The Predictability of Arctic Sea Ice on seasonal to interannual timescales

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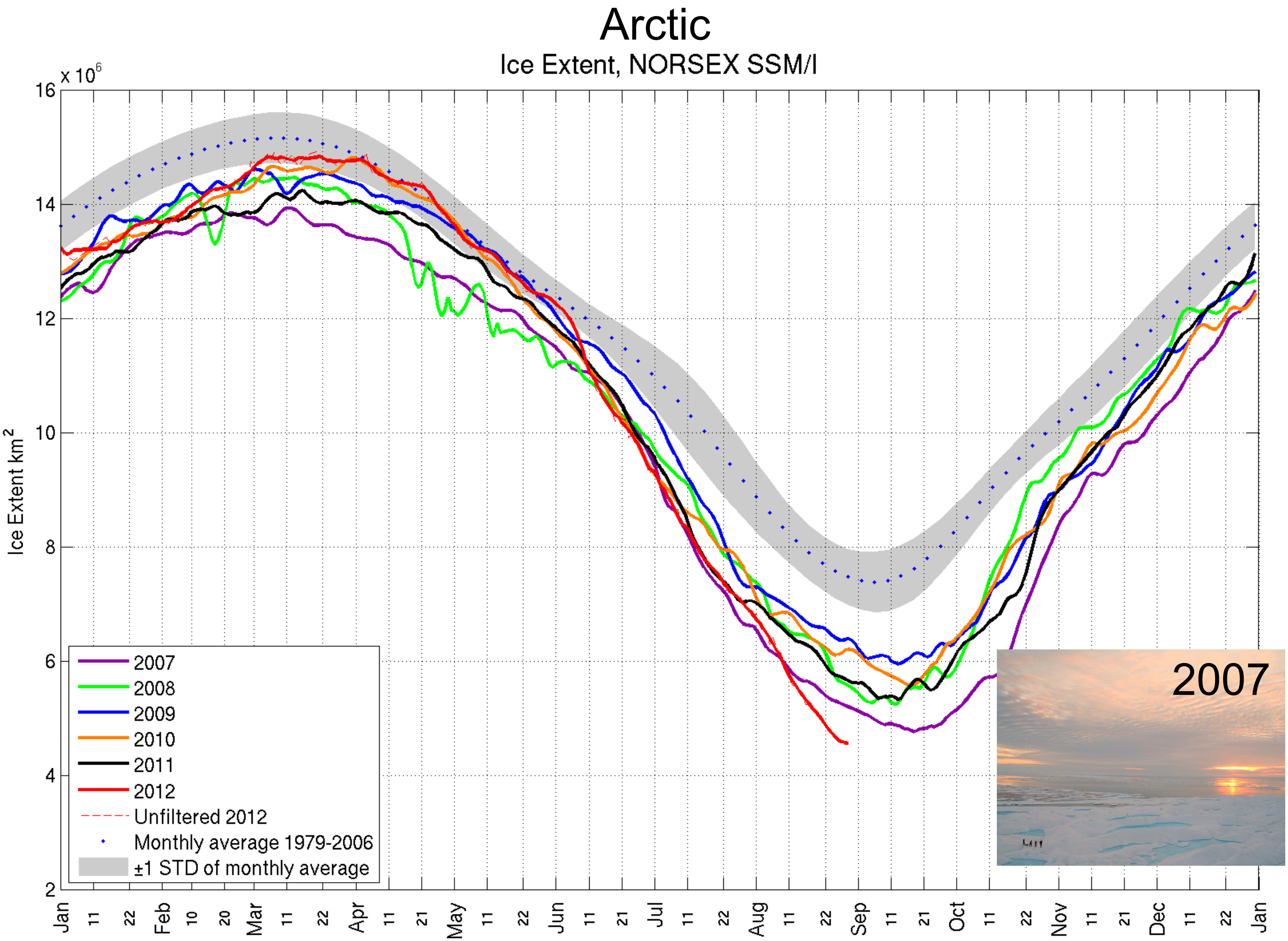
Atmospheric Sciences
University of Washington

Thanks to Marika Holland, NCAR,
Kyle Armour, UW,
and Eric DeWeaver, NSF



The latest date in 2012 is: 08/29

STUDY OF ENVIRONMENTAL ARCTIC CHANGE

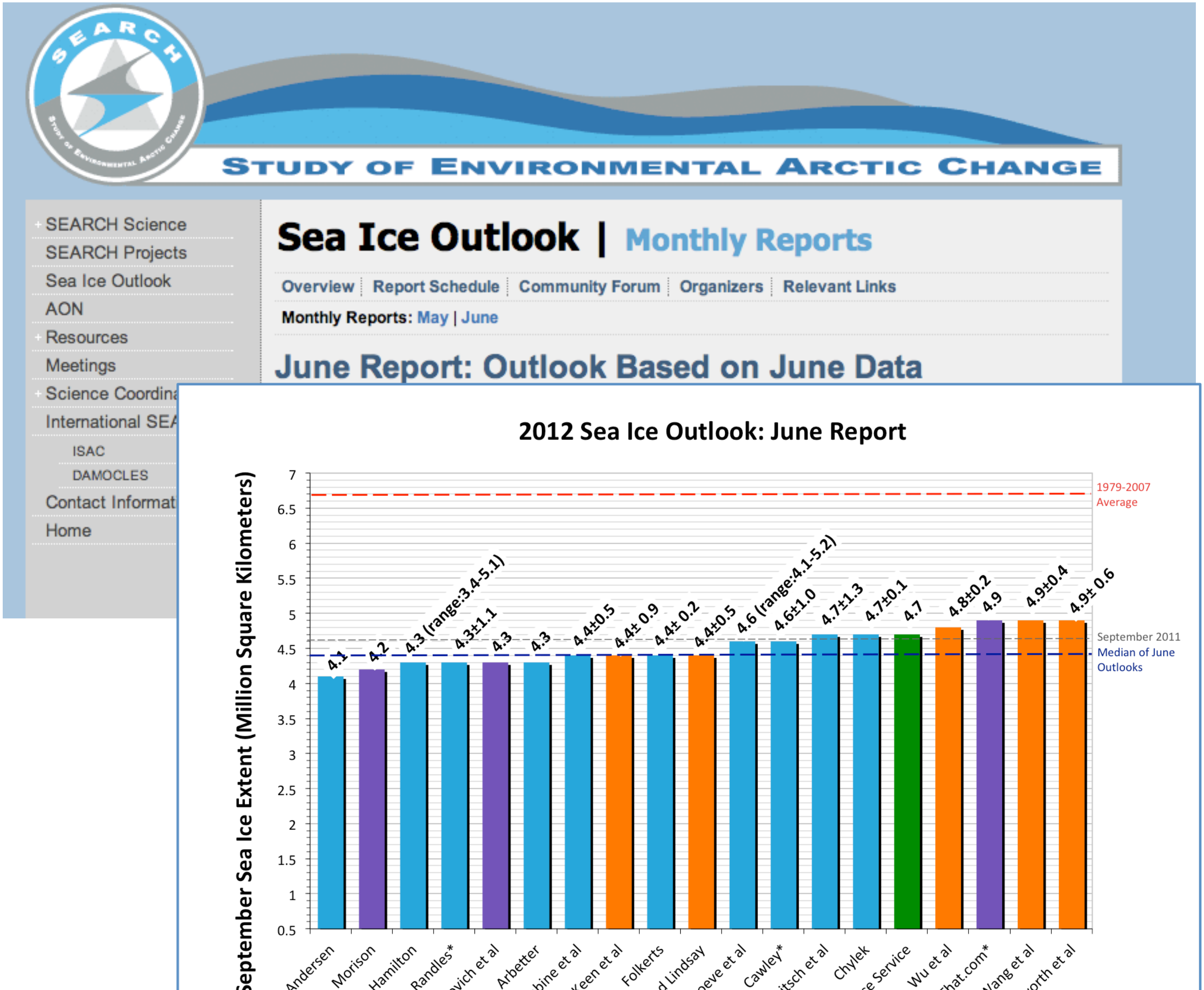
Sea Ice Outlook | Monthly Reports

June Report: Outlook Based on June Data

Report Released 16 July 2008

SUMMARY

The outlook for the pan-arctic sea ice extent in September 2008, based on June data, indicates a continuation of dramatic sea ice loss. The June Sea Ice Outlook report is based on a synthesis of 17 individual projections, utilizing a range of methods. Projections based on June data are similar to those of the May report, with no indication that a return to historical sea ice extent will occur this year.



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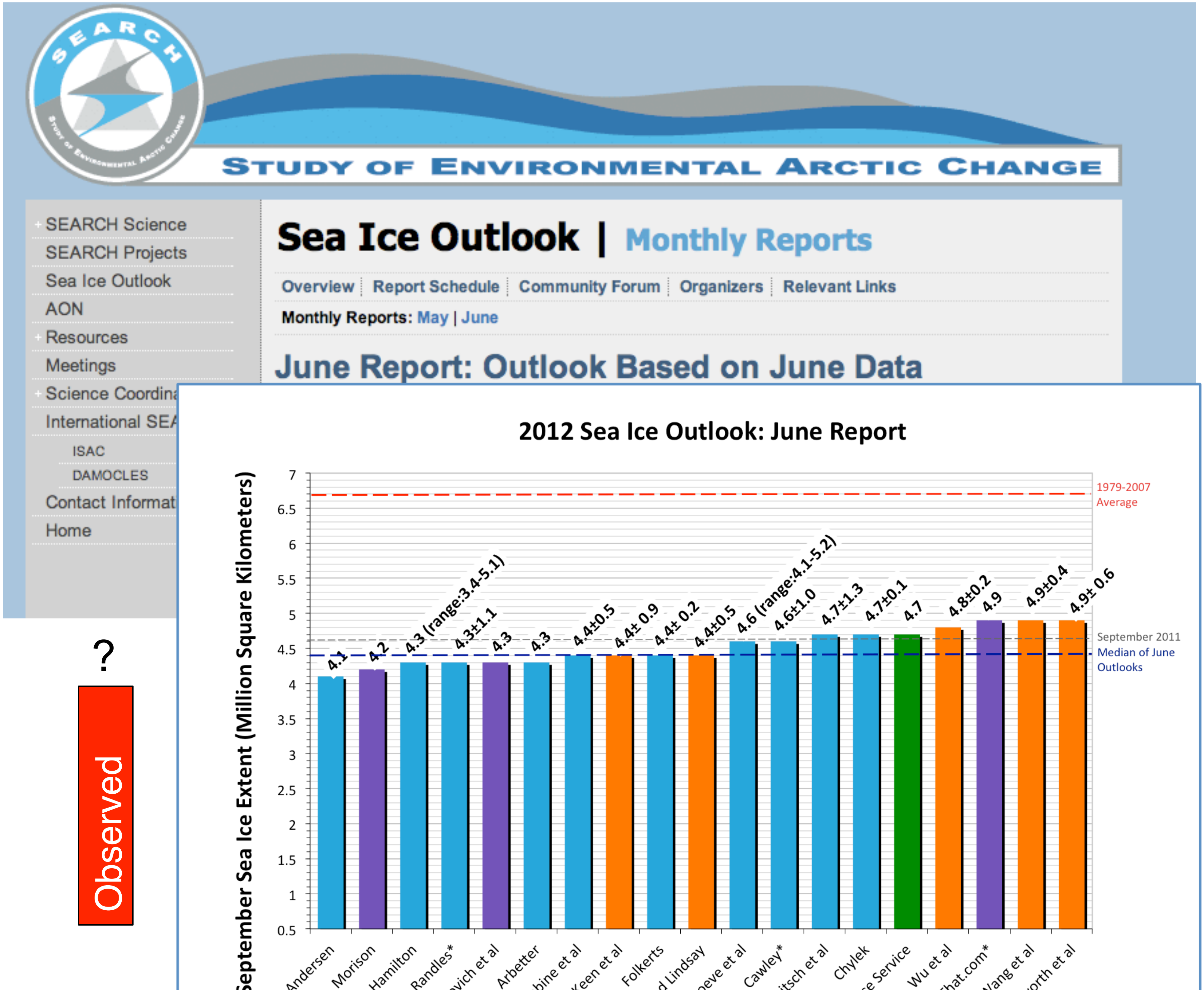
June Report: Outlook Based on June Data
2012 Sea Ice Outlook: June Report
September Sea Ice Extent (Million Square Kilometers)
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1979-2007 Average
September 2011
Median of June Outlooks
4.1
4.2
4.3 (range:3.4-5.1)
4.3±1.1
4.3
4.3
4.4±0.5
4.4± 0.9
4.4± 0.2
4.4±0.5
4.6 (range:4.1-5.2)
4.6±1.0
4.7±1.3
4.7±0.1
4.7
4.8±0.2
4.9
4.9±0.4
4.9± 0.6
Andersen
Morison
Hamilton
Randles*
Arbetter
Folkerts
Cawley*
Chylek
Wu et al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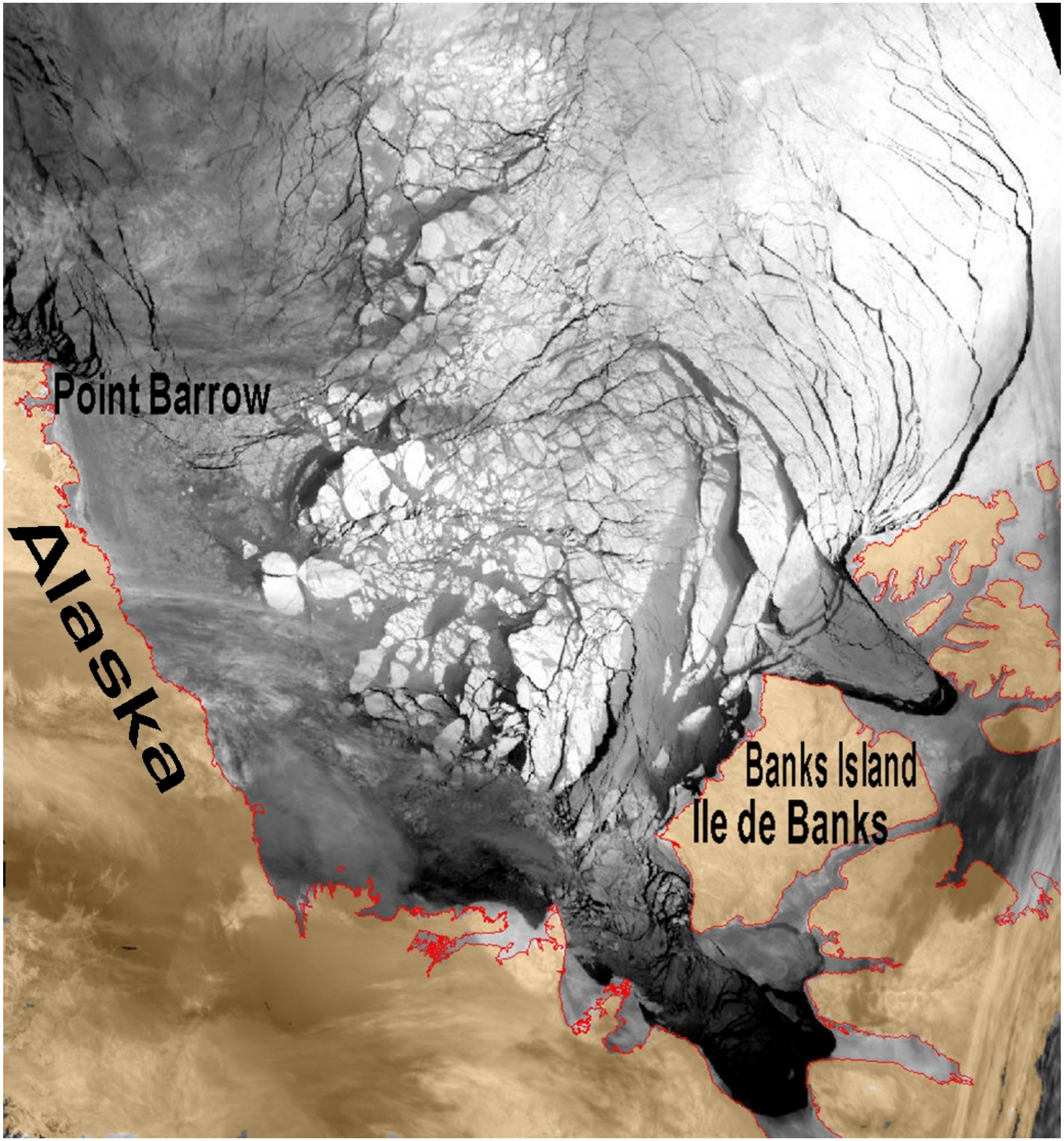
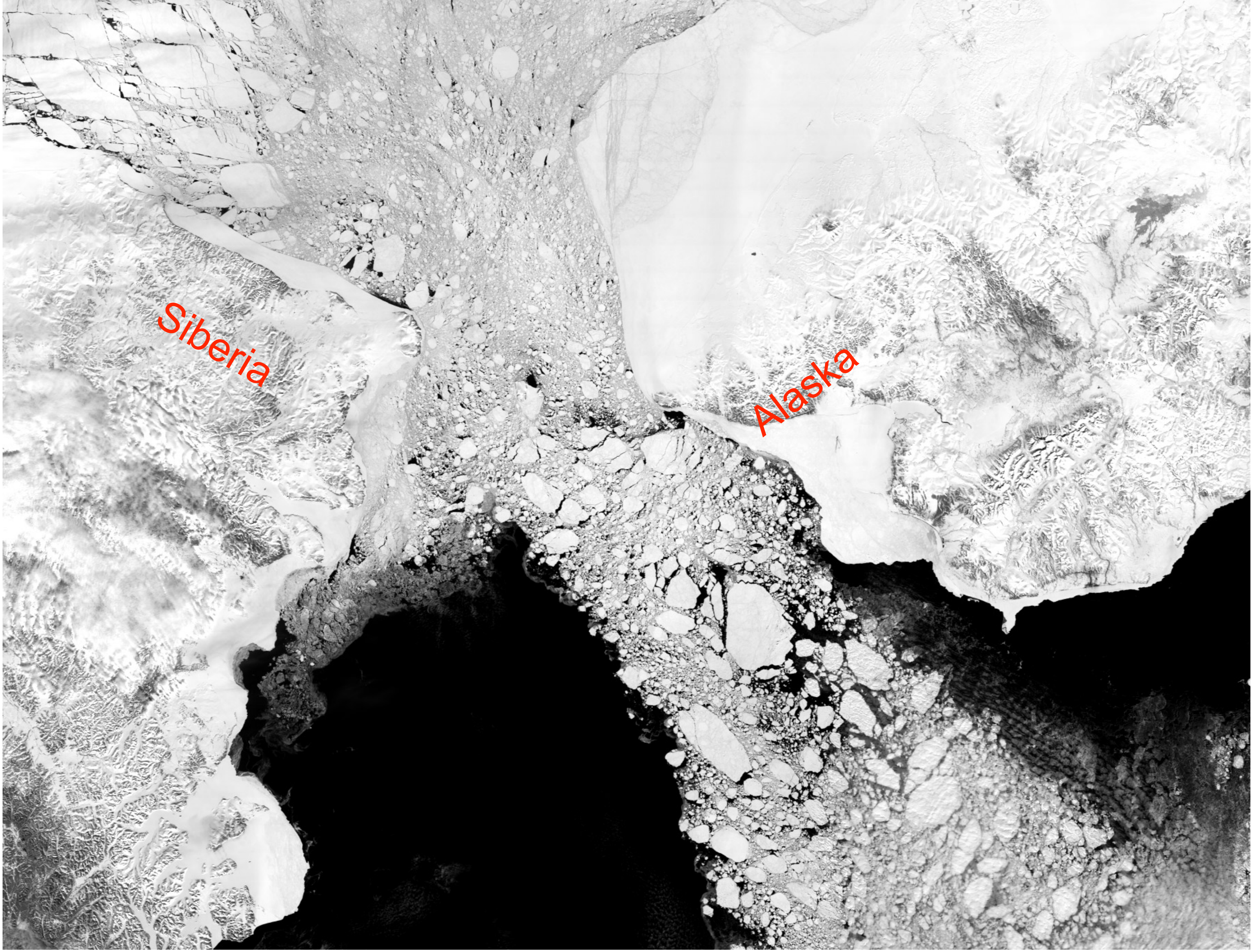
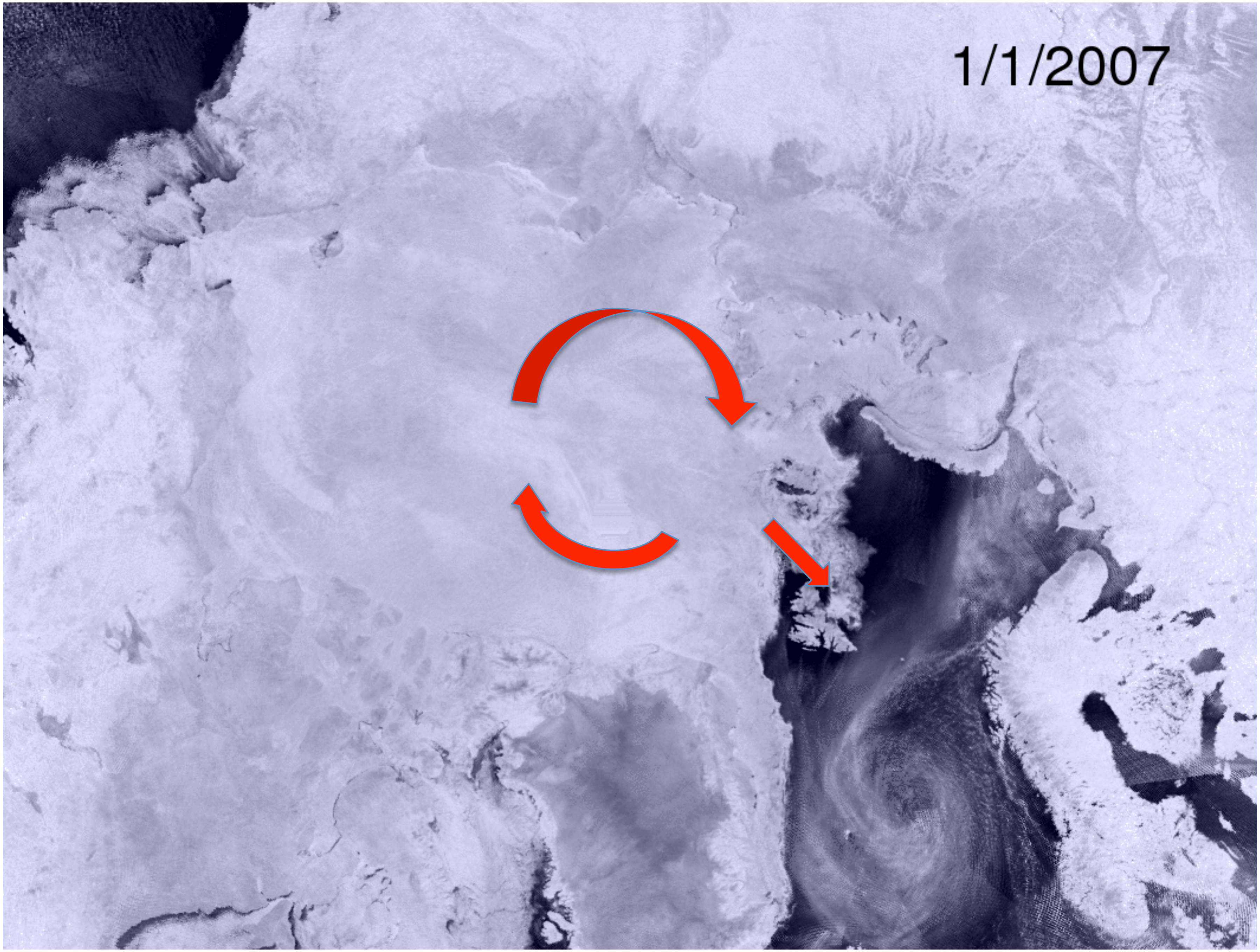
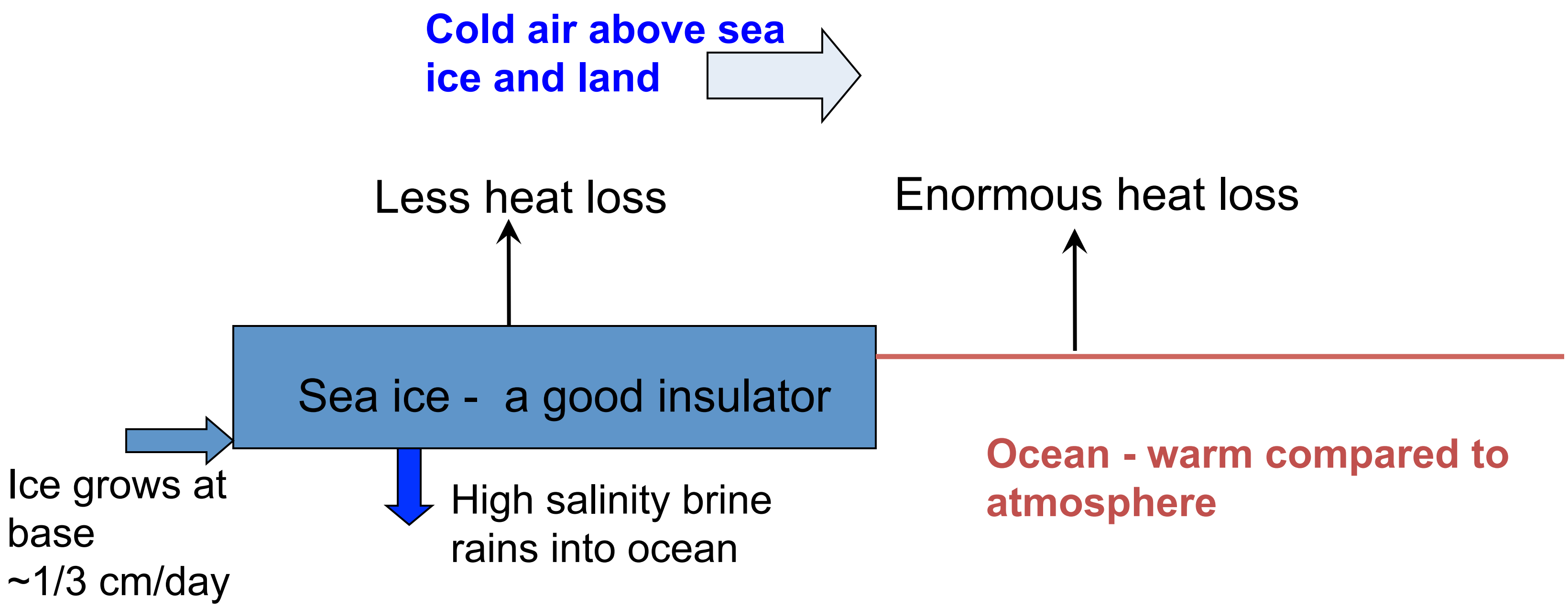
4.7
4.8±0.2
4.9
4.9±0.4
4.9± 0.6
Andersen
Morison
Hamilton
Randles*
Arbetter
Folkerts
Cawley*
Chylek
Wu et al
?
Observed


Point Barrow
Alaska
Banks Island
Île de Banks


Siberia
Alaska


1/1/2007

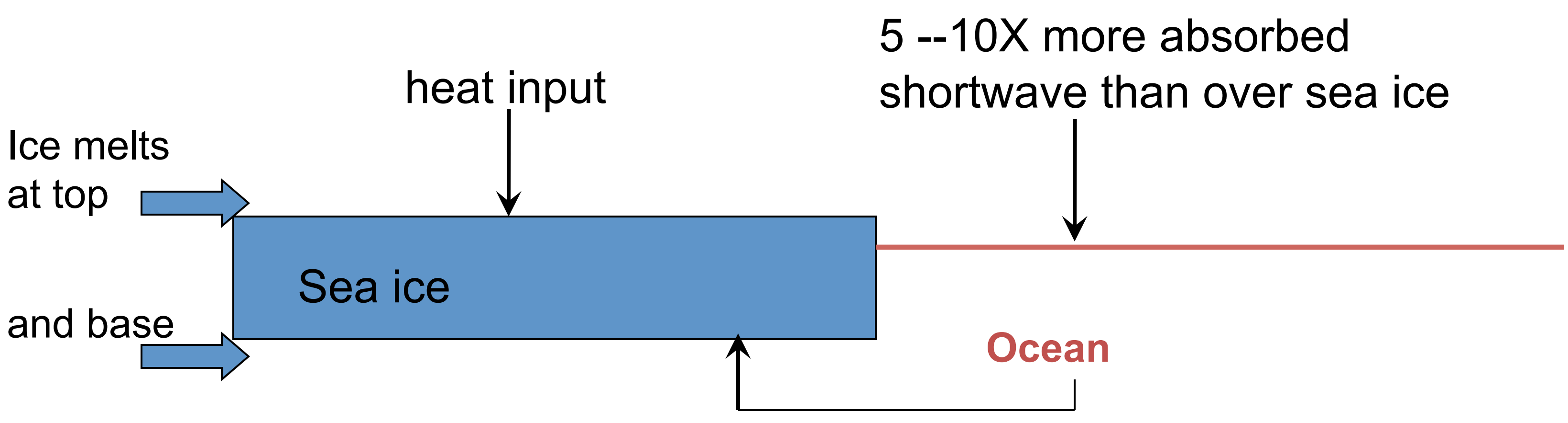
Arctic - In winter (about 9 months)



Sea ice grows when the ocean cools to the freezing point. This happens very quickly in the absence of sunlight, wherever the ocean heat transport cannot keep pace.

