August



+ Perfect-model

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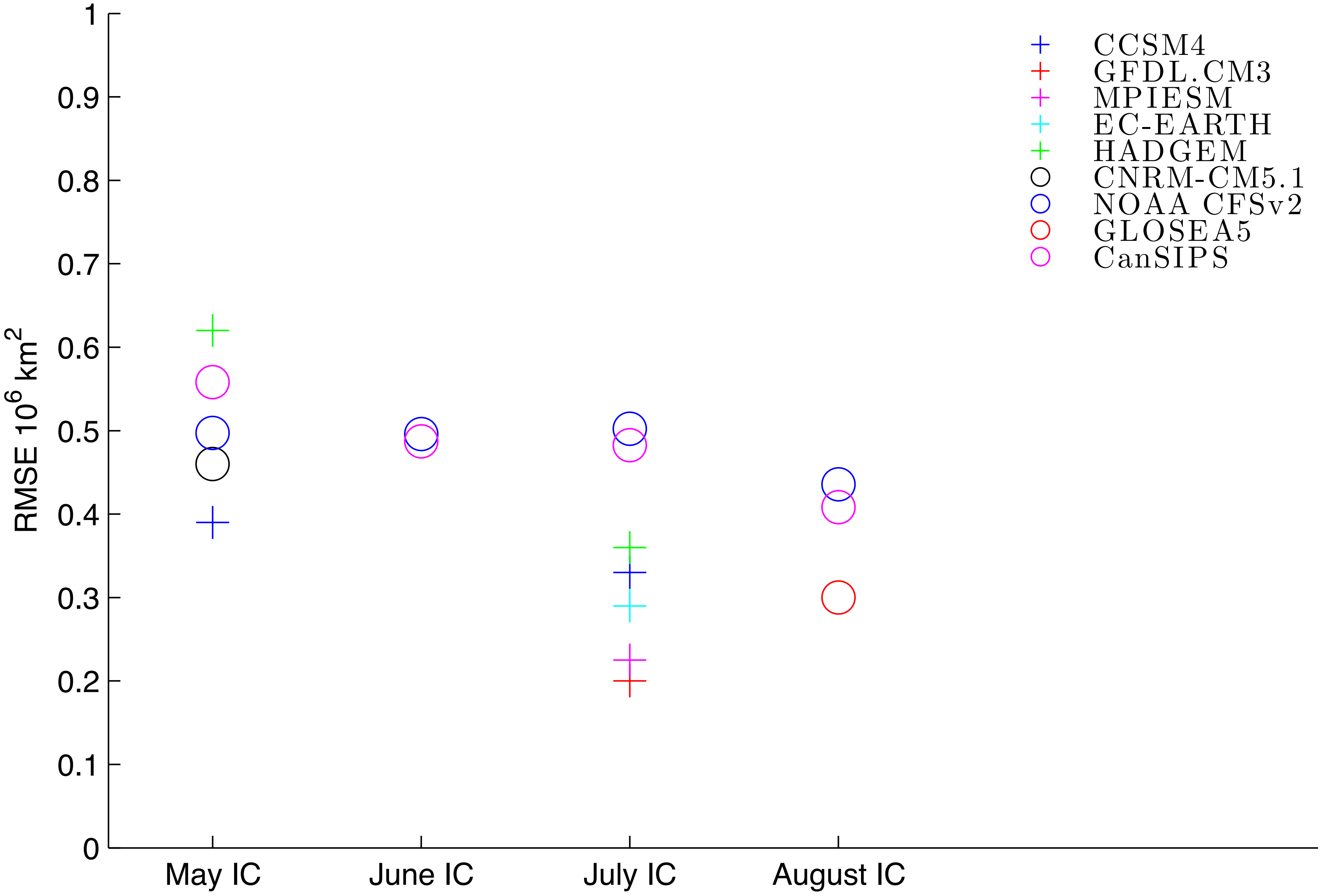

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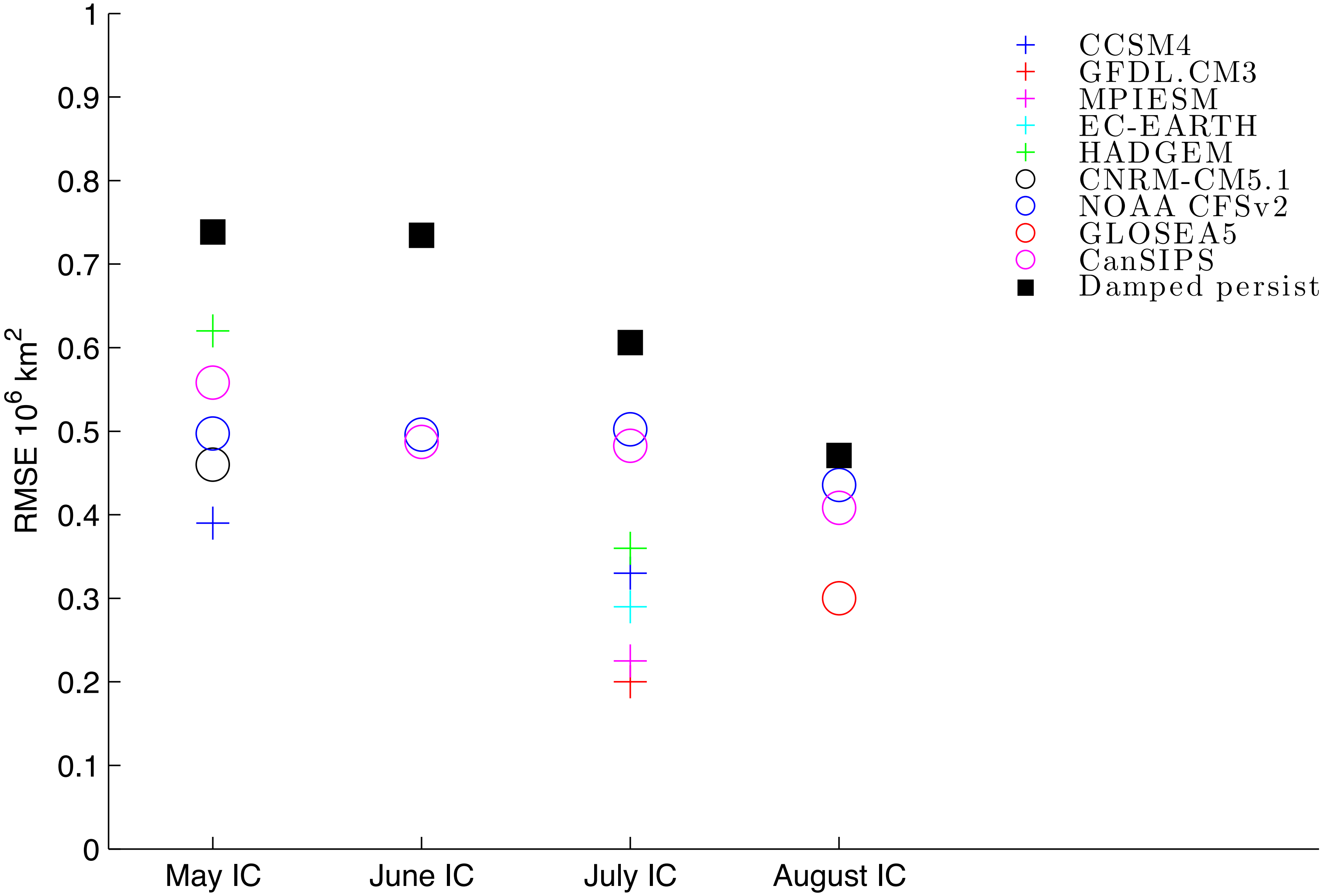

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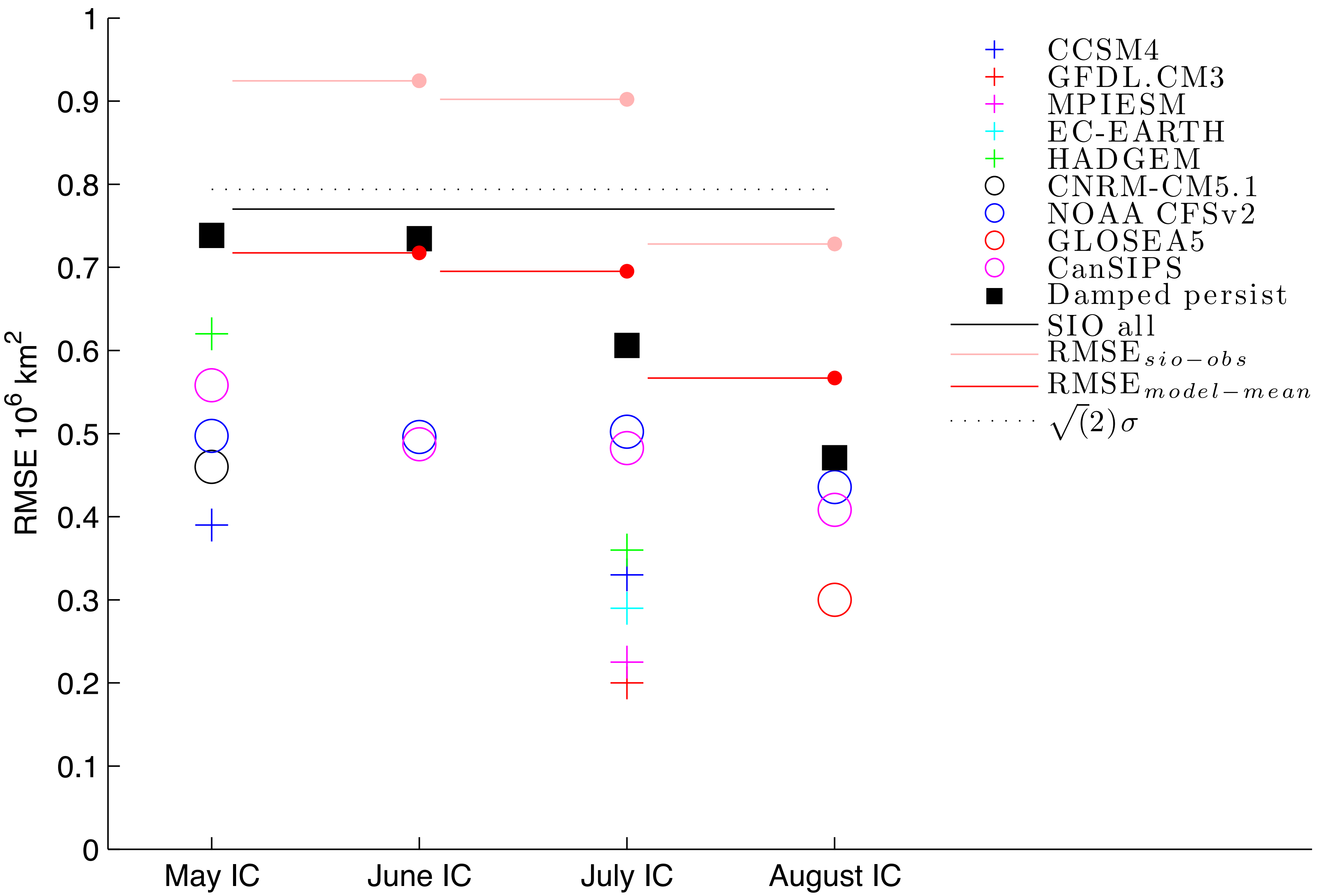

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Satellite record

= SIO

Should we expect skill?

Results from perfect-model experiments, hindcasts, and studies of persistence timescales of sea ice say yes.

SIO models do not even beat damped persistence forecast.

Why is skill so much lower than hindcasts? Some of the models in SIO have performed hindcasts over historical period, found much higher skill.

Has recent period been inherently more unpredictable than earlier decades?

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METOFFICE GLOSEA5: hindcast RMSE (1996-2009): 0.3 million km
SIO RMSE (7 forecasts): 1 million km

Sea ice persistence and predictability

Intrinsically linked (e.g., Day et al 2014)

Persistence can vary, even in control run with no external forcing

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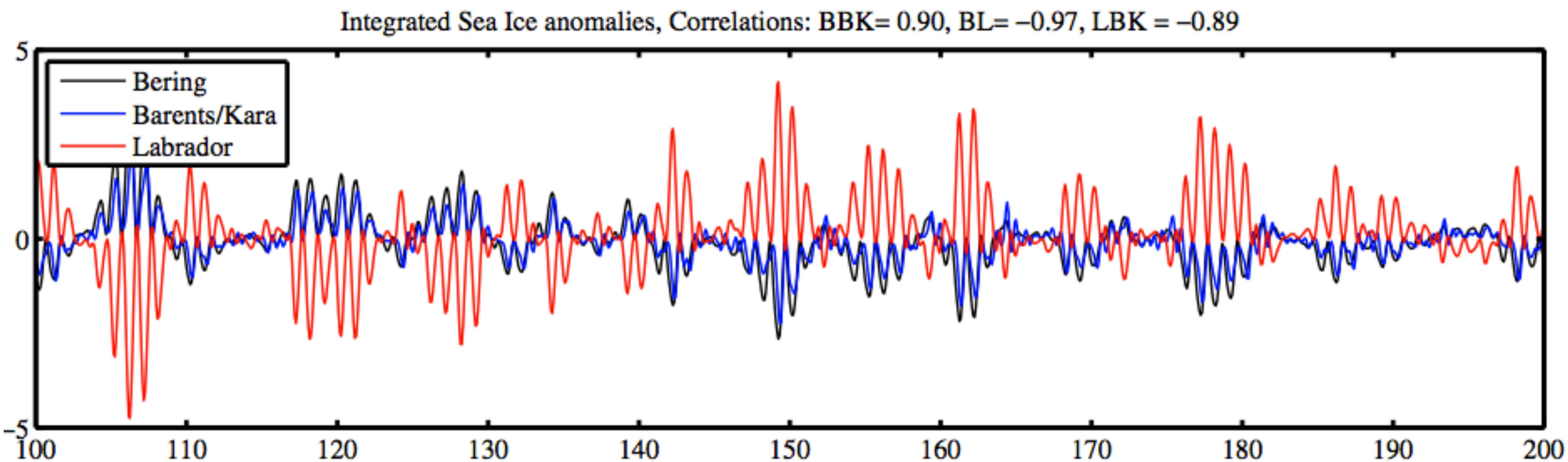

100 years index of the 2nd nonlinar Laplacian spectran analysis (NLSA) mode taken from a 1300 year CCSM4 control run. Active periods of persistence & memory re-emergence when index is high/low (Bushuk et al, in press).

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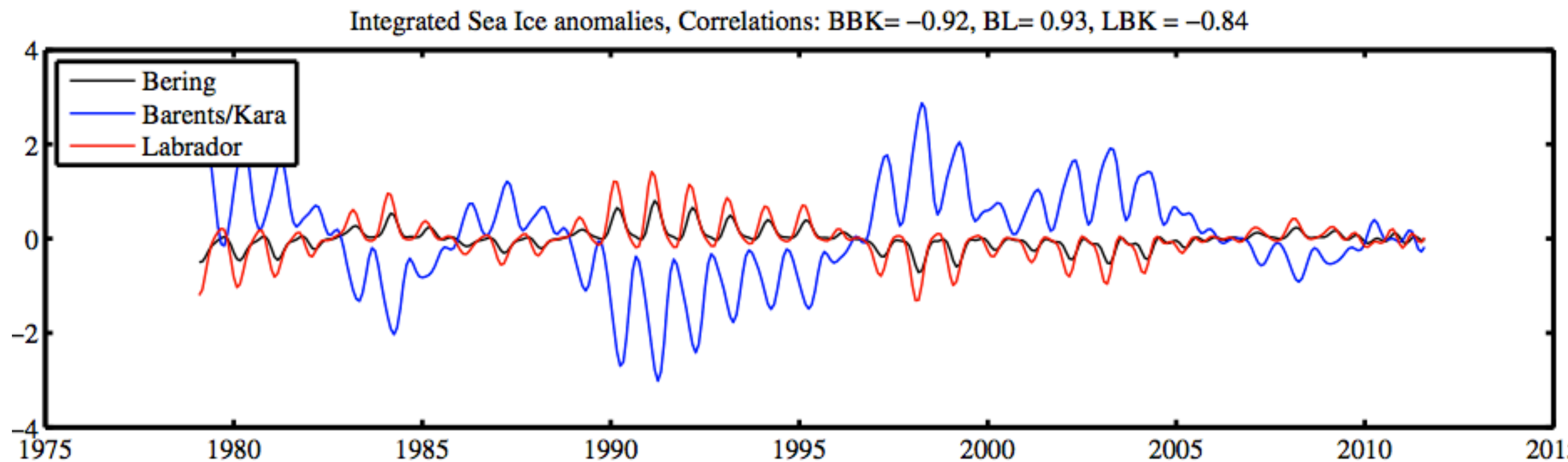

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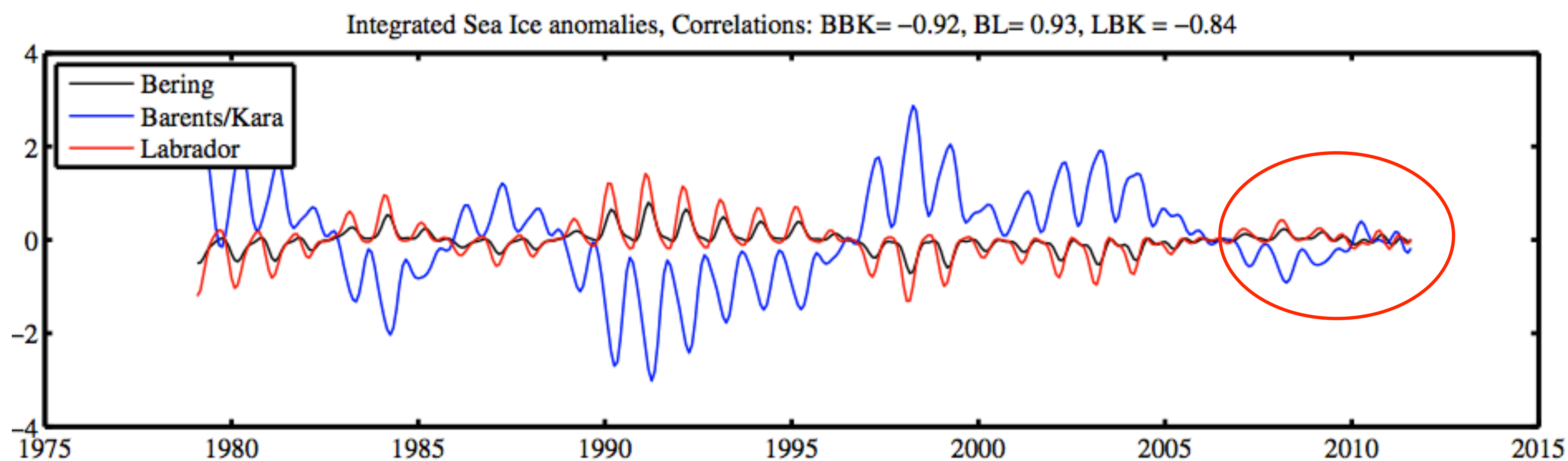

