Changing predictability characteristics of Arctic sea ice in a warming climate

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National Center for Atmospheric Research
Boulder, Colorado

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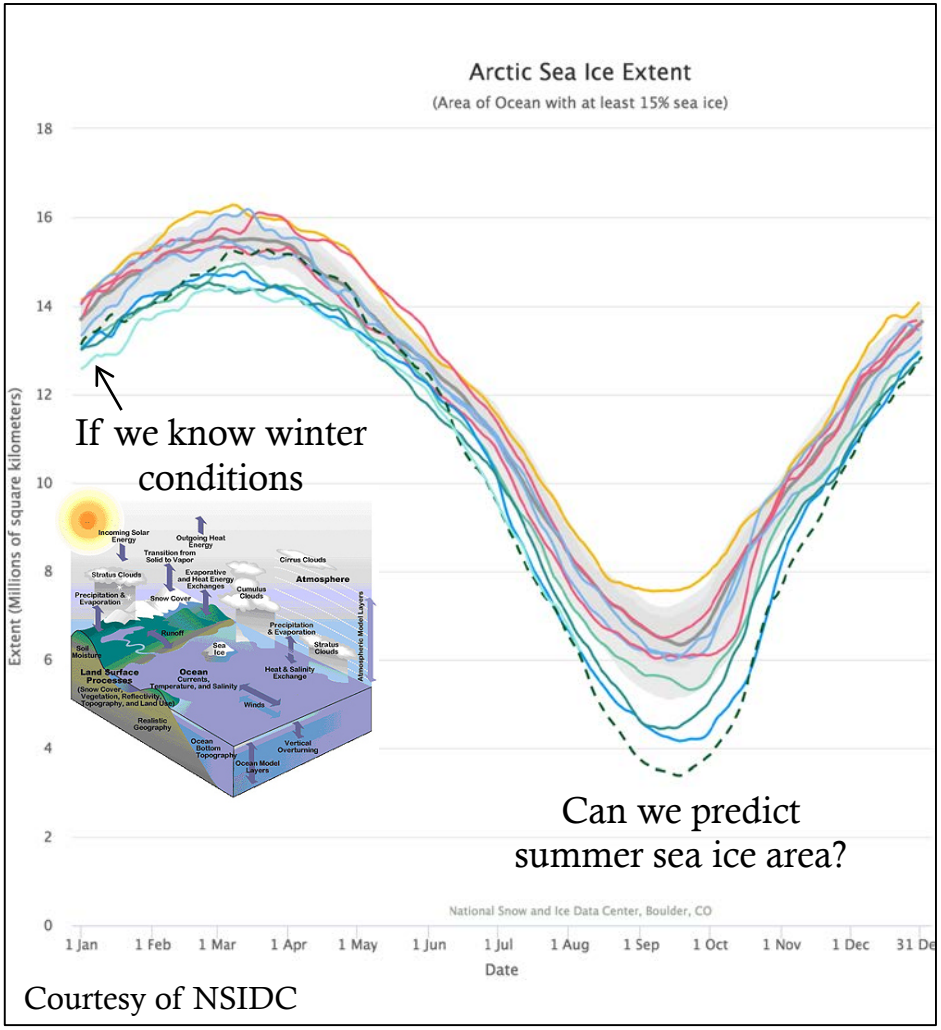
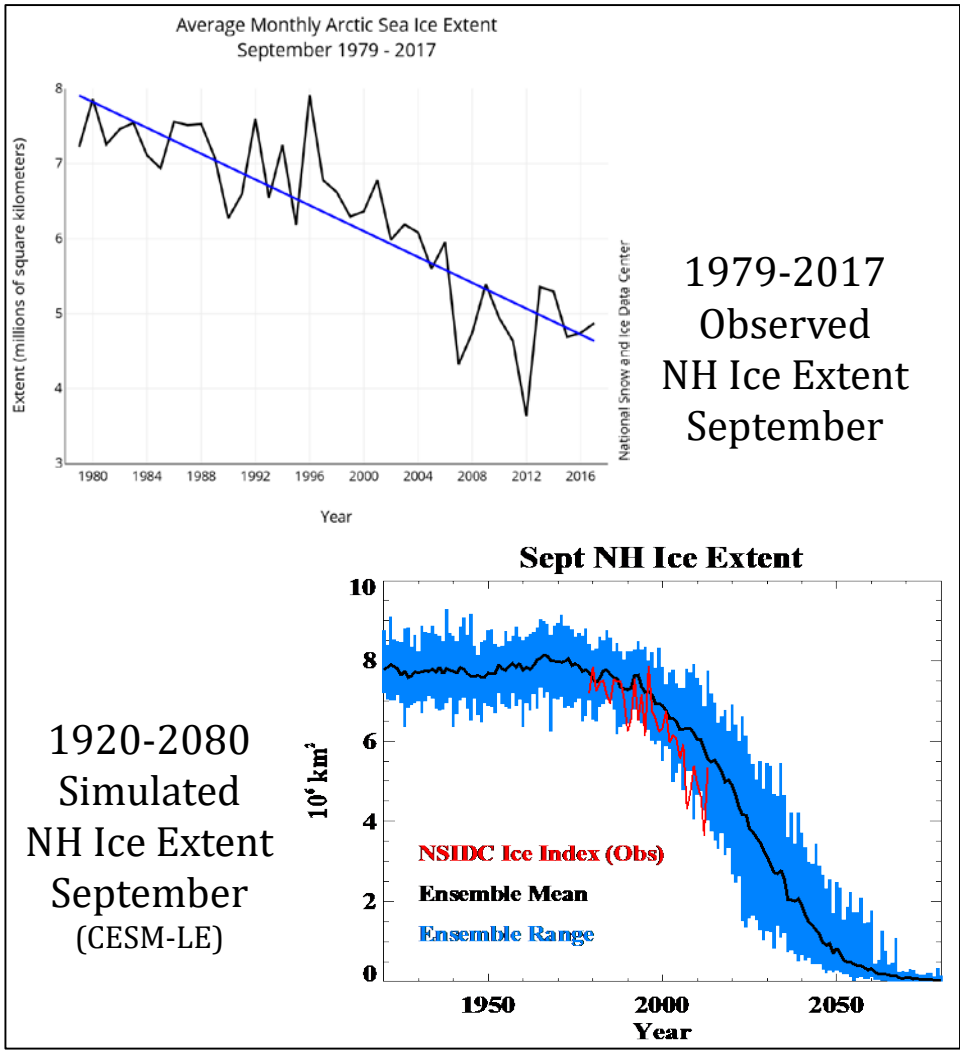
Investigating Seasonal Predictability of Arctic Sea Ice