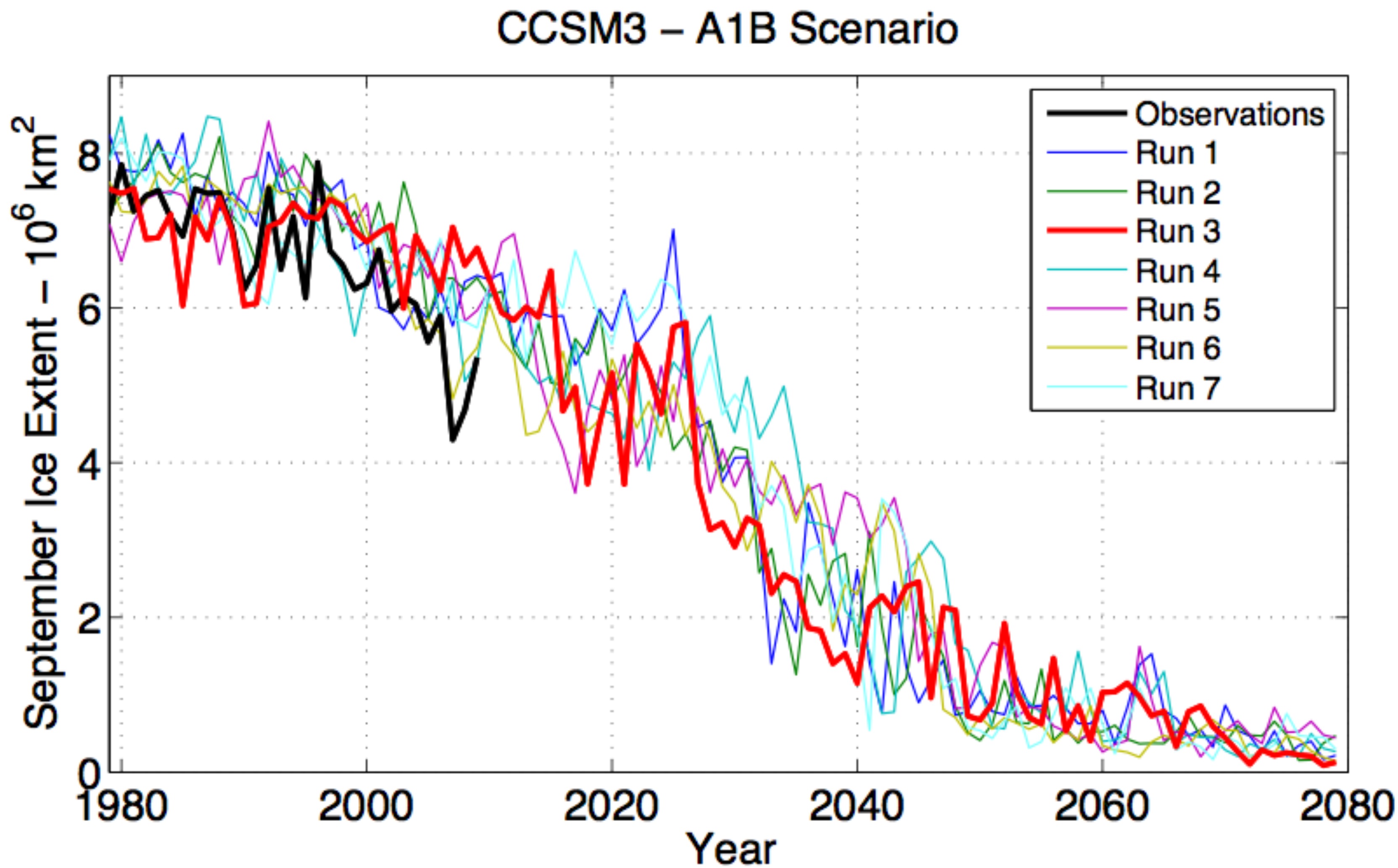
Growth is inversely proportionate to thickness, so thin ice grows very fast, a strong negative feedback

Arctic - In summer (about 3 months)



Ice melts at top and bottom total rate of ~2 cm/day

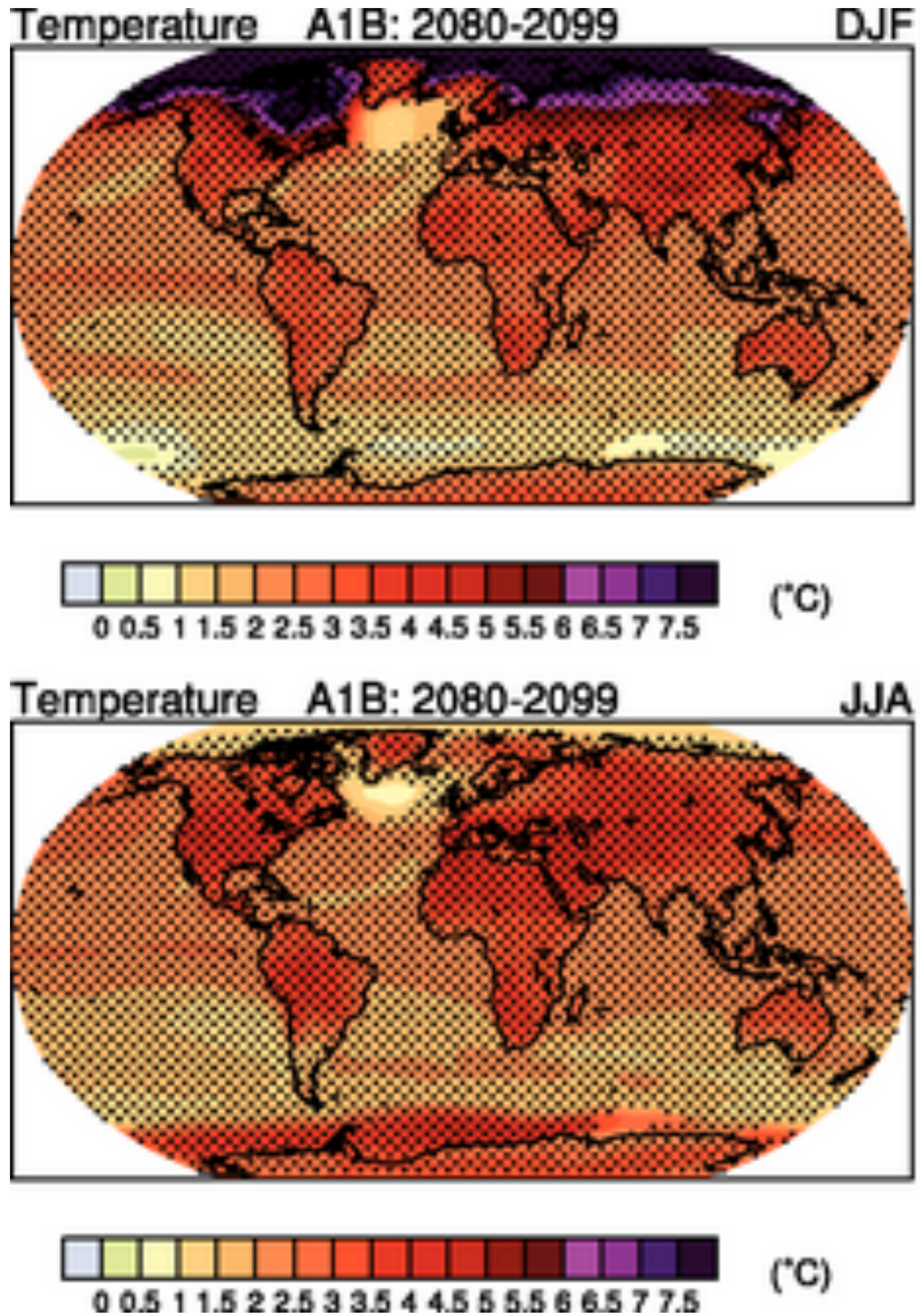
Positive ice-albedo feedback as the ice retreats



Trend and Interannual variability is well represented in some models
note occasional decade of little change

Holland et al 2006, 2008

Polar Amplification occurs only in winter, although the positive ice-albedo feedback occurs only in summer



IPCC AR4 Fig 10.9

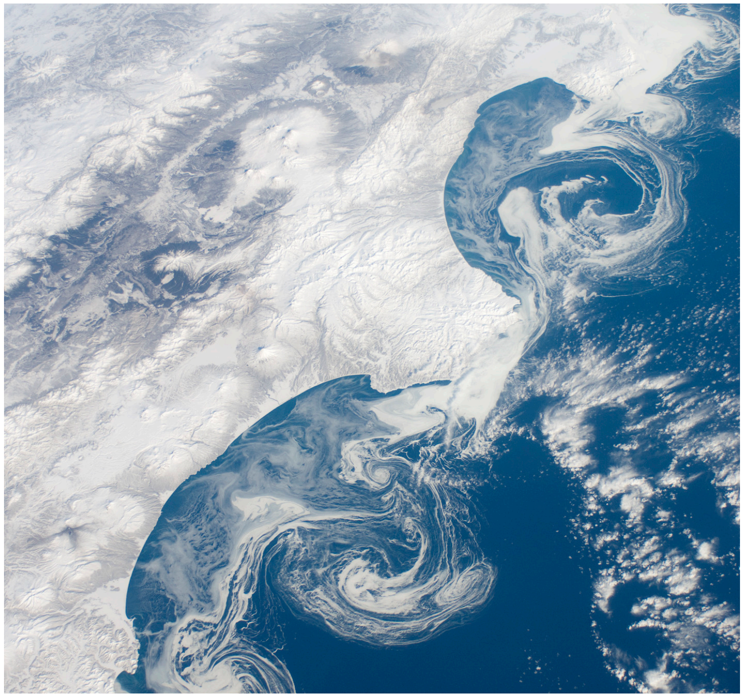
Two ways to study predictability of sea ice

1) Diagnostic analysis of sea ice

Blanchard-Wrigglesworth, Armour, Bitz, and DeWeaver, 2011, Persistence and inherent predictability of Arctic sea ice in a GCM ensemble and observations.

2) Ensembles of initialized predictability runs from perturbing atmosphere

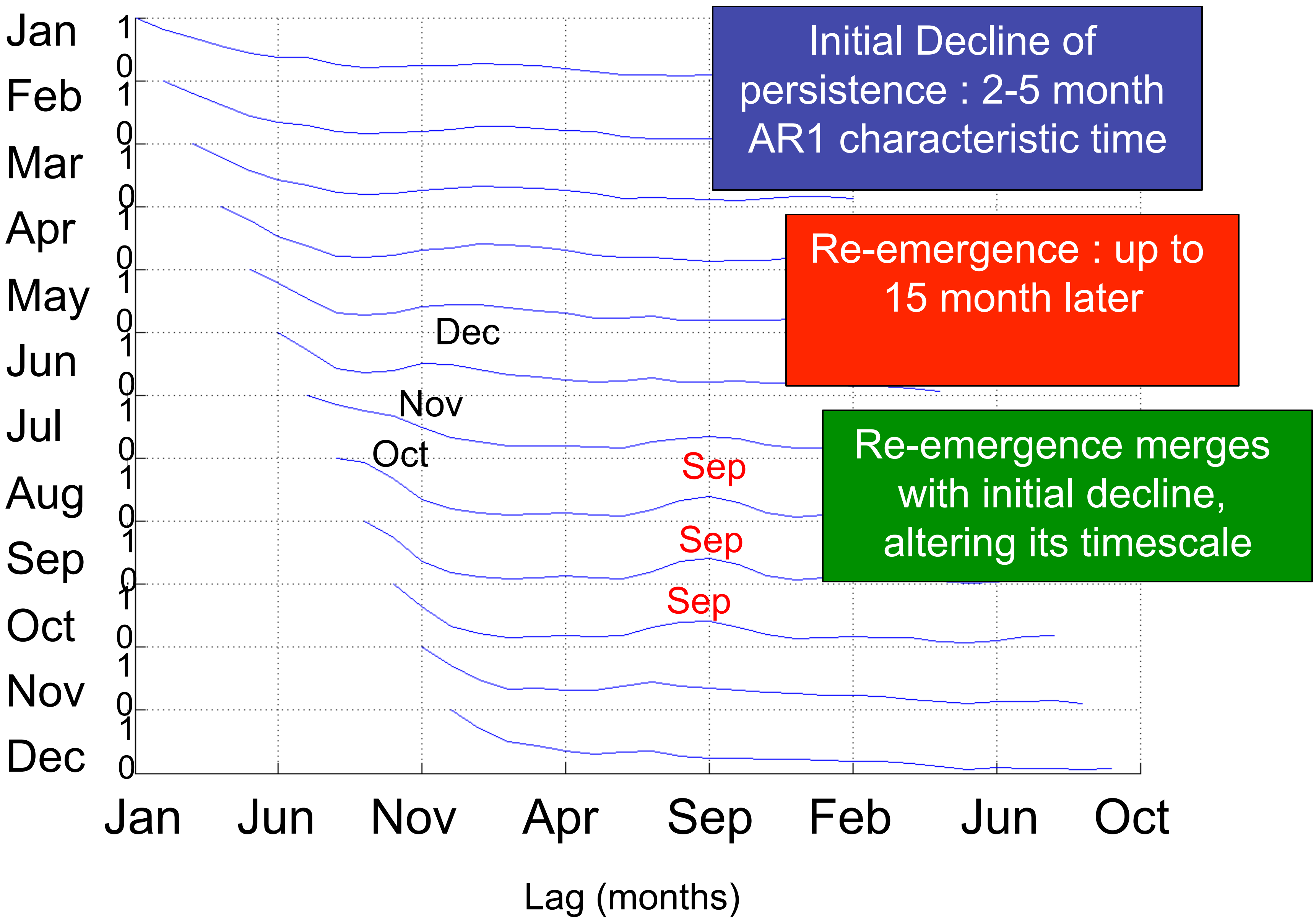
Blanchard-Wrigglesworth, Bitz, and Holland, 2011: Influence of Initial Conditions and Climate Forcing on Predicting Arctic Sea Ice



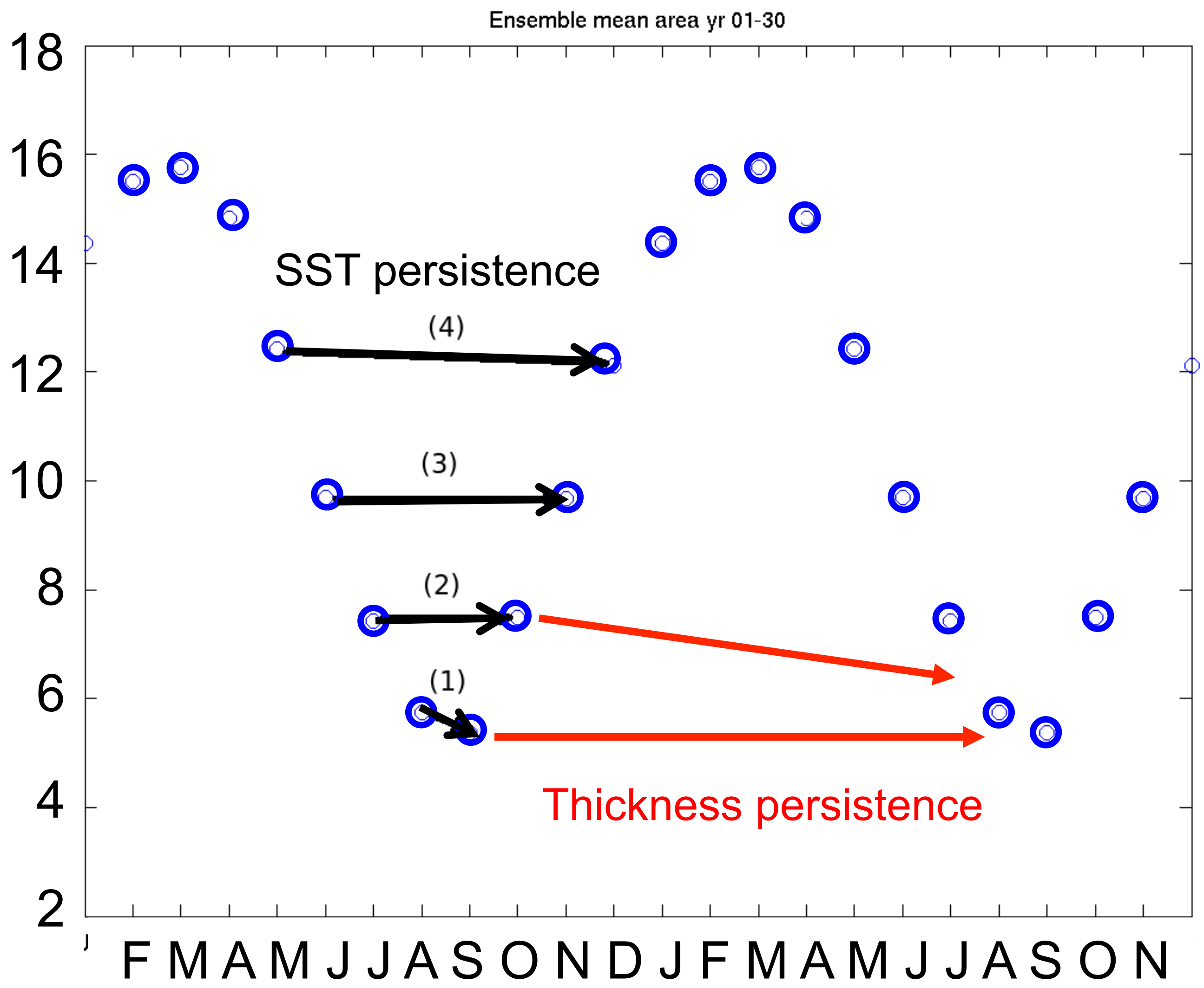
Use CCSM3 & and CCSM4

Diagnostic predictability

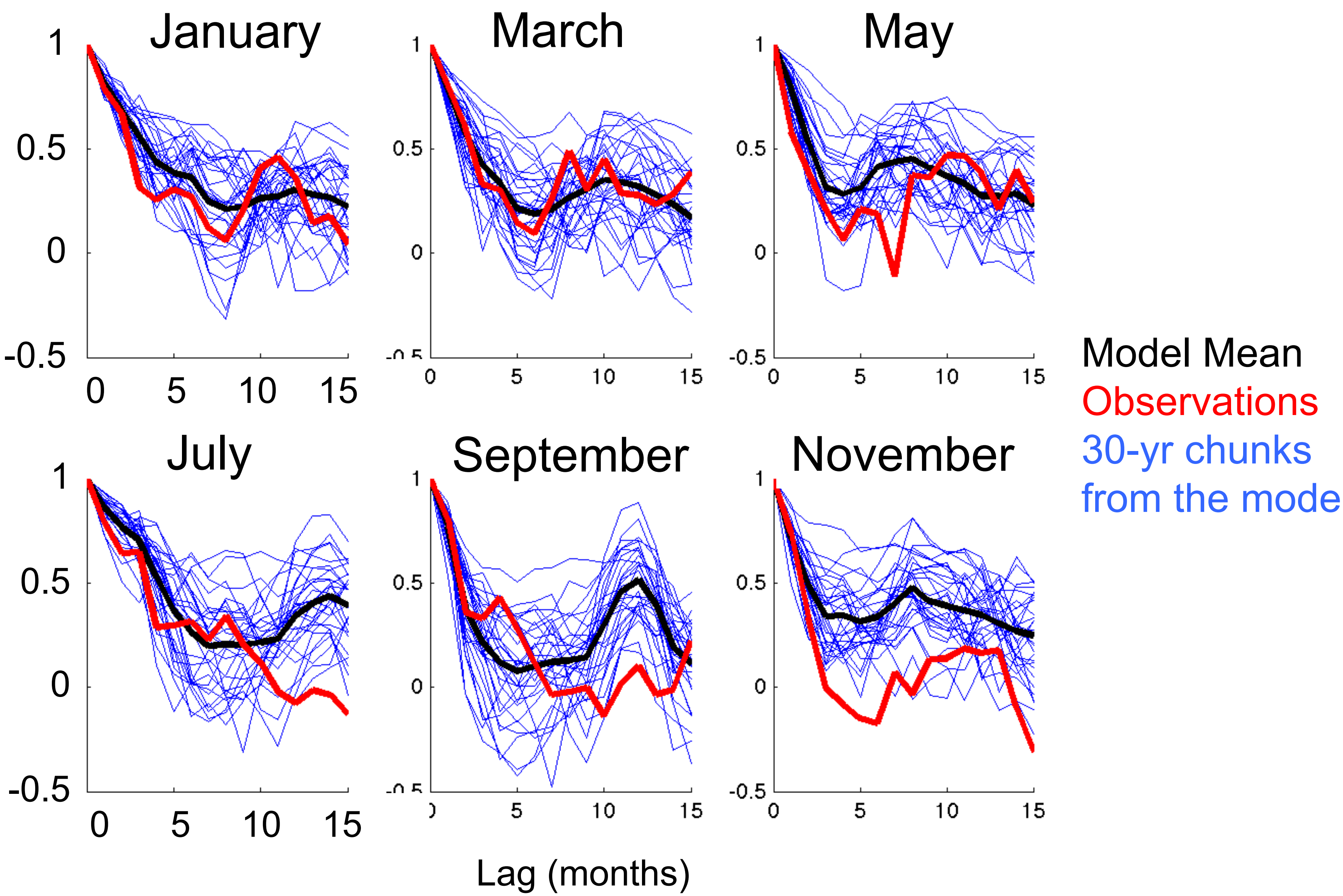
Lagged Correlation of pan-Arctic Sea Ice Area for 900 Years



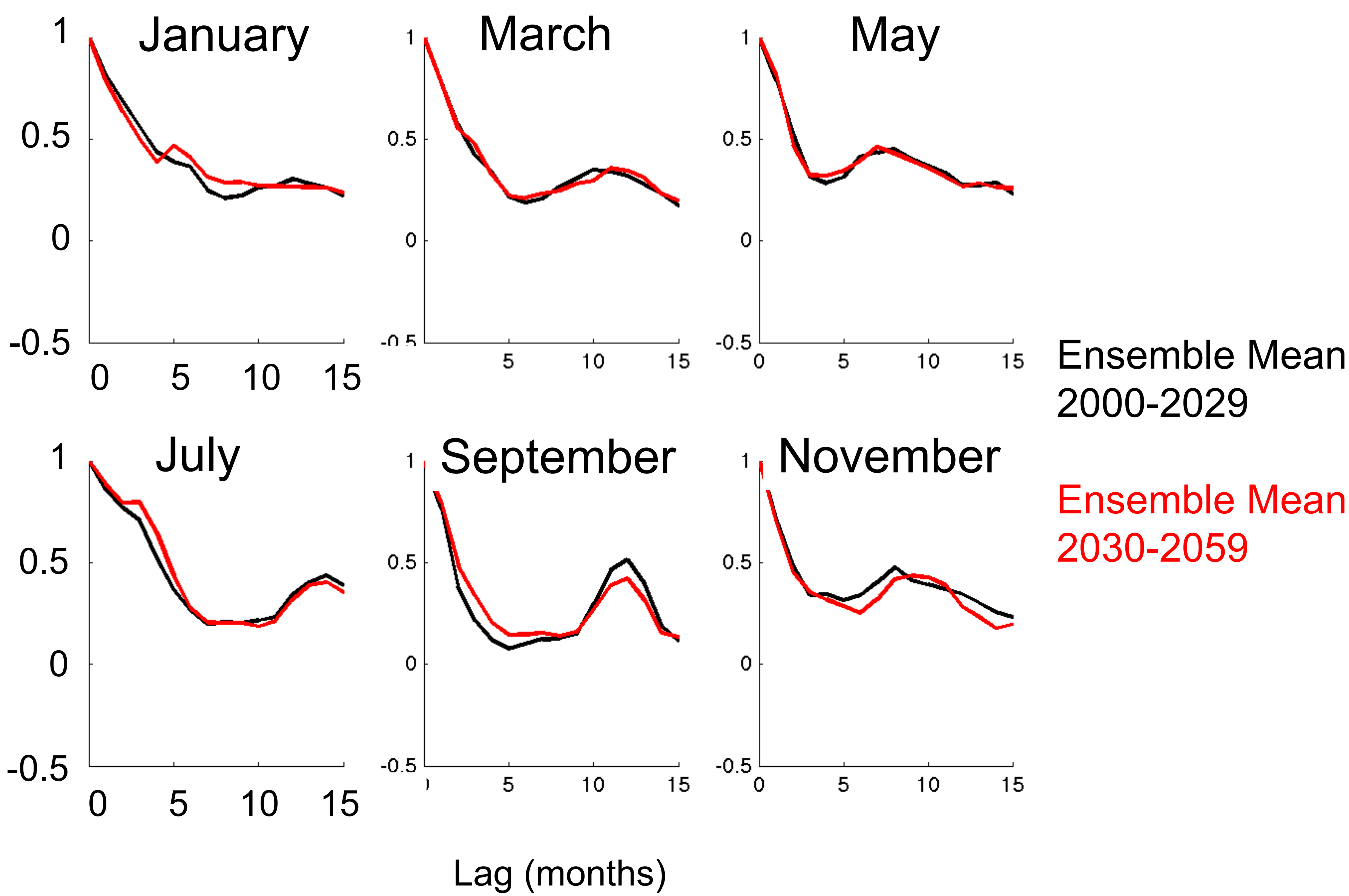
Sea ice Area Climatology in 10^6 km^2



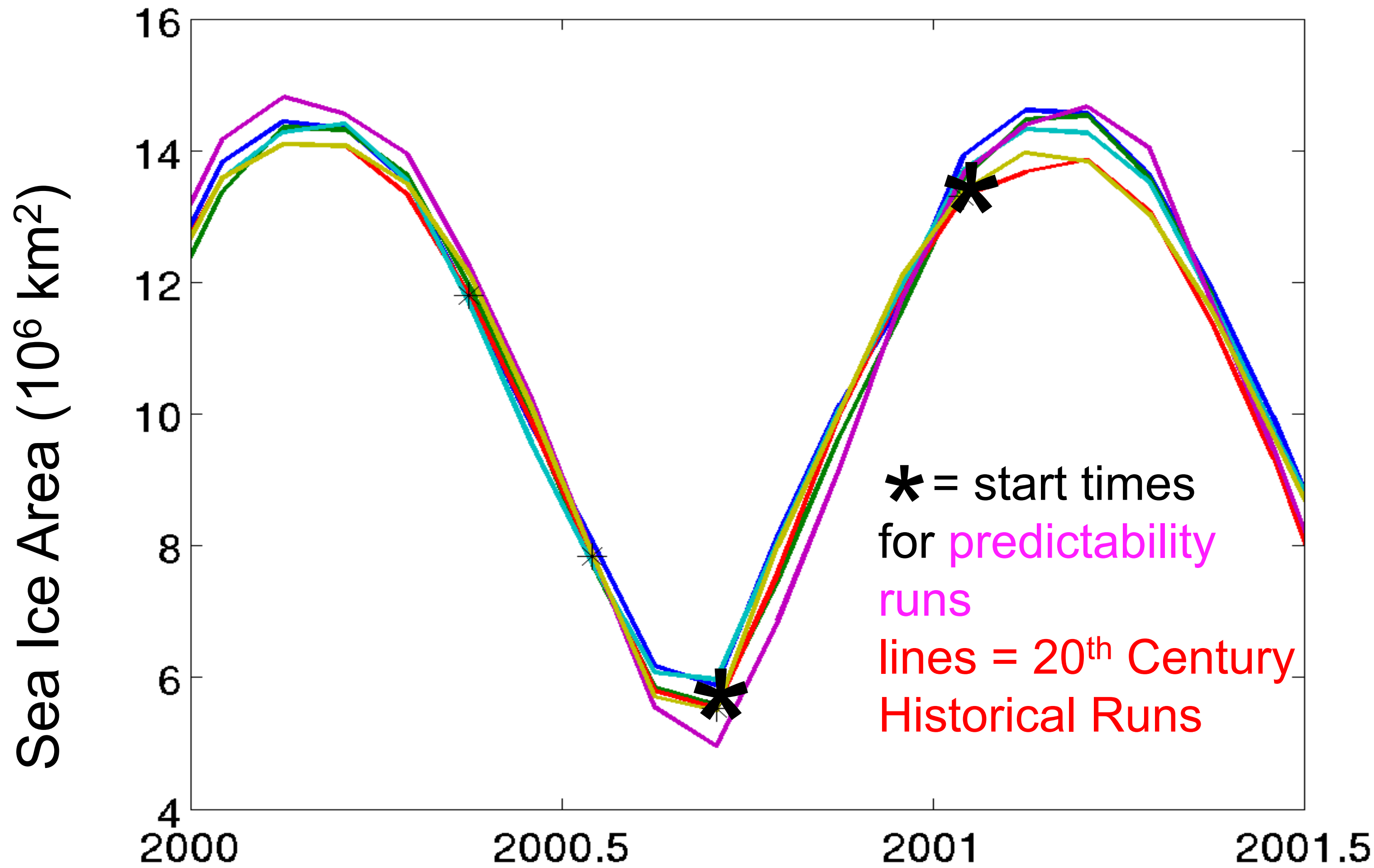
Lagged Correlation of pan-Arctic Sea Ice area



Lagged Correlation of Arctic Sea Ice area



Prognostic Predictability
"Perfect Model" Studies



Initialized in year ~2000 of a 20th century run at two start times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Prediction Run Details