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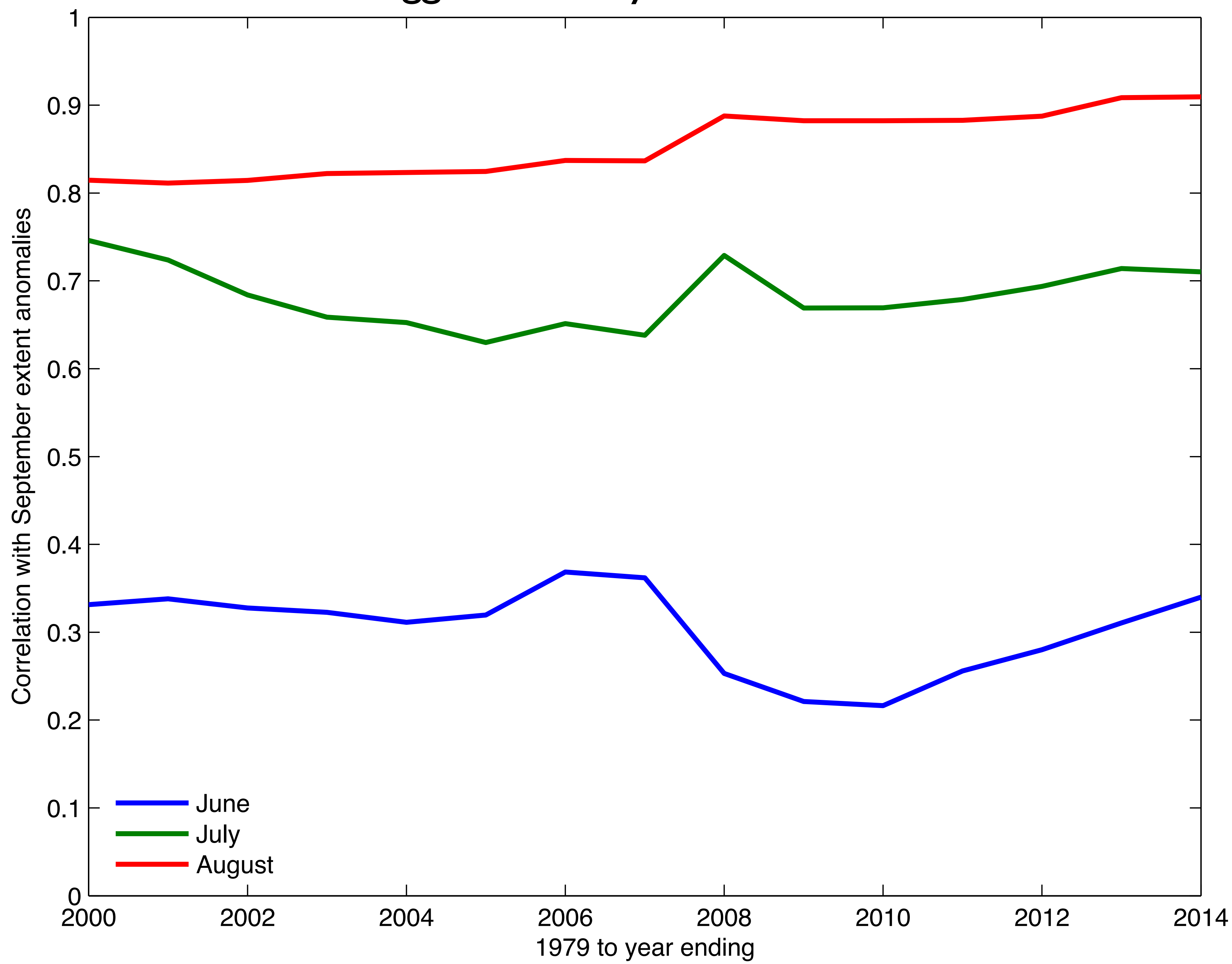
Persistence and predictability

Intrinsically linked (e.g., Day et al 2014)

Has summer persistence changed?

lagged anomaly correlation



Persistence and predictability

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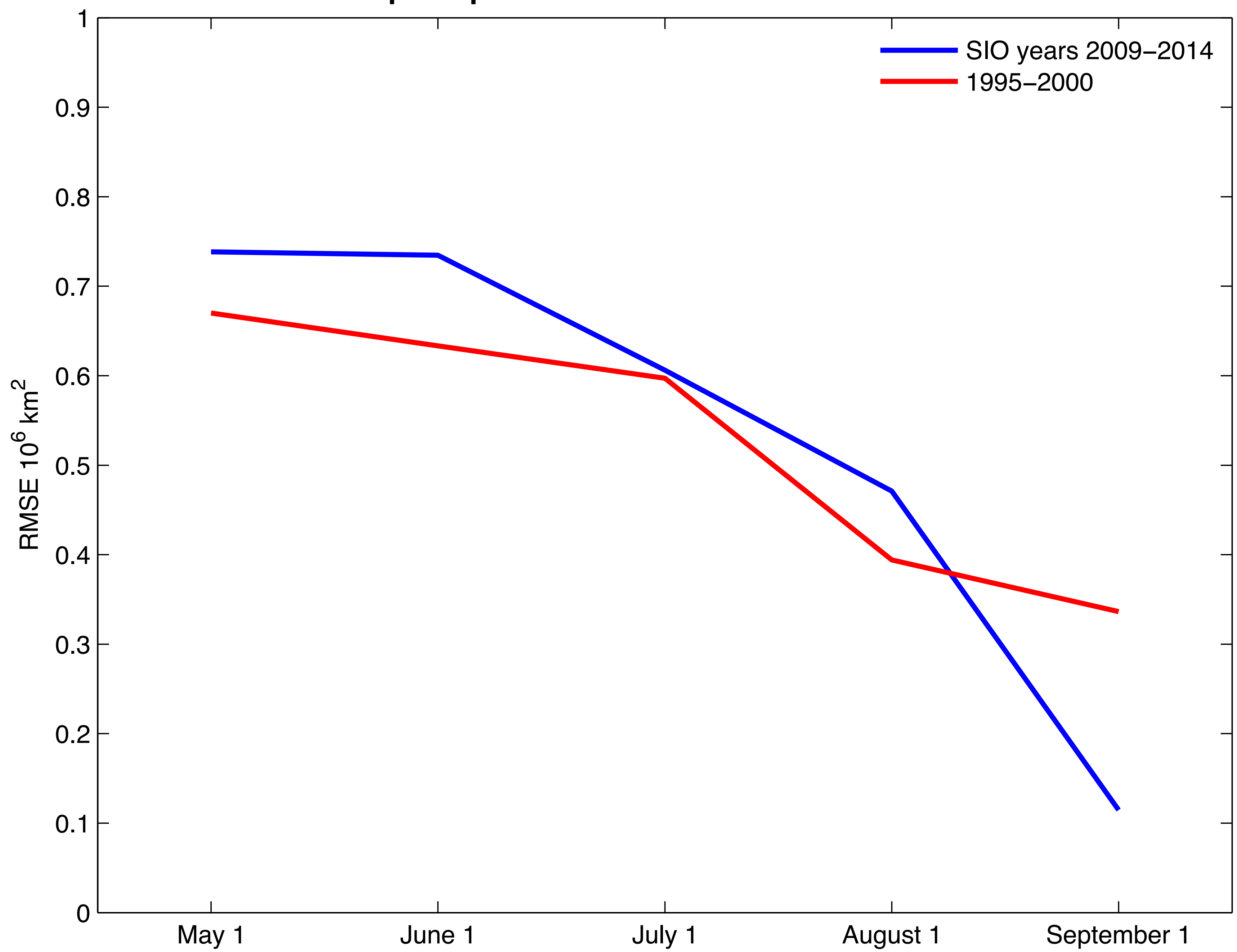
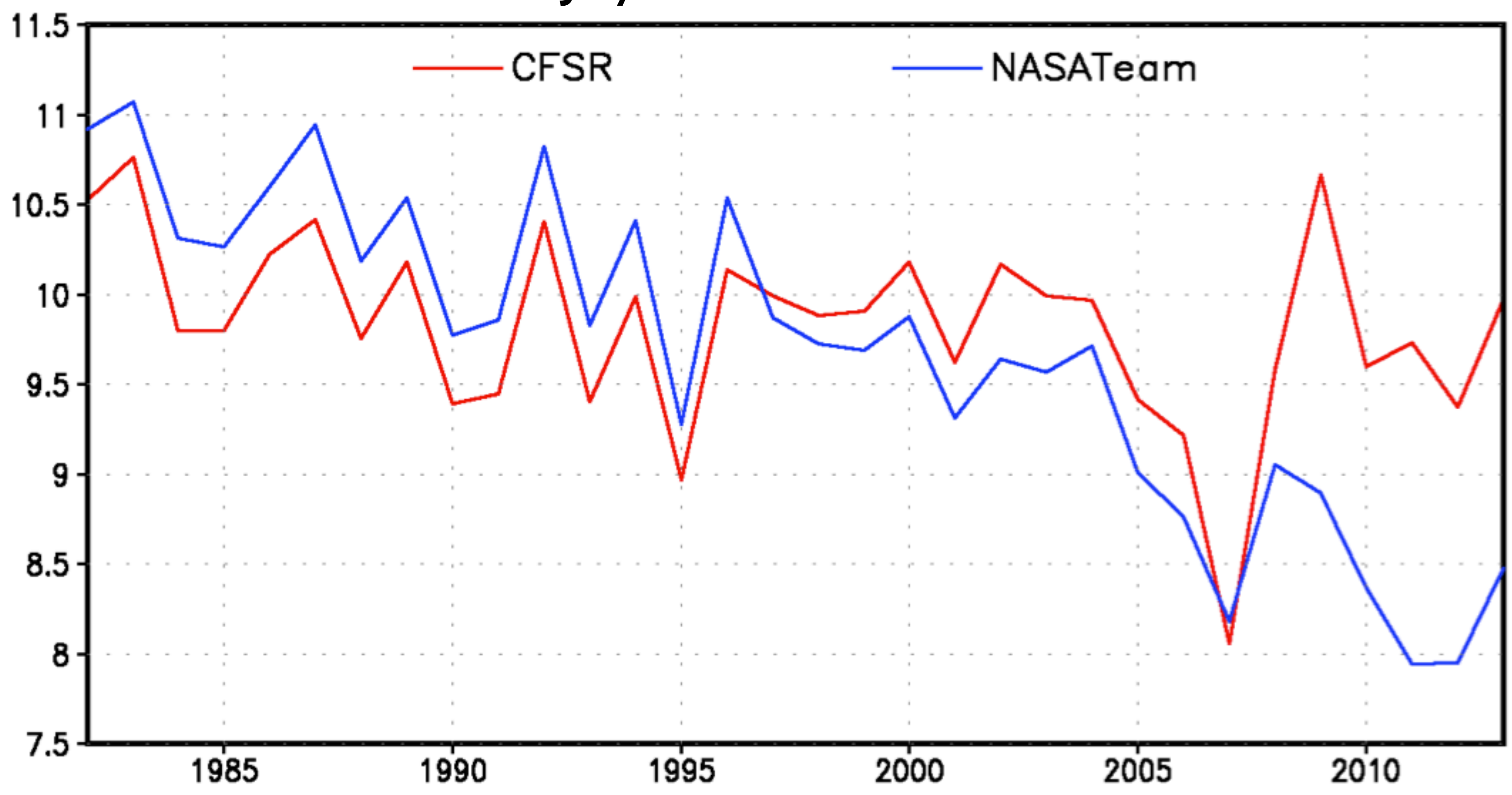
Has summer persistence changed?

damped persistence forecast RMSE



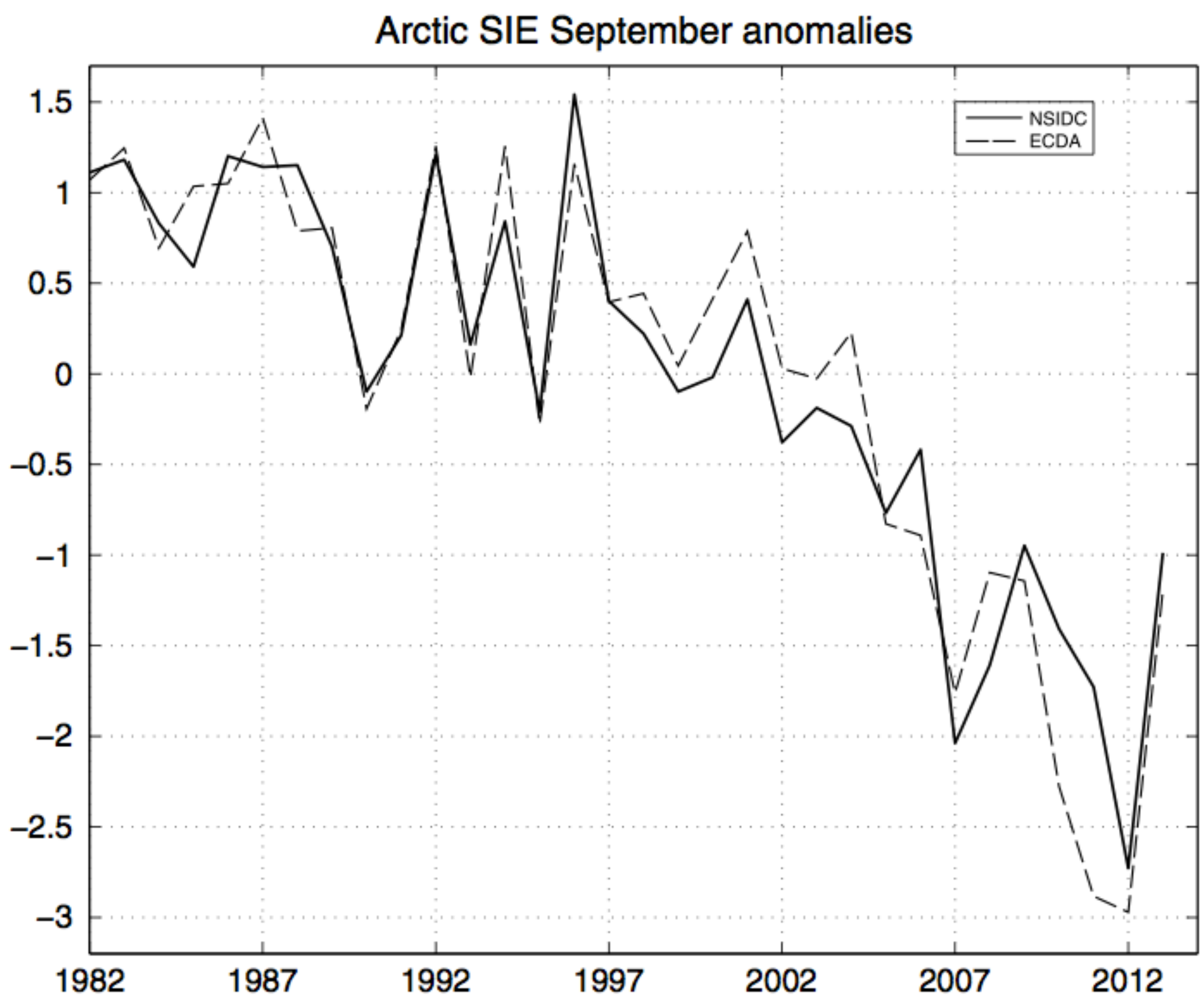
Errors in reanalysis: Climate Forecast System Reanalysis - ICs for NOAA CFSv2

July sea ice extent



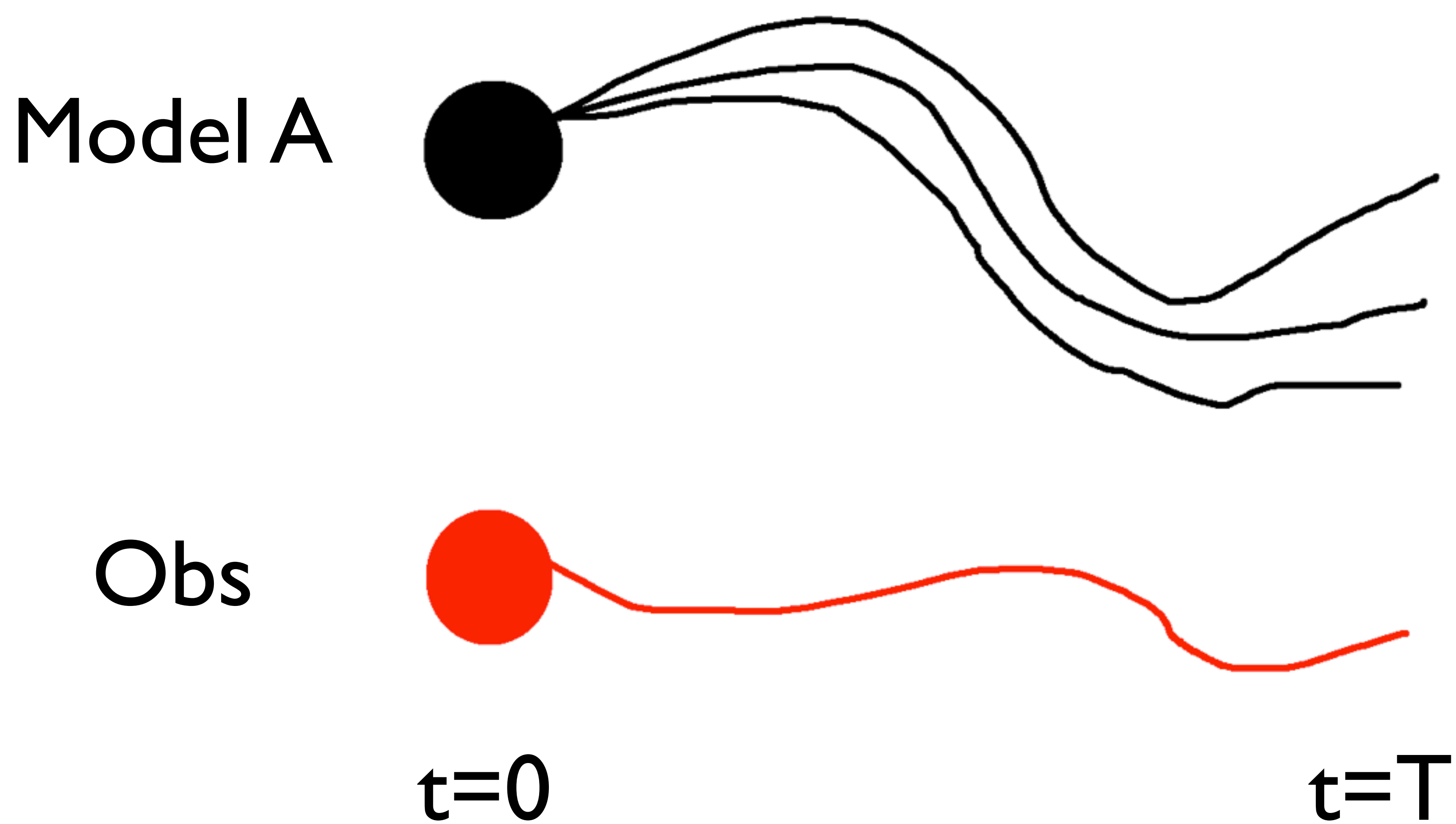
Courtesy Wanqiu Wang

Errors in reanalysis: ECDA - ICs for GFDL CM2.1



Msadek et al, 2014

Can the different models 'predict' each other?
(and does it matter?)