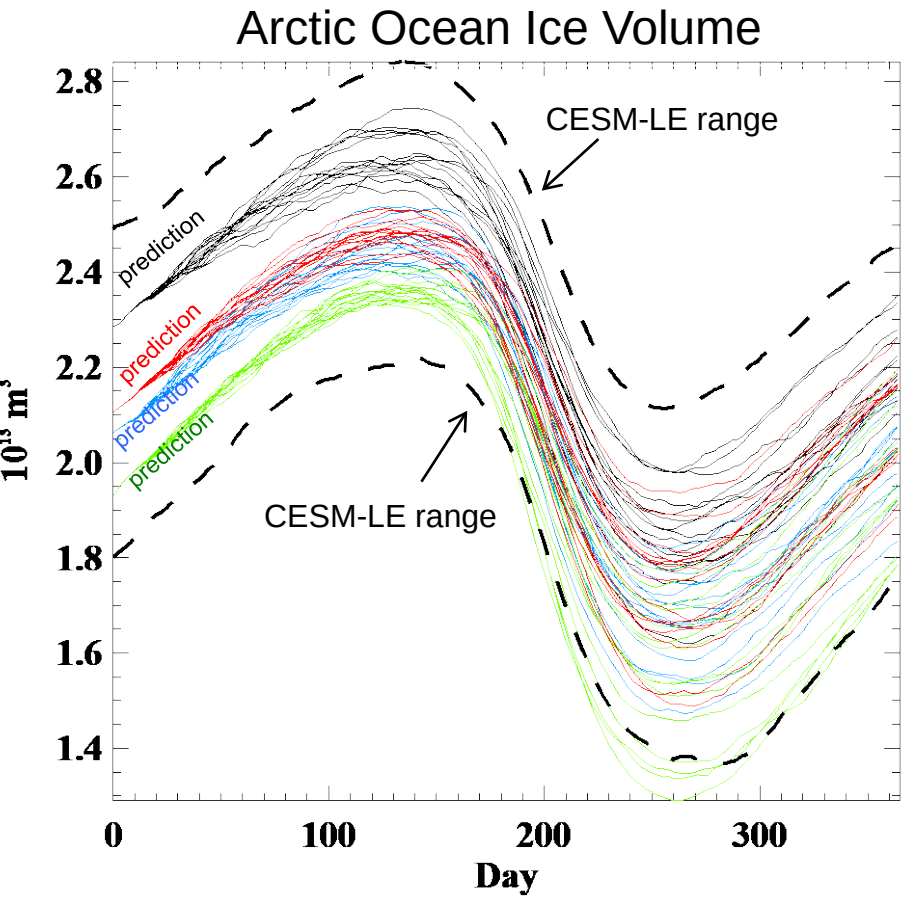
Courtesy of NSIDC



Do winter conditions provide predictive capability for sea ice the next summer?