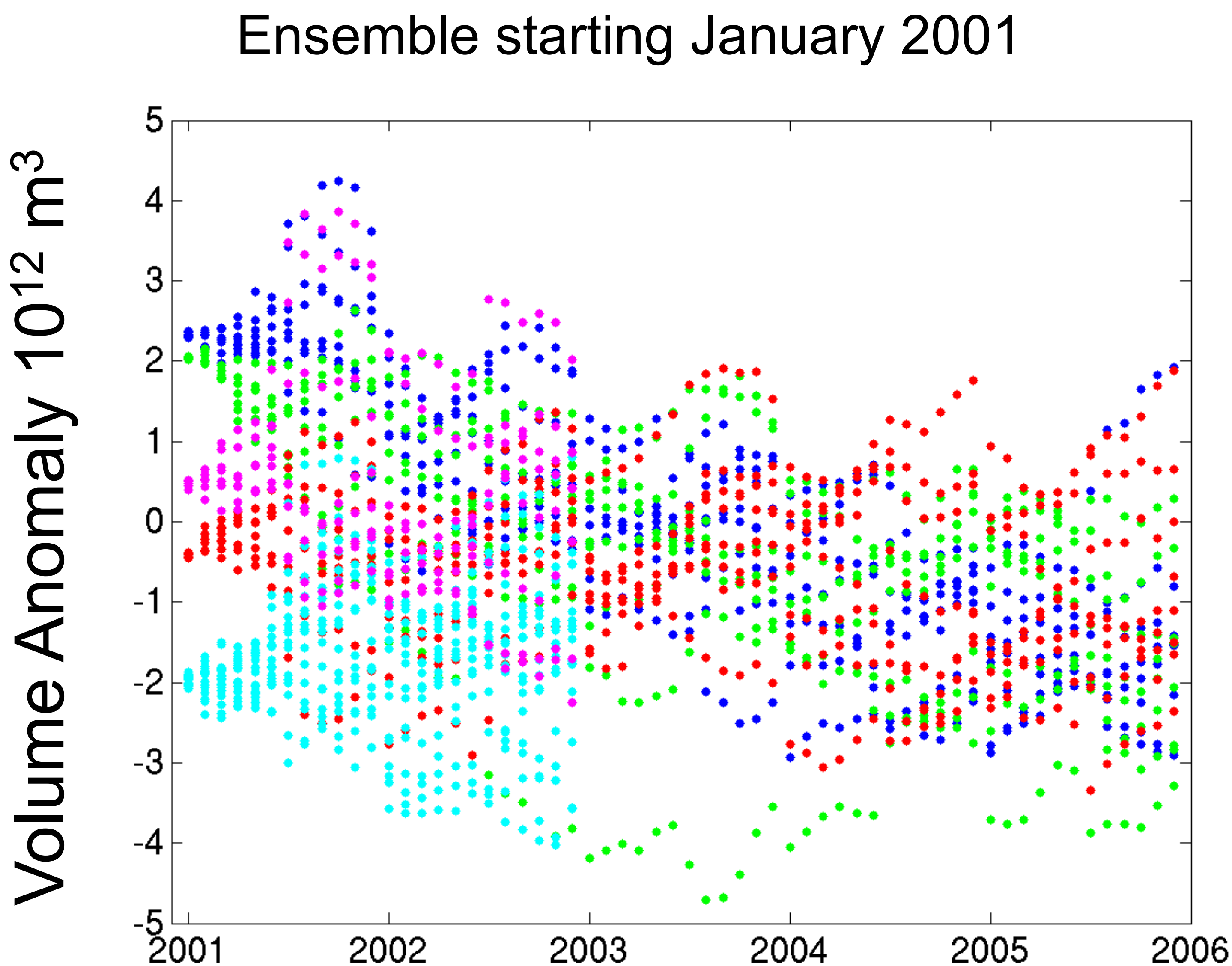
60 Ensemble members for each initial conditions start date (2 start times = 120 total runs)

Initial conditions from 6 members of 20th century historical runs near year 2000, make 6 “subsets” of the ensemble for each start date

Perturbed using adjacent days in atmosphere, same sea ice, ocean, land in each “subset”

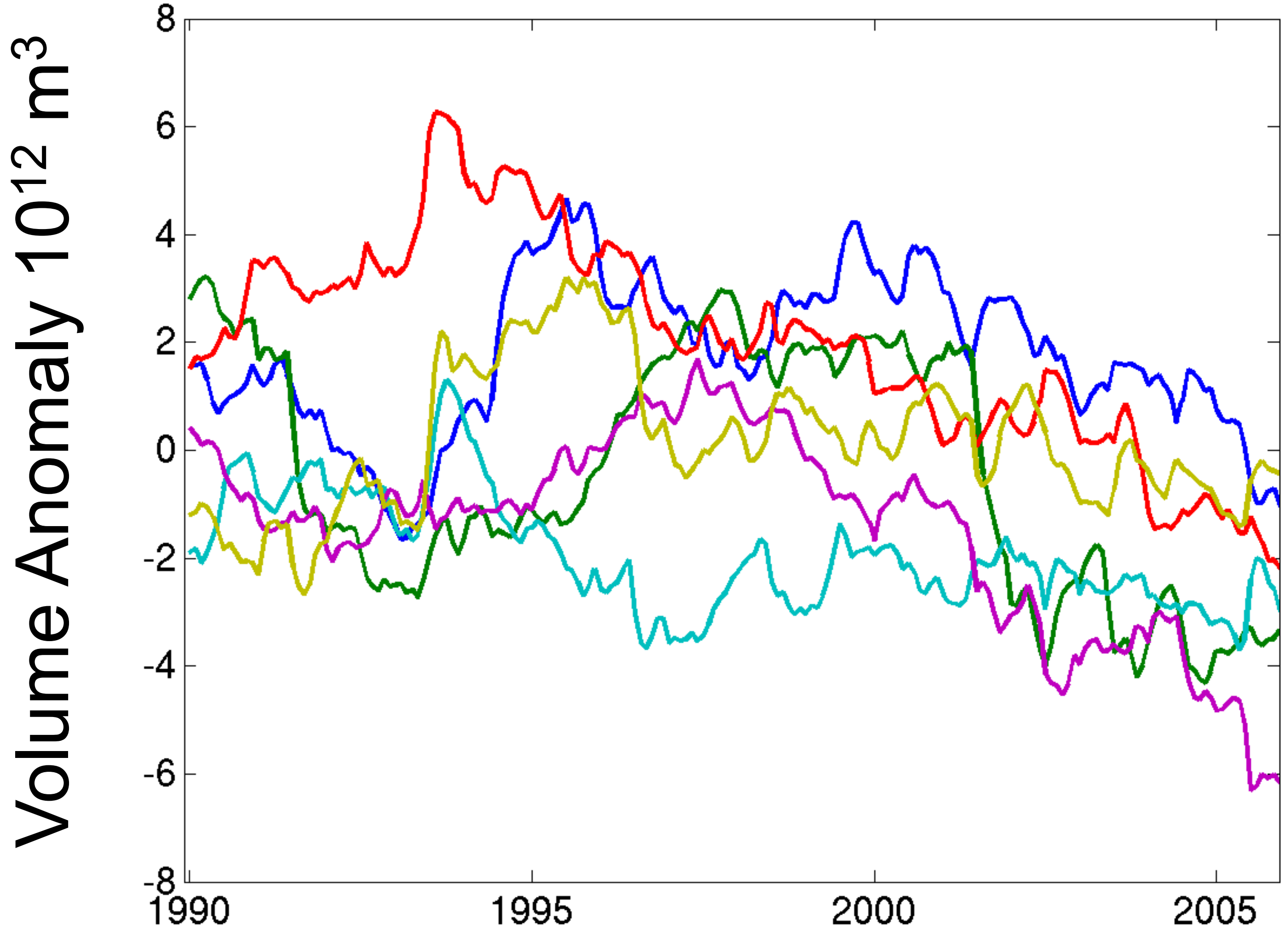
Runs are 2-5 years long

CCSM4 at 1° resolution



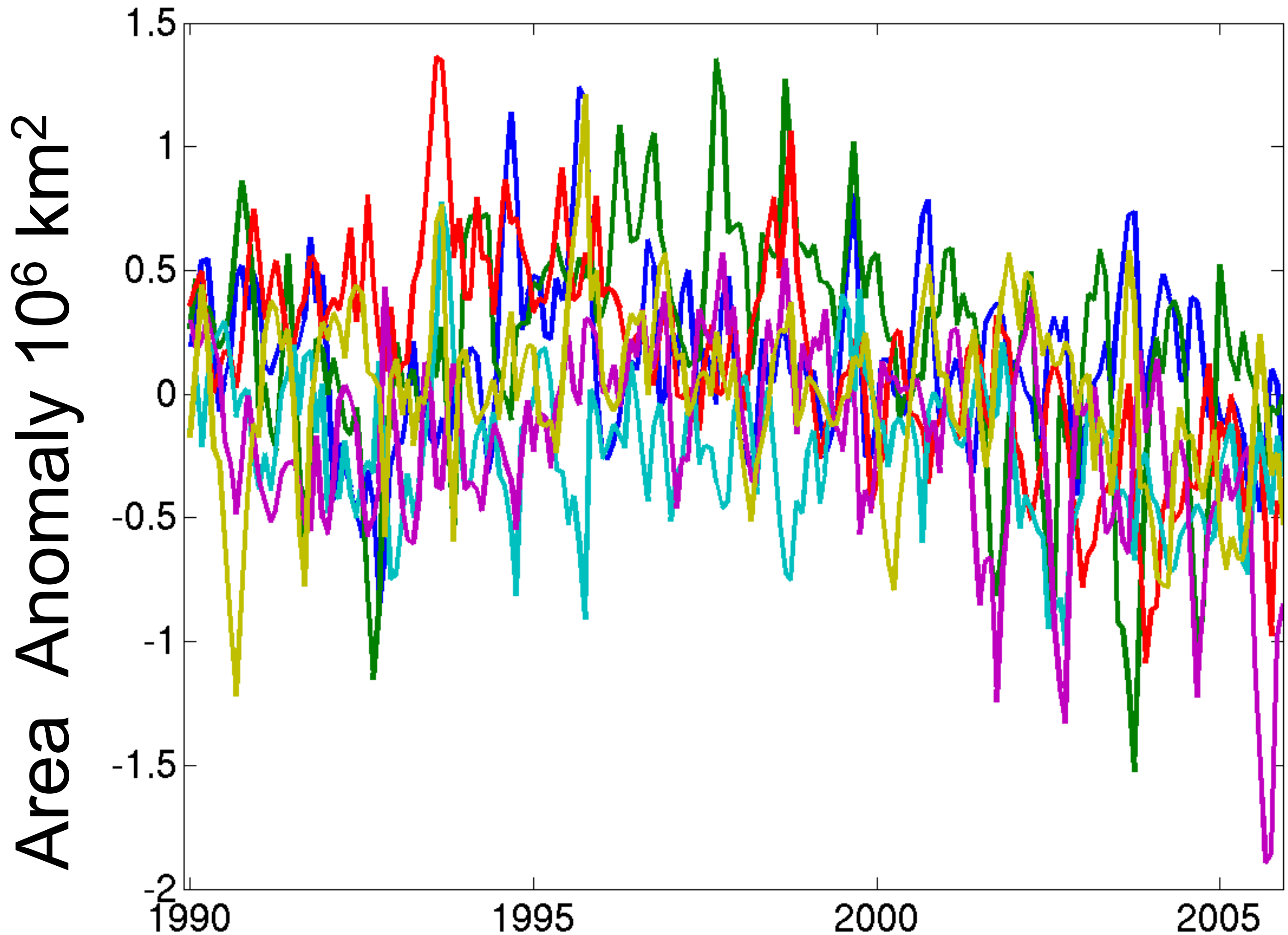
Ensemble starting January 2001
Volume Anomaly 10^{12} m^3
5
4
3
2
1
0
-1
-2
-3
-4
-5
2001
2002
2003
2004
2005
2006

Issue 1: Large Trend



6 ensemble members of 20th Century run

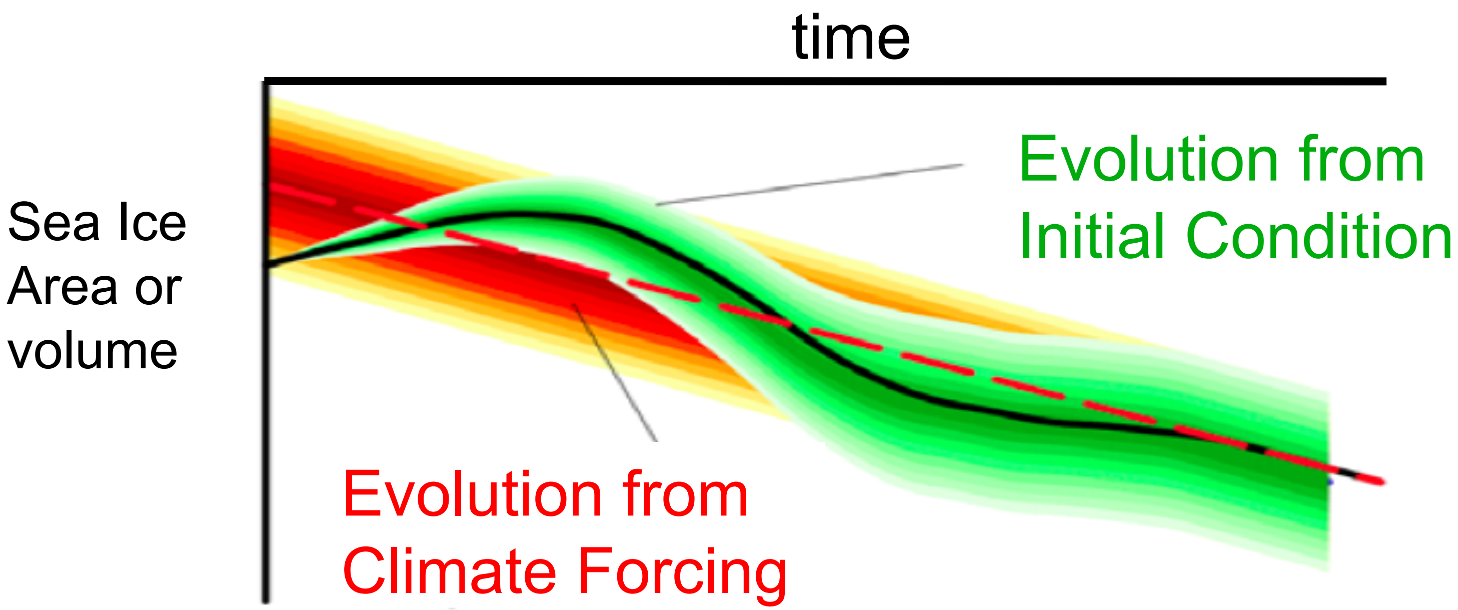
Issue 2: Seasonal Cycle in Area Anomaly



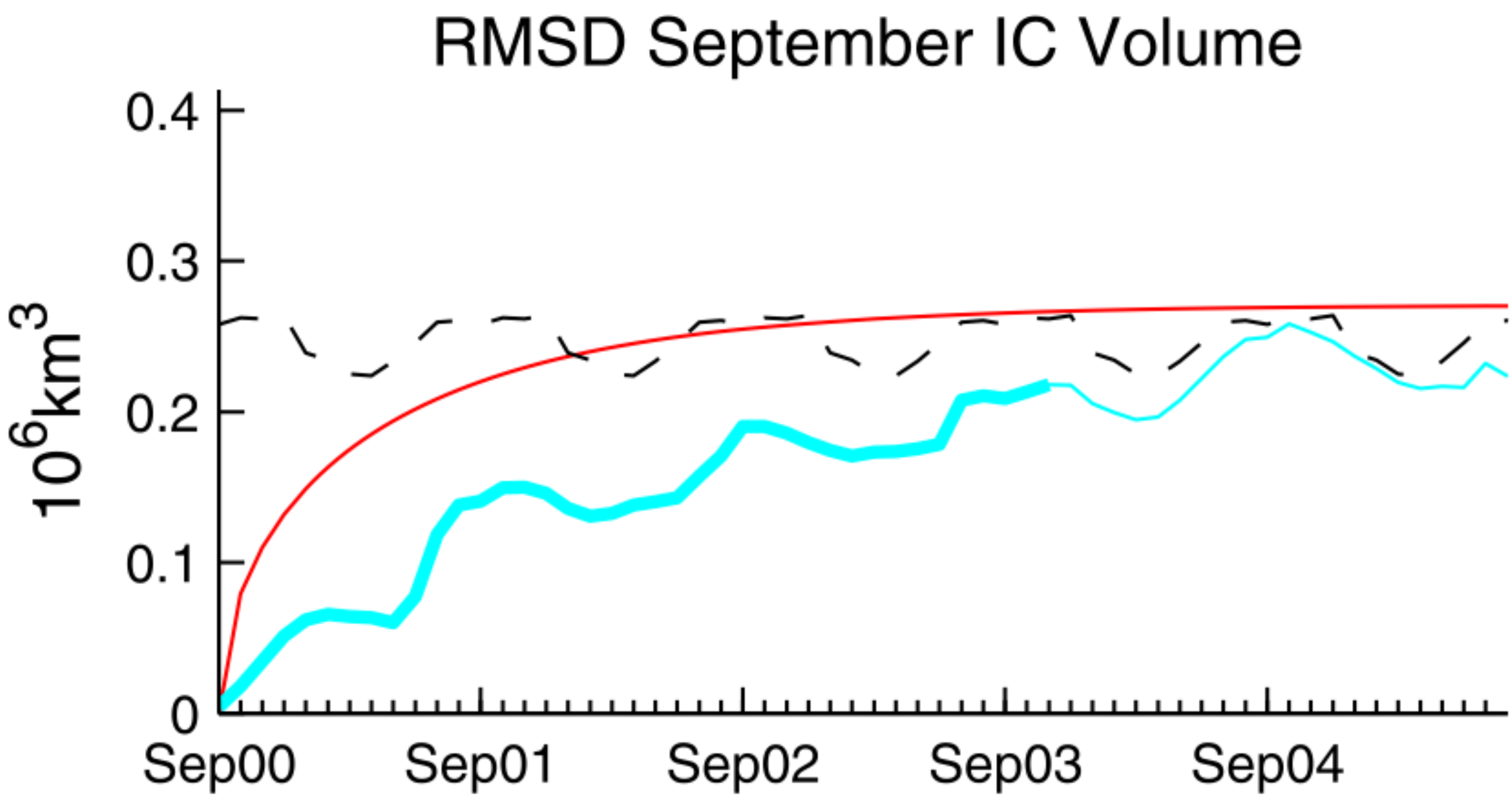
6 ensemble members of 20th Century run

Sea ice is predictable due to

1) Persistence of thickness and SST (under advection)
2) Dependence of area on thickness in summer and ocean heat
3) Response to climate forcing



Branstator and Teng (2010) Two limits of Initial Value Predictability in a GCM (I flipped their figure)

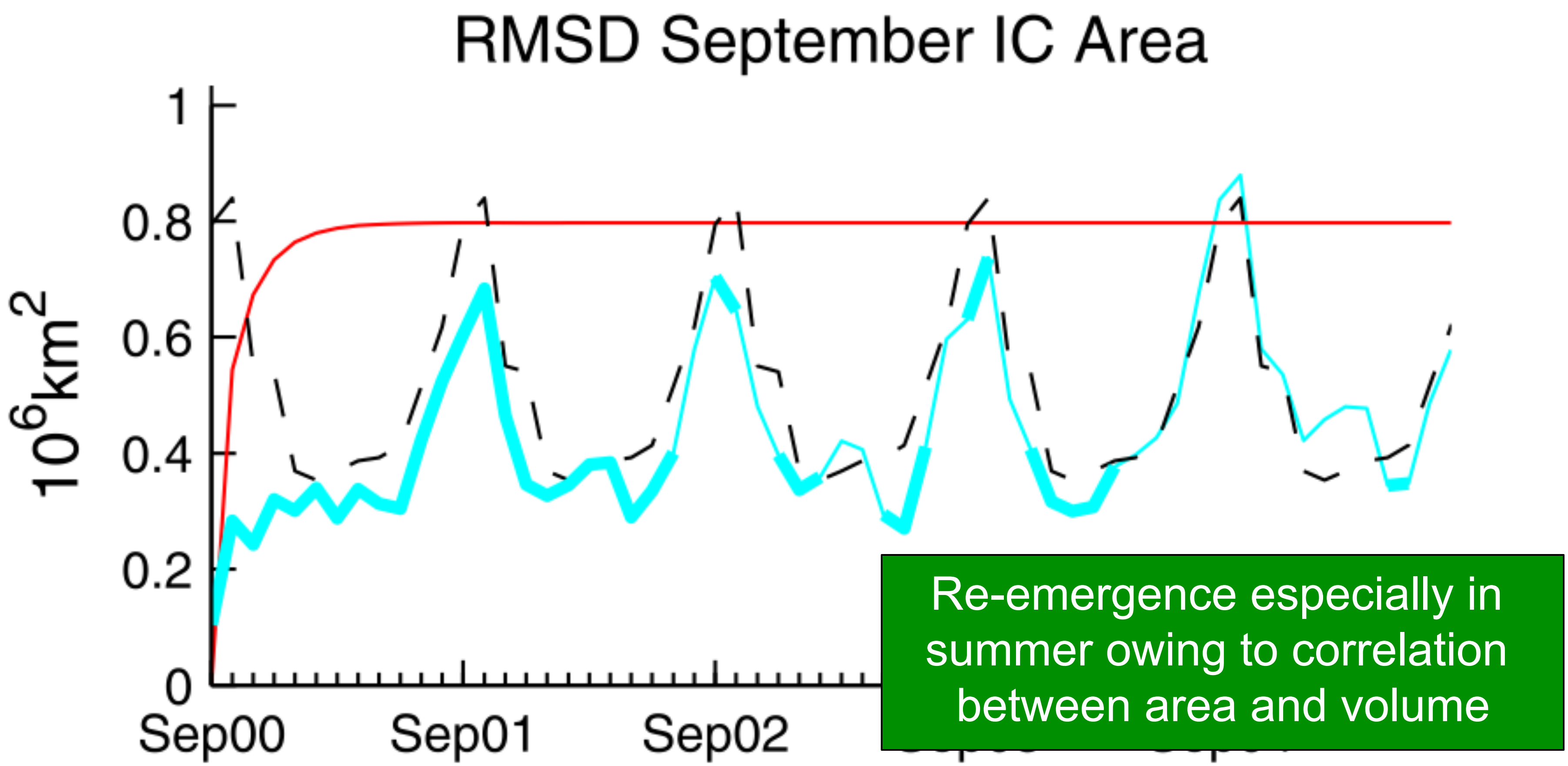


Initialized Ensemble on September 2000

Baseline from detrended 20th Century Runs

AR1 model estimate

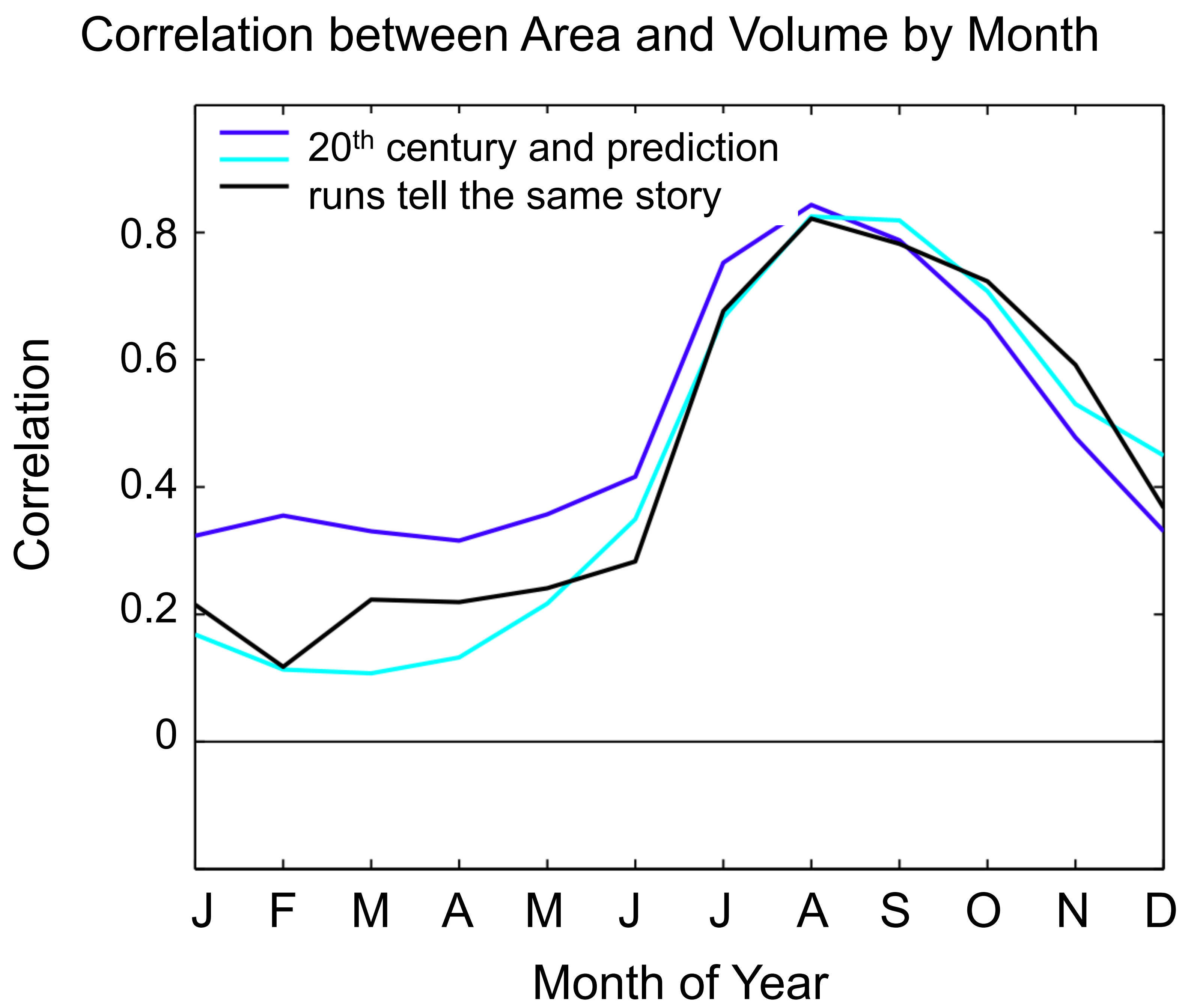
RMSD = rms of differences of all combinations of runs

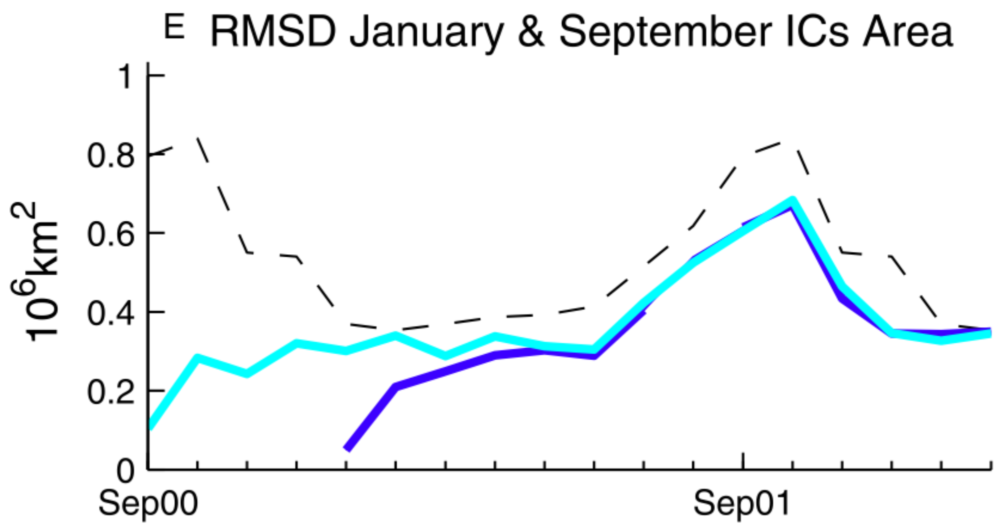


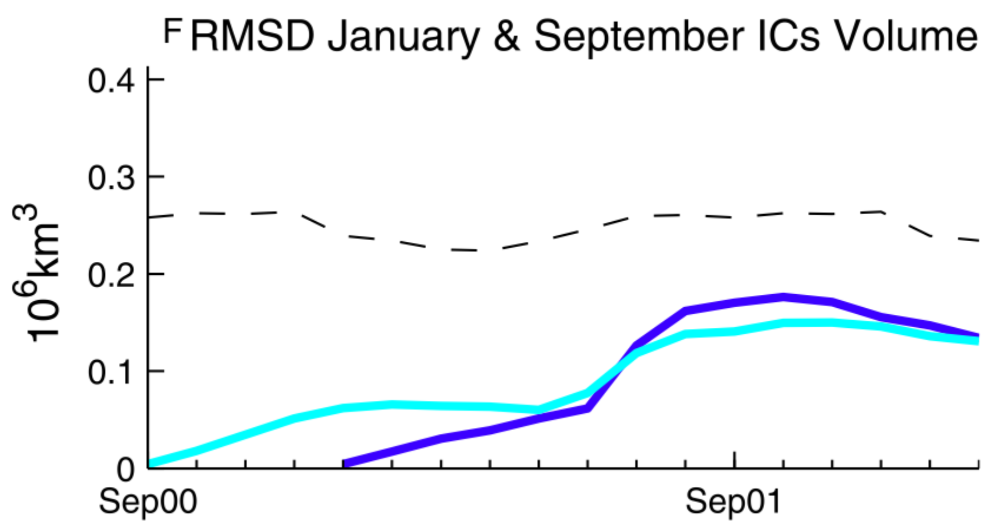
Initialized Ensemble on September 2000

Baseline from detrended 20th Century Runs

AR1 model estimate (only right for summer)