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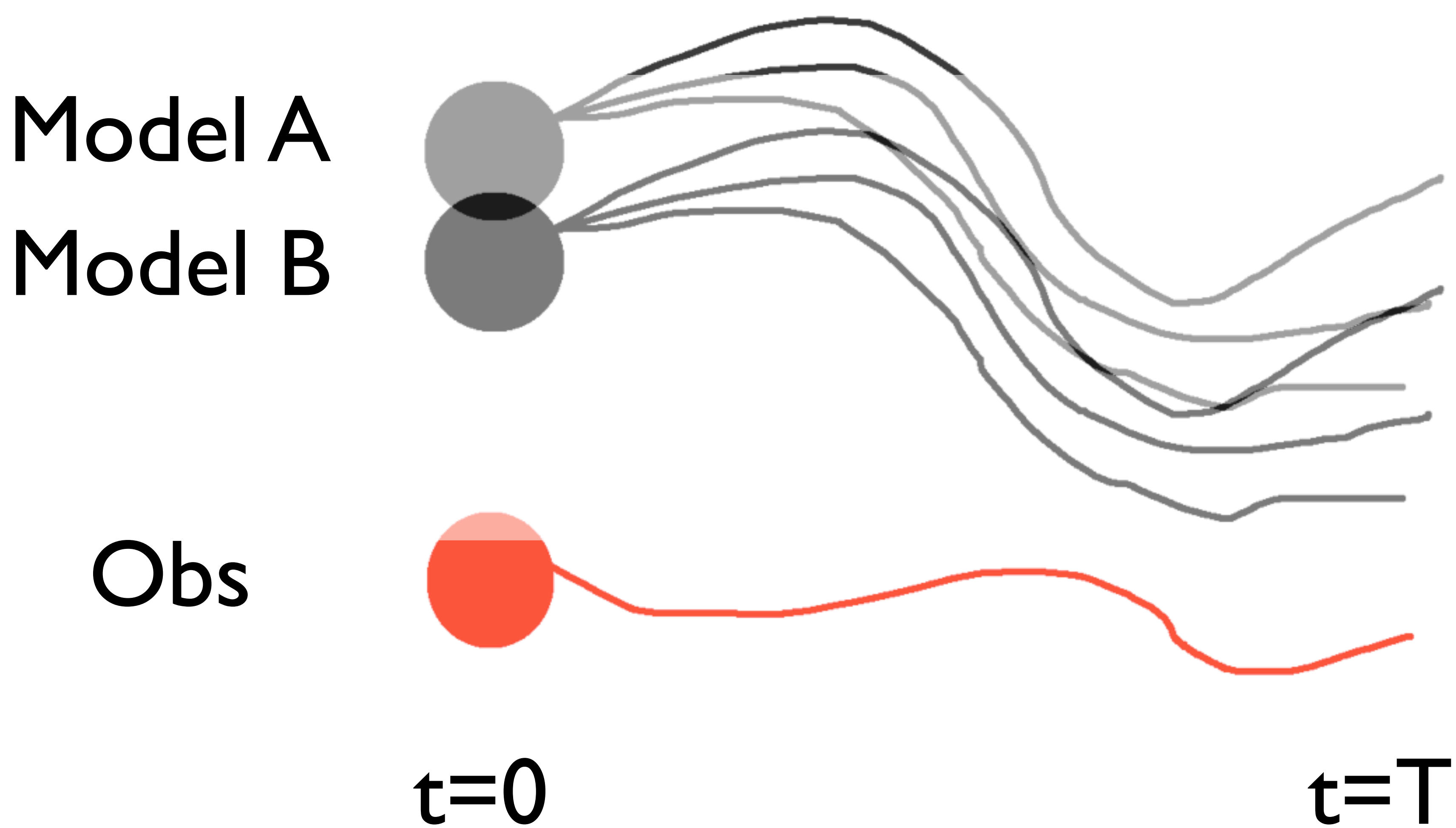

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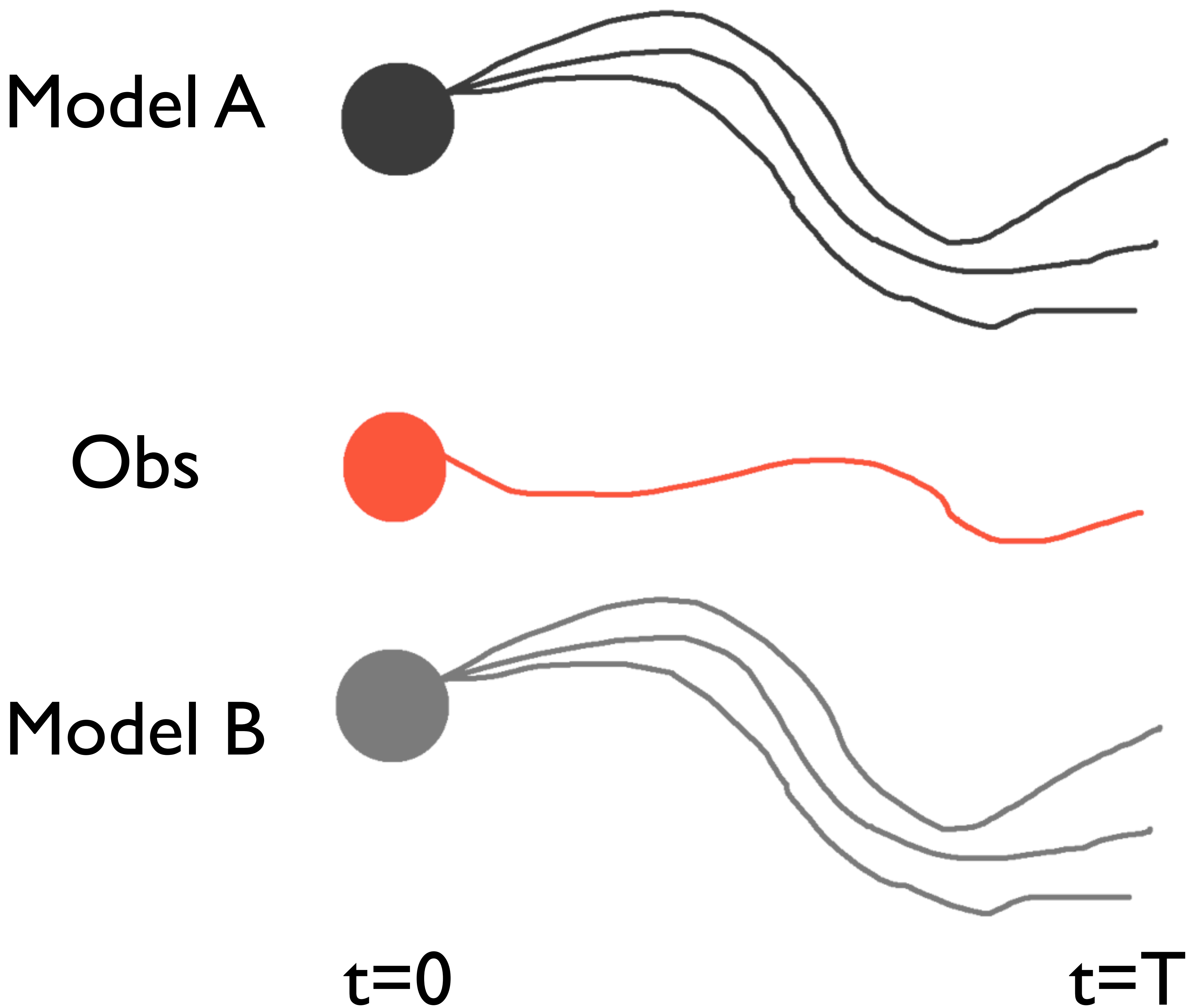

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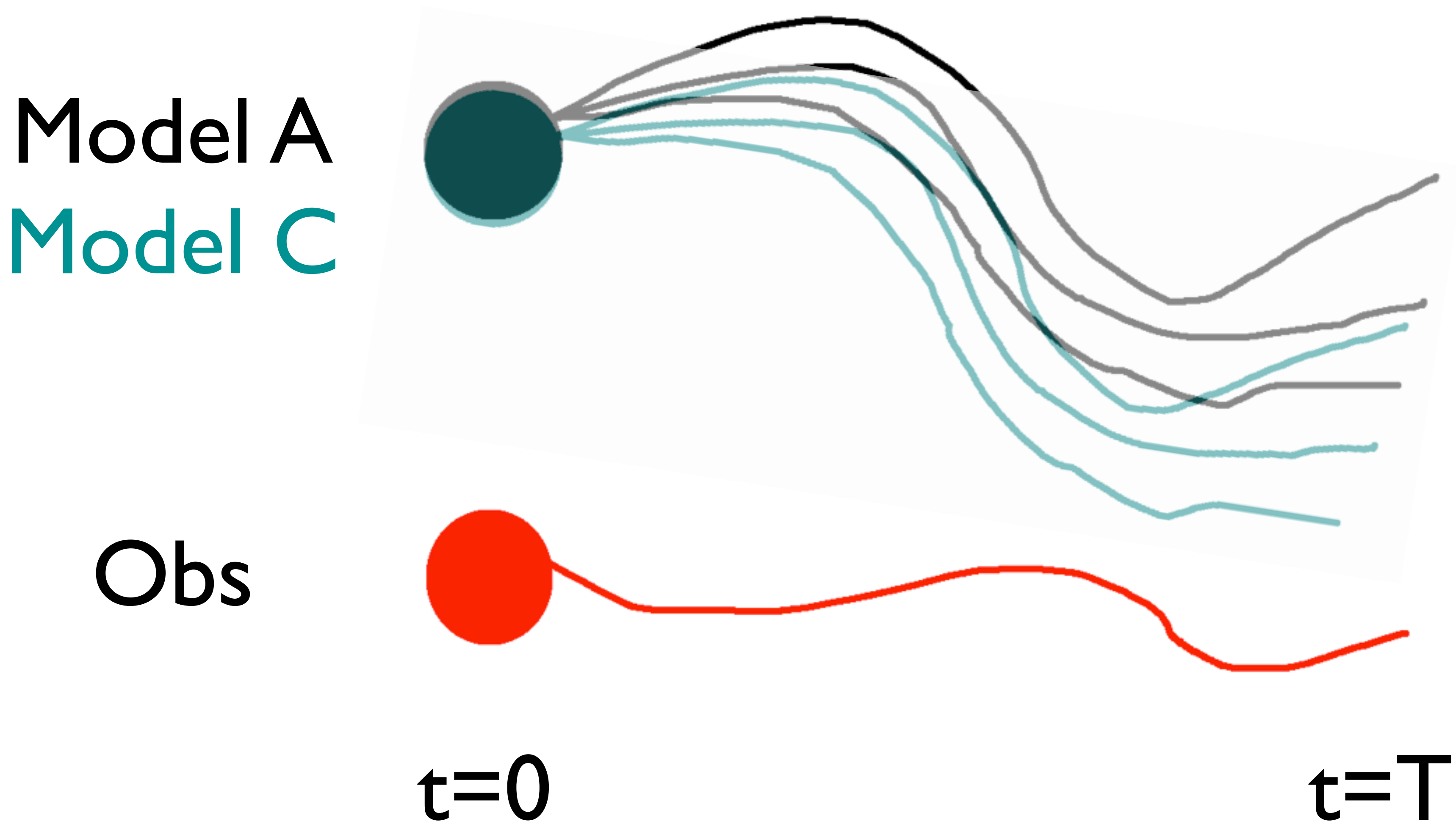

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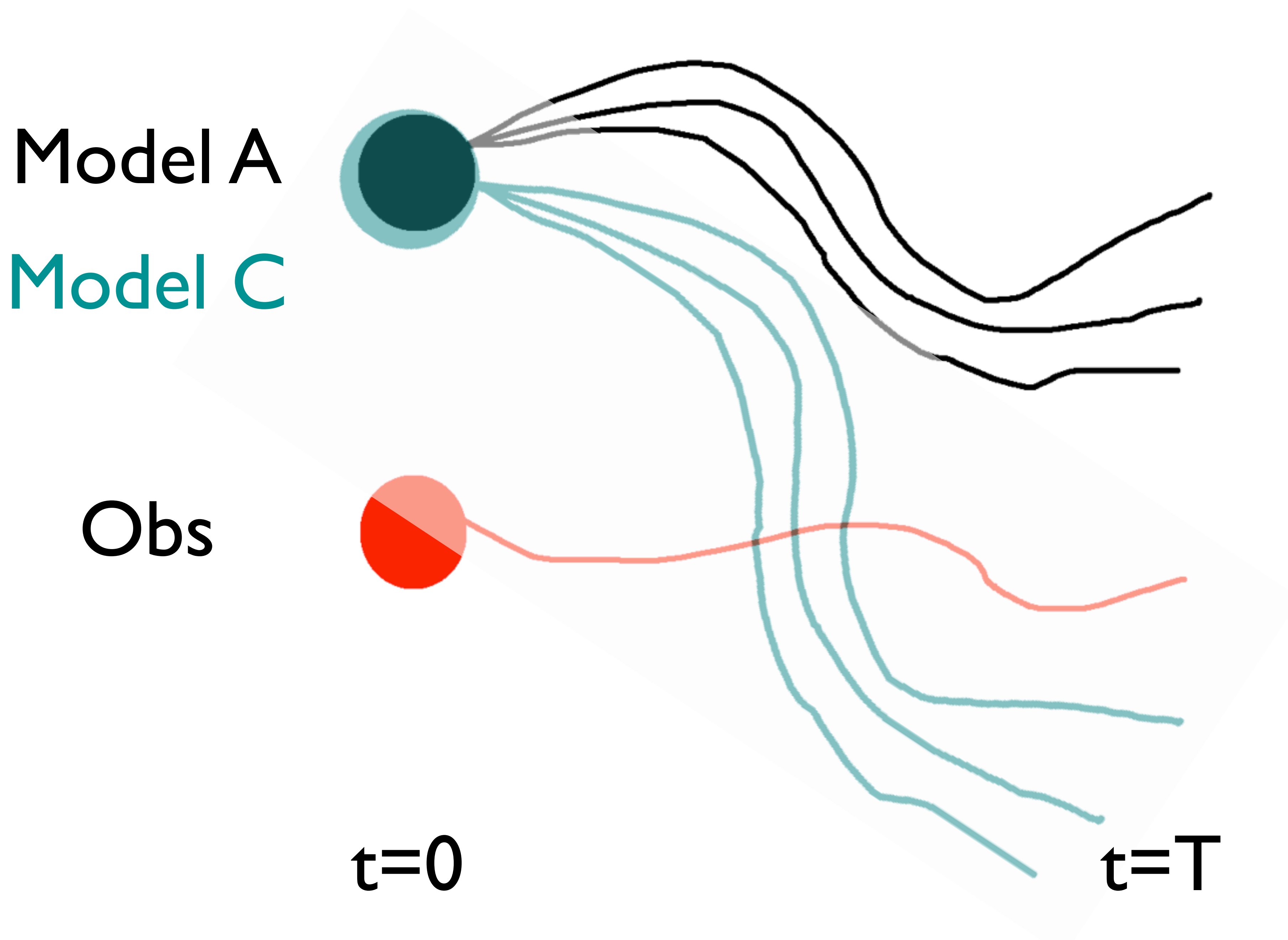
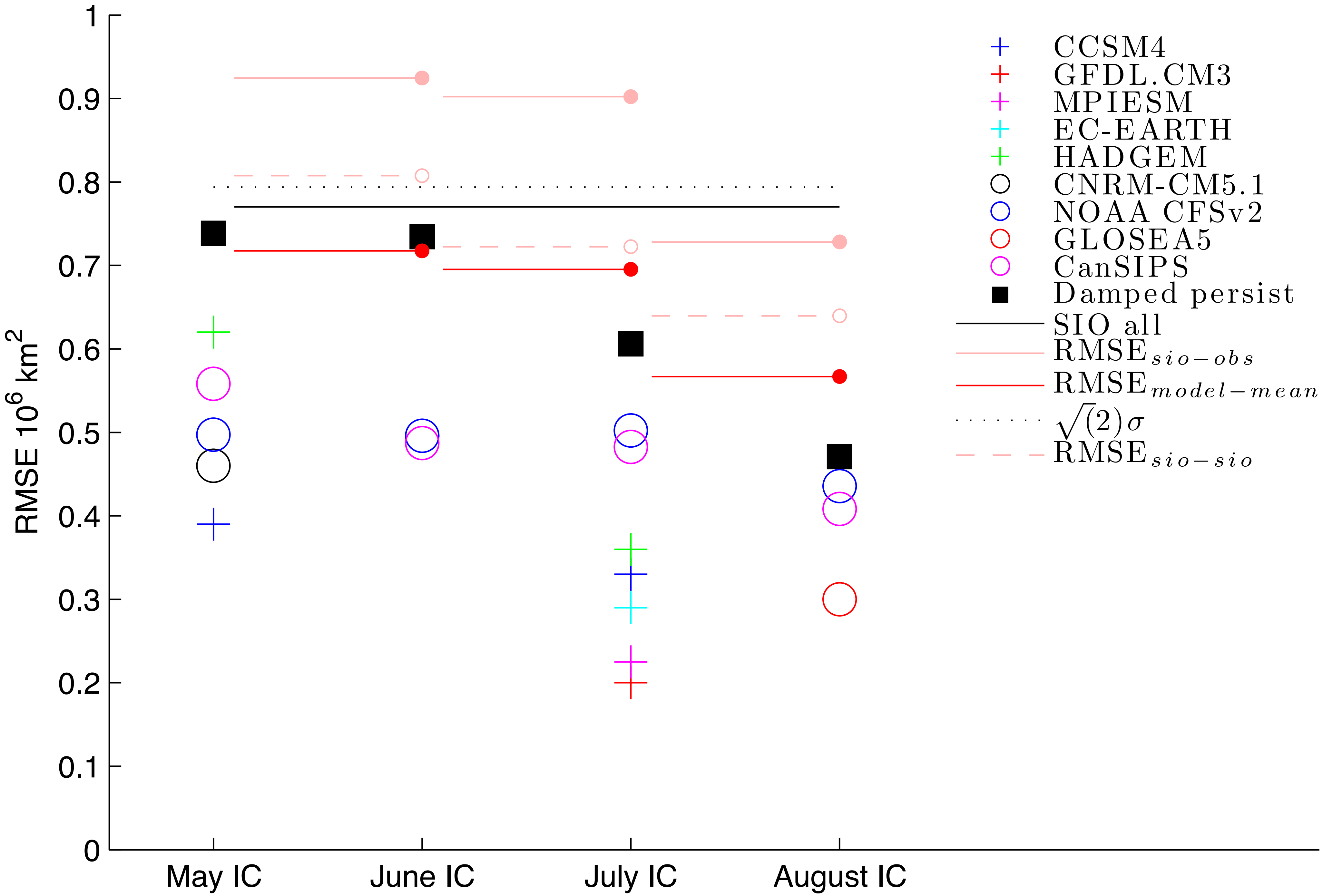


If the SIO models predict each other better than observations -> consistent error in ICs and physics

Can the different models ‘predict’ each other? (and does it matter?)