How might these predictability characteristics change in a changing climate?

CESM Experiments to Assess Inherent Predictability



1980 Ensemble Set

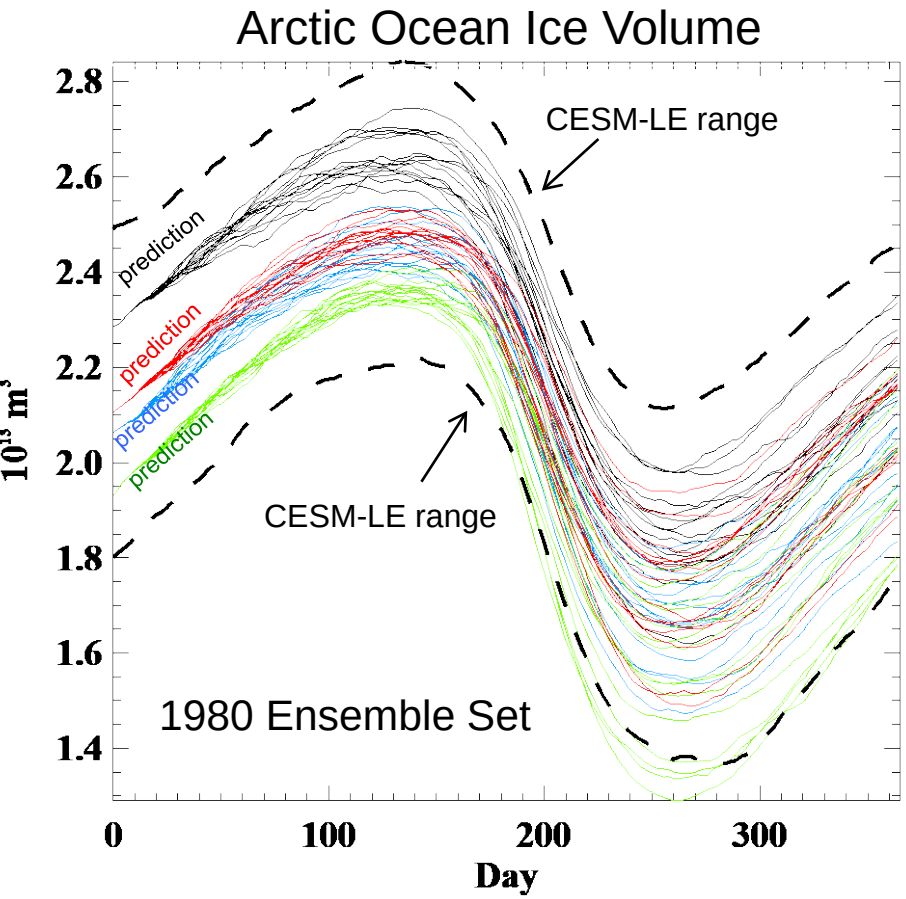
Sets of "perfect model" predictions

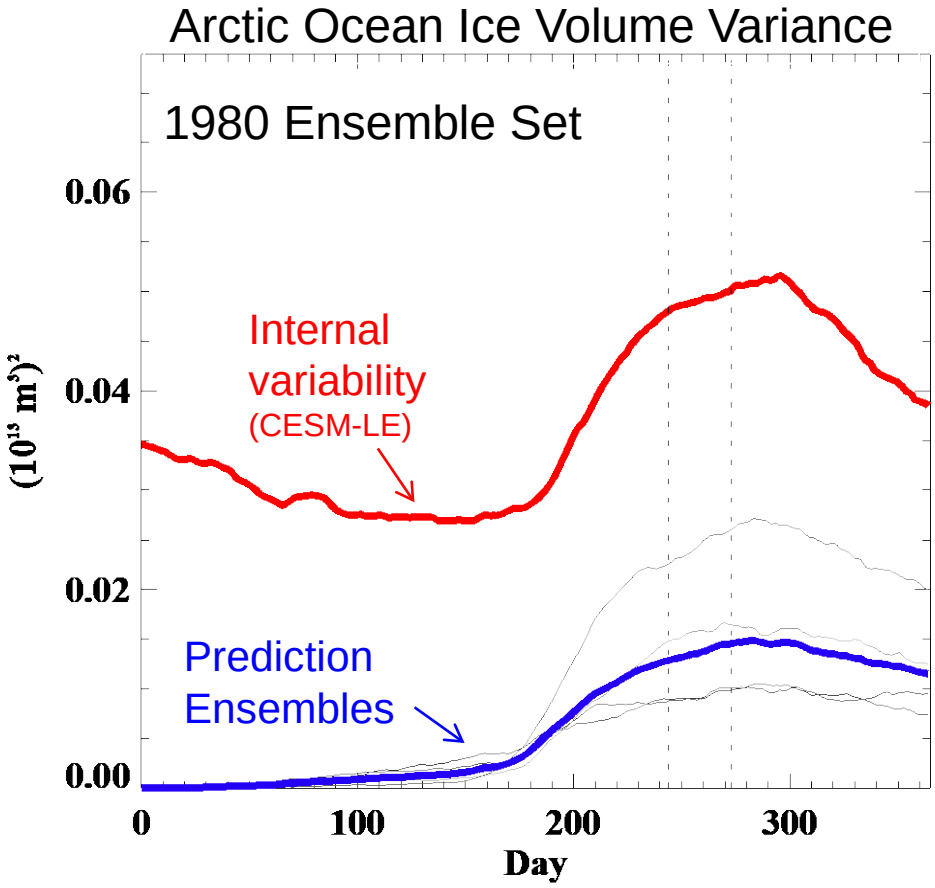
- For each decade from 1980 to 2030
- Initialized on Jan 1 using conditions from the CESM Large Ensemble (LE)
- For each decade, 4 ensemble sets performed (4 different LE initial states)
- 15 ensemble members with round off perturbation for each initial state

CESM Large Ensemble

- 40 members from 1920-2100
- Spread across members is measure of internal variability
- Serves as a control for our prediction runs

CESM Experiments to Assess Inherent Predictability

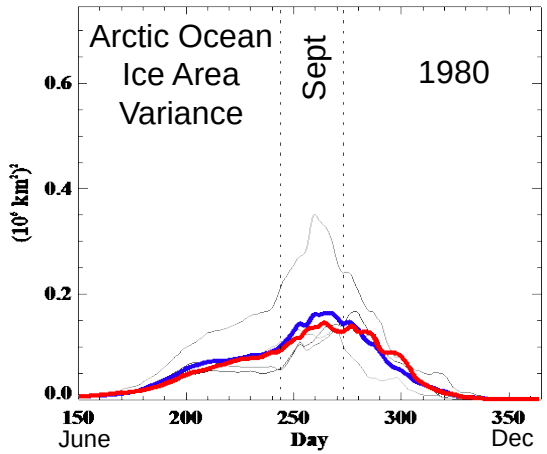




By comparing initialized ensemble prediction spread to internal variability, we obtain a measure of predictability

As shown here for 1980, ice volume has high predictability

(initialized ensemble spread is much less than internal variability)