Correlation between Area and Volume by Month
20th century and prediction
runs tell the same story
Correlation
0.8
0.6
0.4
0.2
0
J F M A M J J A S O N D
Month of Year





Equally good summer forecast from prior September or January

"Barrier" to volume predictability in spring

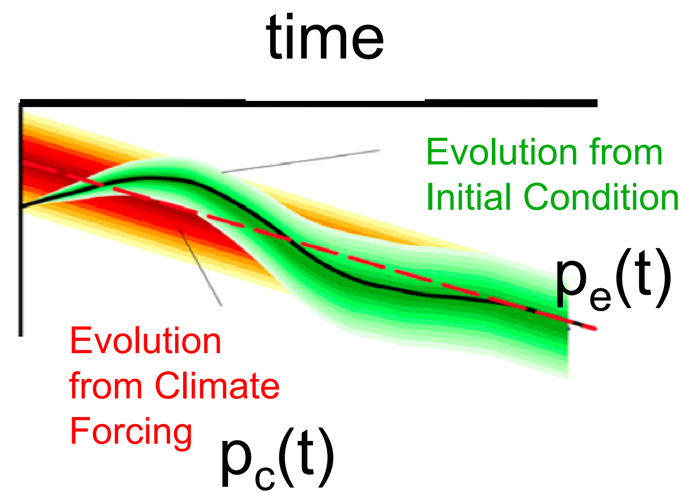
Relative Entropy

$$RE = \int p_c(x)\ \ln\left(\frac{p_c(x)}{p_e(x)}\right) dx$$

For 1D variable (e.g., x=sea ice area)
assuming Gaussian distributions

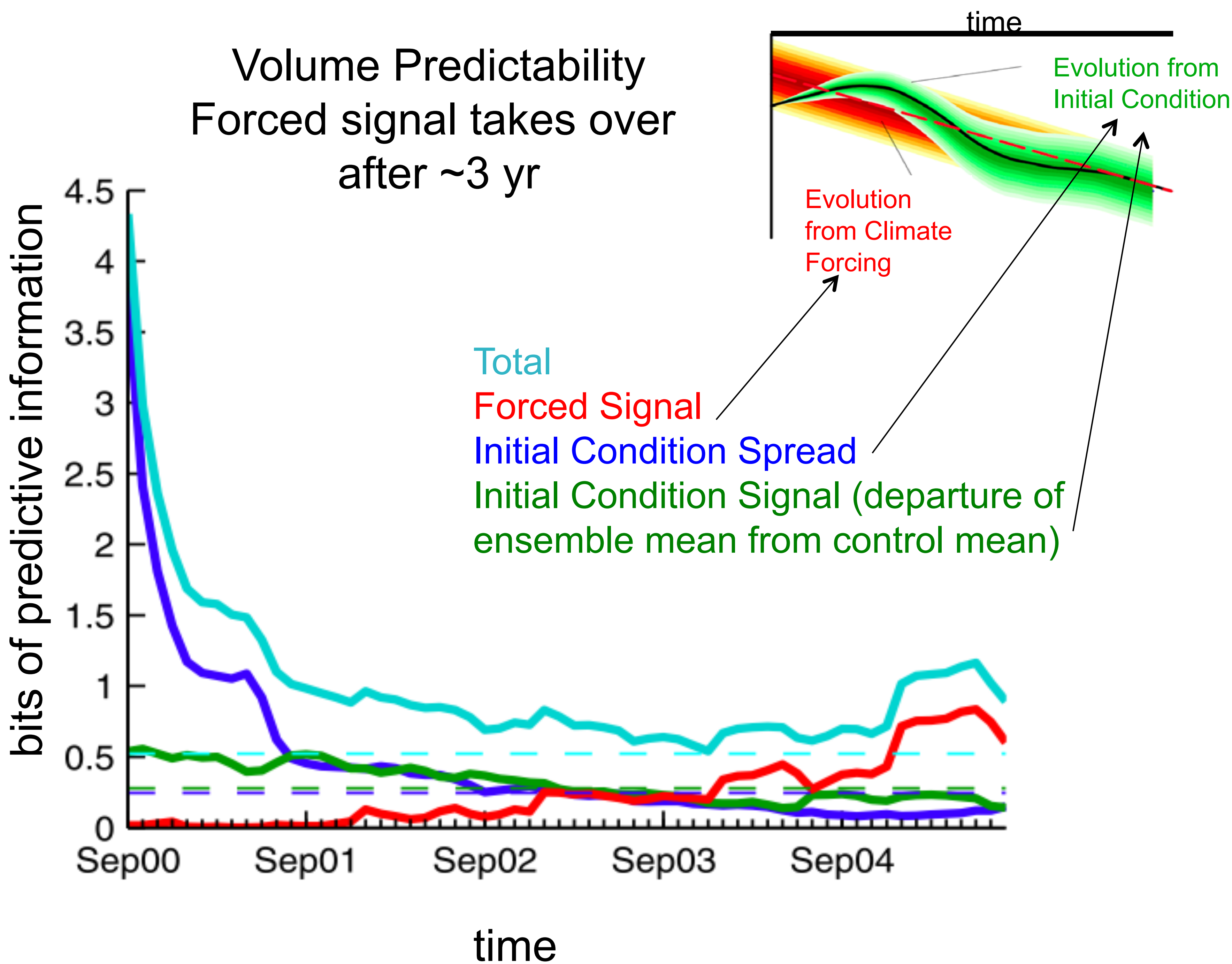
$$RE = \frac{1}{2}\left[\underbrace{ln\left(\frac{\sigma_c^2}{\sigma_e^2}\right) + \frac{\sigma_e^2}{\sigma_c^2}}_{\text{“dispersion”}} + \underbrace{\frac{(\mu_e - \mu_c)^2}{\sigma_c^2}}_{\text{“signal”}} - 1\right],$$

“dispersion” “signal”



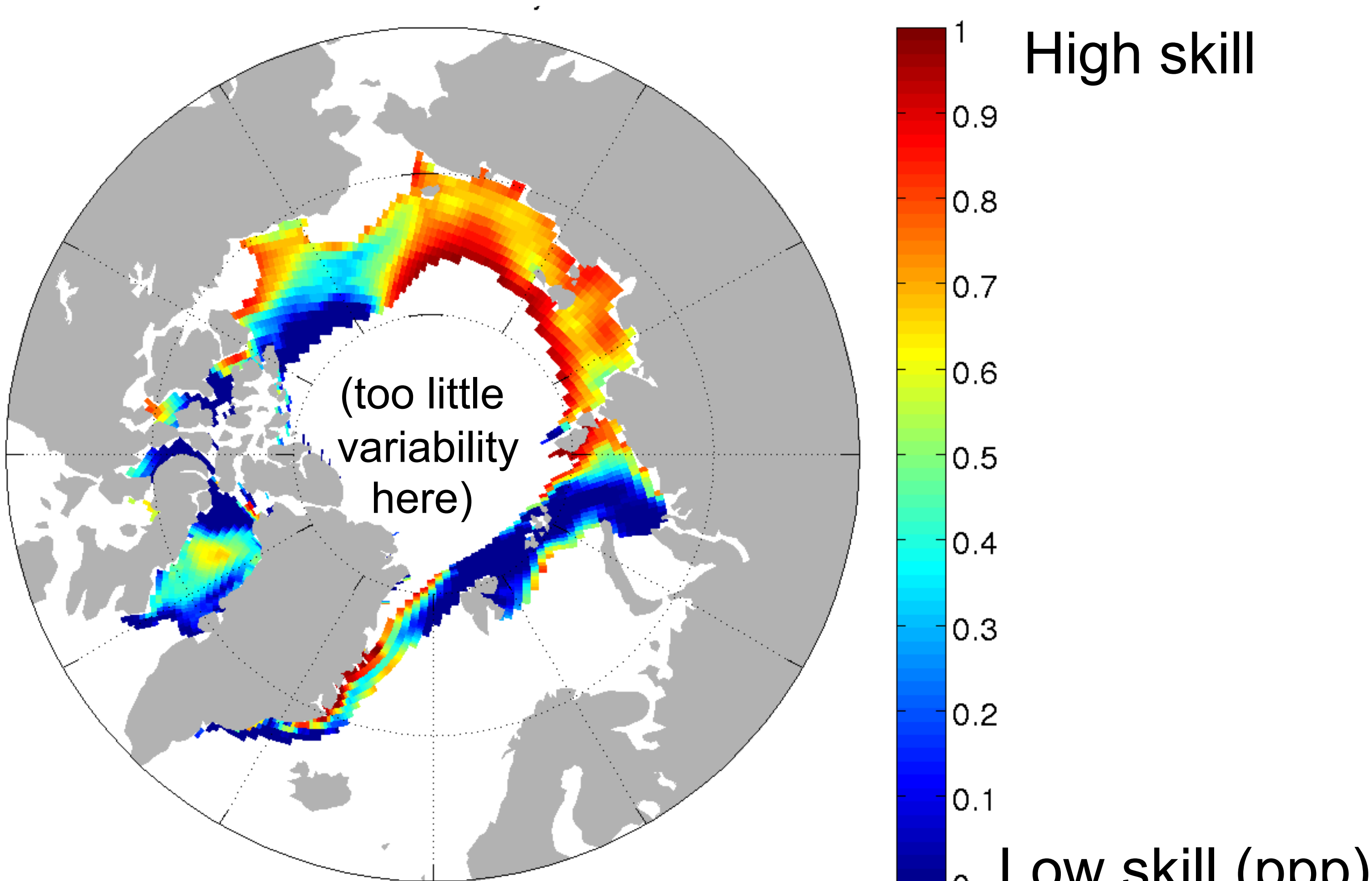
Measuring dynamical prediction utility using relative entropy, Kleeman (2002)
and
Information theory and predictability for low-frequency variability, Abramov, Majda, Kleeman (2005)

Volume Predictability
Forced signal takes over after ~3 yr



Is there any hope of predicting spatial patterns?

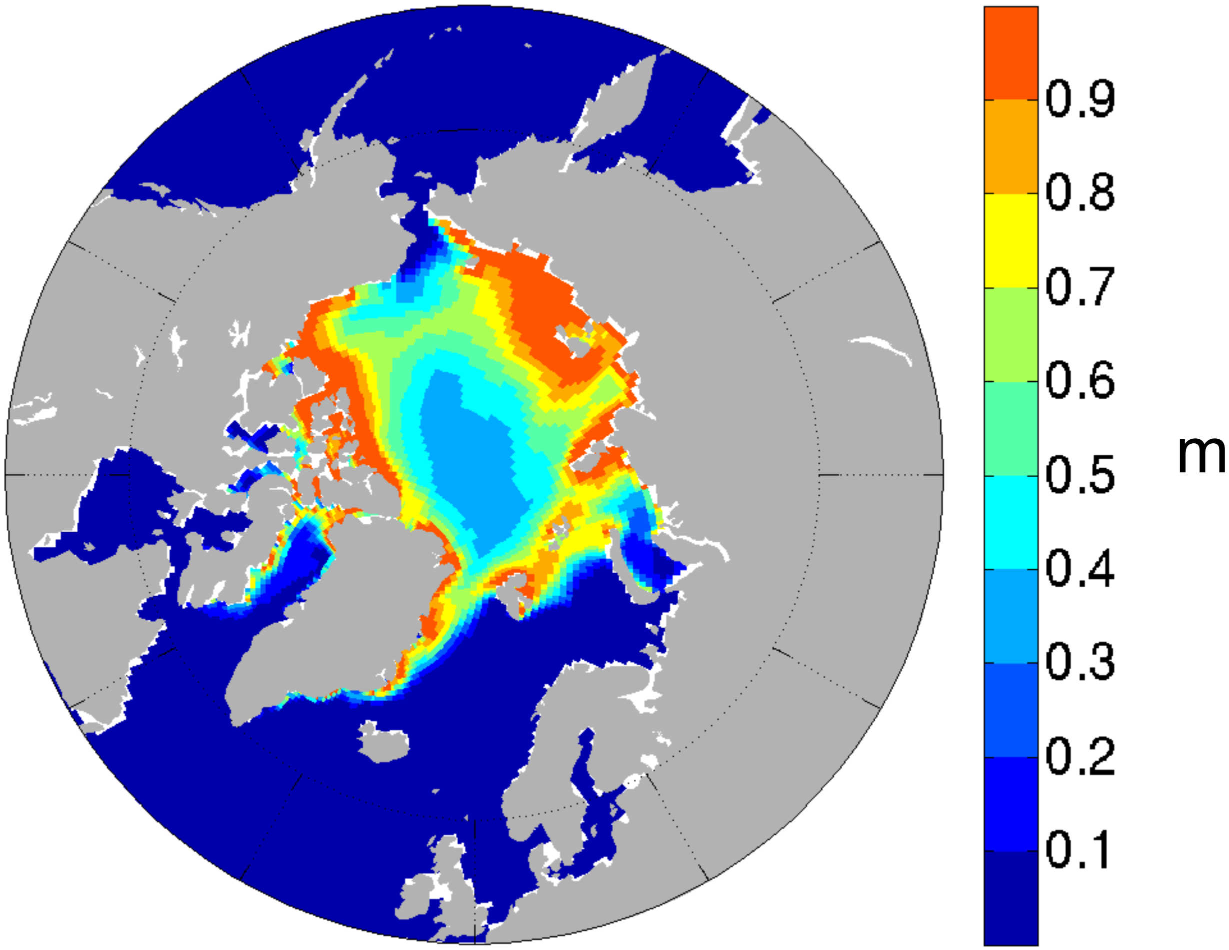
Concentration Predictability in October



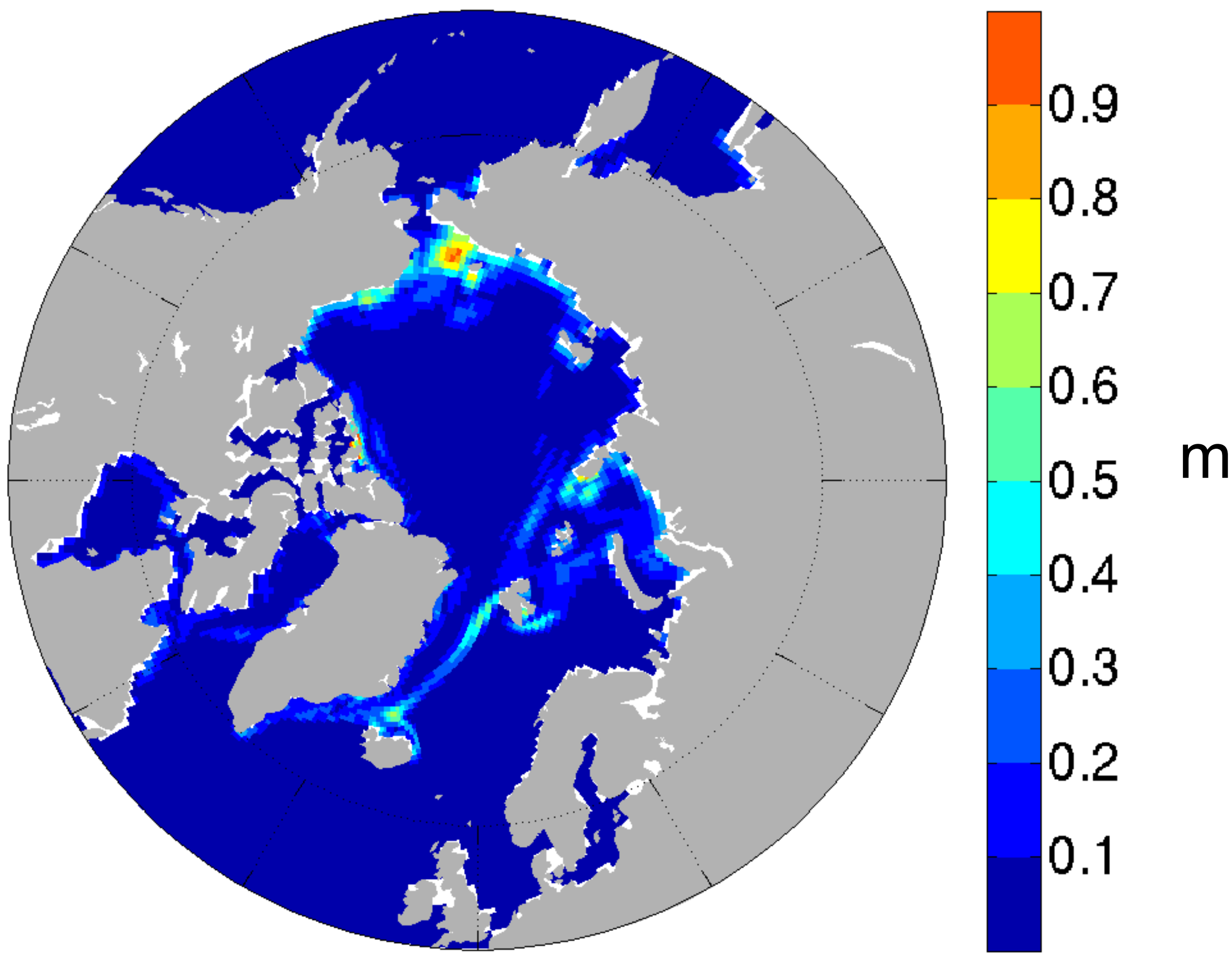
Blanchard-Wrigglesworth (in prep)