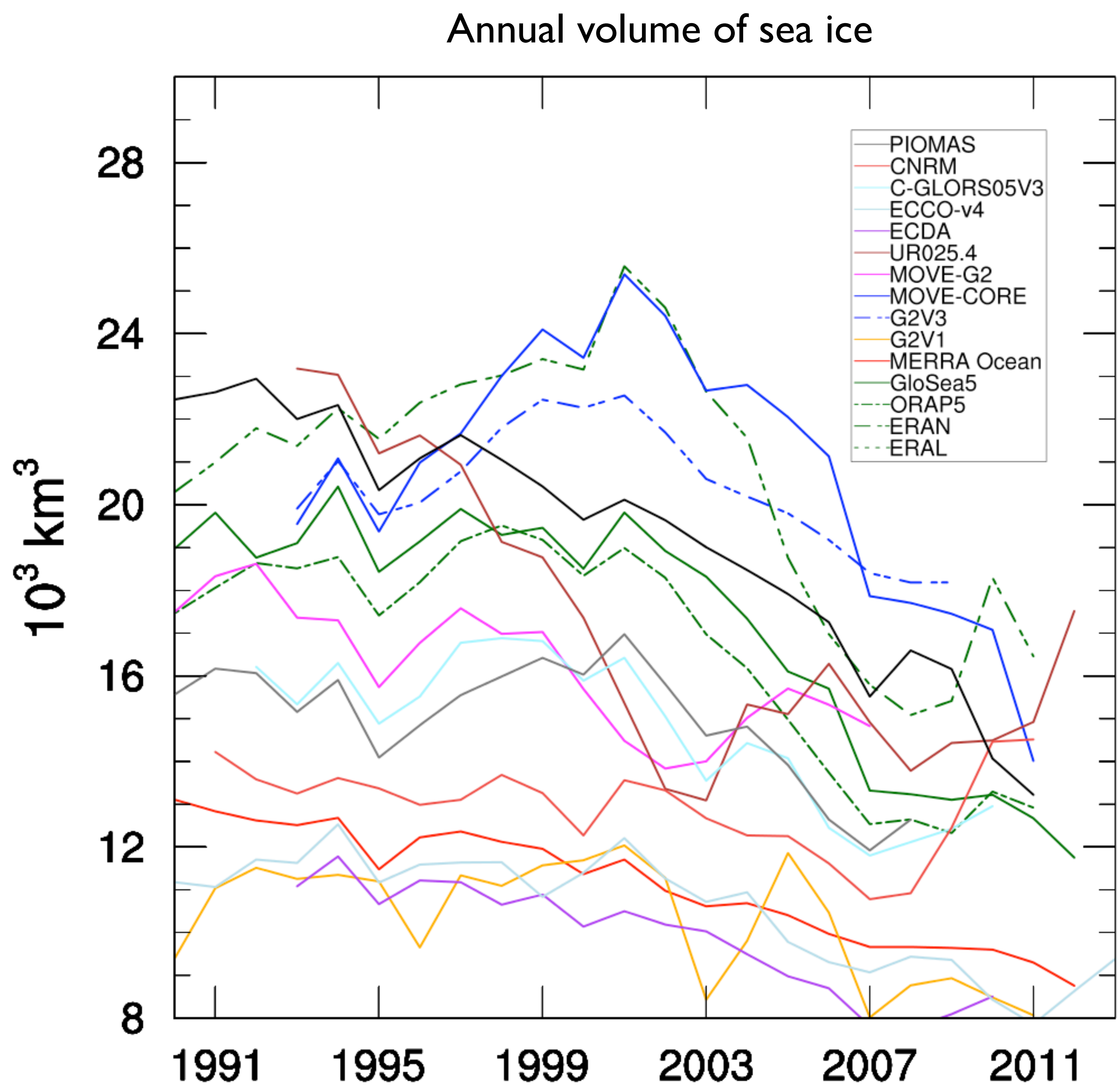


SIO models are about as unskilled at predicting each other as at predicting observations.

How different are the initial conditions they use?

Even if they used identical initial conditions, what effect would different physics have?

Errors in reanalysis (from which ICs are taken)



Courtesy Matt Chevallier

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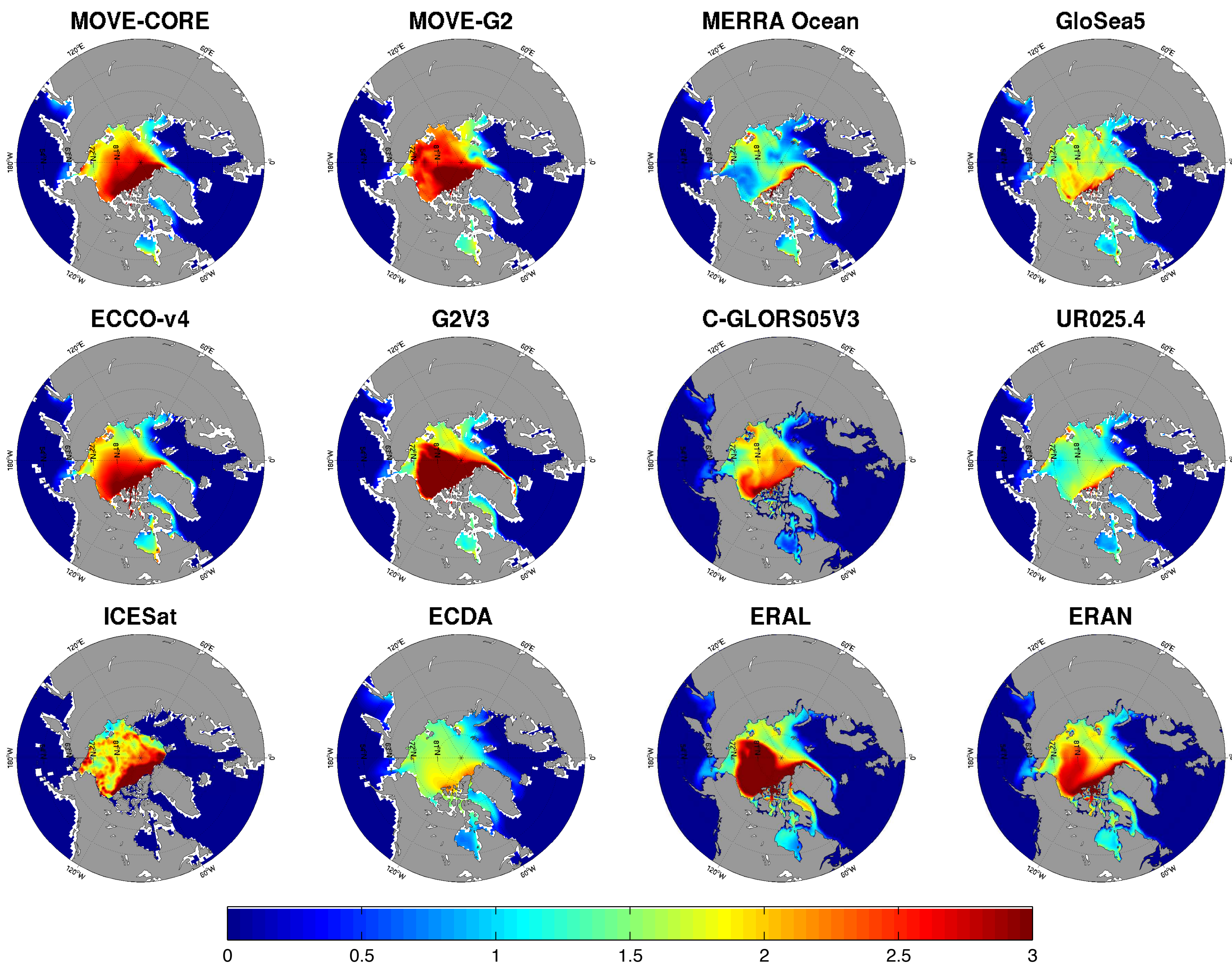

March 2007 Sea Ice Thickness (m) in global ocean-sea ice reanalyses with assimilation of sea ice concentration

Courtesy Matt Chevallier

ICs are extremely different. But even if they were identical...

For the 2014 SIO workshop, we proposed an initial condition perturbation experiment, inviting all SIO dynamical model groups to re-run their 2013 forecasts with a -1m sea ice thickness perturbation

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4 groups performed experiment

NCAR CCSM4 (UW group)

PIOMAS (Zhang & Lindsay)

NASA GMAO (Cullather et al)

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GCM with ice thickness anomalies from PIOMAS

PIOMAS (Zhang & Lindsay)

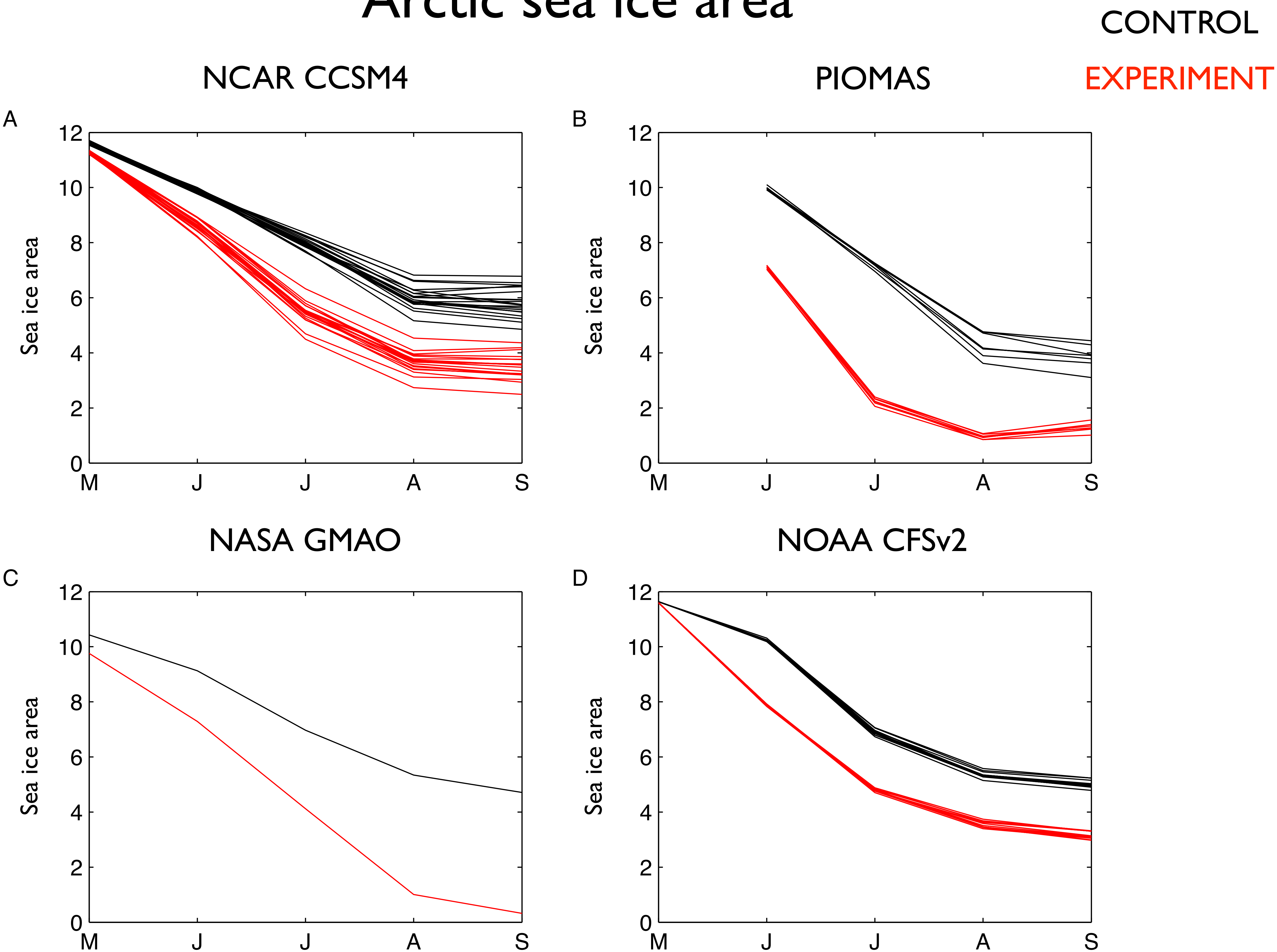
Regional ice-ocean model forced with past atmospheres

NASA GMAO (Cullather et al)

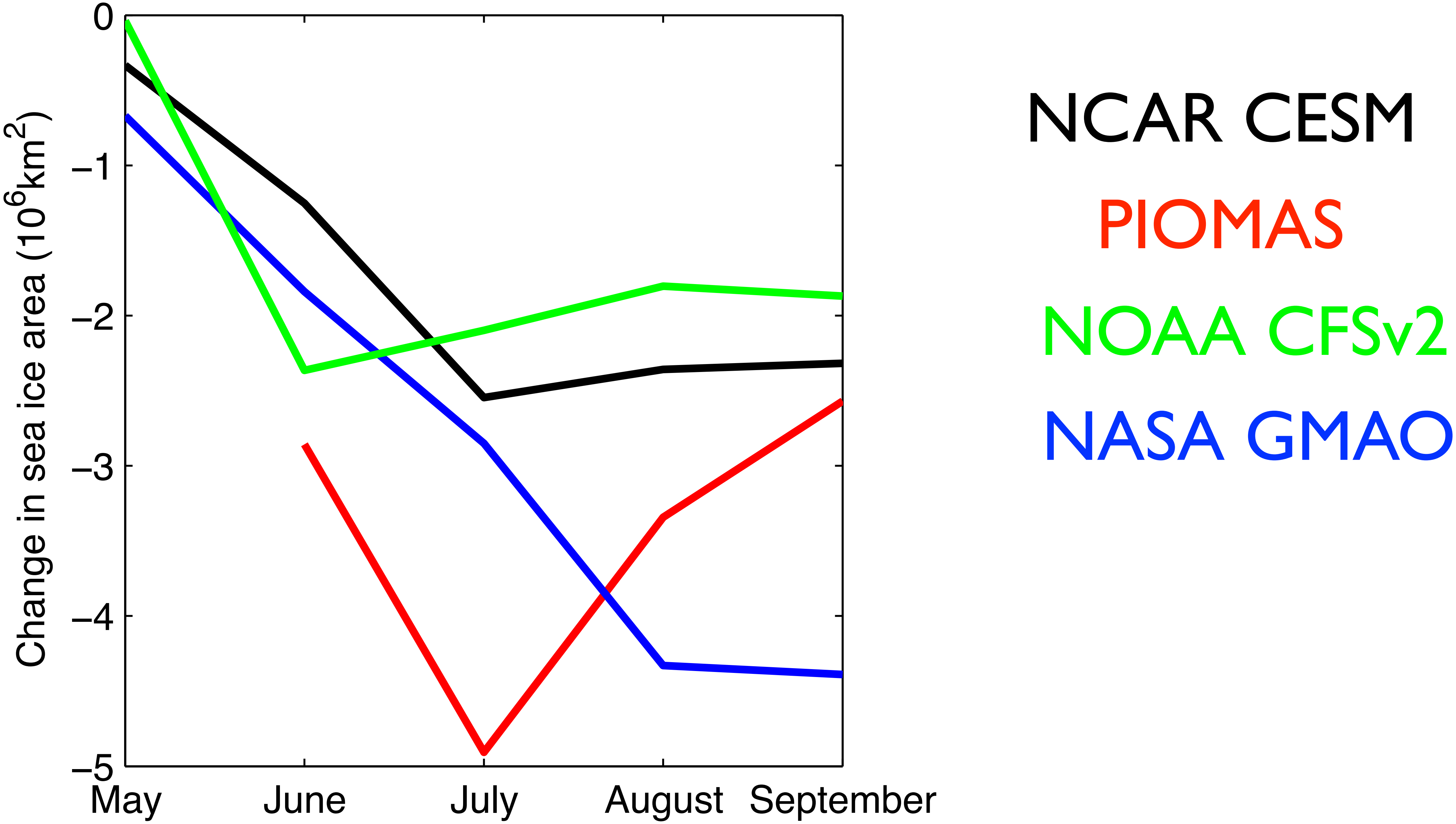
NOAA CFSv2 (Wang et al)

Seasonal forecasting systems

Arctic sea ice area

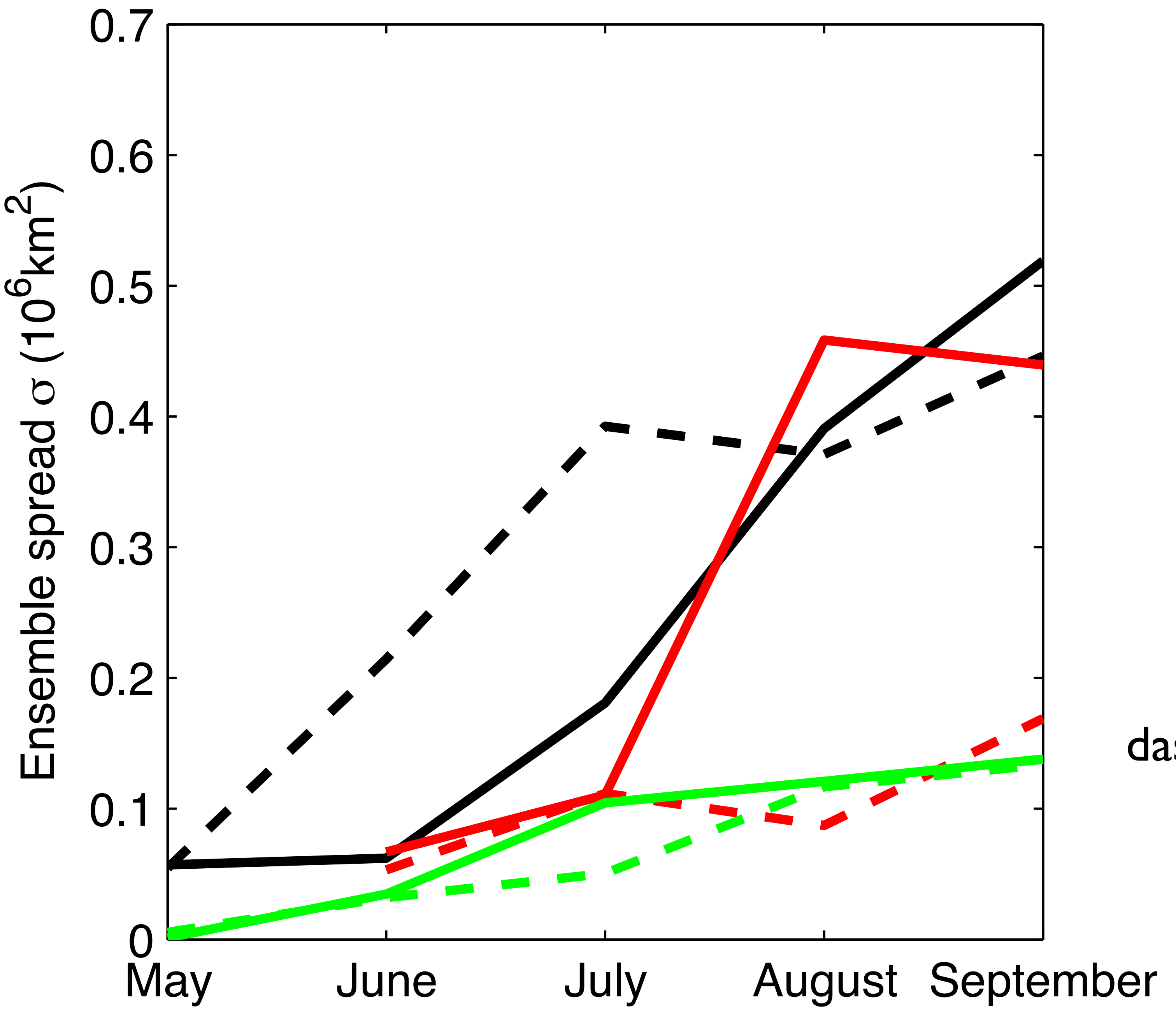


Arctic sea ice area response



All models have their own unique response, not only in September sea ice, but through summer season (relevant for ice-free dates).