Internal variability
Prediction Ensemble

Predictability of Summer Arctic ice area

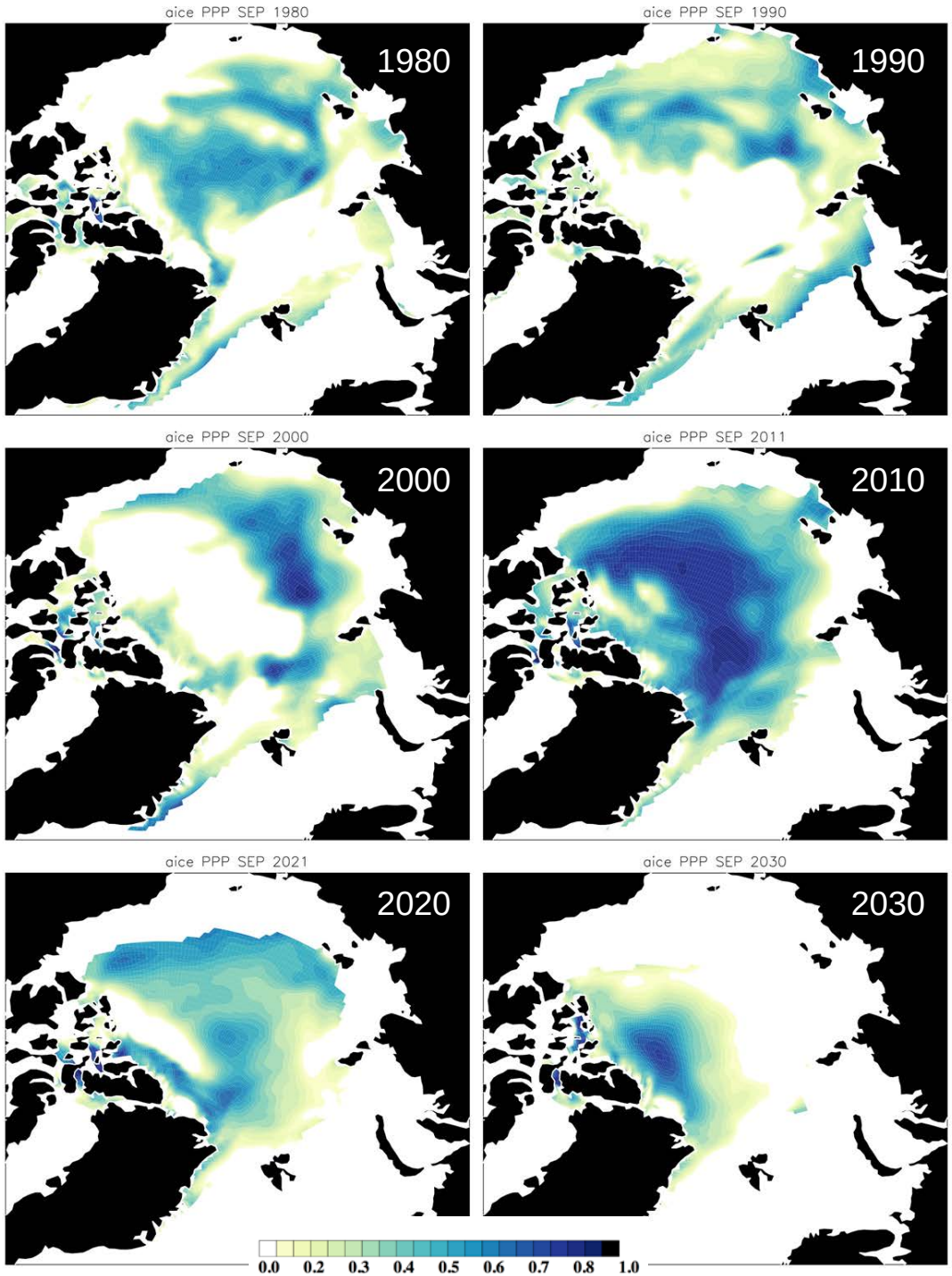
For **1980**,

- Spread of prediction ensemble = internal variability
- **NO PREDICTABILITY** for forecasts initialized on Jan 1

For predictions in **later decades**