Initialized in July

Standard Deviation of Sea Ice Thickness



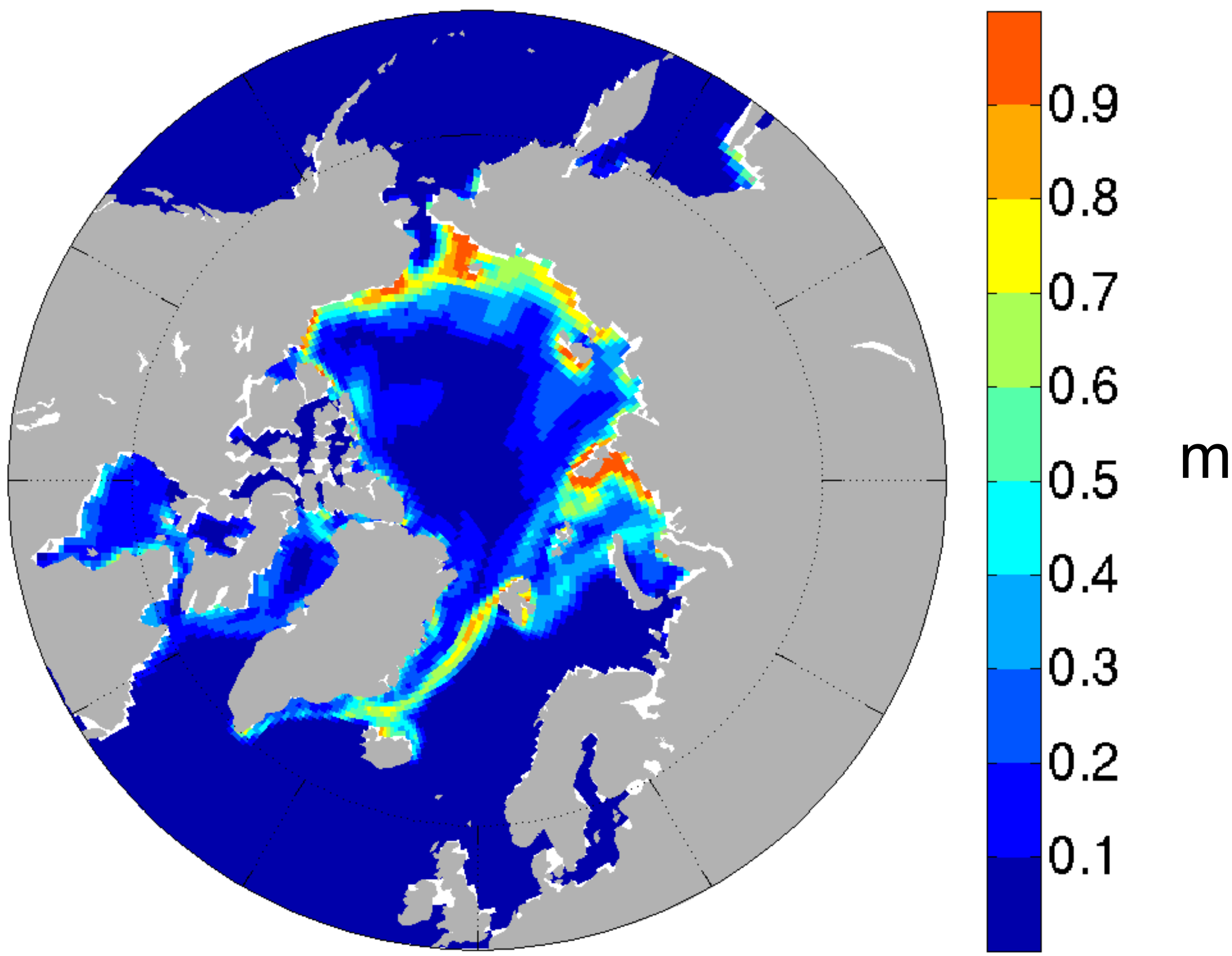
Standard Deviation of Sea Ice Thickness



1 month Lead Time

Initialized in May

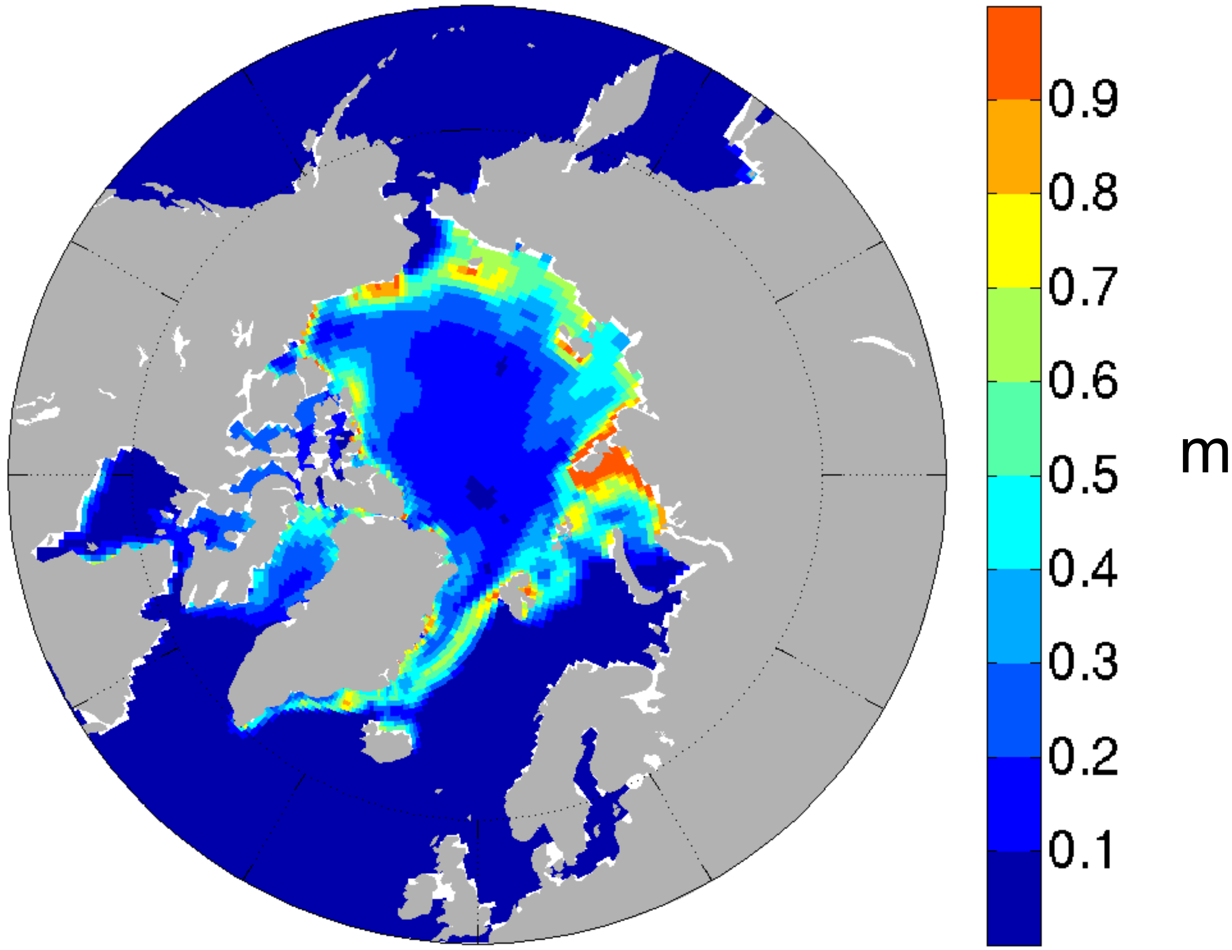
Standard Deviation of Sea Ice Thickness



2 month Lead Time

Initialized in May

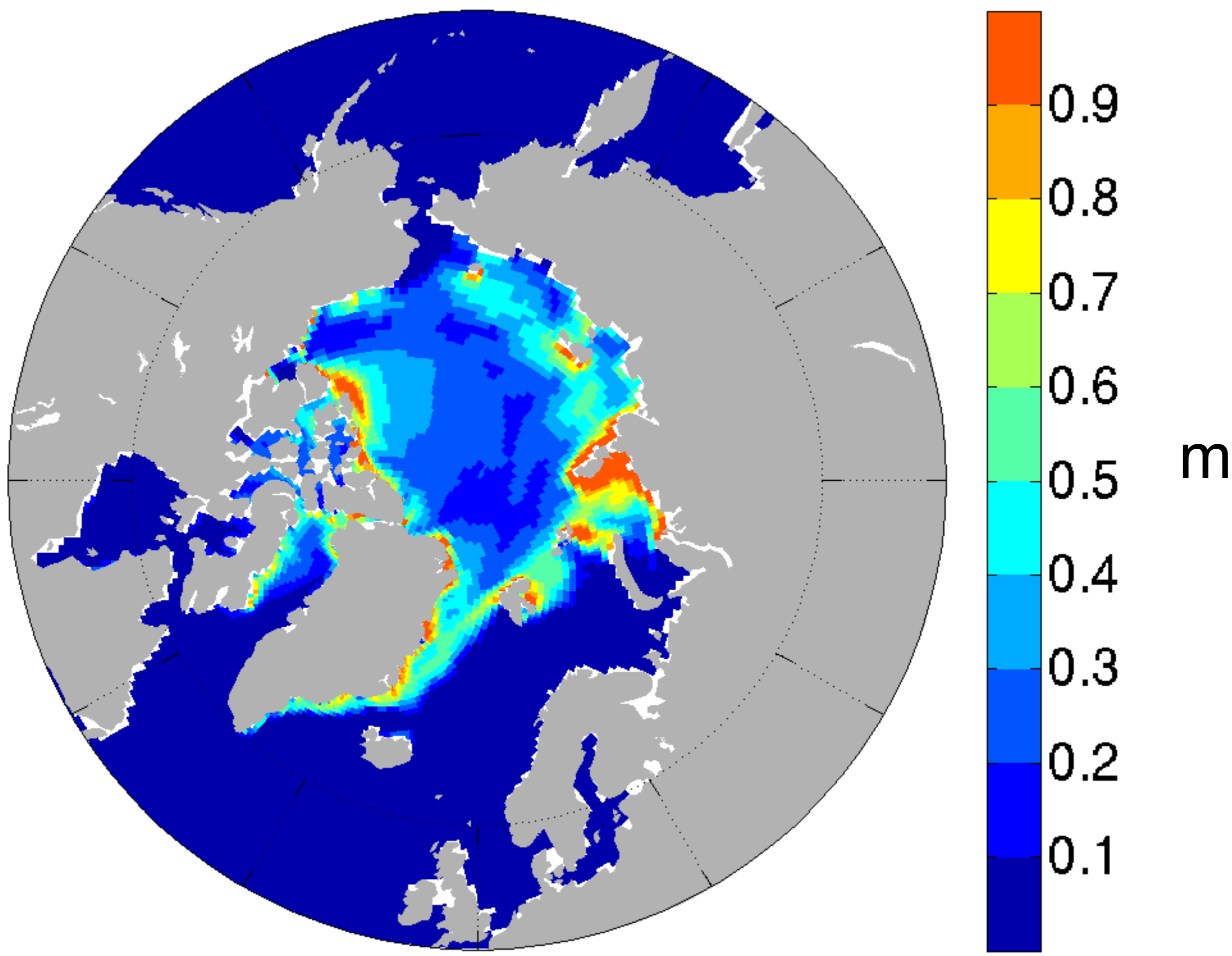
Standard Deviation of Sea Ice Thickness



3 month Lead Time

Initialized in May

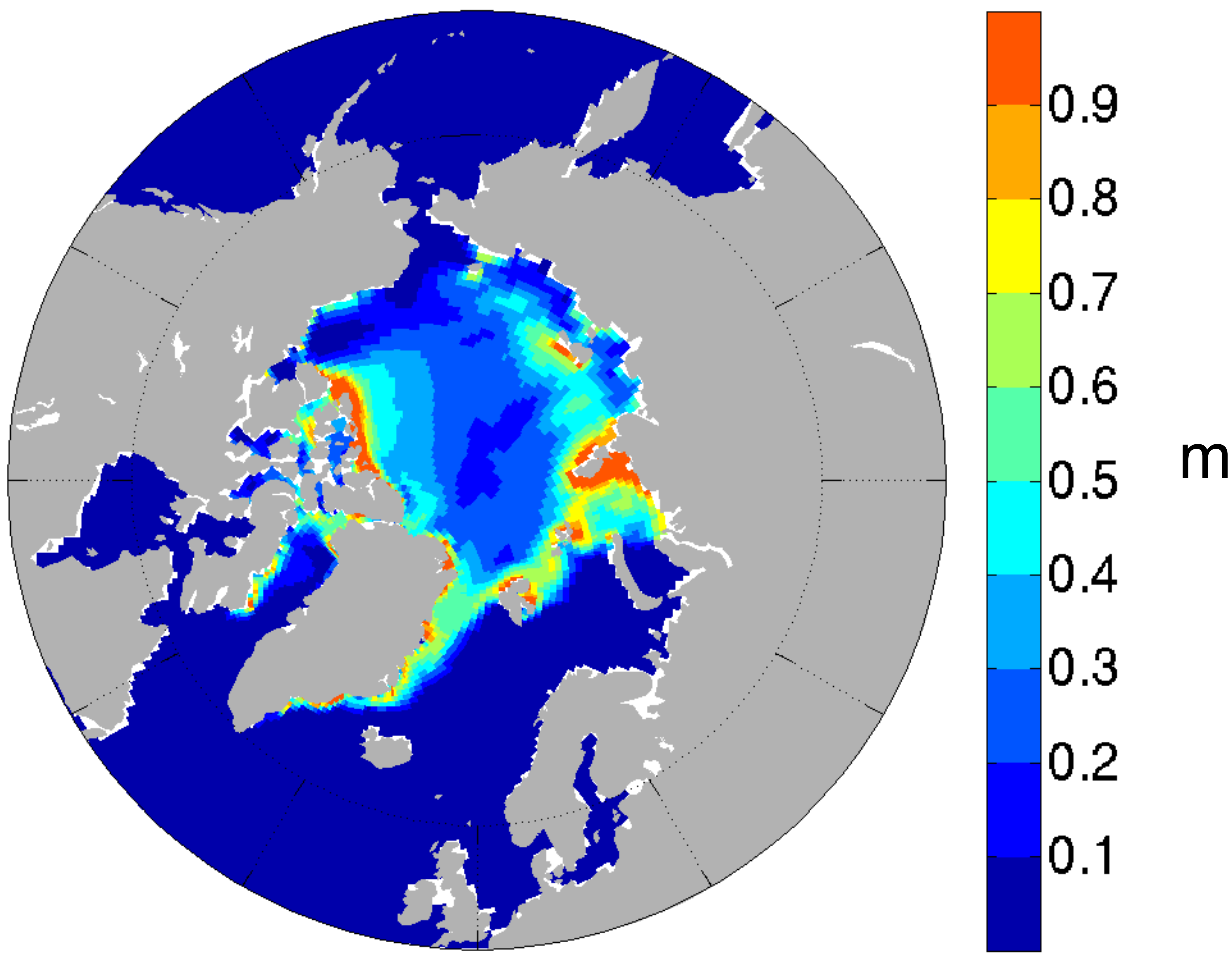
Standard Deviation of Sea Ice Thickness



4 month Lead Time

Initialized in May

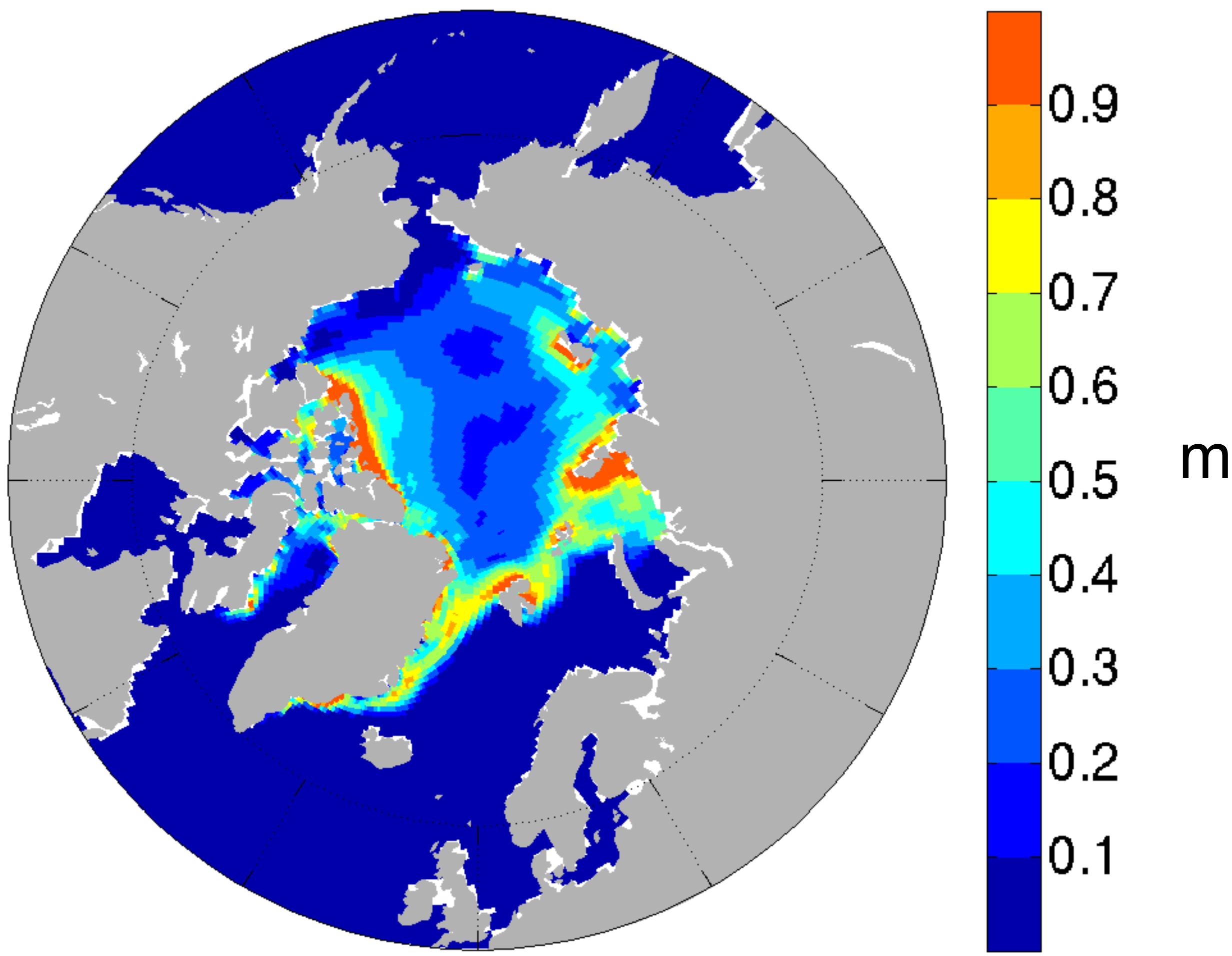
Standard Deviation of Sea Ice Thickness



5 month Lead Time

Initialized in May

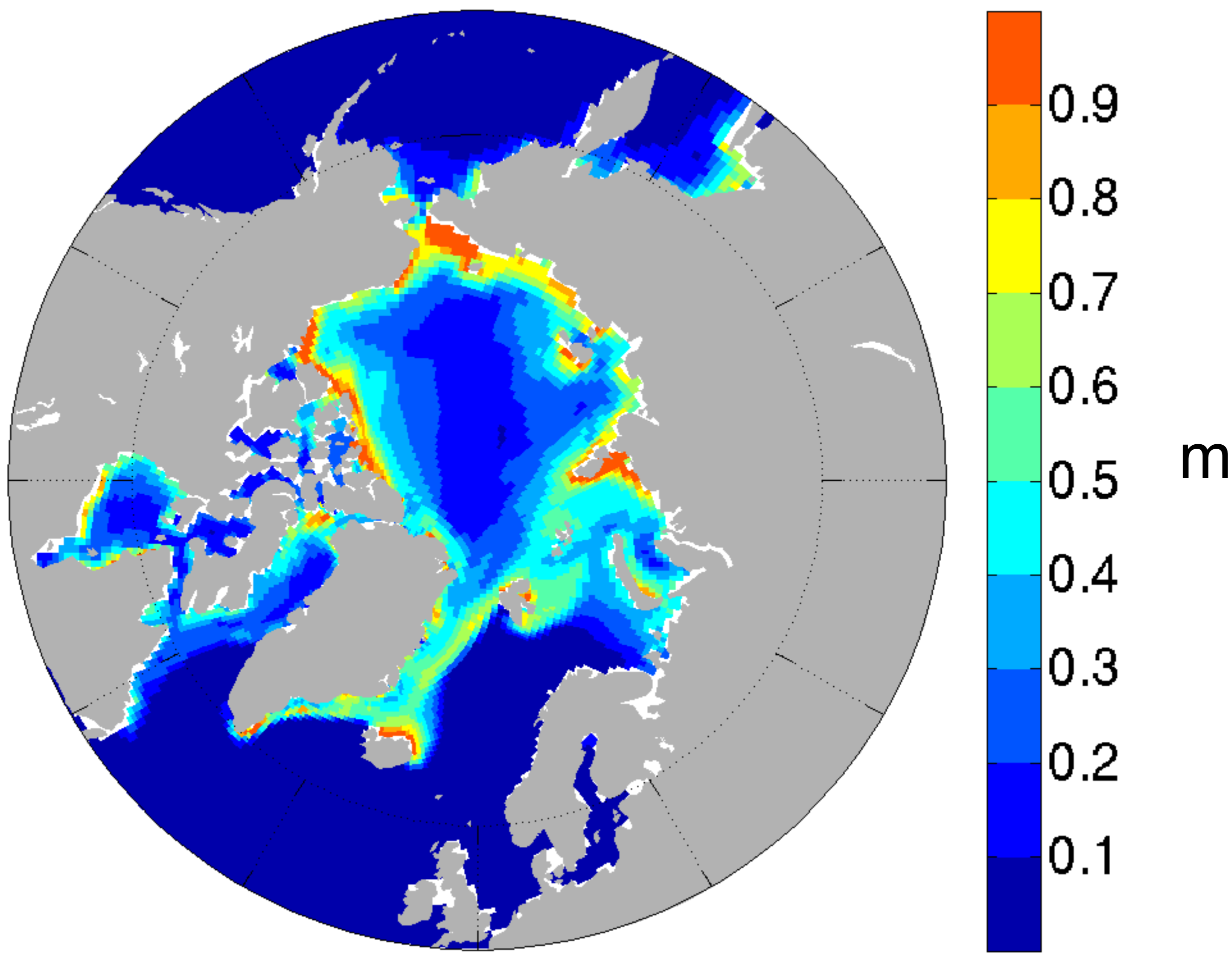
Standard Deviation of Sea Ice Thickness



6 month Lead Time

Initialized in May

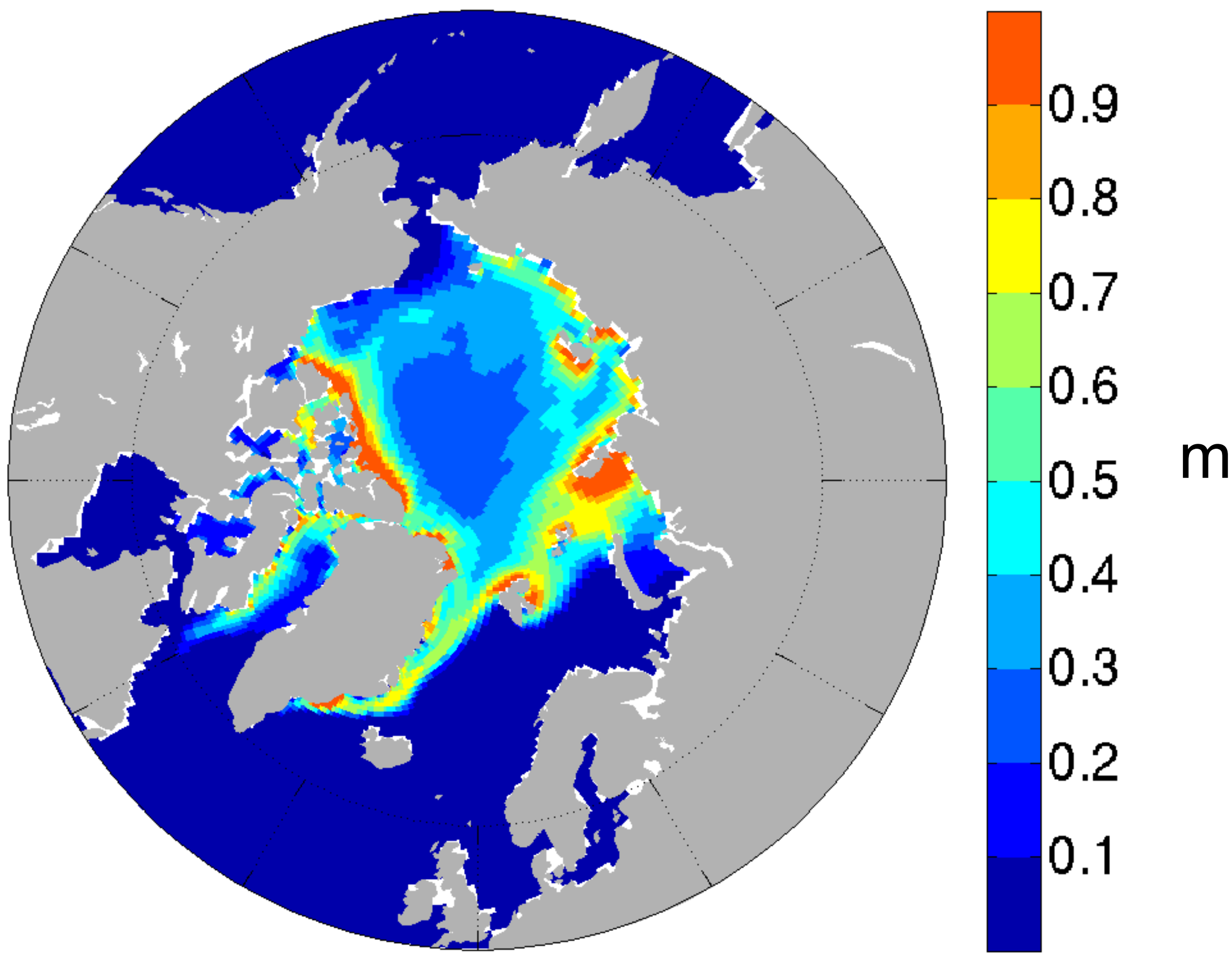
Standard Deviation of Sea Ice Thickness



12 month Lead Time

Initialized in May

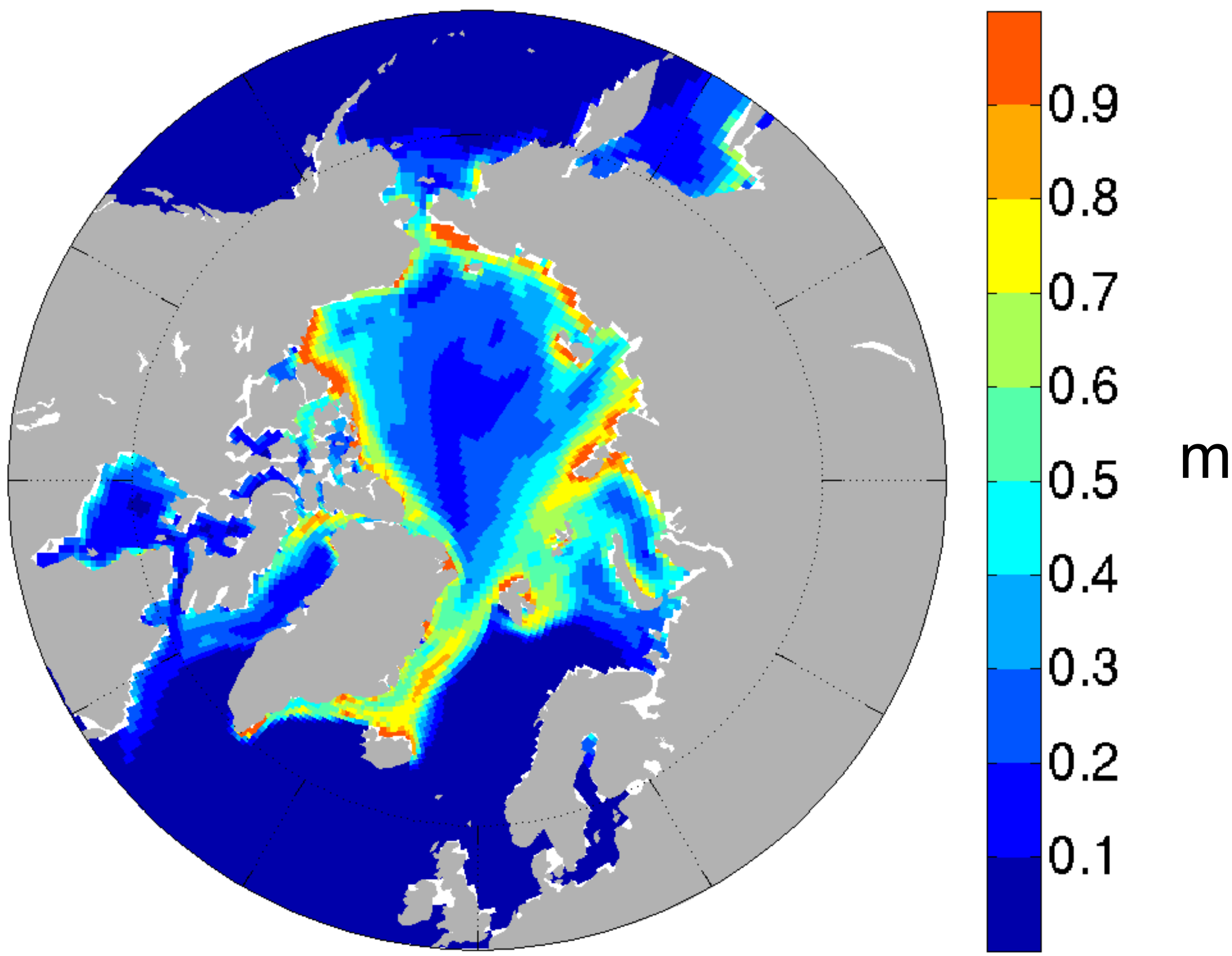
Standard Deviation of Sea Ice Thickness



18 month Lead Time

Initialized in May

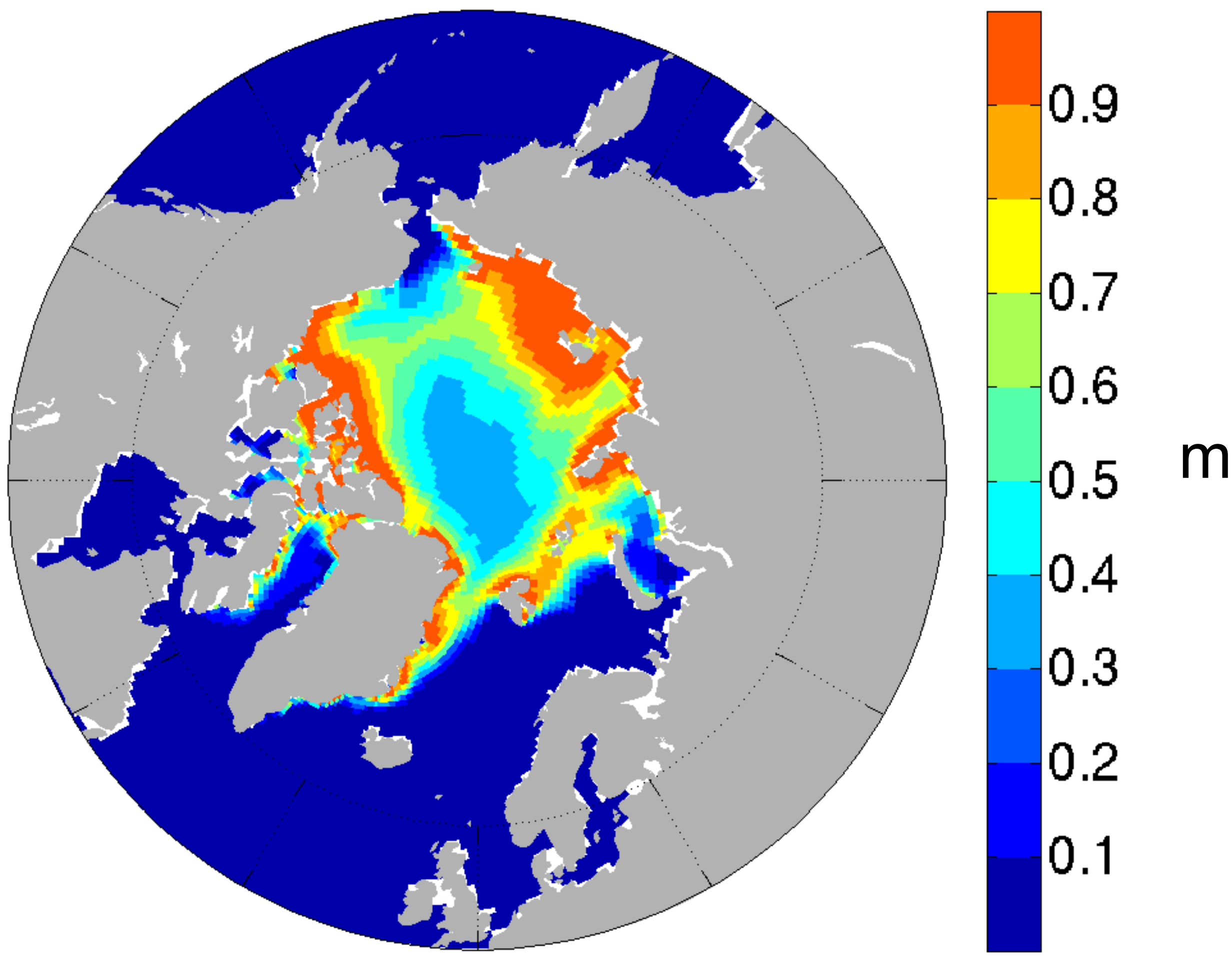
Standard Deviation of Sea Ice Thickness



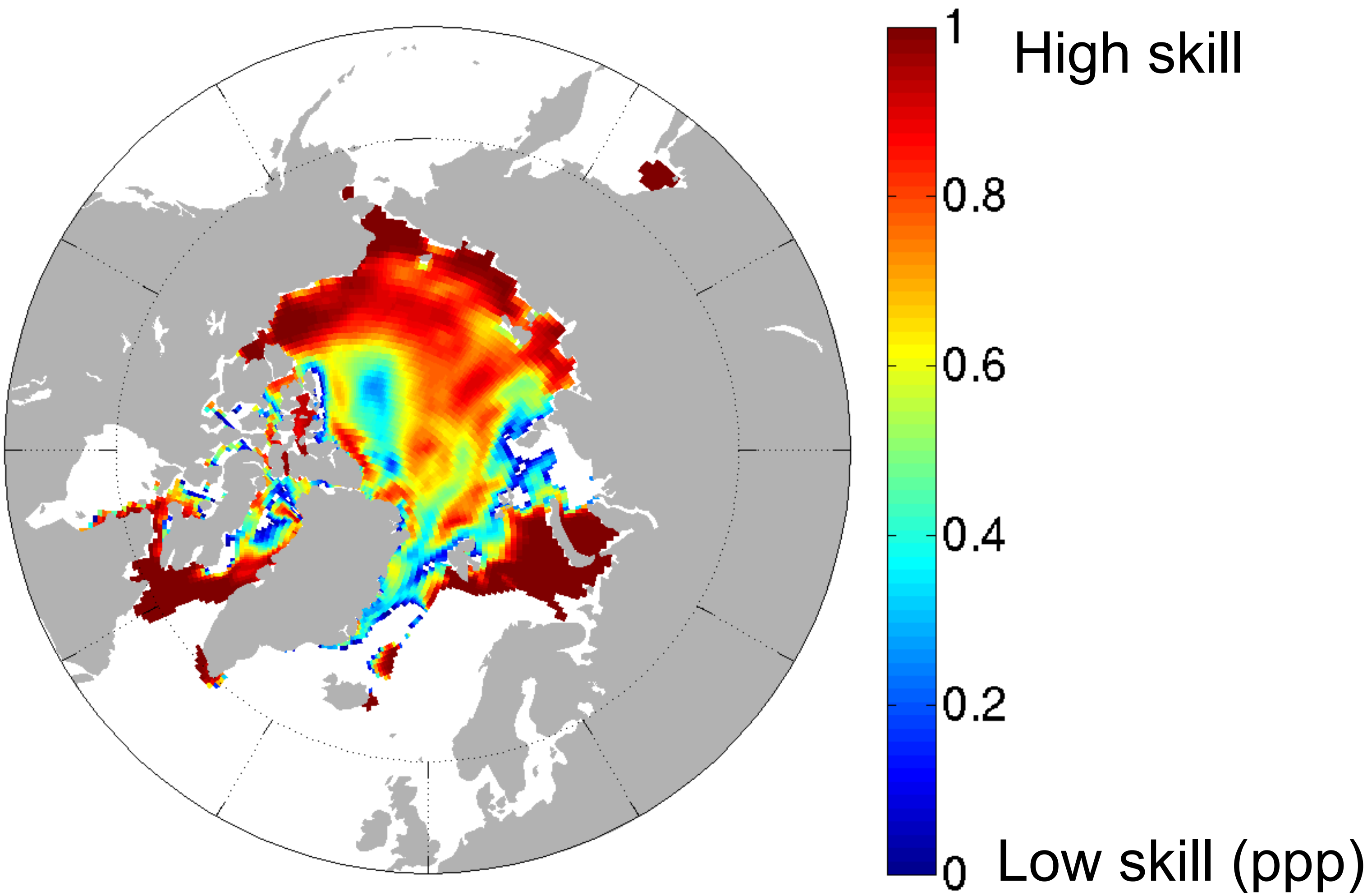
23 month Lead Time

Initialized in May

Standard Deviation of Sea Ice Thickness

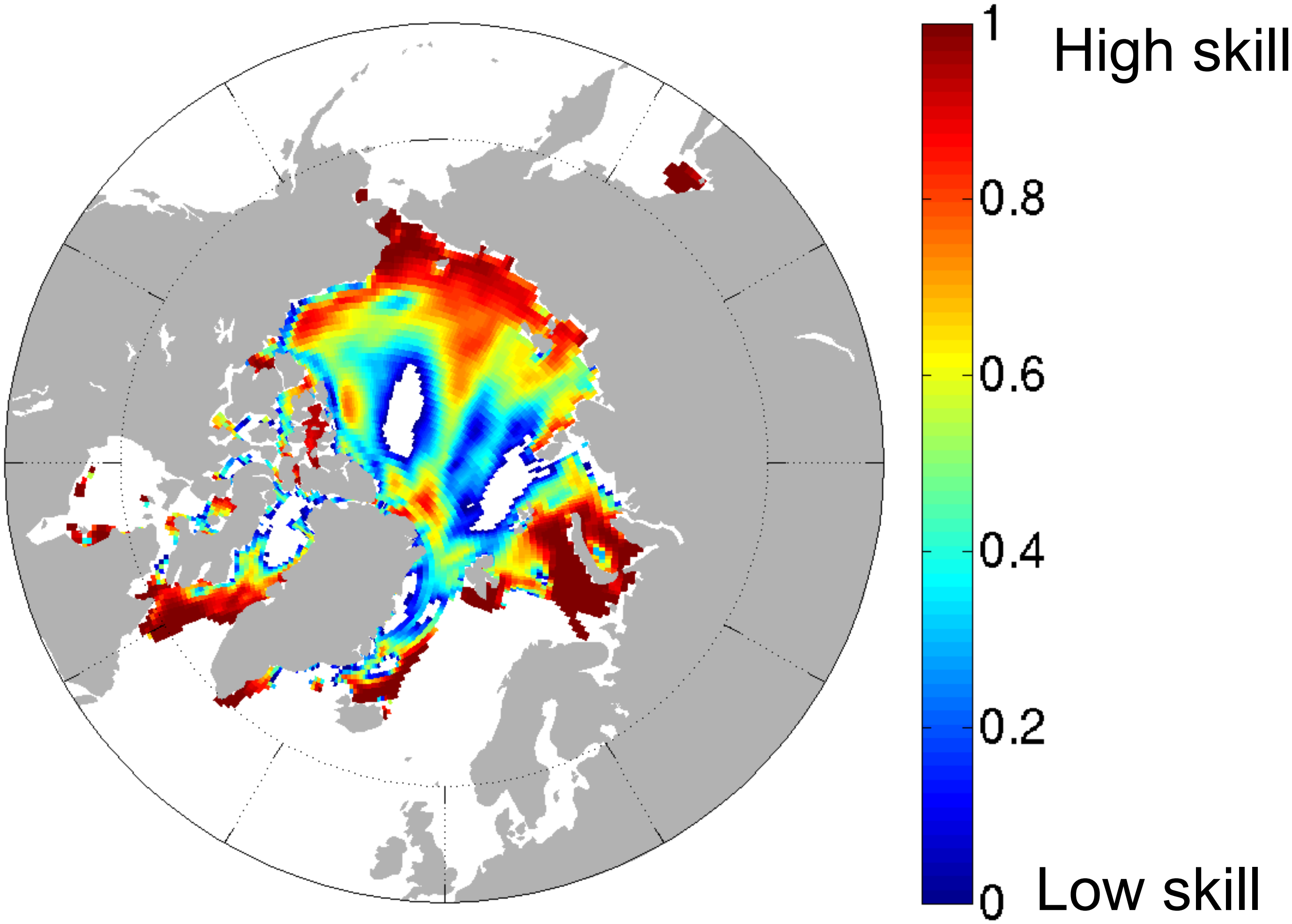


Thickness Predictability in September



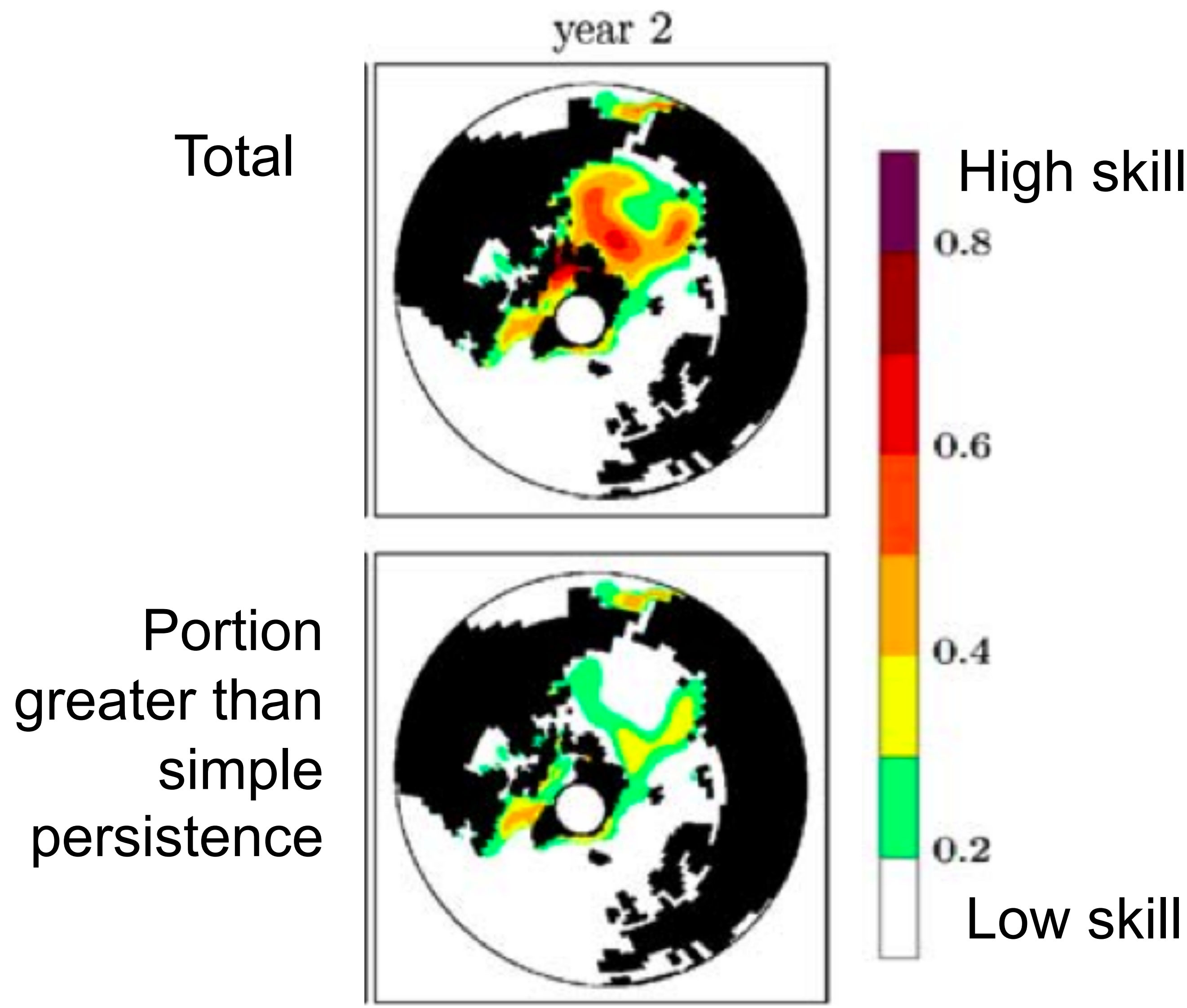
Initialized in May

Thickness Predictability in September



Initialized in September

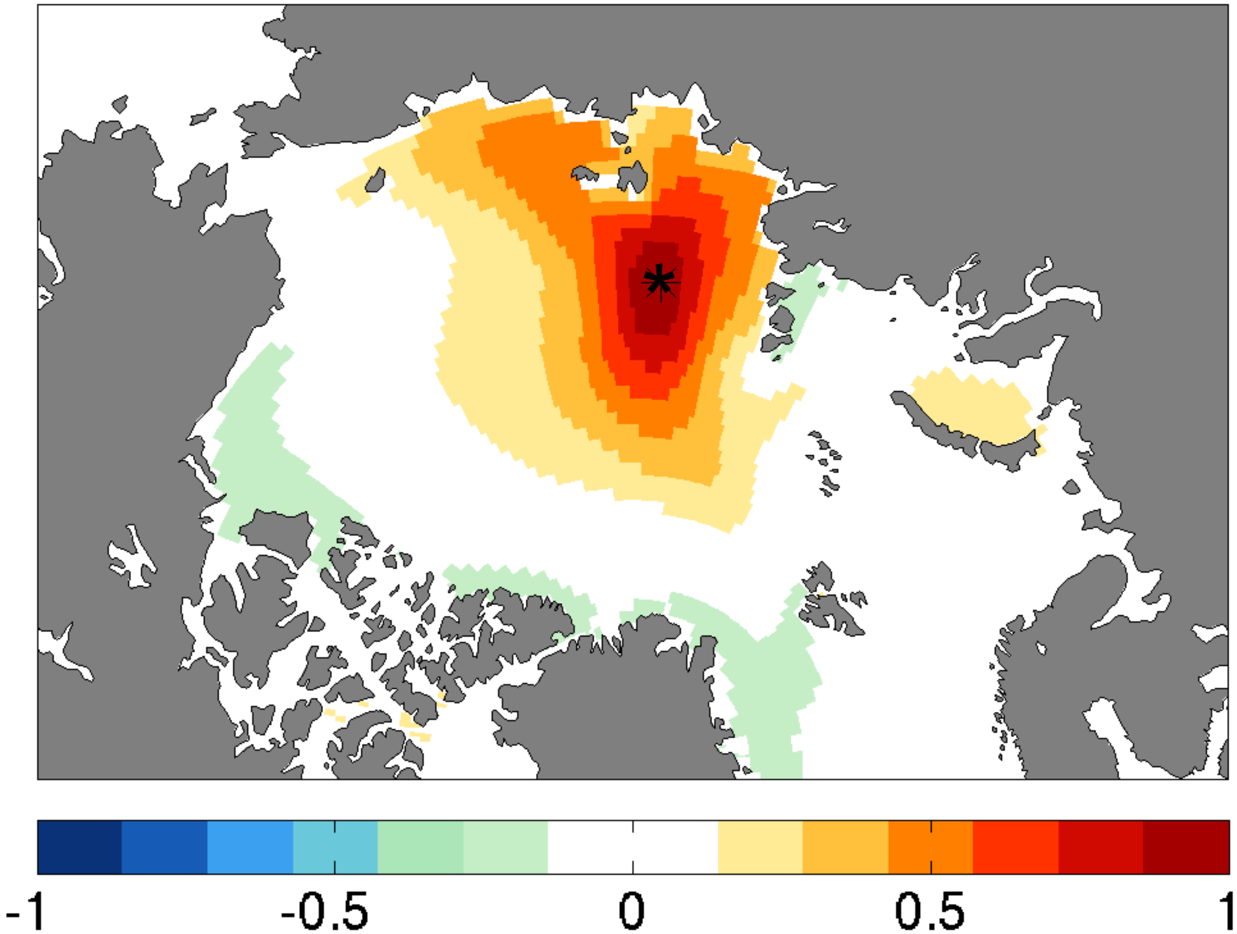
Thickness Predictability for year 2 – A Spatial Evaluation



Koenigk and Mikolajewicz (2009)