Potential predictability response



NCAR CESM

PIOMAS

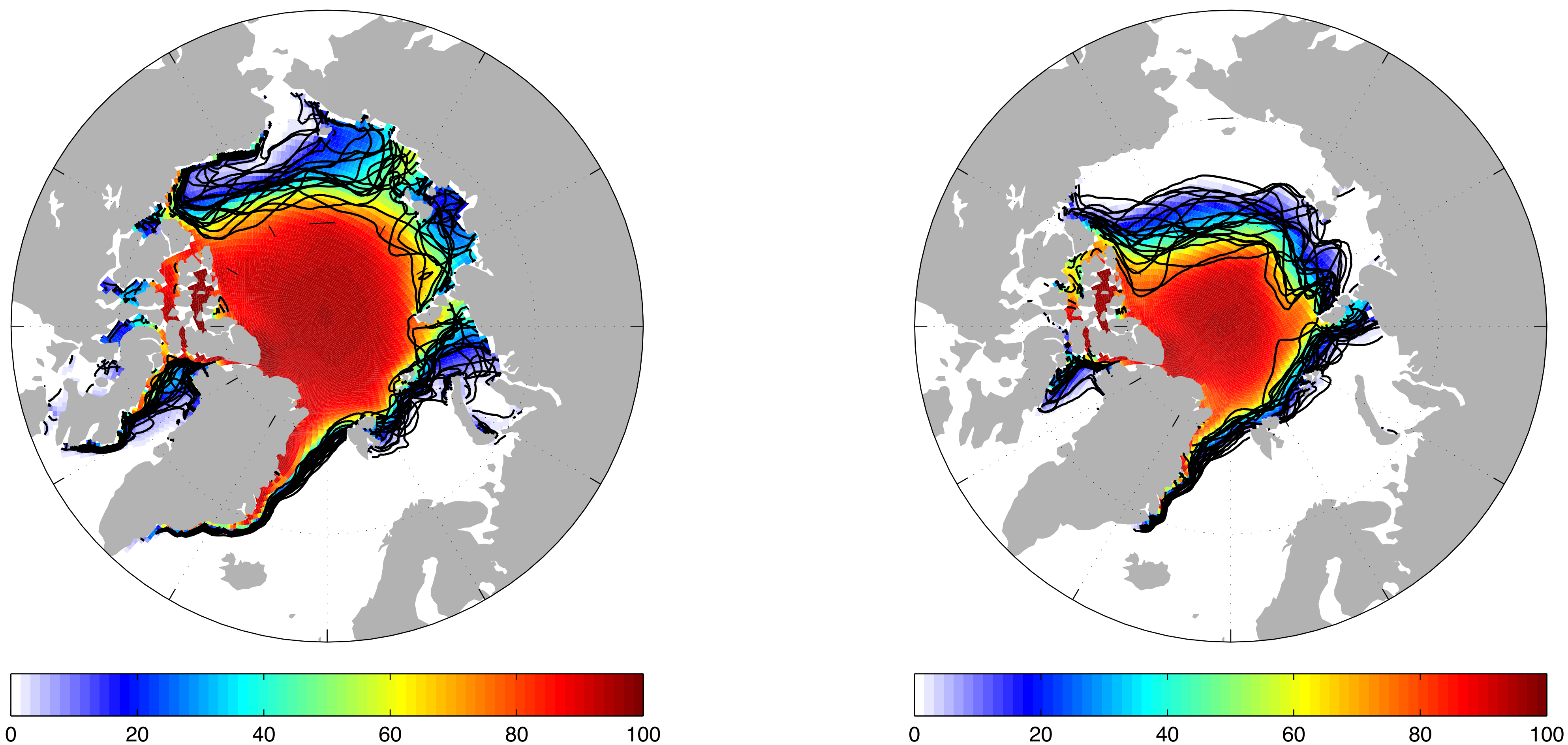
NOAA CFSv2

Solid - control ensemble spread

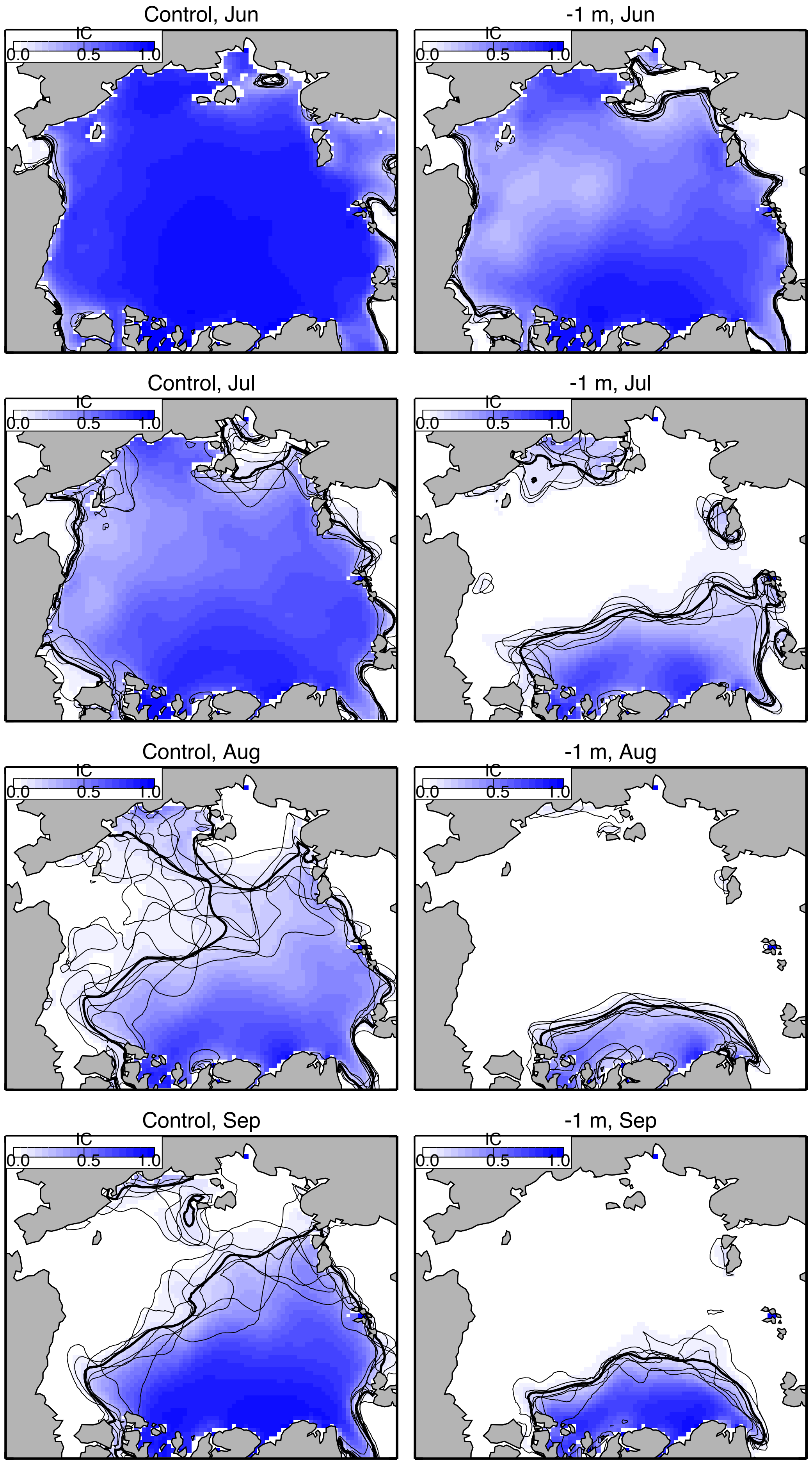
dashed - experiment ensemble spread

The potential predictability of each model also responds differently

Control | Experiment



CCSM4
Ice concentration



PIOMAS
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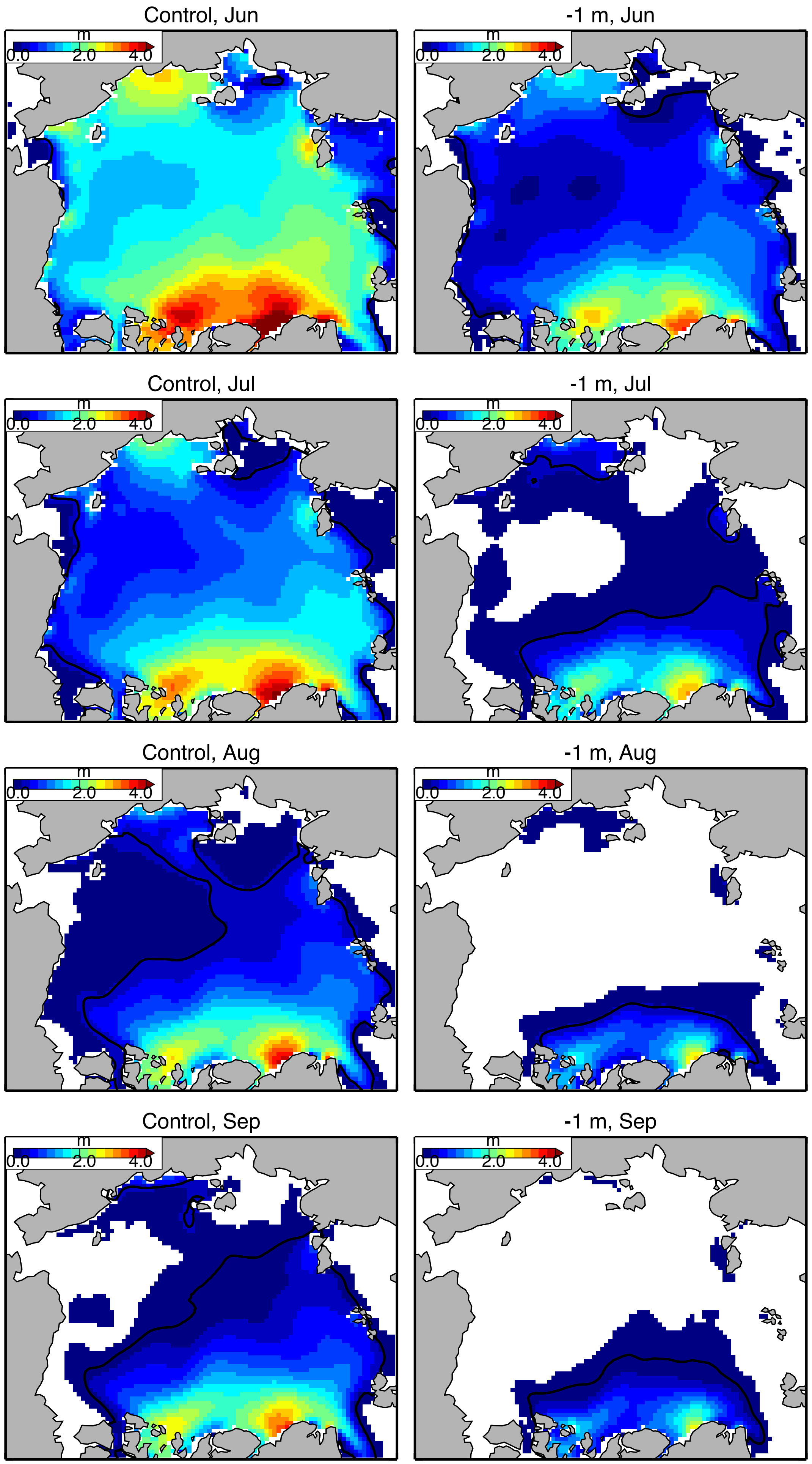
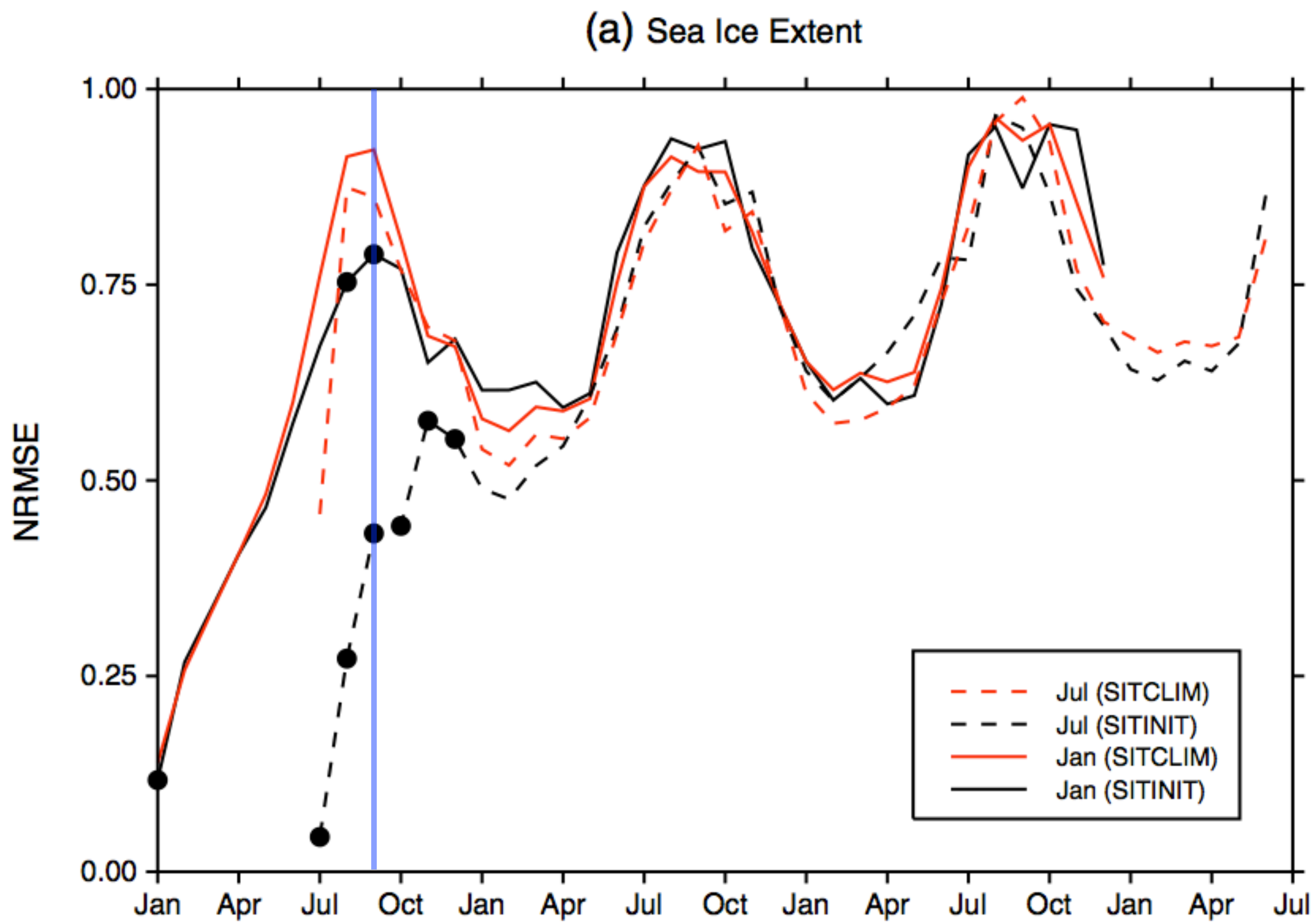


PIOMAS
Ice thickness

On sea ice thickness (and its variability)

Key predictor for summer sea ice extent. Day et al 2014 performed a ‘data-denial’ experiment: control: perfect-model, experiment: identical ICs but with climatological sea ice thickness