- Initialized prediction spread < internal variability
- January initial conditions provide ice area **predictability**
- Caused by long-lived thickness anomalies that affect summer melt out

Internal variability (CESM-LE)
Prediction Ensembles



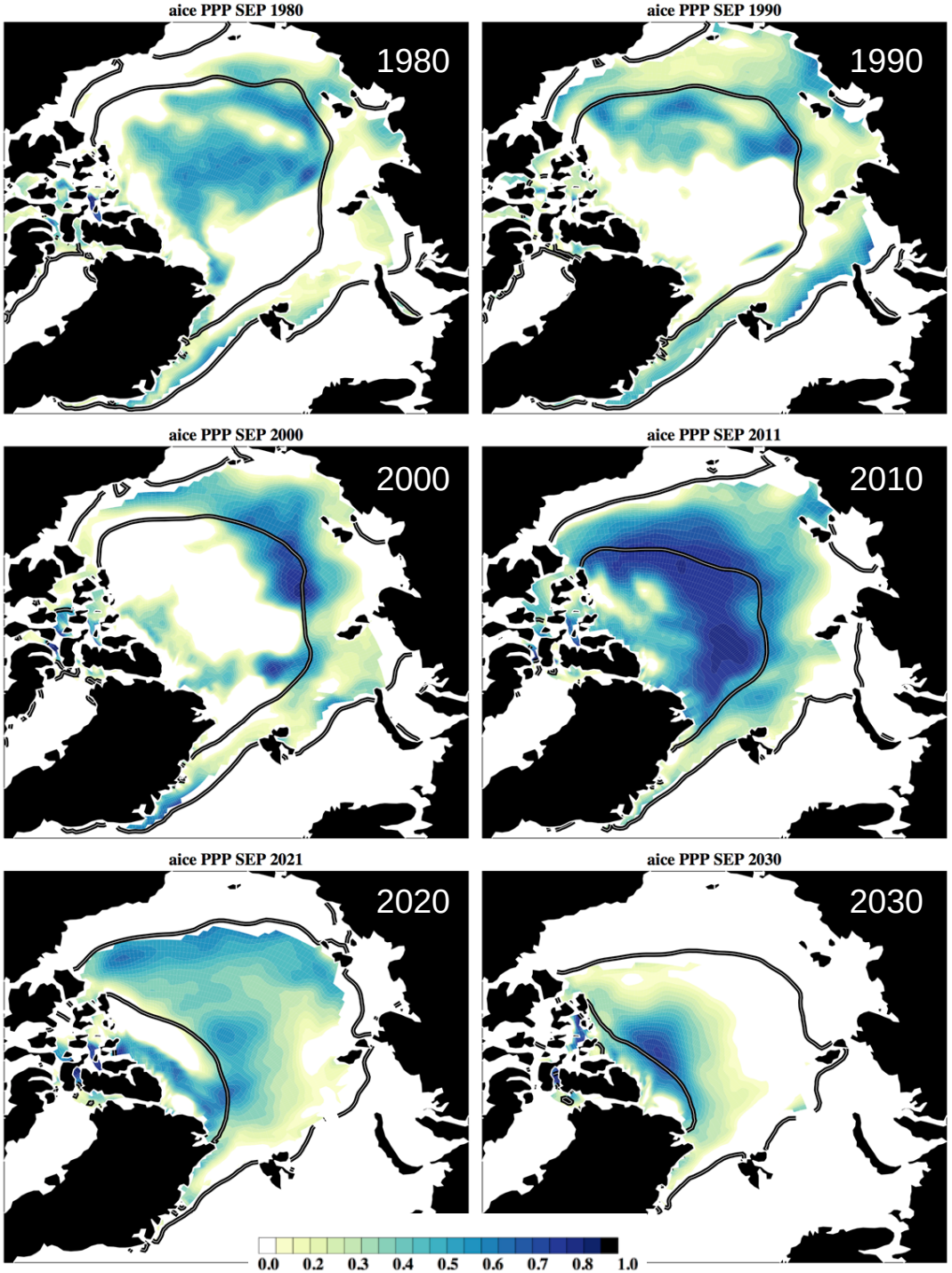
Predictability of Summer ice concentration