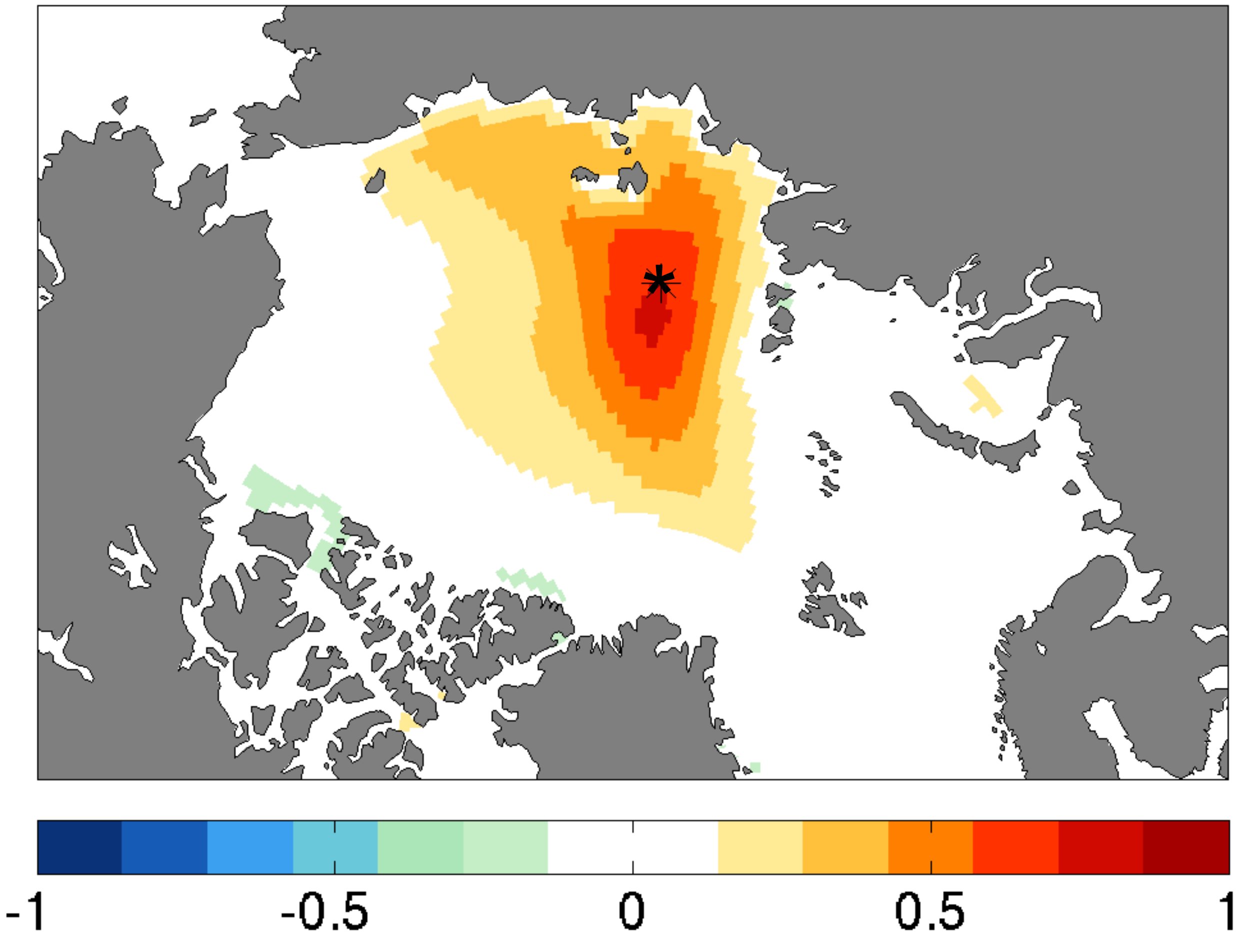
Initialized in January

One-Point Correlation Map



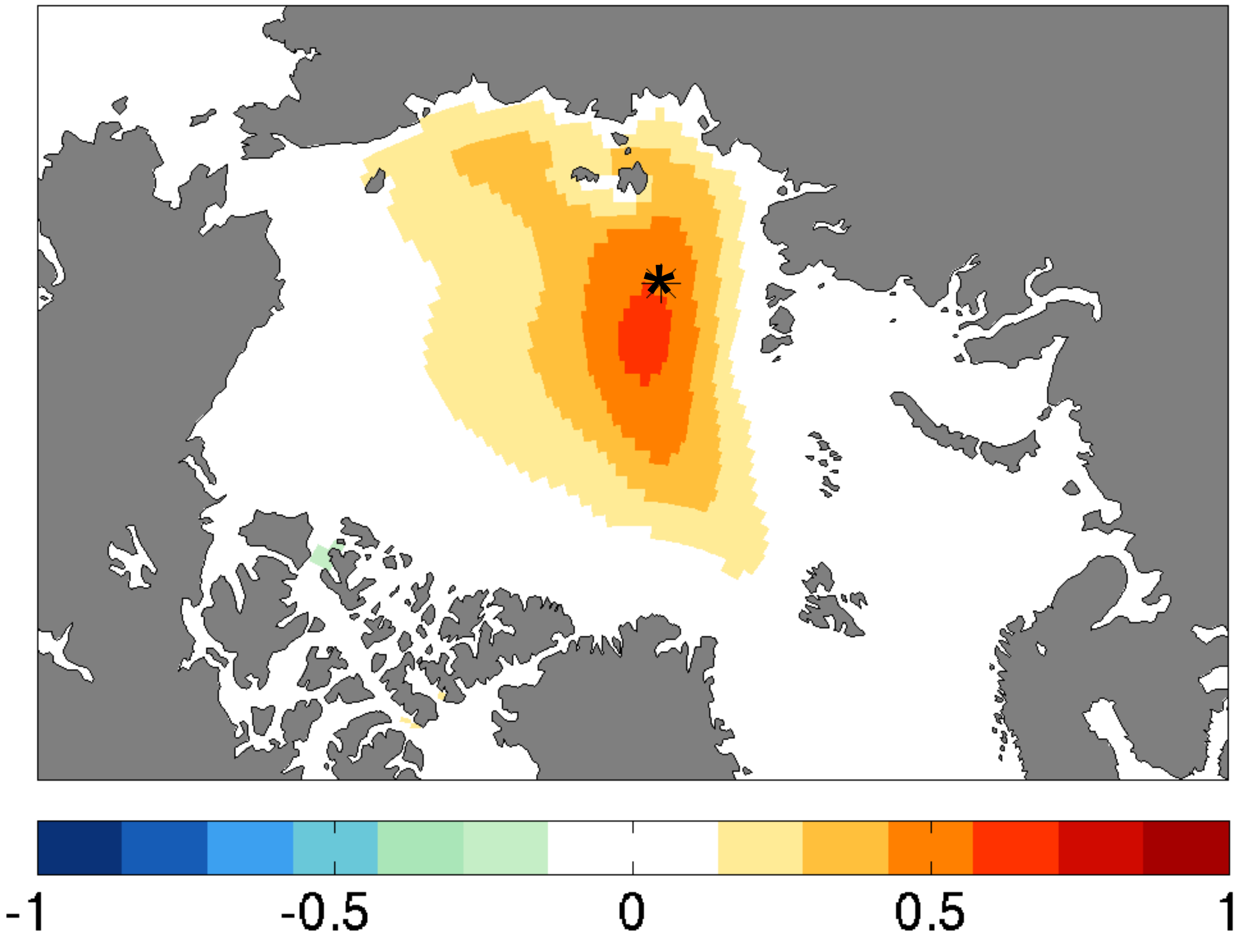
Correlation
Zero Lag

One-Point Correlation Map



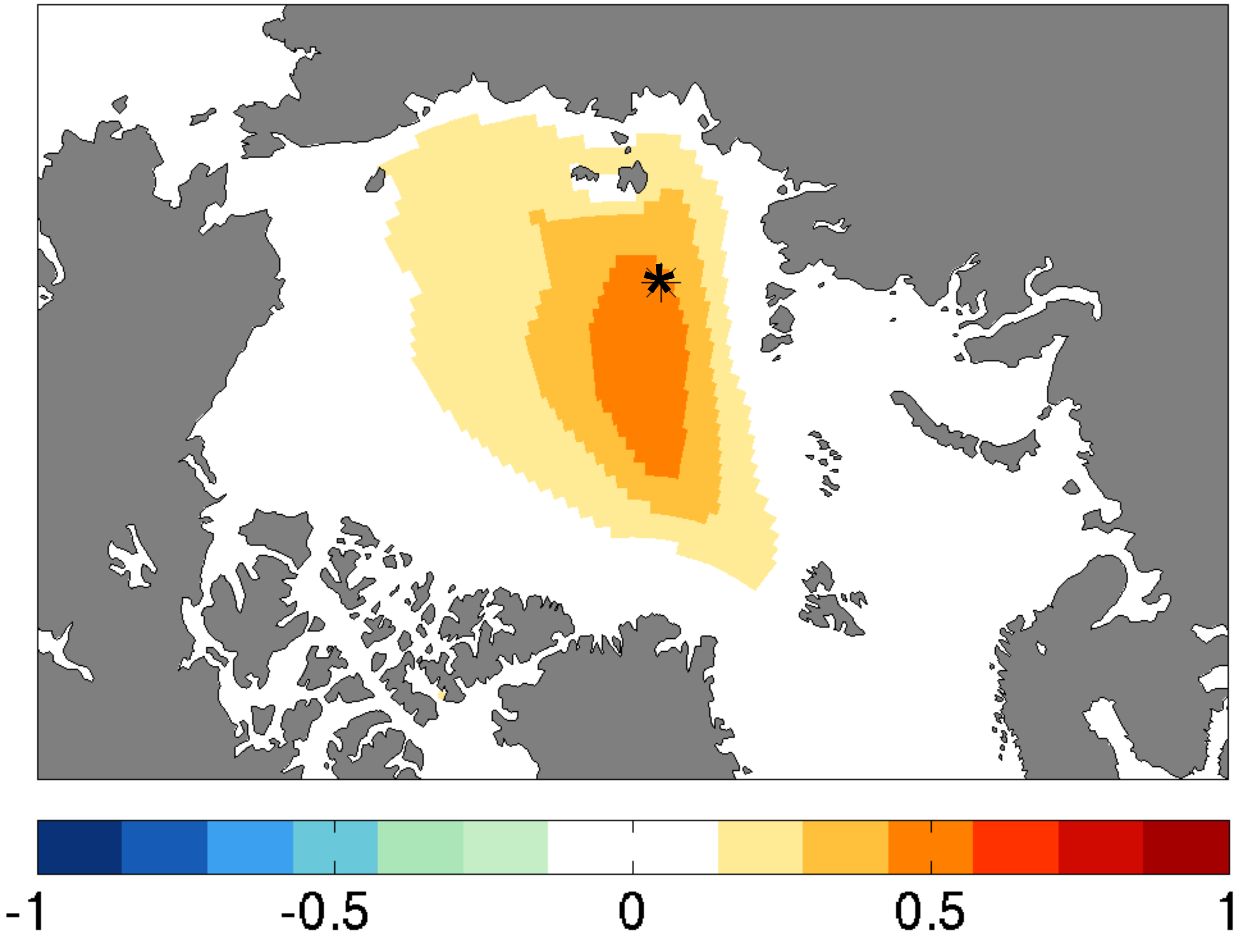
Correlation
3 month Lag

One-Point Correlation Map



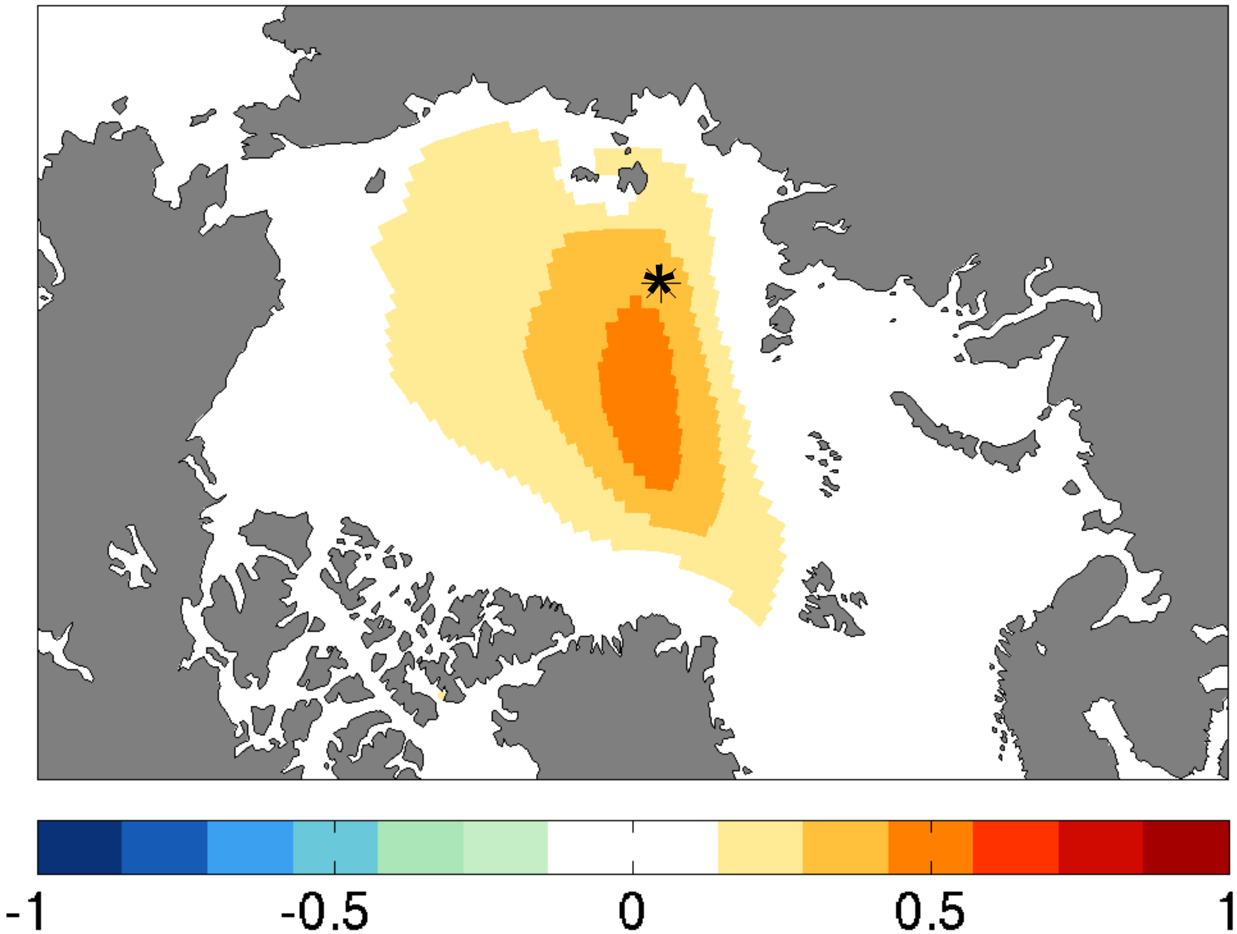
Correlation
6 month Lag

One-Point Correlation Map



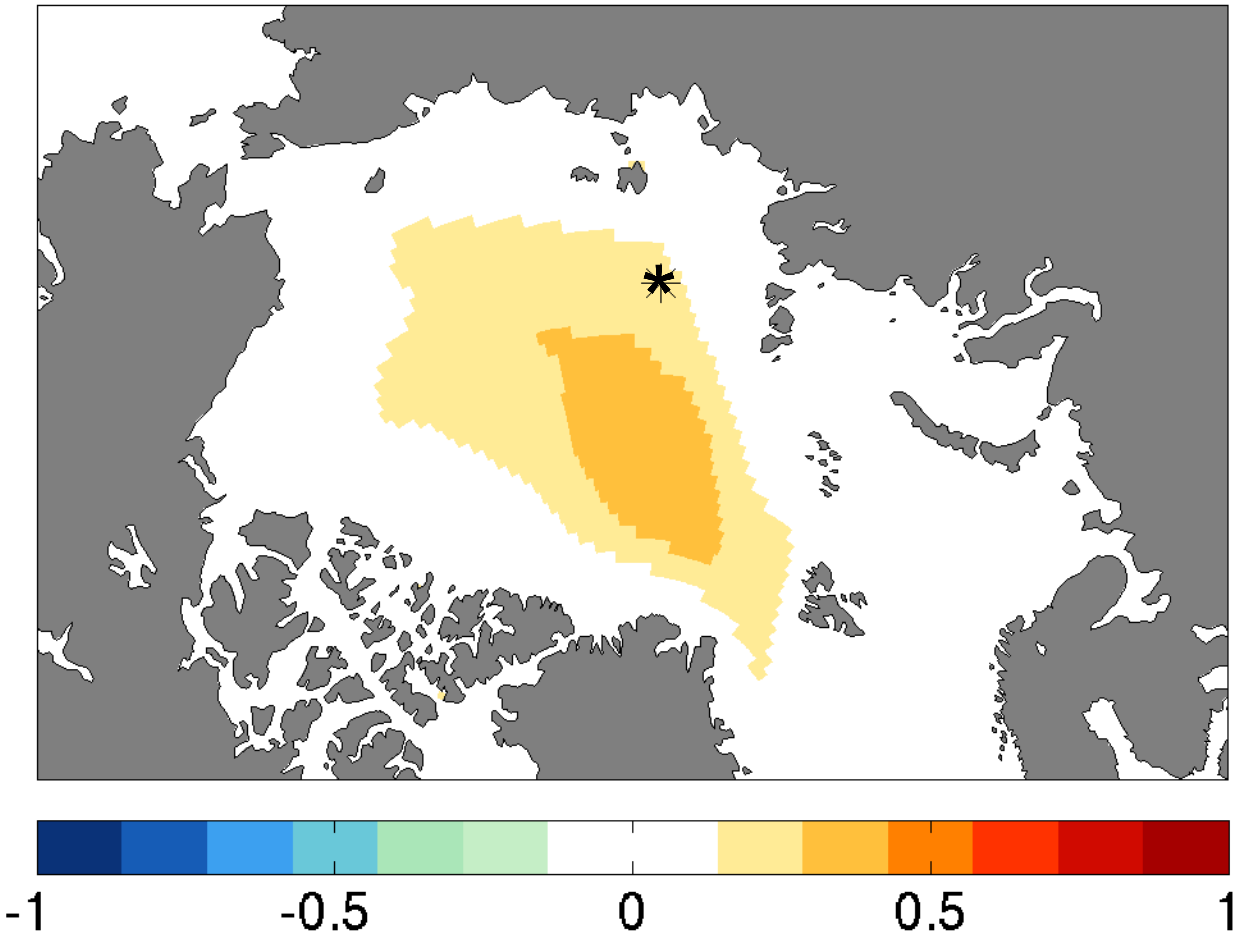
Correlation
9 month Lag

One-Point Correlation Map



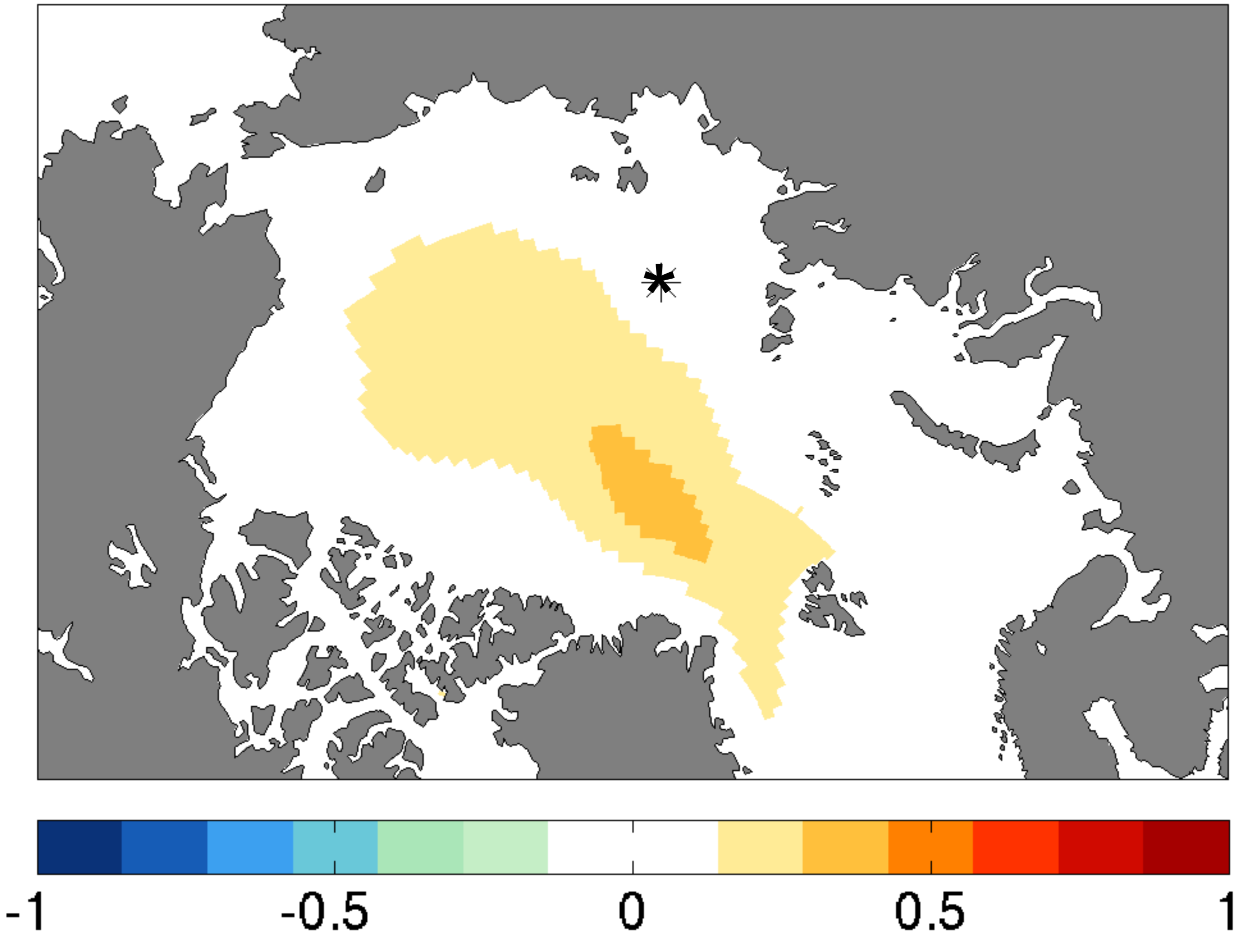
Correlation
12 month Lag

One-Point Correlation Map



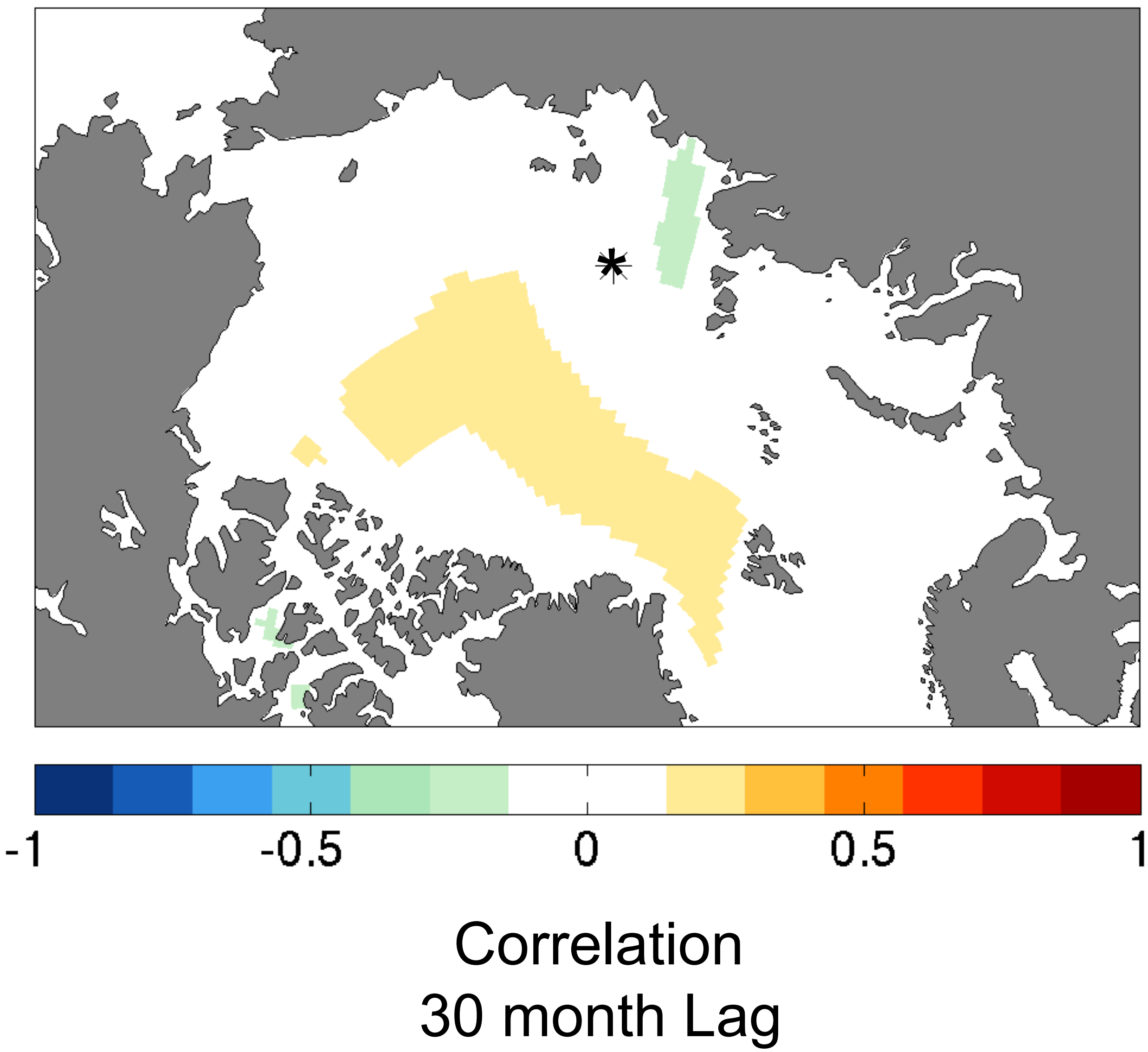
Correlation
18 month Lag

One-Point Correlation Map

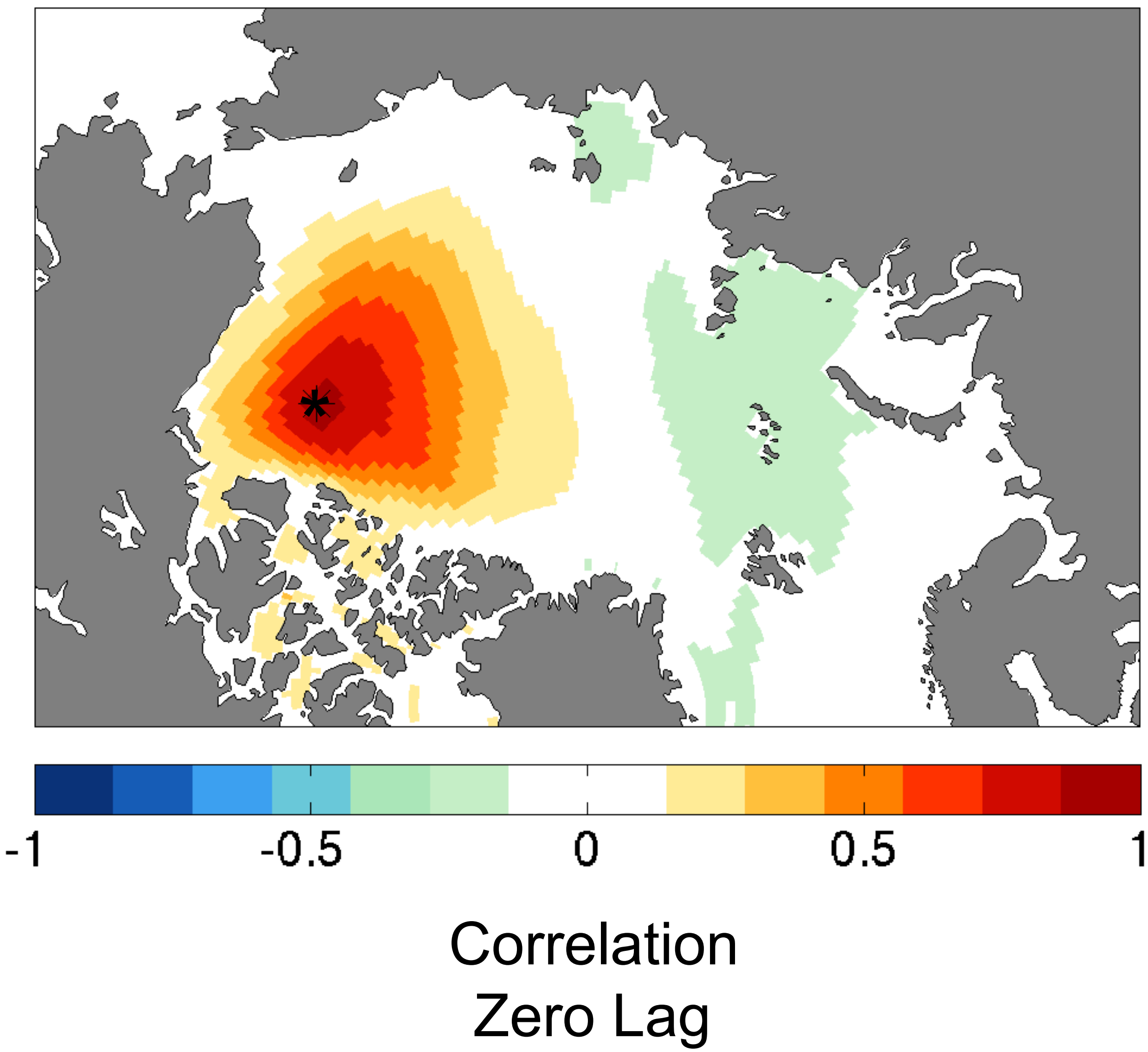


Correlation
24 month Lag

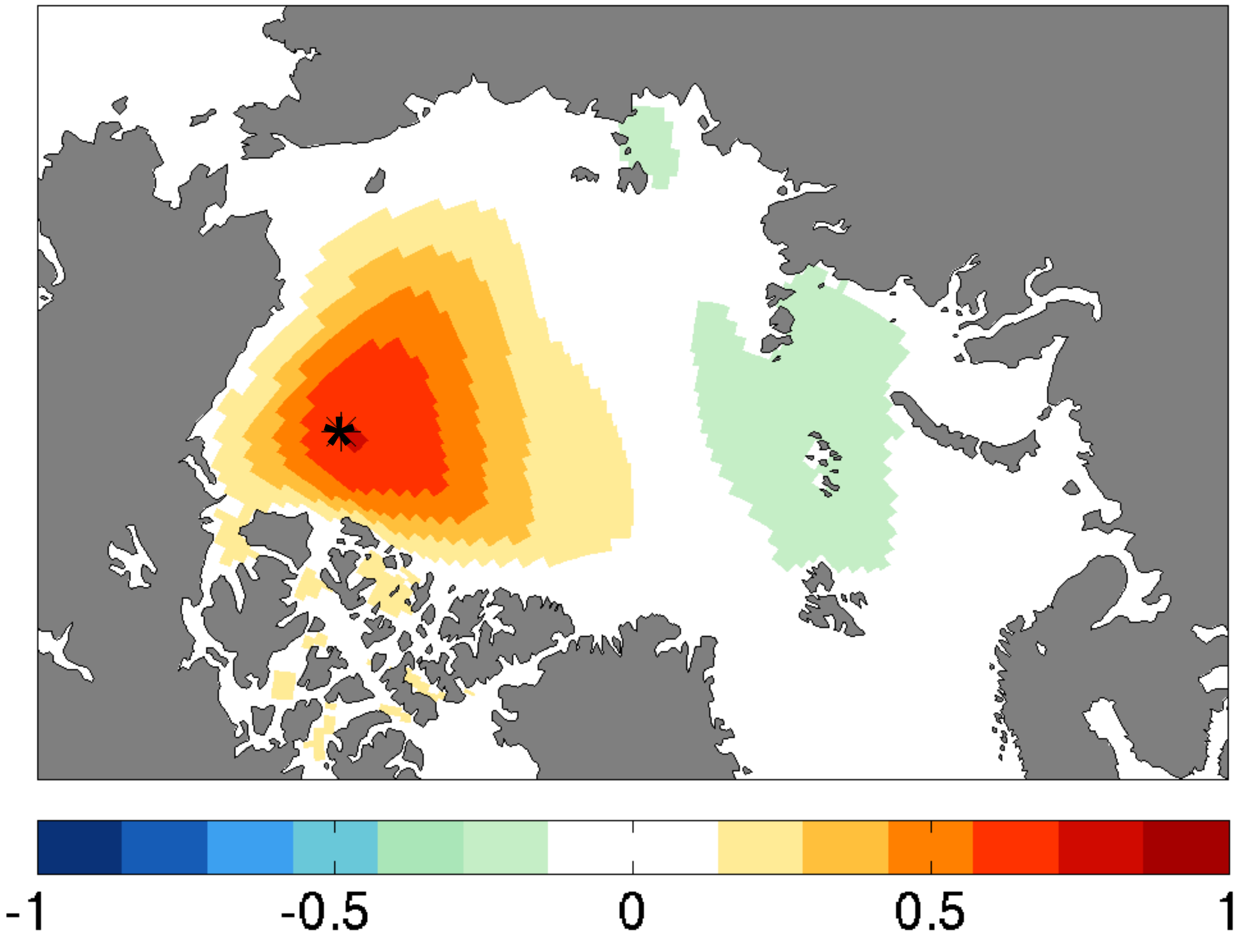
One-Point Correlation Map



One-Point Correlation Map

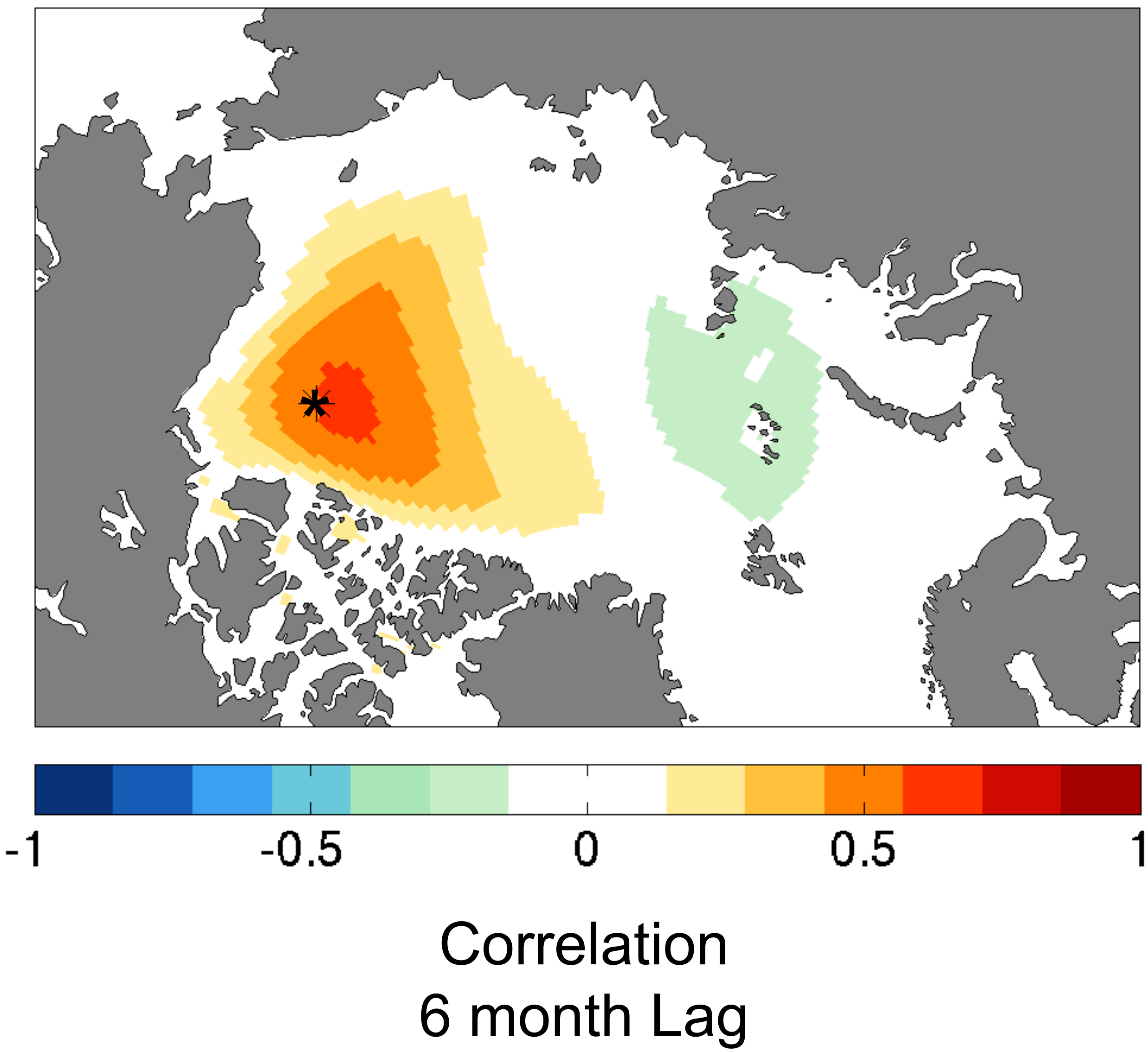


One-Point Correlation Map

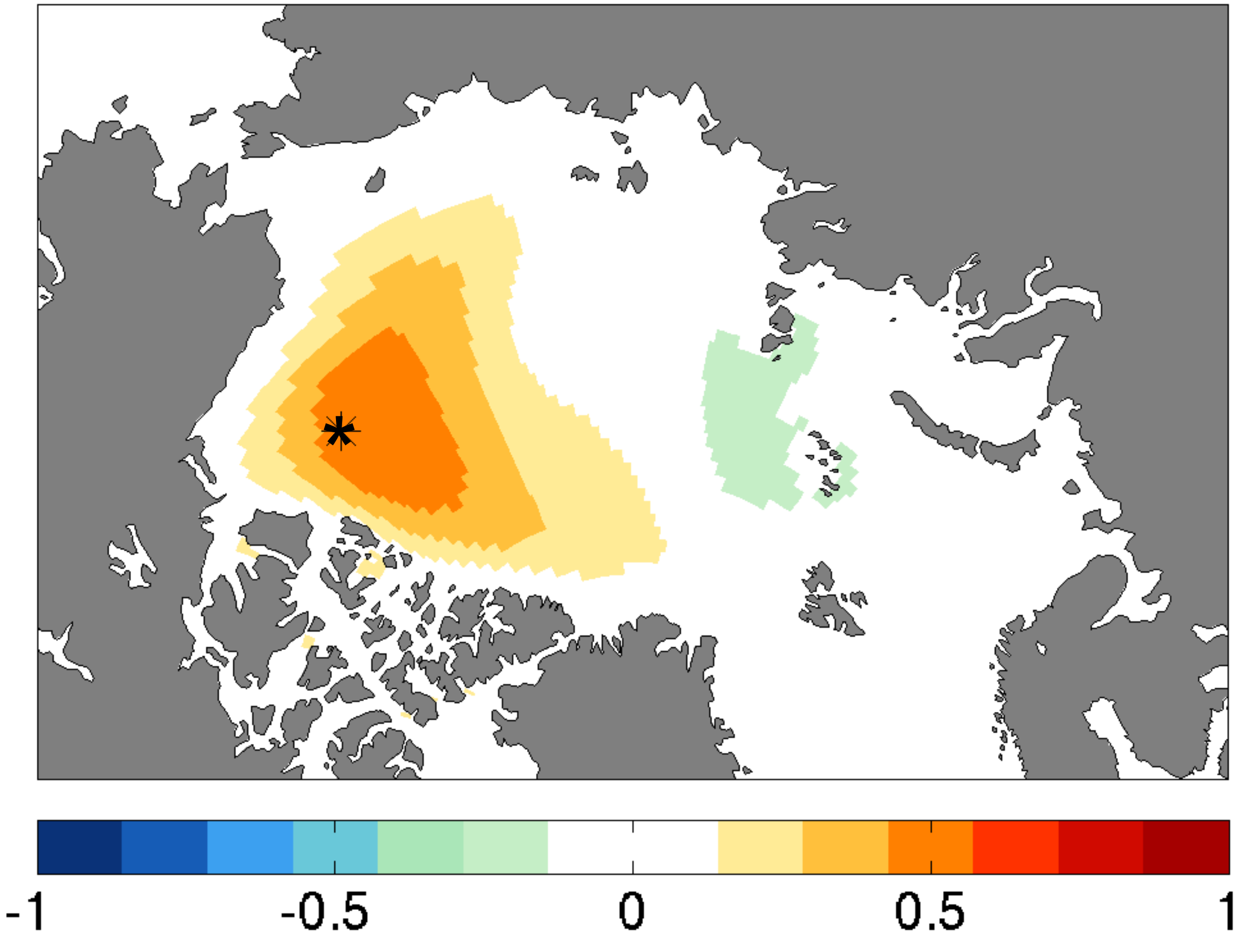


Correlation
3 month Lag

One-Point Correlation Map

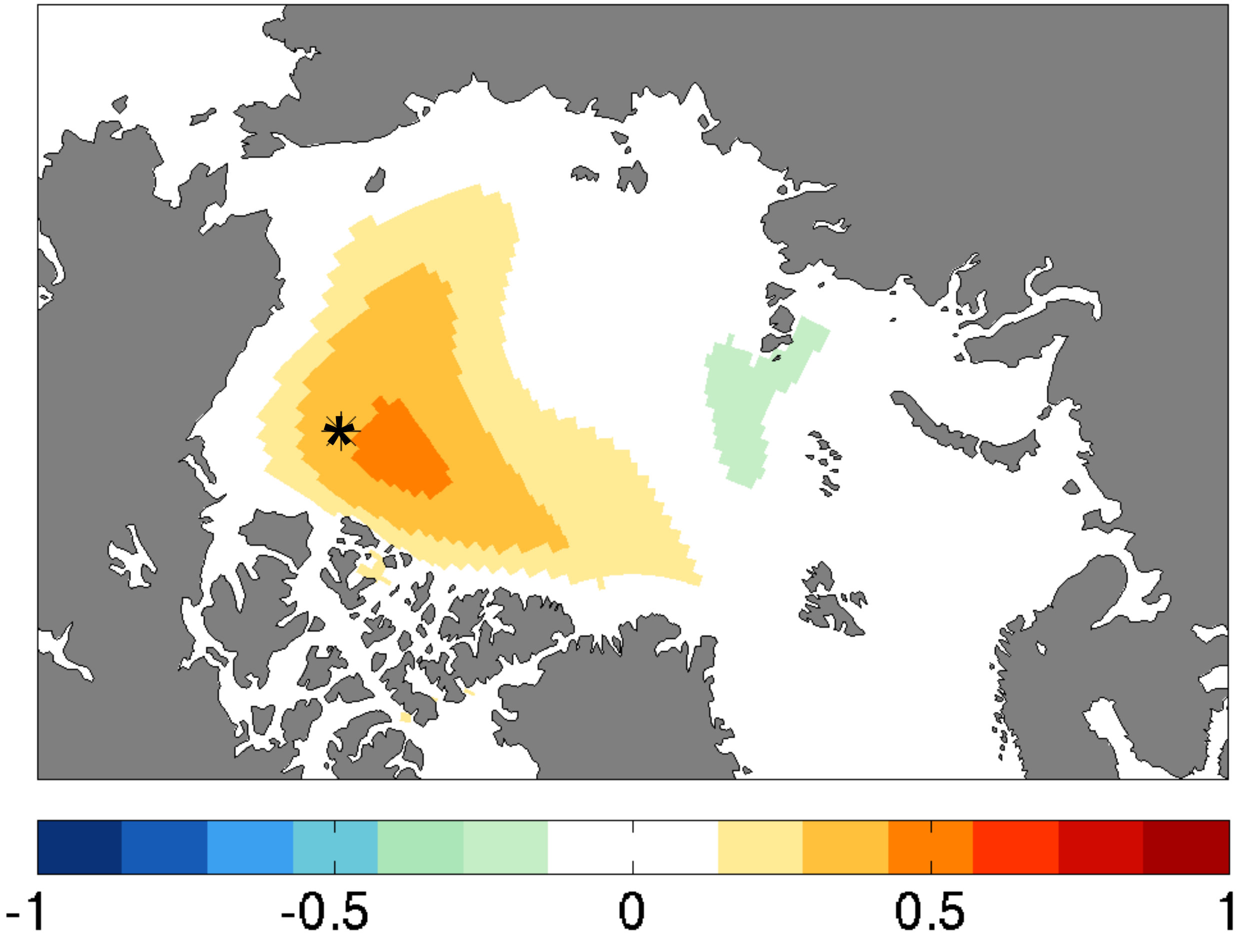


One-Point Correlation Map



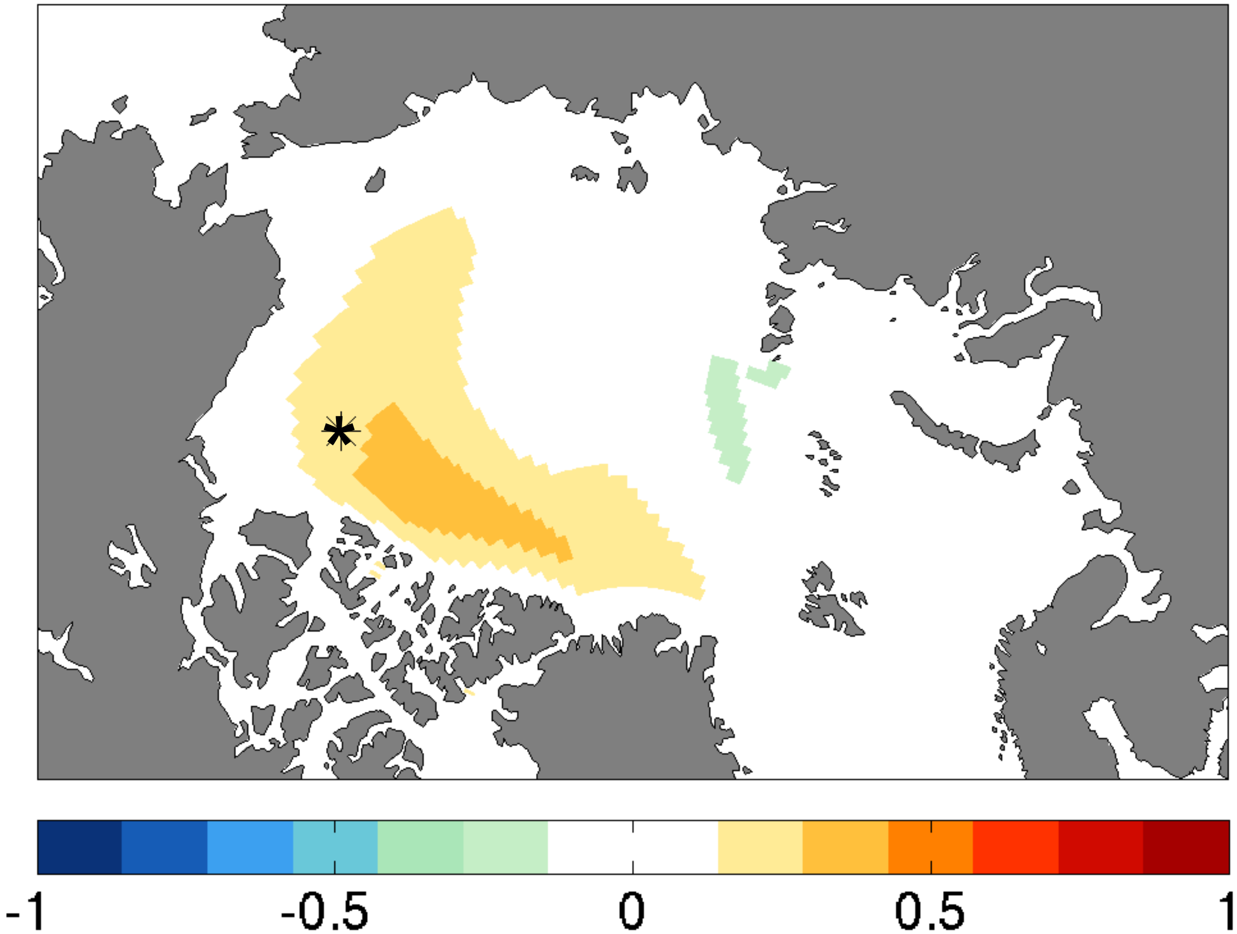
Correlation
9 month Lag

One-Point Correlation Map

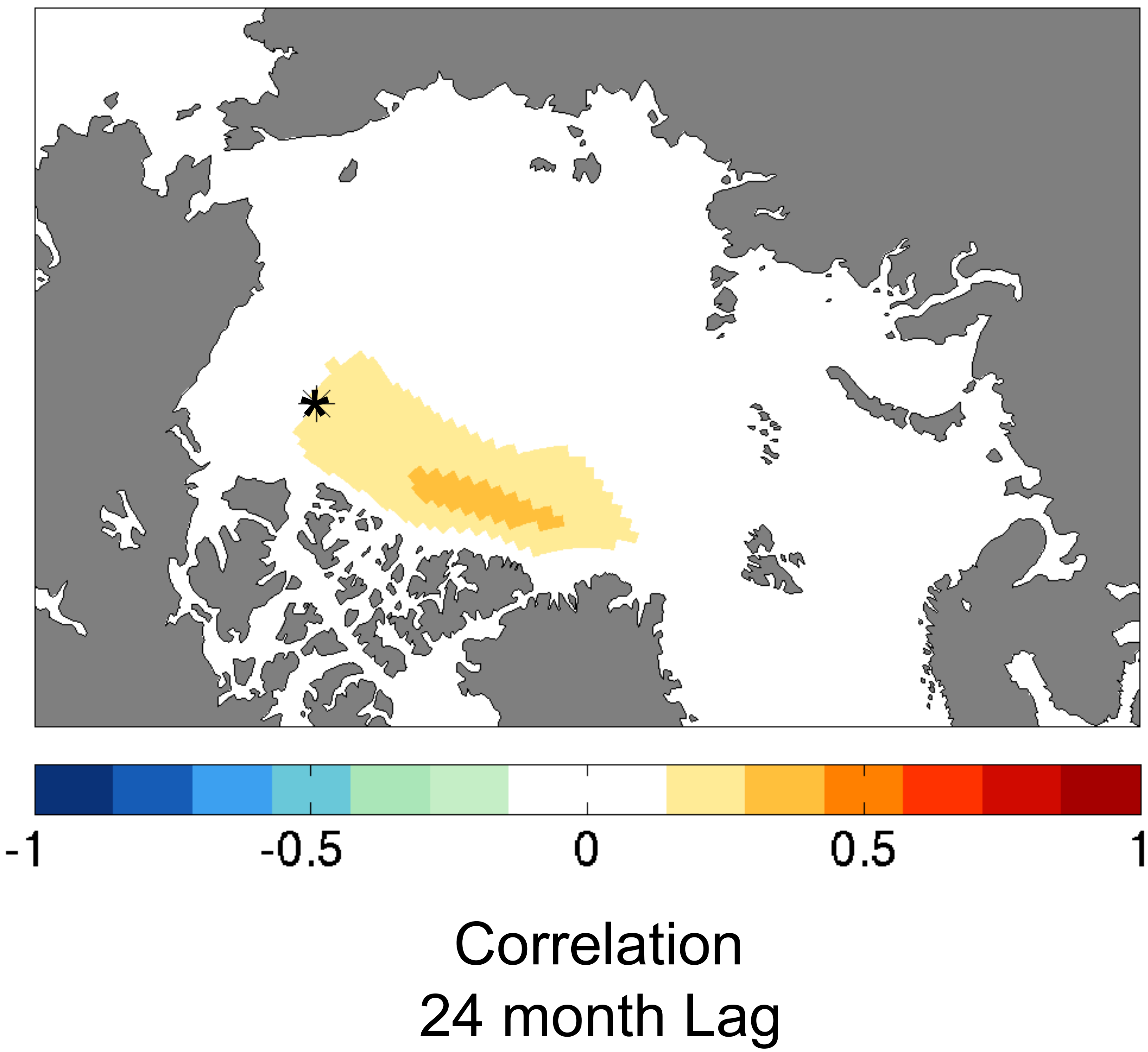


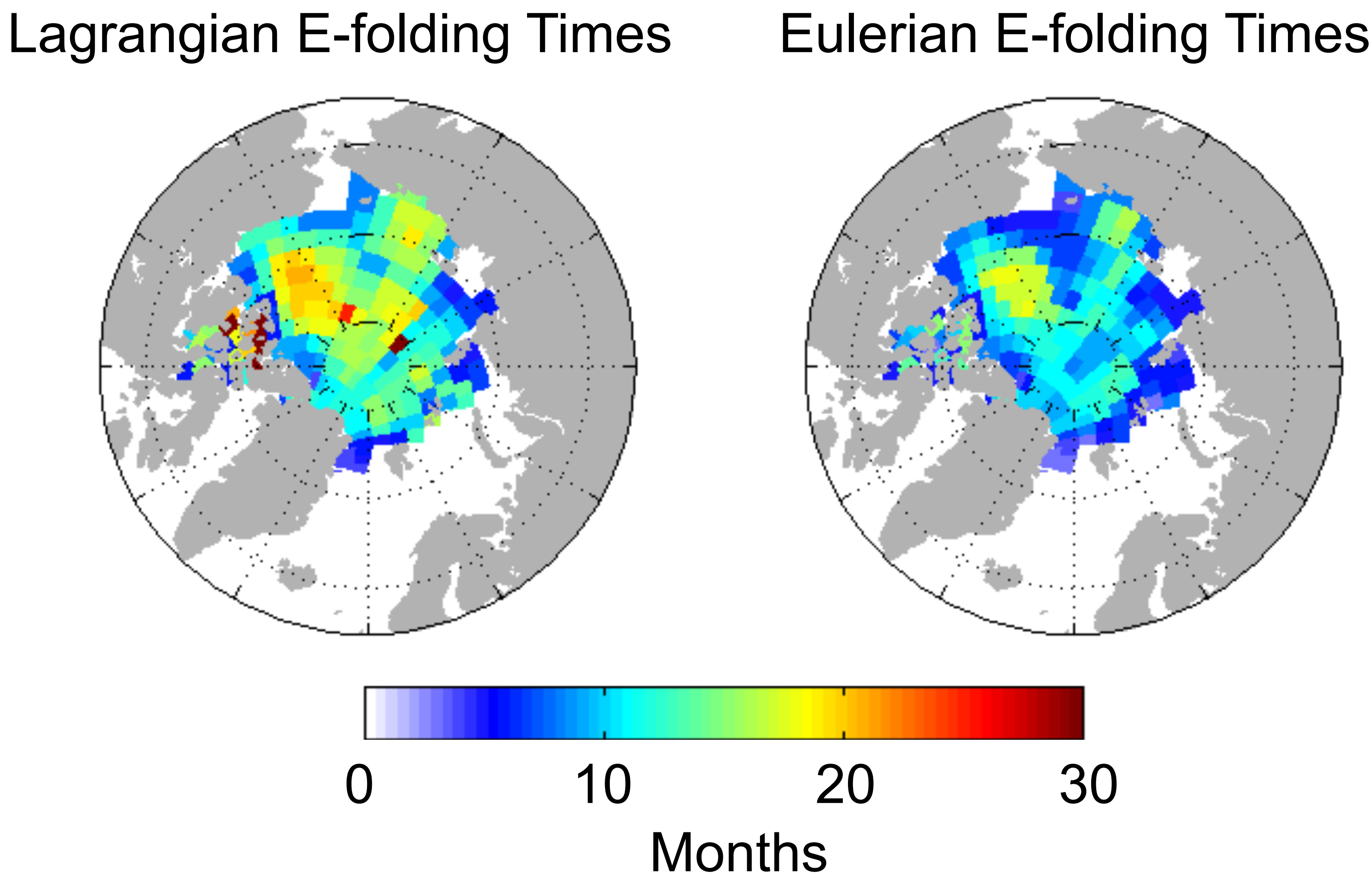
Correlation
12 month Lag

One-Point Correlation Map



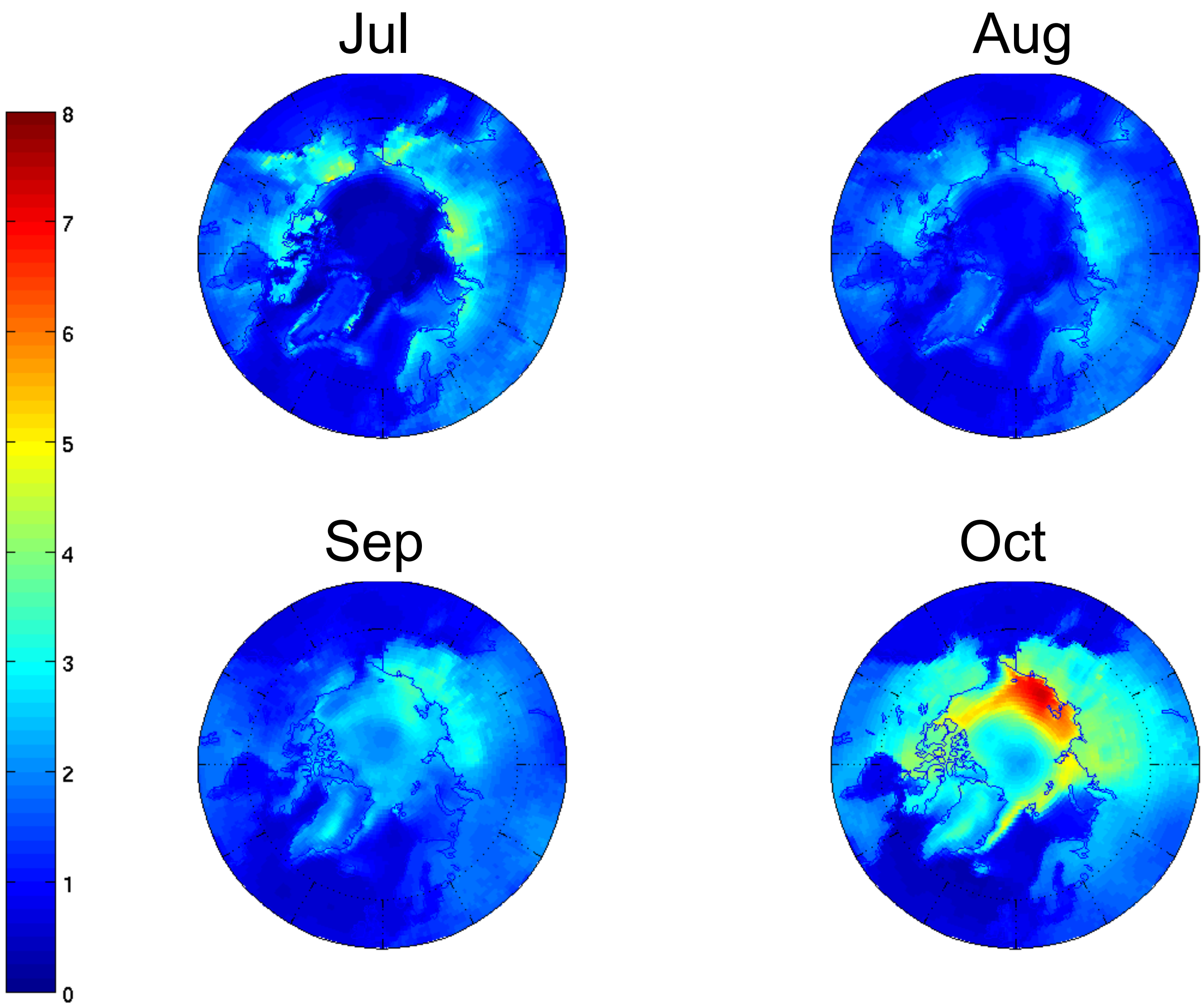
One-Point Correlation Map





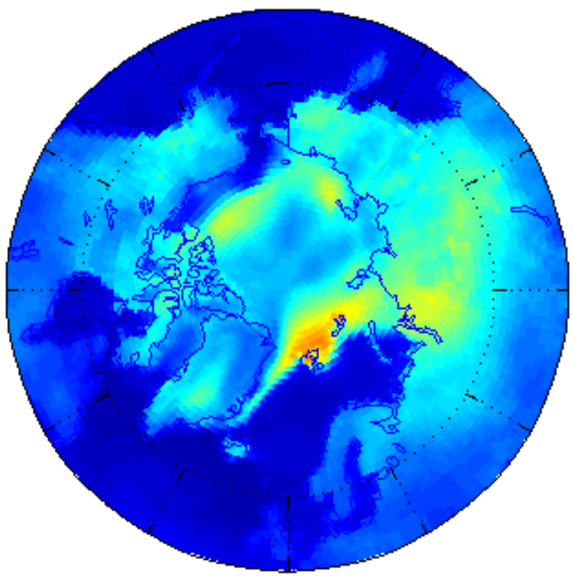
Accounting for transport in estimates of predictability
(here as decorrelation time of perturbations)
increases time by ~50%