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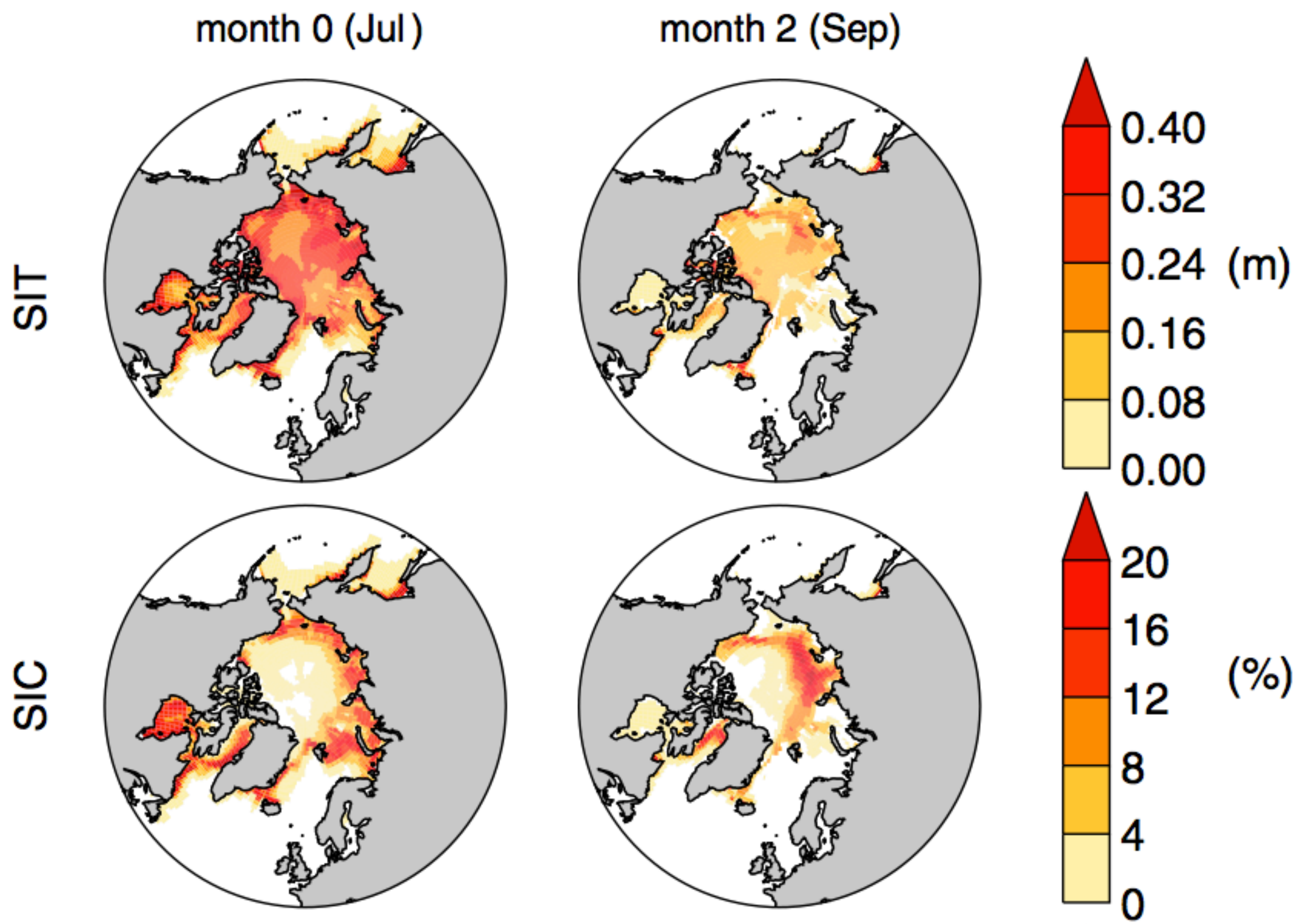


On sea ice thickness (and its variability)

But there is a very large spread in how models simulate sea-ice thickness variability

Monthly ice thickness anomalies (meters) in a model A

2

1.5

1

0.5

0

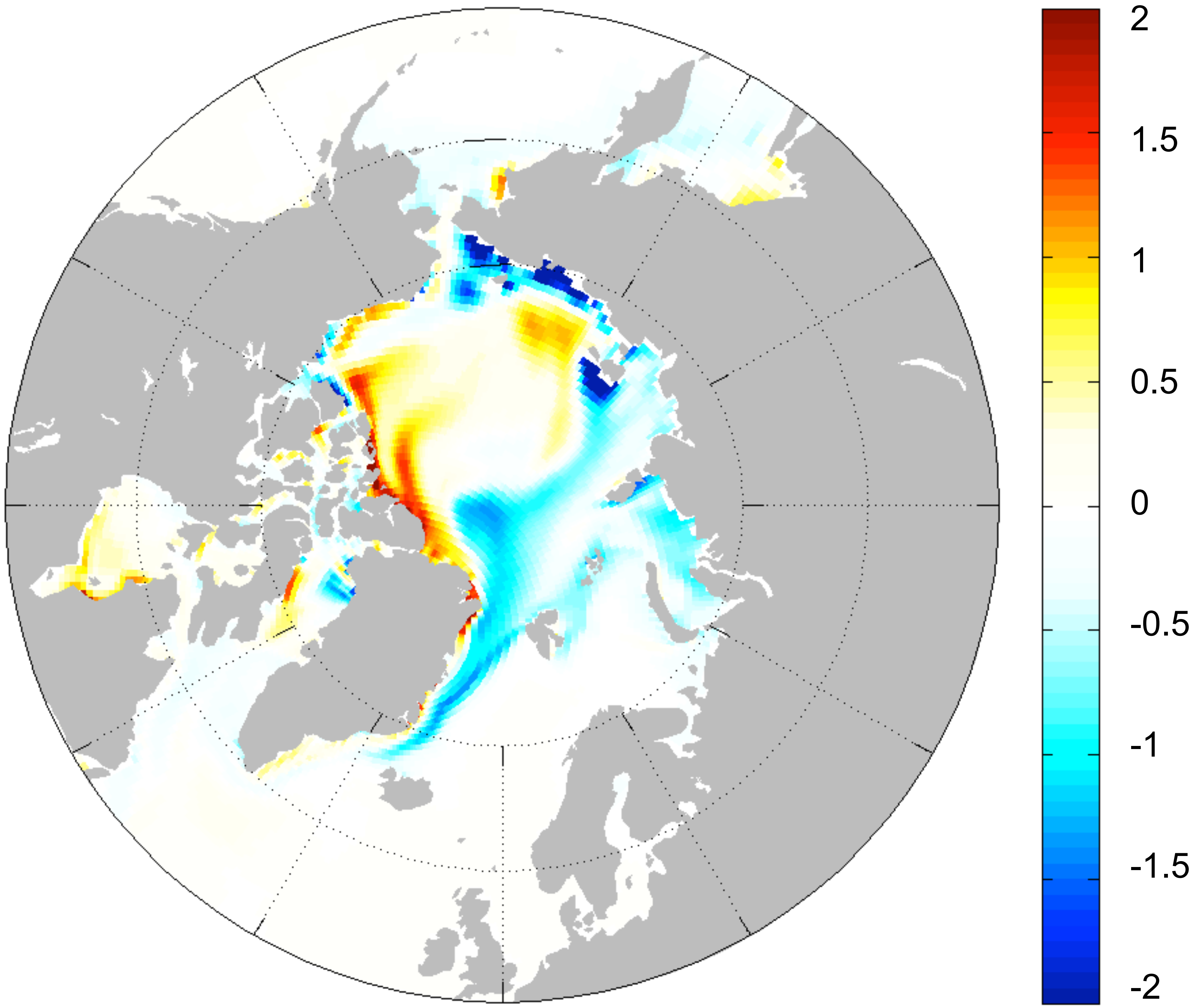
-0.5

-1

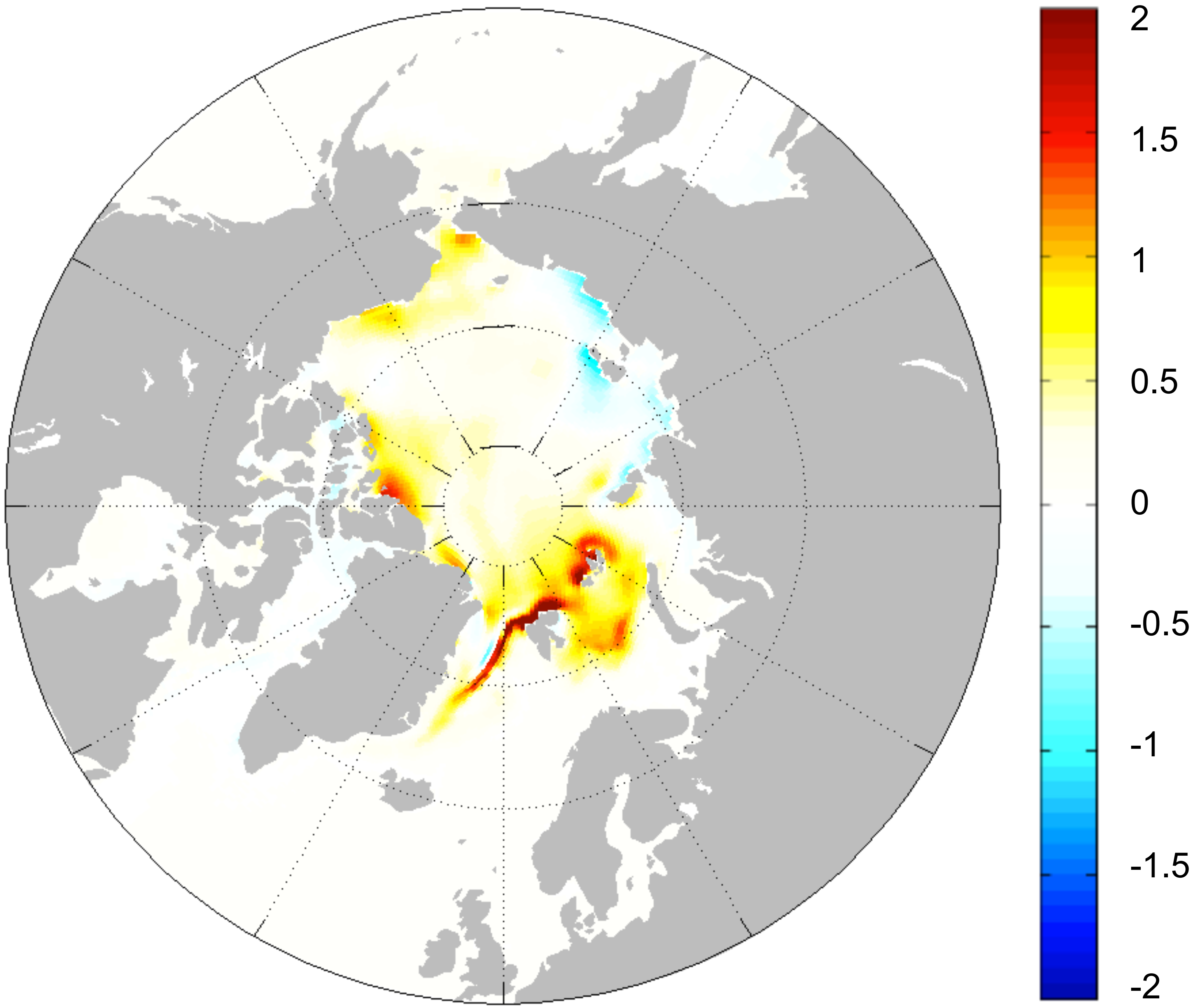
-1.5

-2

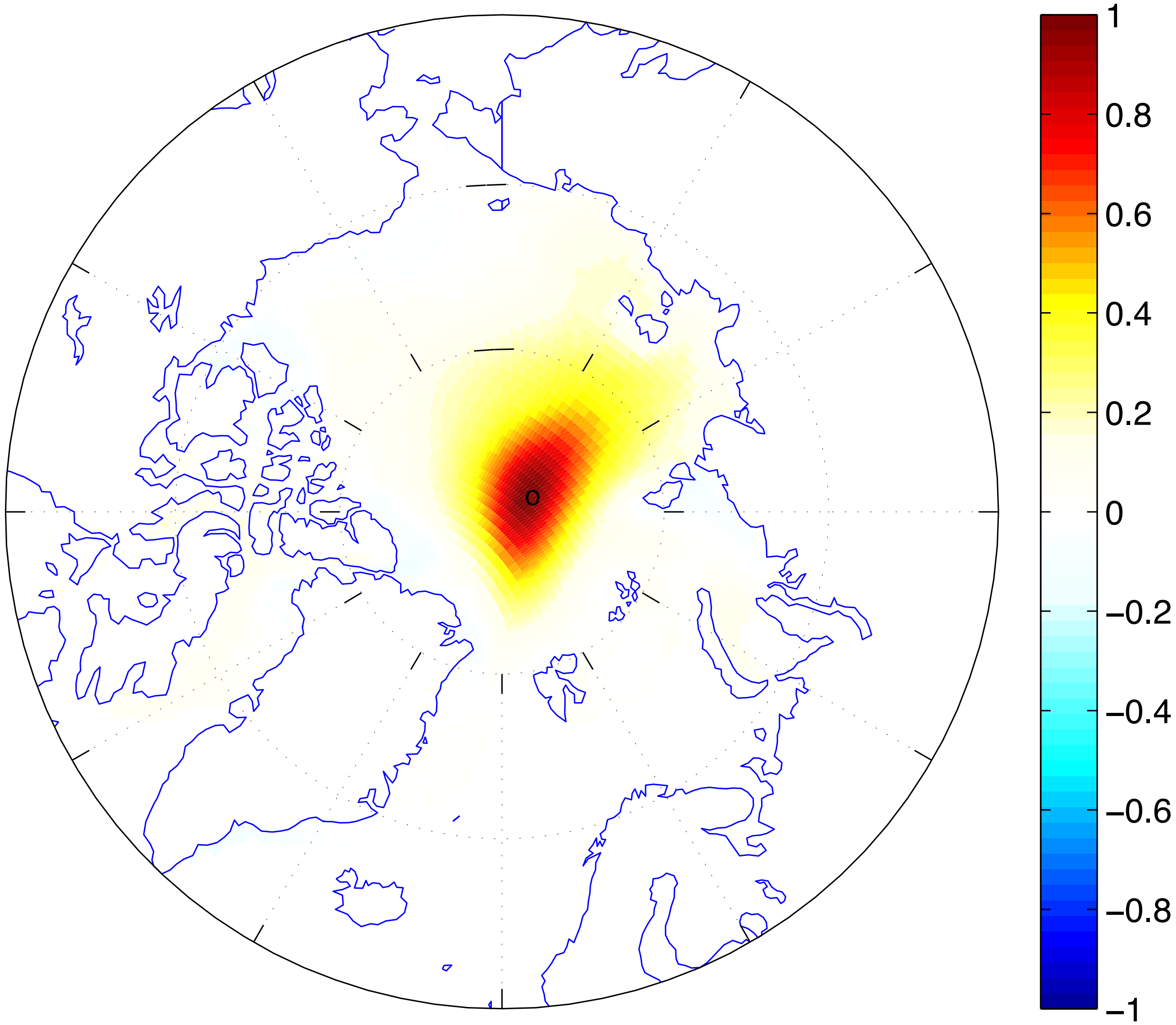
Monthly ice thickness anomalies (meters) in a model A



Monthly ice thickness anomalies (meters) in a model B



One point correlation map of monthly thickness anomalies



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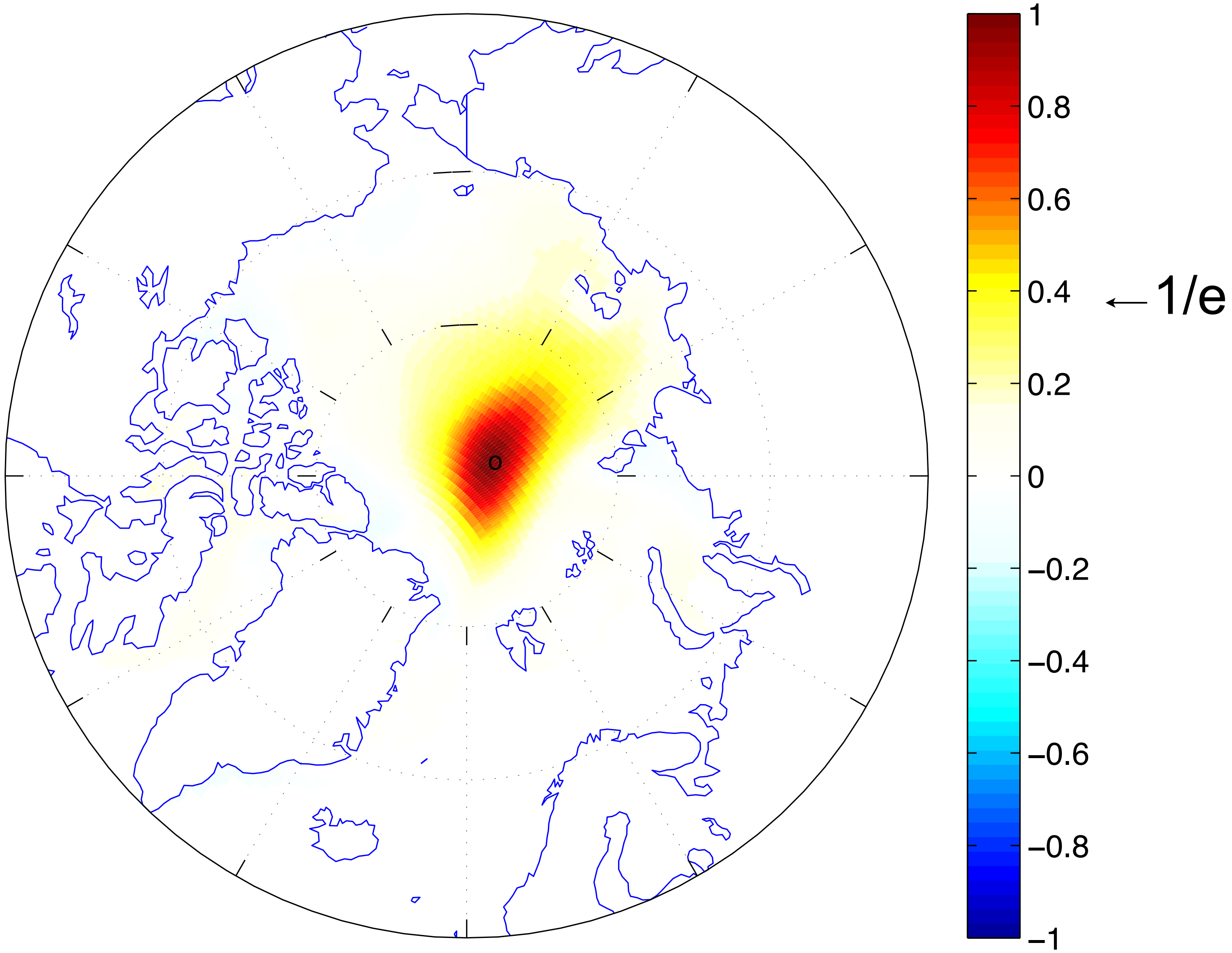