Darker = more predictable

Predictability of September ice concentration*

Predictions in 2010 are most highly predictable

*Potential prognostic predictability = Reduction in prediction ensemble variance relative to internal variability



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Also true if only consider region of high ice area variance

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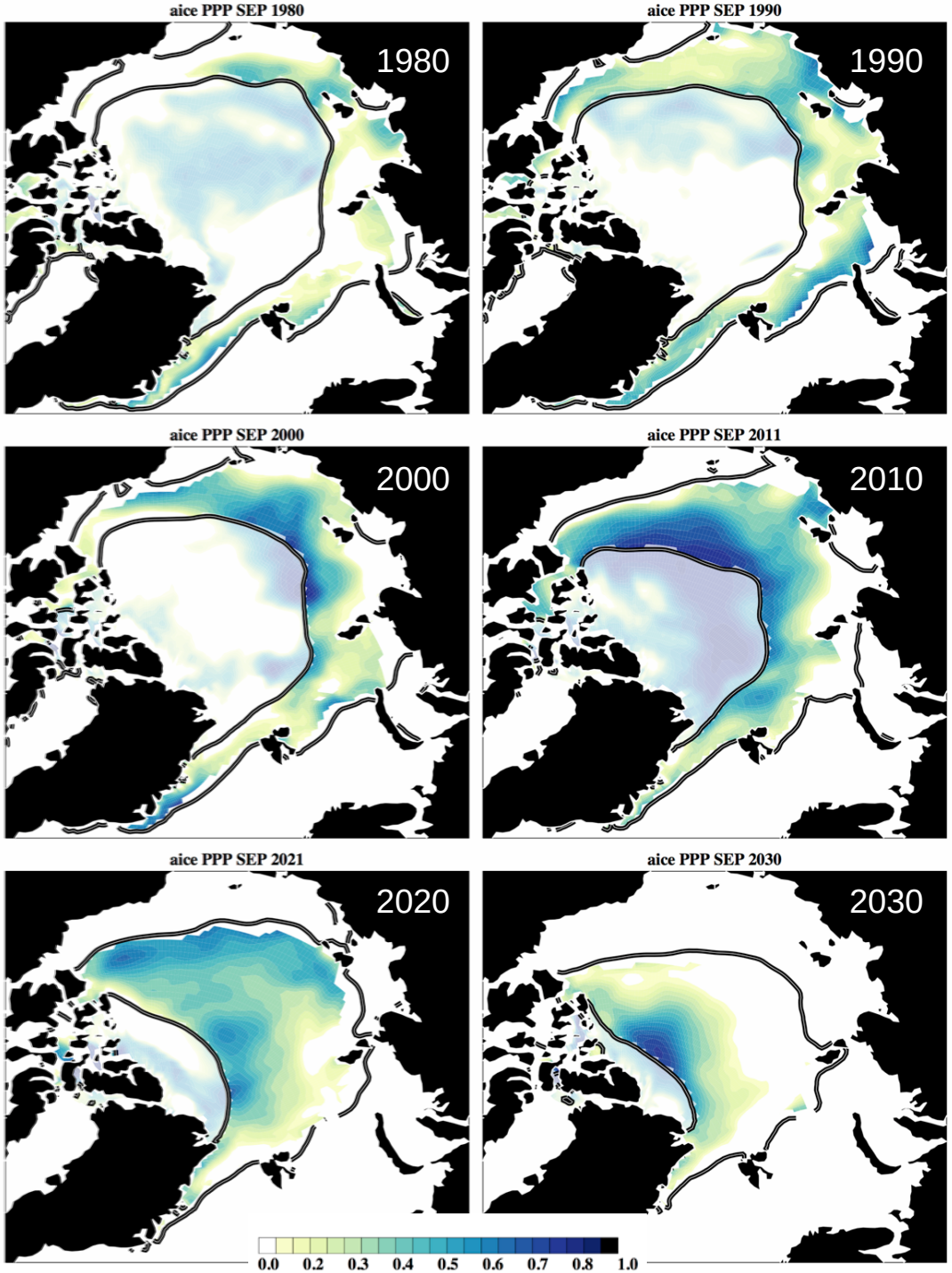