$\sigma_{control}$ Standard Deviation of Surface Temperature in 1995-2005 of 20th century runs

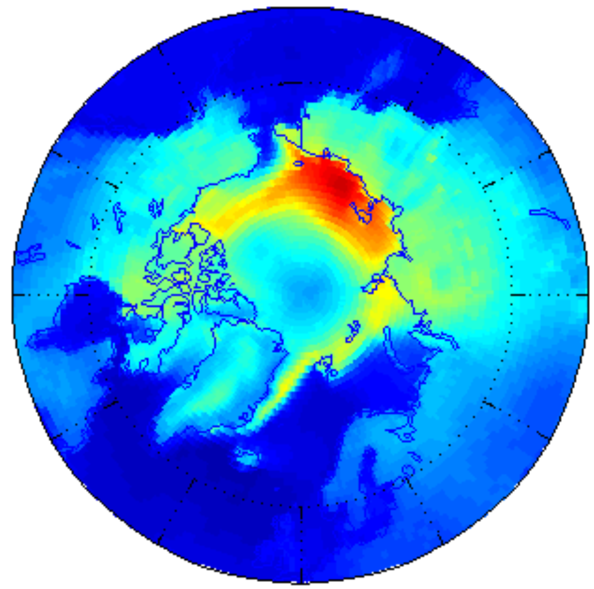


Standard Deviation of Surface Temperature in October

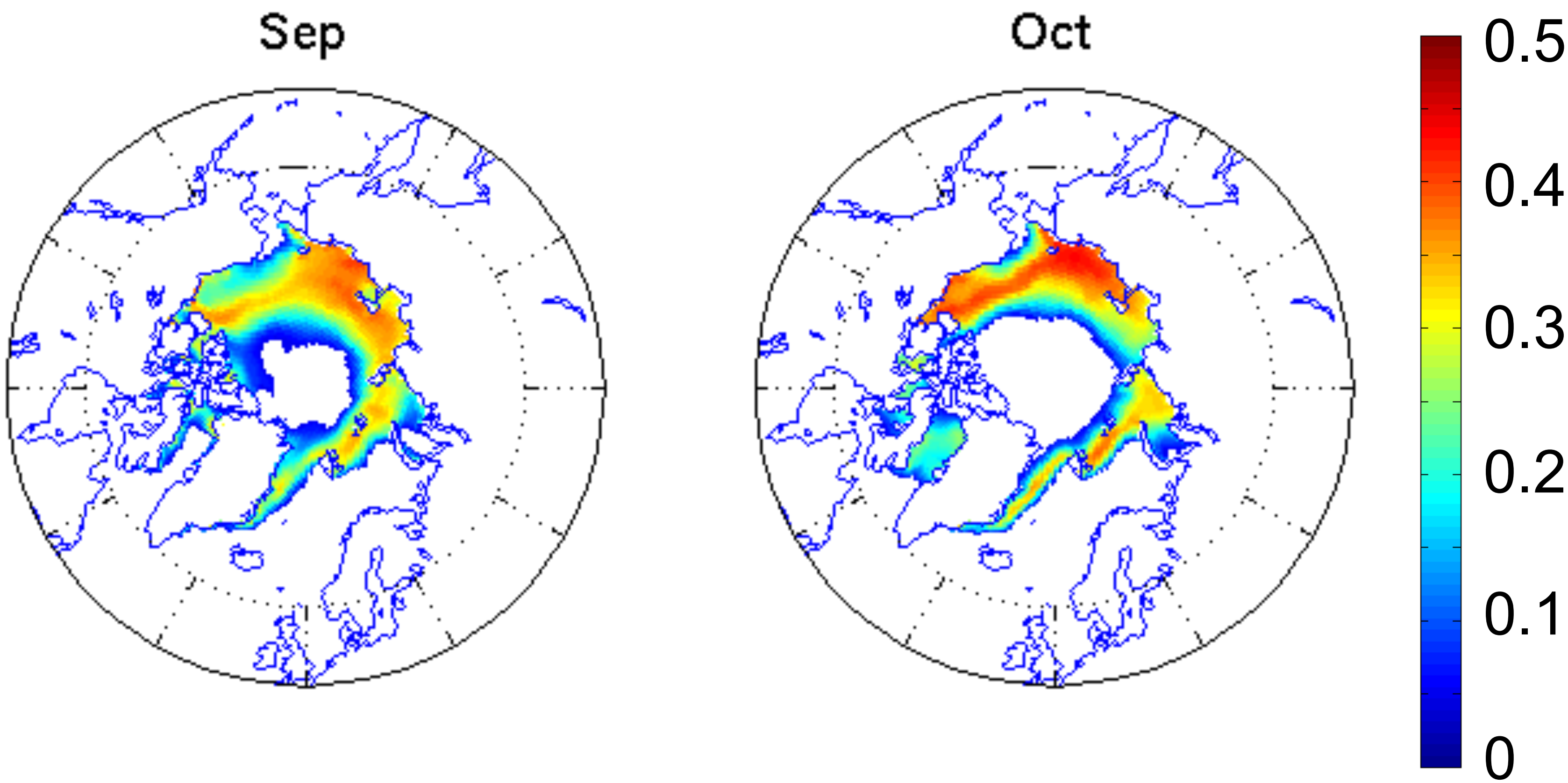
$\sigma_{ensemble}$ July start



$\sigma_{control}$



Standard Deviation of Ice Area (10^6 km^2) in the 20th Century "Control" for 1995-2005



Potential collaborations/networks

WWRP/THORPEX POLAR PREDICTION PROJECT – Thomas Jung

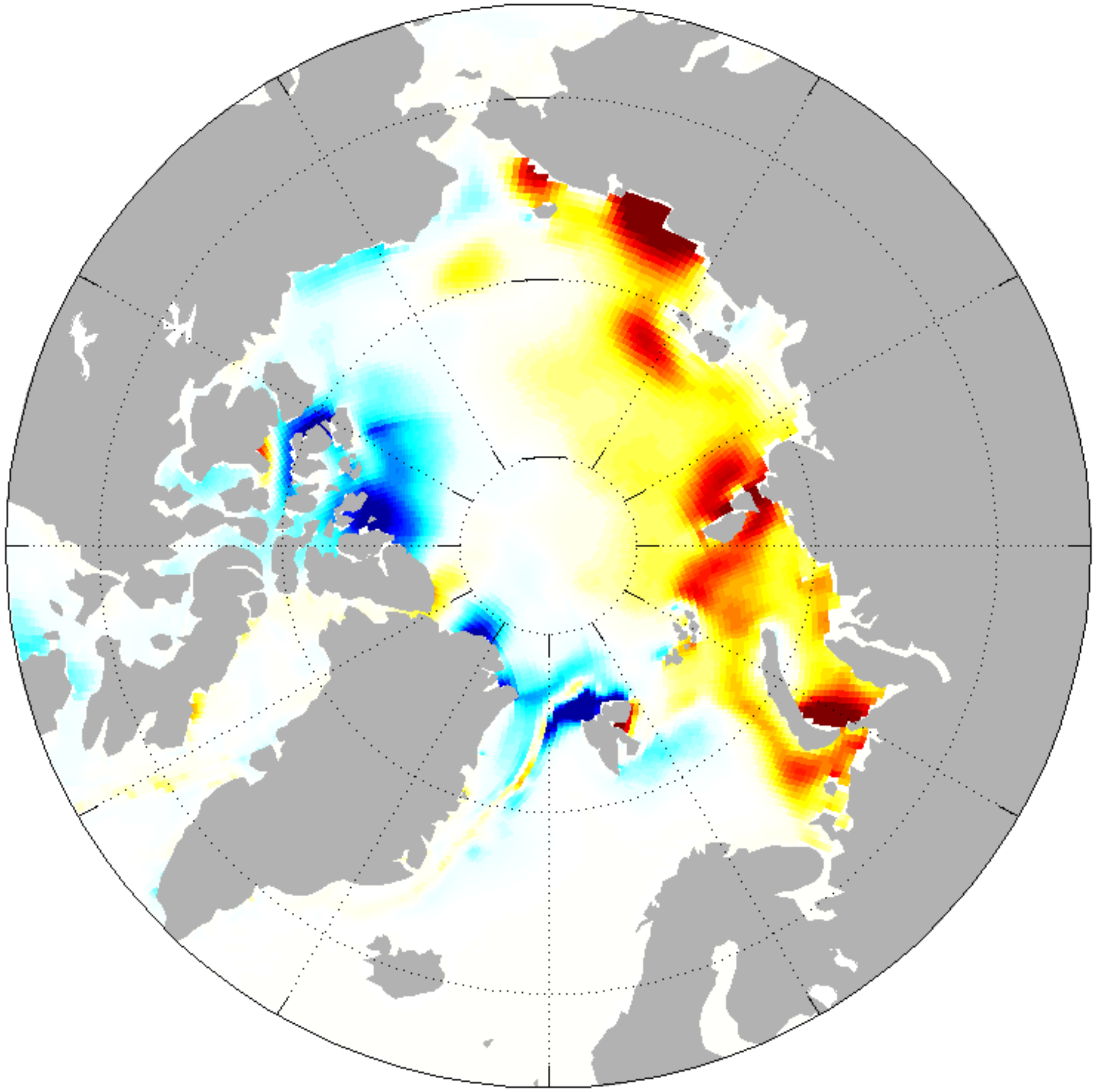
WCRP polar climate predictability initiative – Ted Shepherd

CanSISE – Paul Kushnir

Sea ice outlook network (?) – Hajo Eicken, me

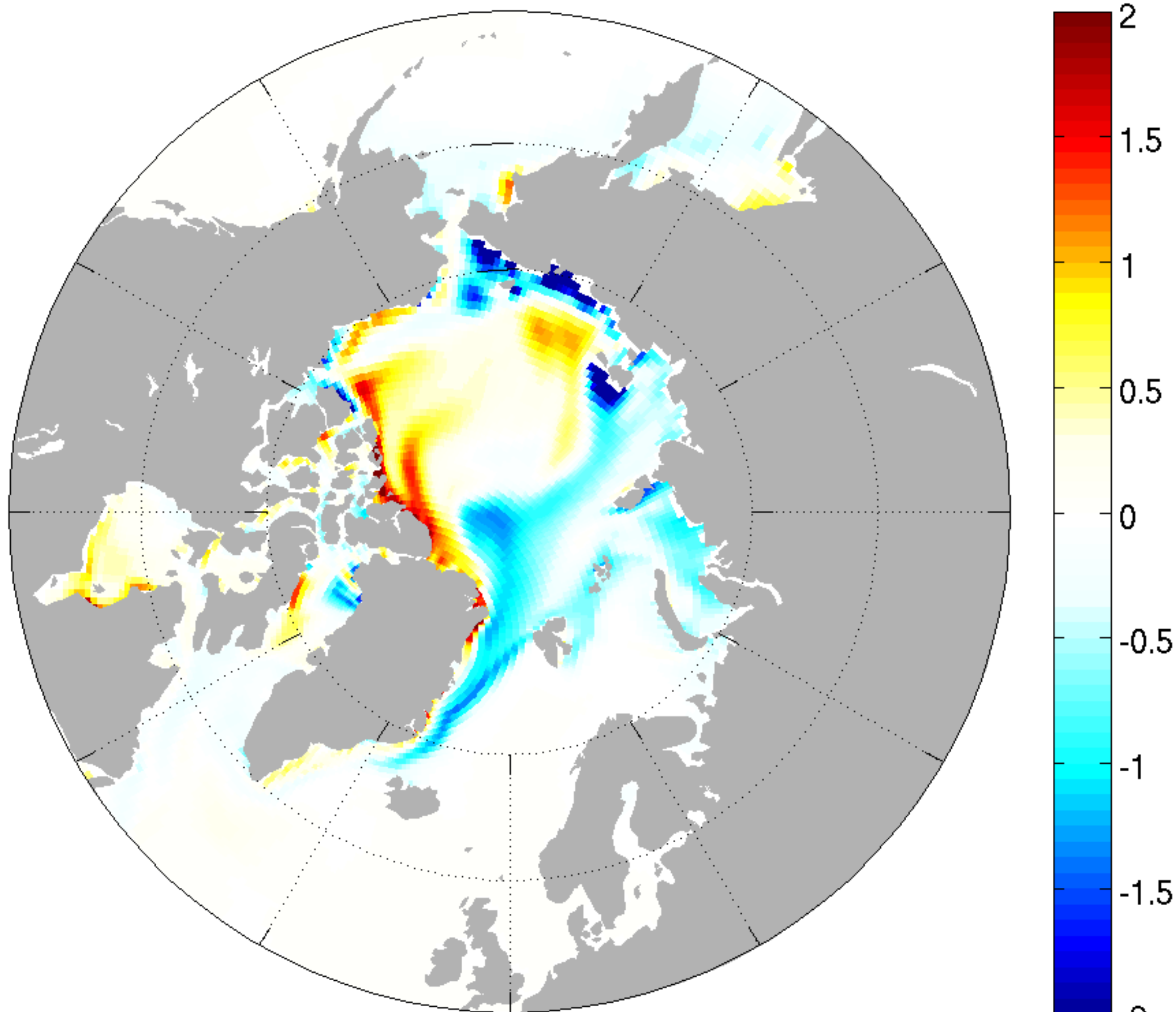
Some challenges

A ocean-ice model with sea ice data assimilation forced with atmospheric reanalysis (referred to as “other” model)



dark red/blue = +/- ~1m

CCSM4



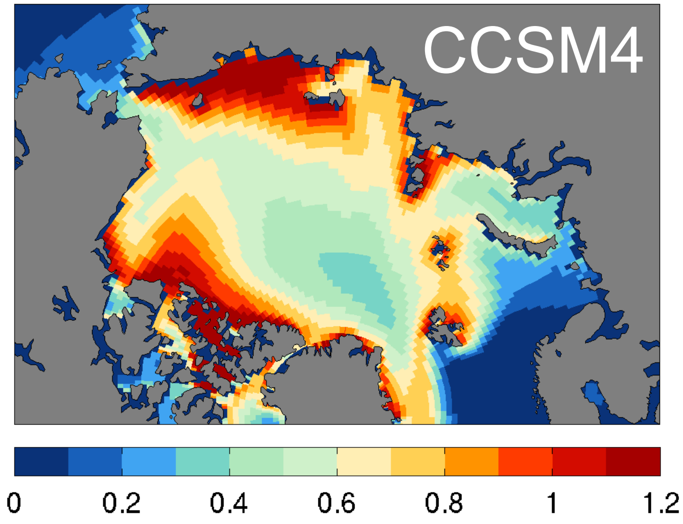
Some observations from watching these animations

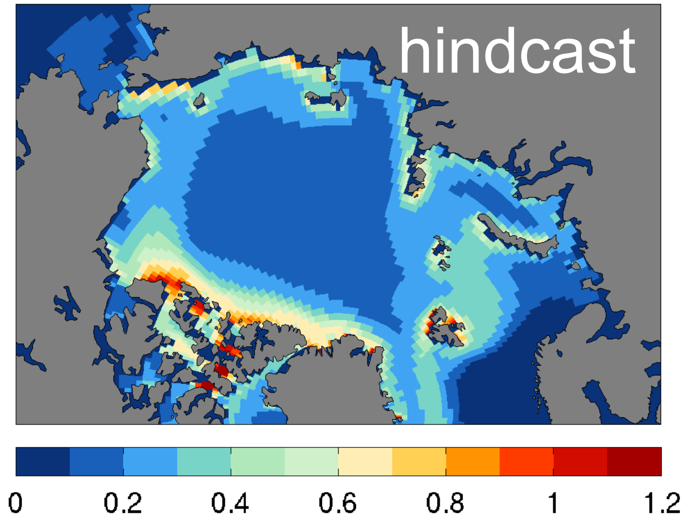
The other model (with data assimilation) looks strange

The GCM anomlies are about twice as big in magnitude but half the spatial extent

The same ice-ocean components as the GCM forced with reanalysis “hindcast” has circulating anomalies like the GCM, but magnitude is small (as in other model with data assimilation)

standard deviation of sea ice thickness (m)





How can we make better real forecasts?

Does the strong seasonality of sea ice processes inhibit error correction?

Can we improve the models/assimilation so we don't have to error correct so much?

We need thickness or something like it