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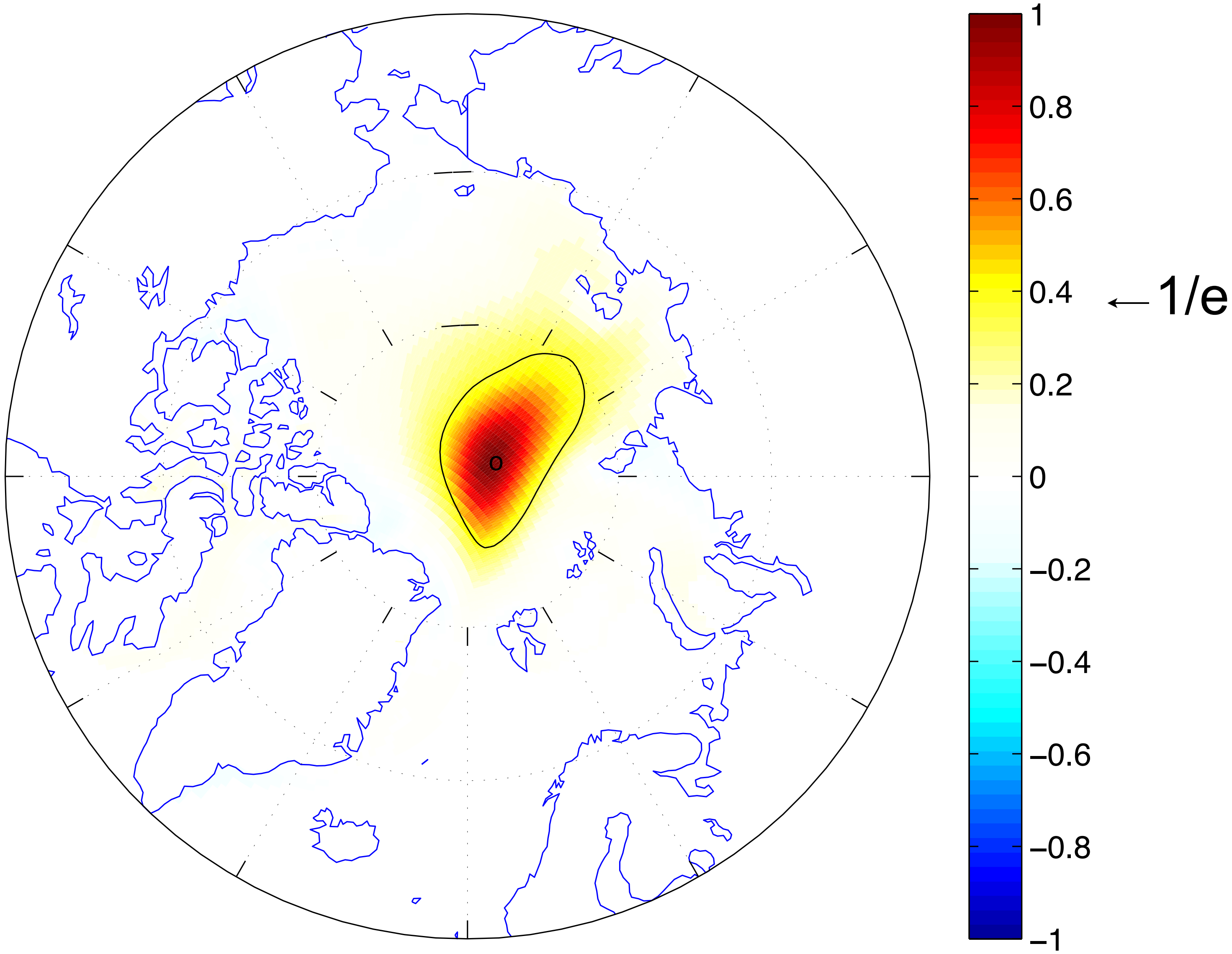

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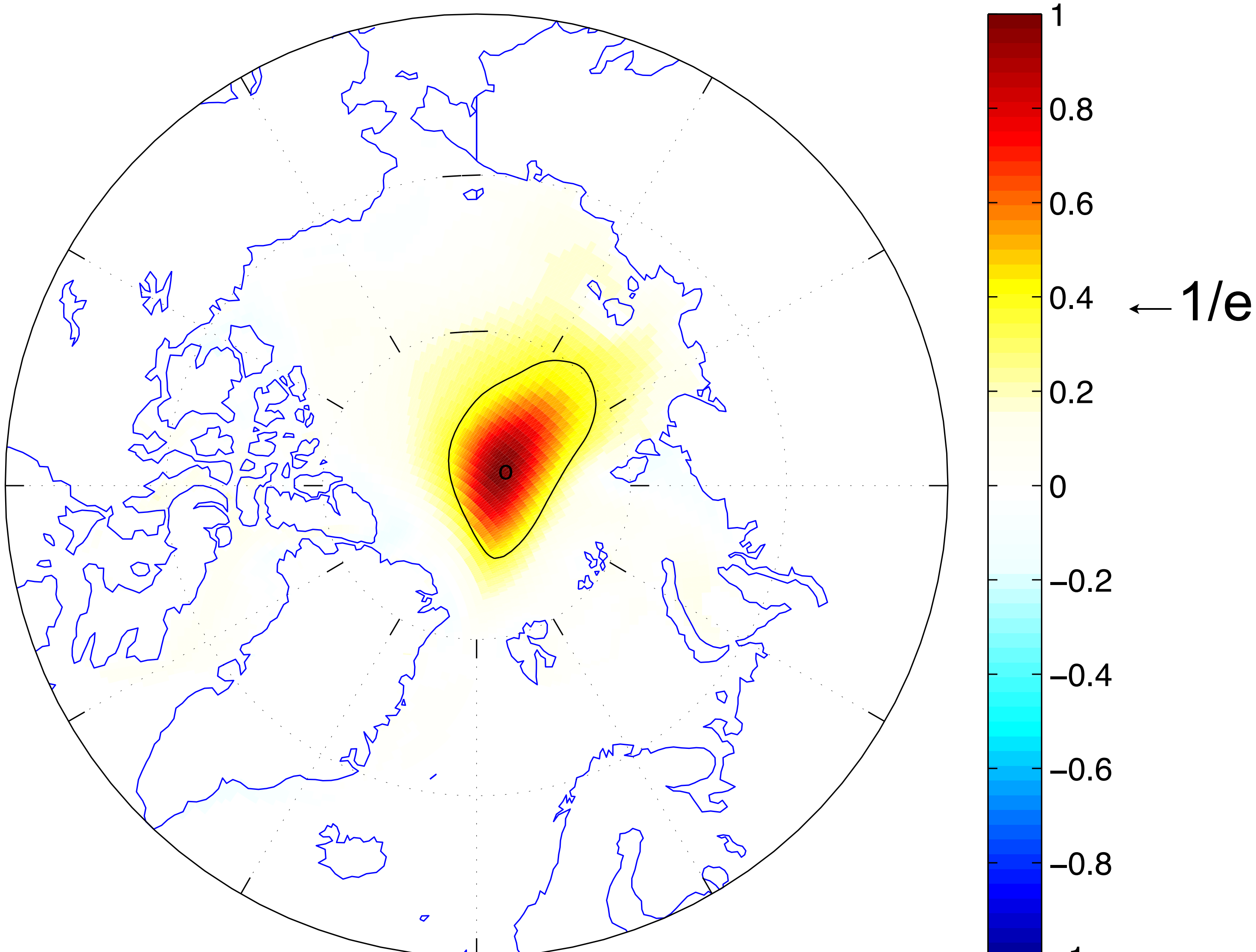

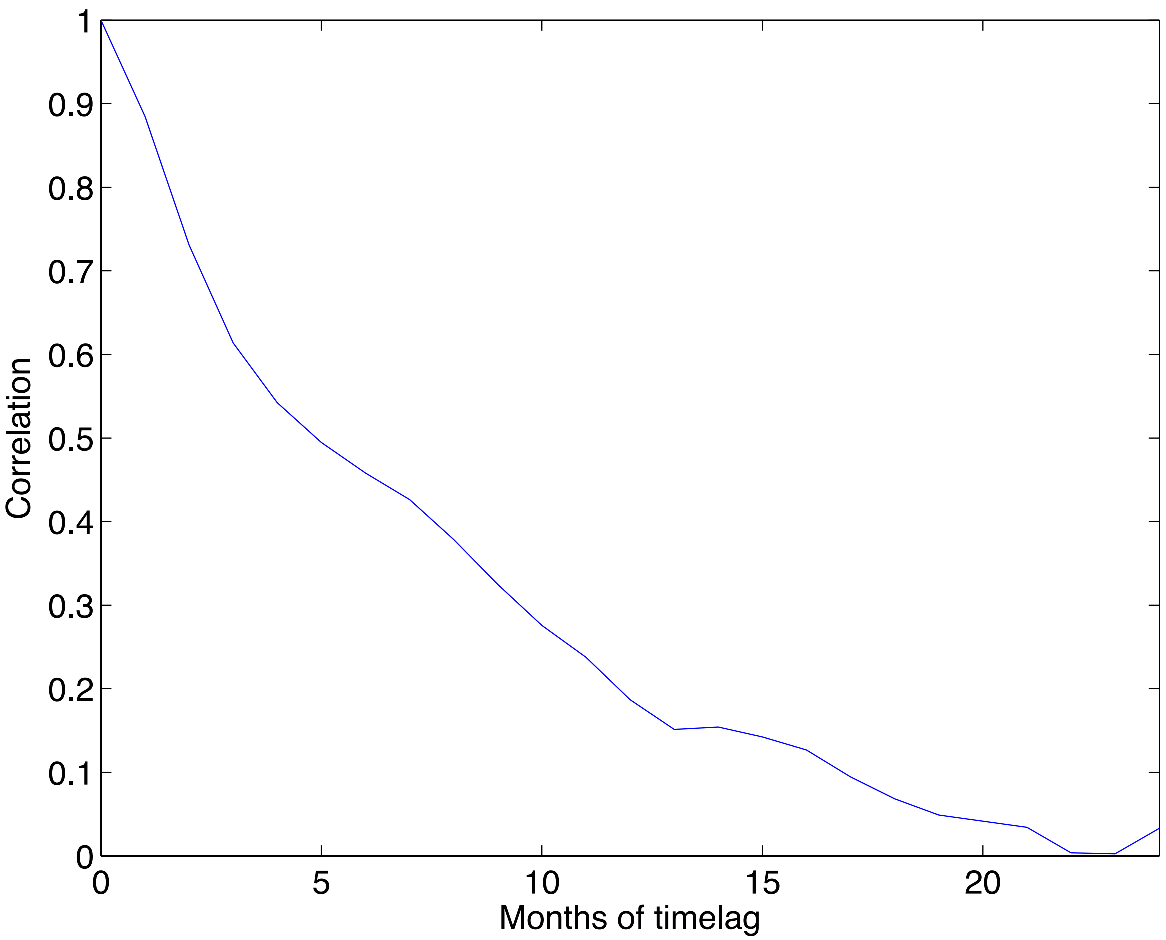

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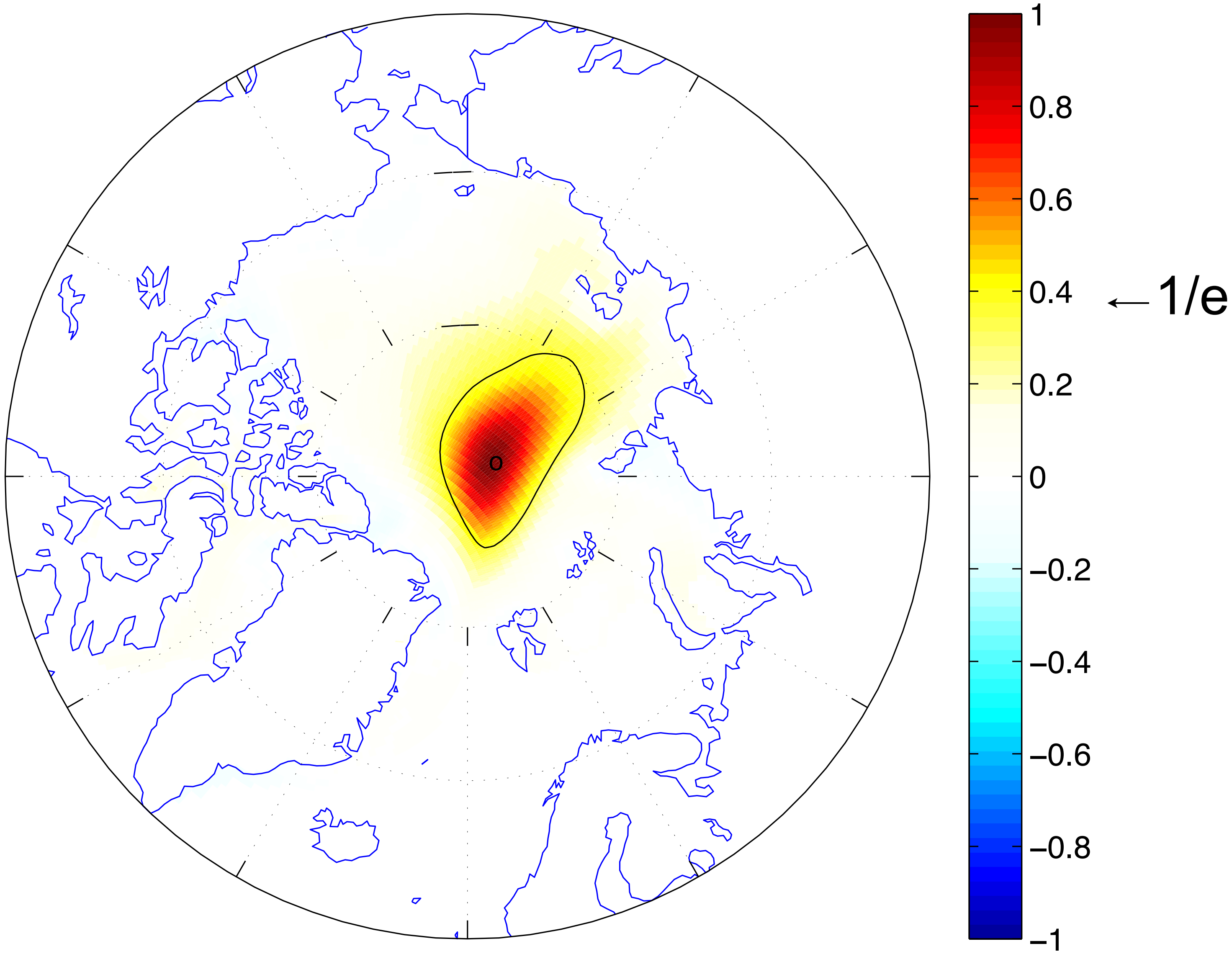
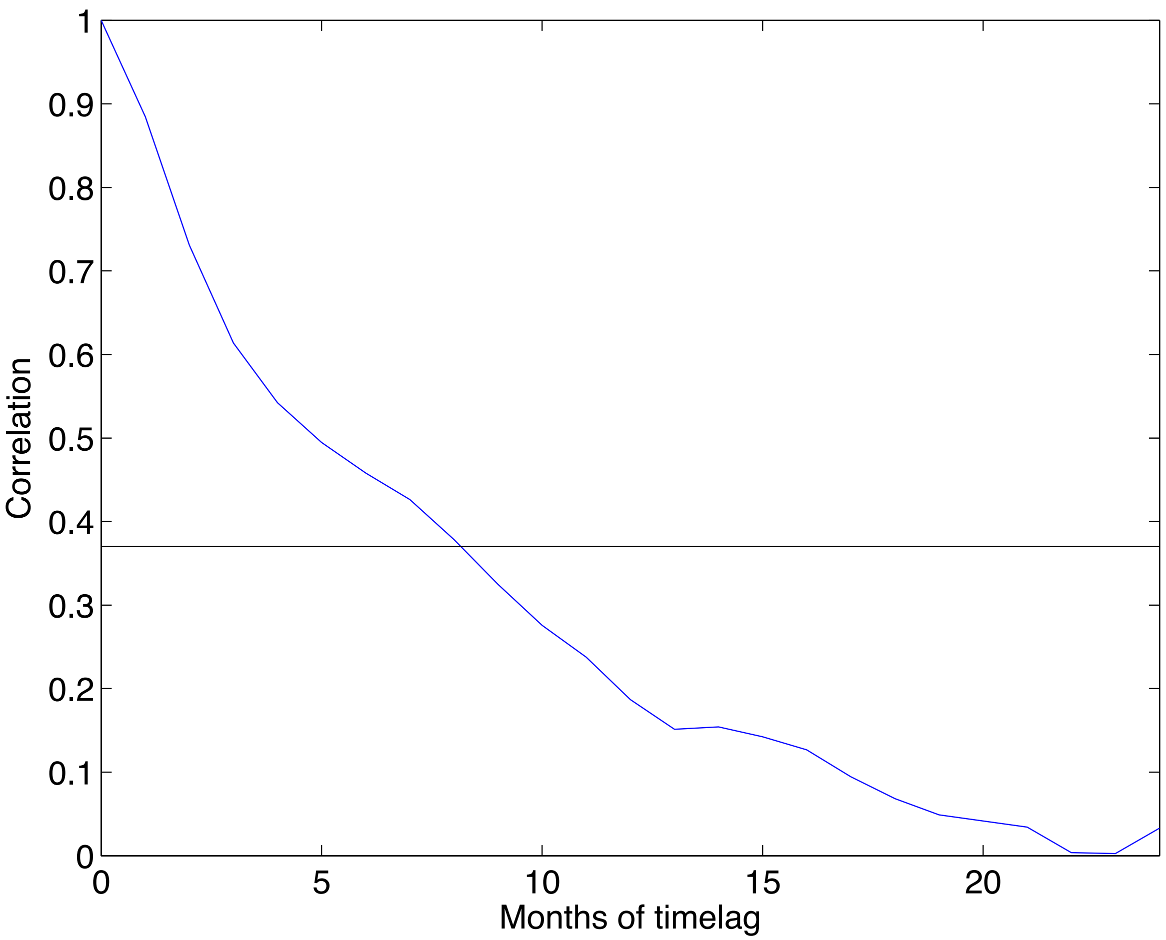
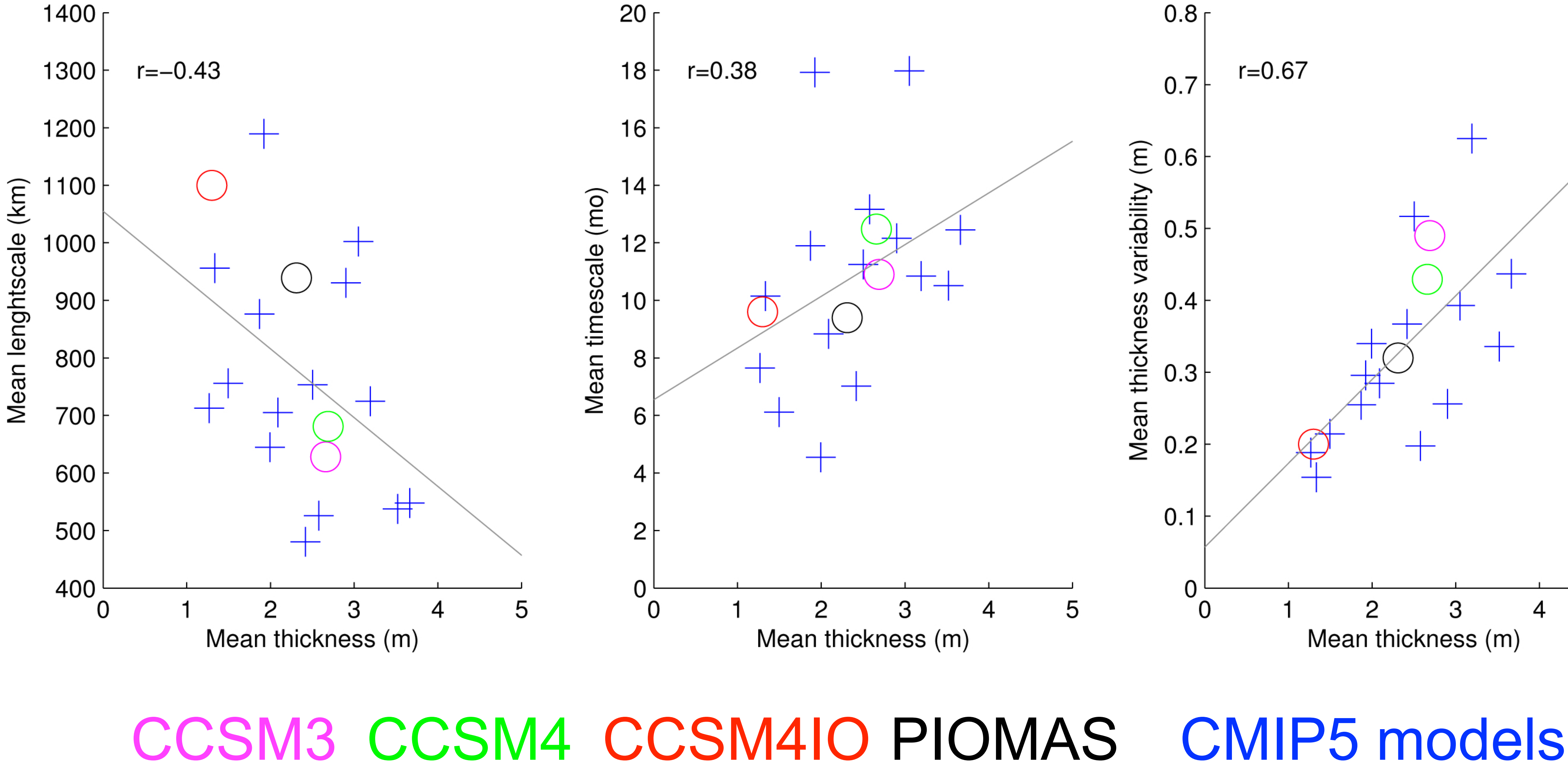




Mean values in Arctic for all models



Huge spread in sea ice thickness variability, in magnitude, timescale, and lengthscale, across all CMIP5 models, and PIOMAS (Blanchard-Wrigglesworth & Bitz, 2014).

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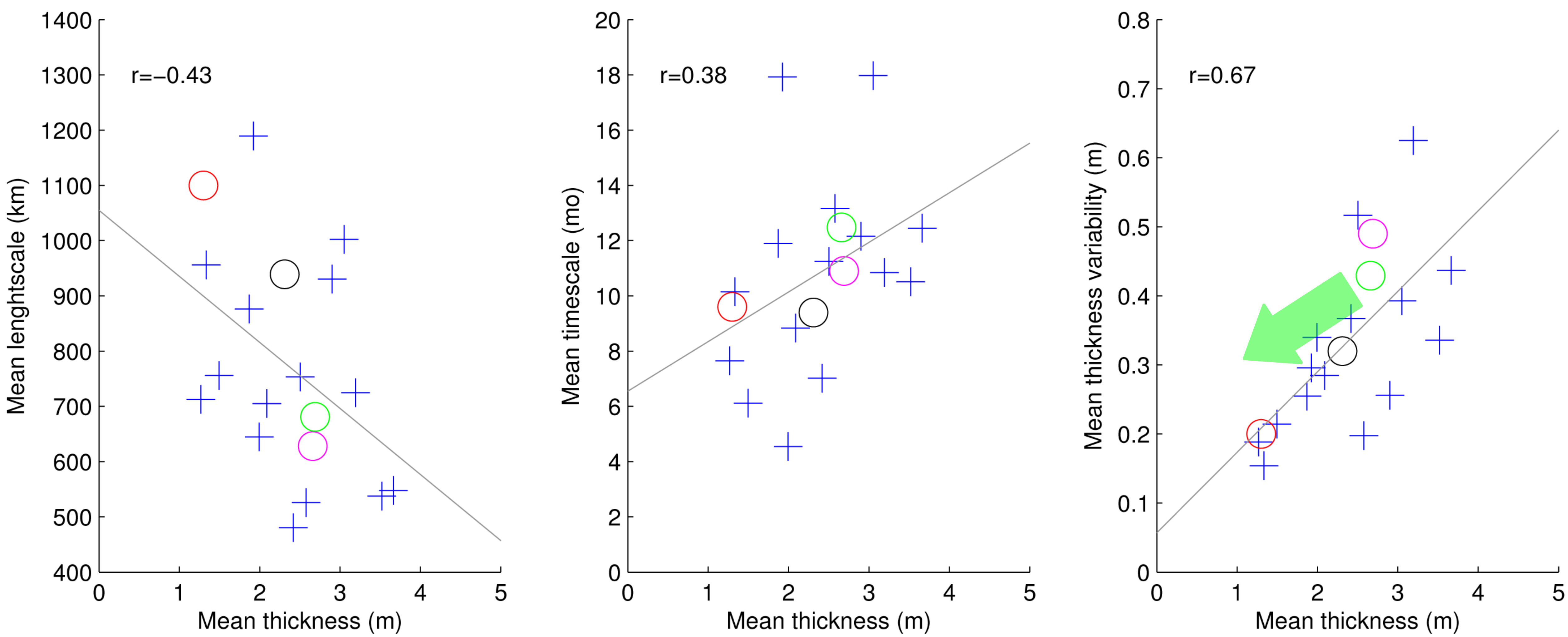

CCSM3 CCSM4 CCSM4IO PIOMAS CMIP5 models

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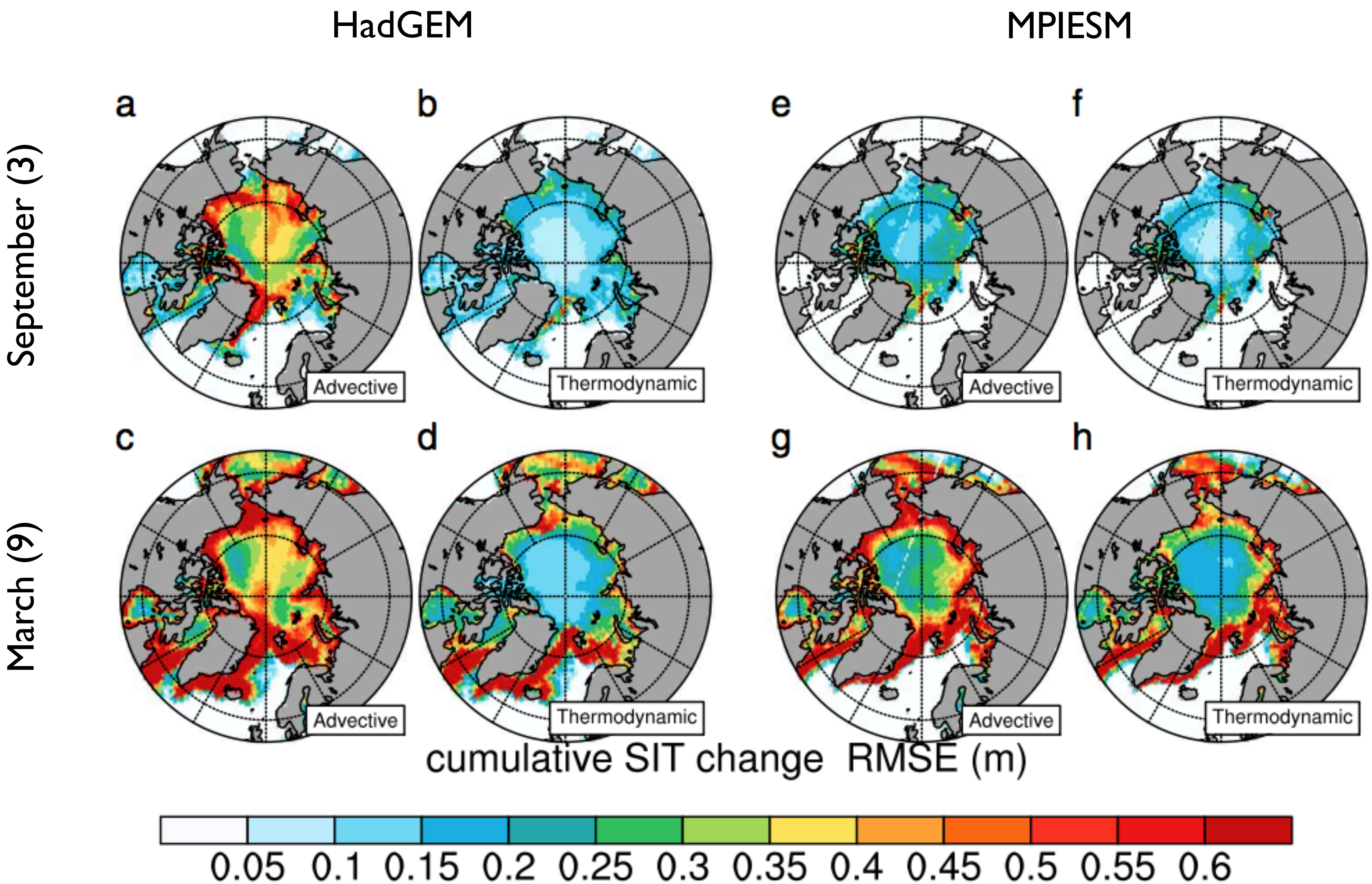
On sea ice thickness (and its variability)

Dynamic or thermodynamic?



Tietsche et al, 2014

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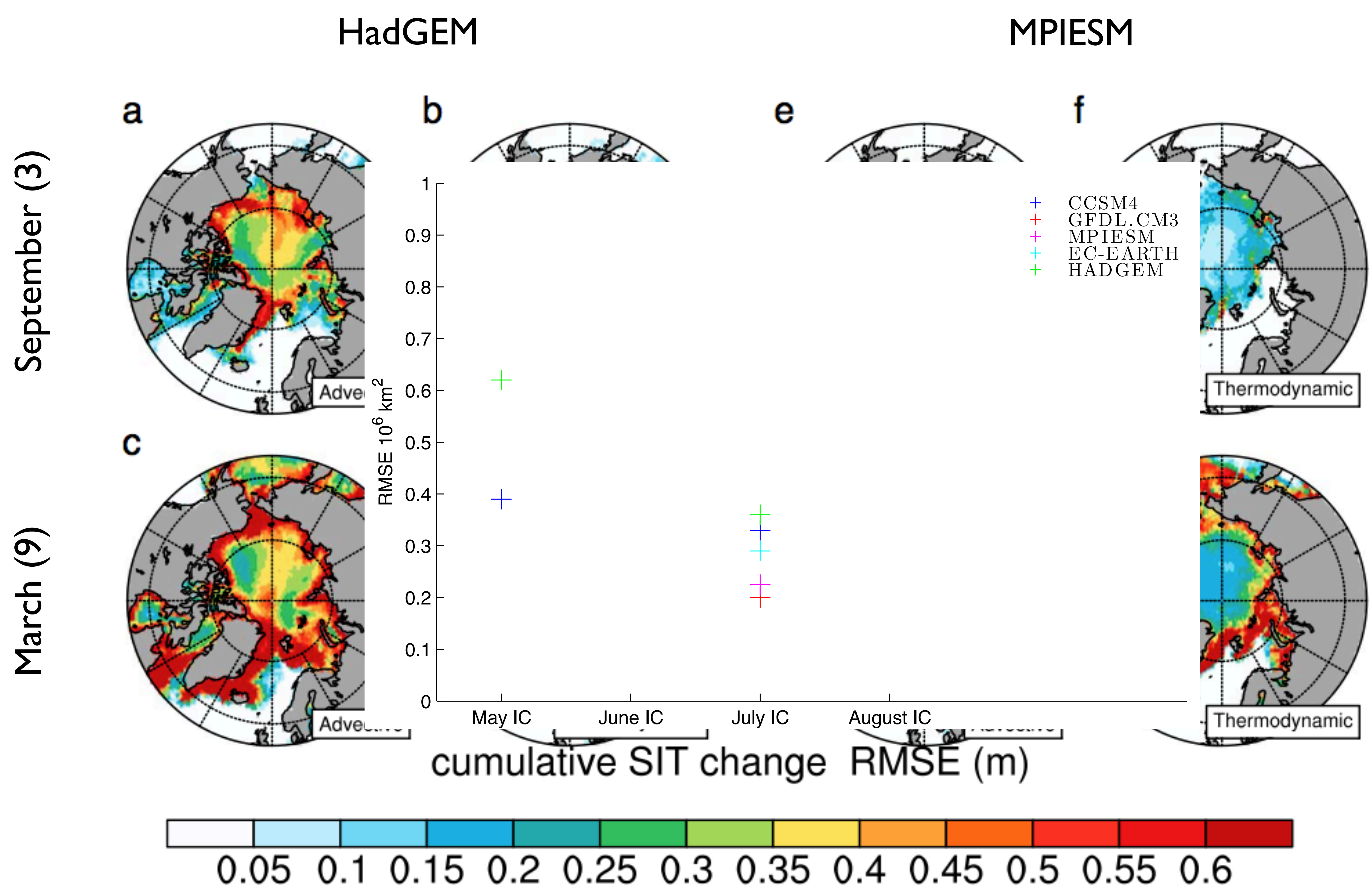
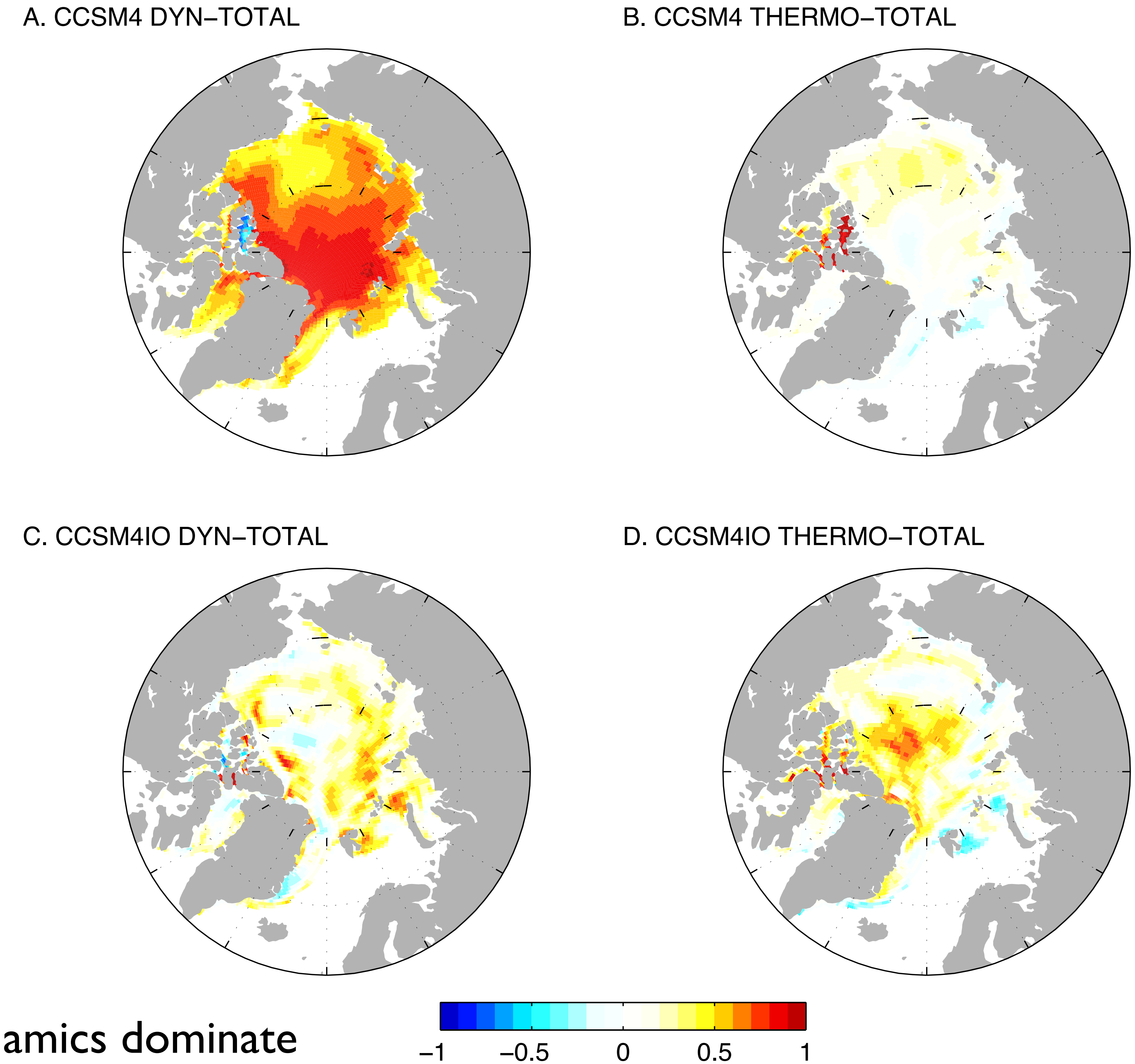


Tietsche et al, 2014

On sea ice thickness (and its variability)

Correlation between dynamic/thermodynamic & total sea ice thickness



In CCSM4, dynamics dominate regional sea ice thickness variability

Blanchard-Wrigglesworth & Bitz, 2014

Final thoughts

Dynamical models in SIO show negligible skill. The multi-model mean is only slightly better, and does not beat damped persistence.

Historical hindcasts (and perfect models) show better skill.

It is unclear why this gap occurs. It is possible that recent years have been inherently more unpredictable, yet summer persistence has not decreased.

Tellingly, models are almost as unskilled at predicting each other, indicating large divergence in initial conditions and/or model physics.

There is a huge spread in reanalysis of sea ice thickness (that are used by different groups). Additionally, SIO models respond differently to identical initial condition perturbations, hinting to large spread in model physics.

Huge spread across CMIP5 models in simulating sea ice thickness variability. Sea ice dynamics play a key role.

Final thoughts (II)

So about that icecream...