(can we use sea ice age from passive microwave)?

Can we use laser altimetry thickness from 2 months prior to forecast start? (beware that it only has been around, and with gaps, since 2001)

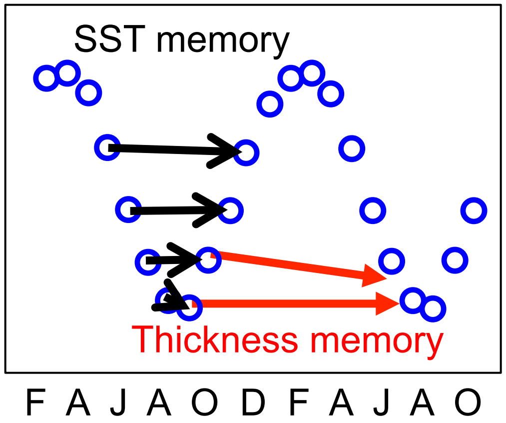
Part 1 Summary

Arctic sea ice area month-to-month persistence (decorrelation timescale) of 3-5 months, depending on the reference month

Arctic sea ice area re-emergence mechanism

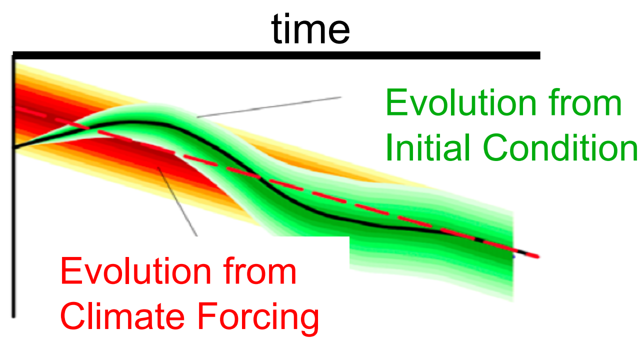
Spring to Fall re-emergence is due to SST, seen in model and observations

Summer to Summer is due to thickness, only seen in model



Re-emergence mechanism modulates seasonal cycle of initial decorrelation times. Longest persistence after July.

Most predictable month of pan-Arctic area one-year later is September, can explain at least 20% of the variance starting a year in advance, raises to 70% one month in advance.



Part 2 Summary

In prognostic, perfect-model study

Pan-Arctic sea ice area is intermittently predictable for several years

Volume is predictable for 3-4 years, couples to area

Climate forcing overwhelms initial condition predictability at about ~3 years

Summer predictions begun the prior September equal those begun in January

Partial barrier to predictability in spring from ice-albedo feedback

Part 3 Summary

Spatially – concentrations is most predictable near Siberia, thickness has long-lived predictability throughout the Arctic basin (though seasonally varying)

One-point lagged correlation maps tell us

Thickness anomalies decay much more slowly when we account for mean transport

Where to observe