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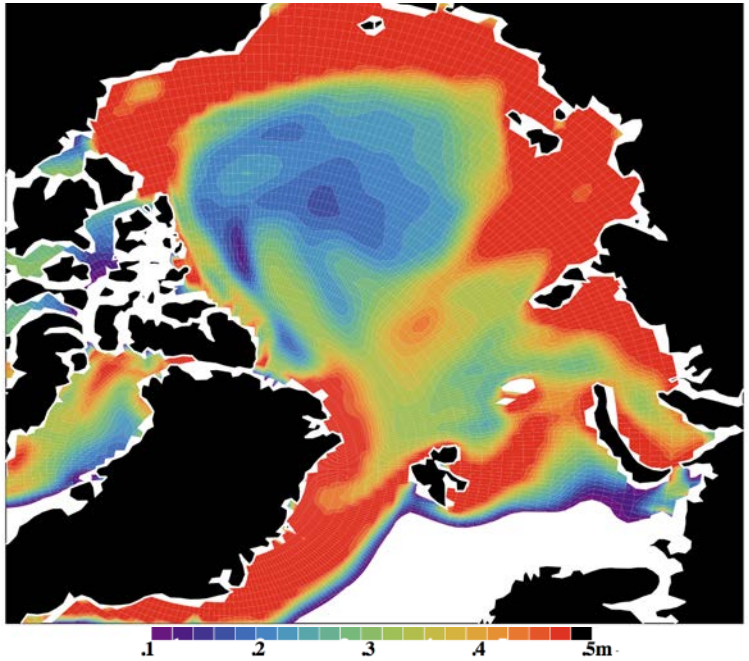
What causes ice area predictability to change in different decades?

Summer predictability due to long-lived thickness anomalies that affect melt out

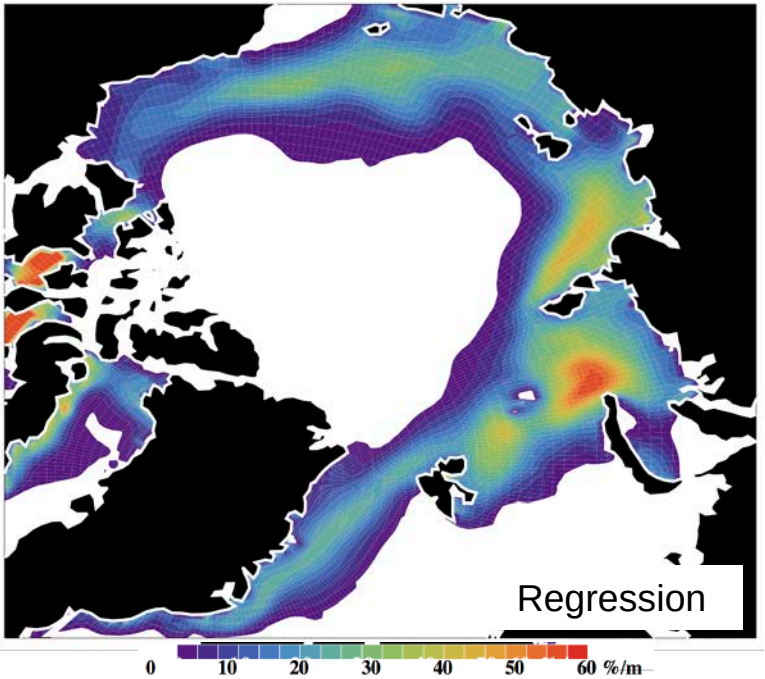
Loss of predictability (or spread of ensembles) can be related to:

Standard Deviation of ice thickness in July



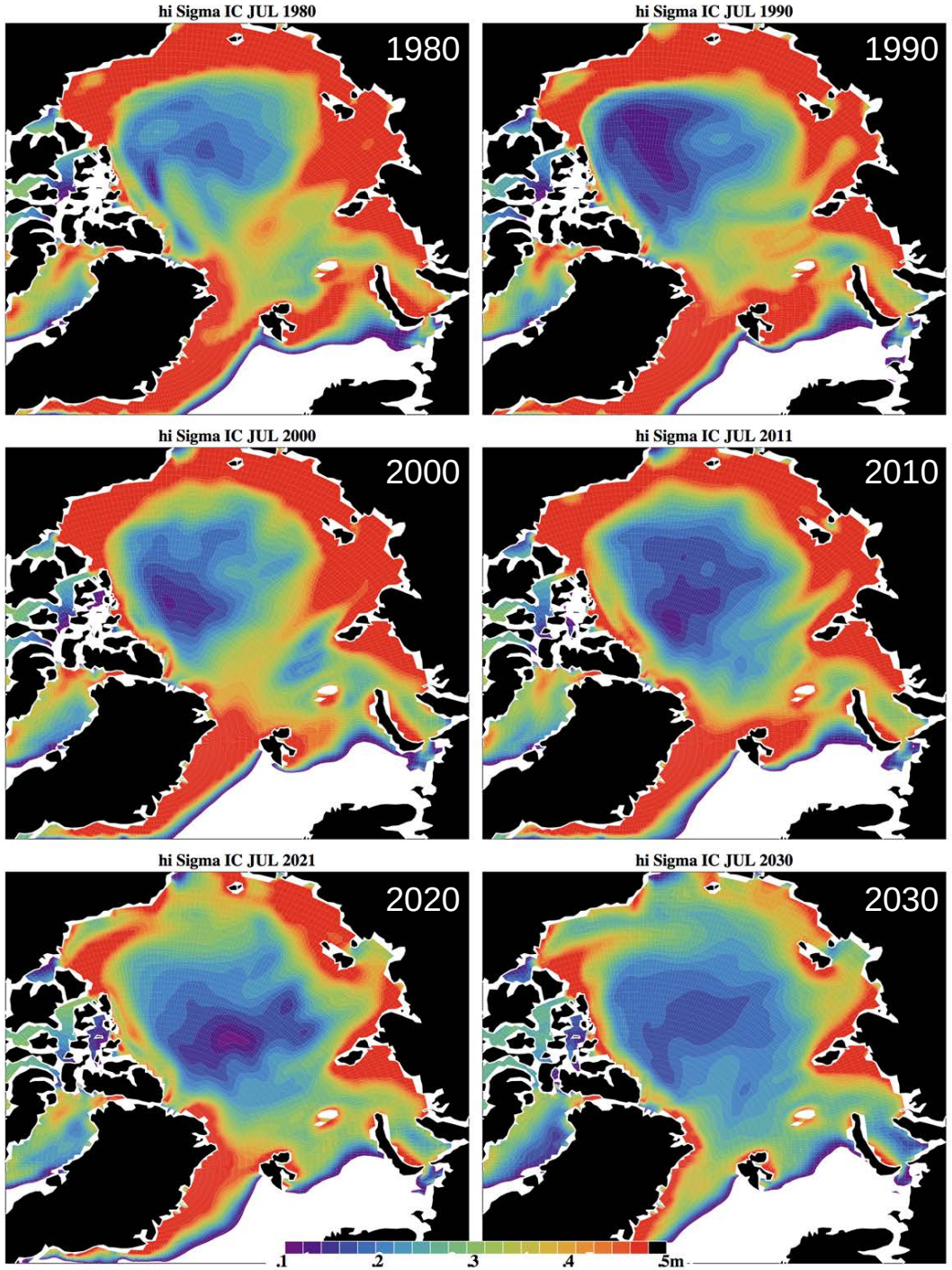
1. Growth of ice thickness errors from initialized state

Sept ice area change per July thickness anomaly



2. How those ice thickness anomalies affect summer melt out

1980 Predications

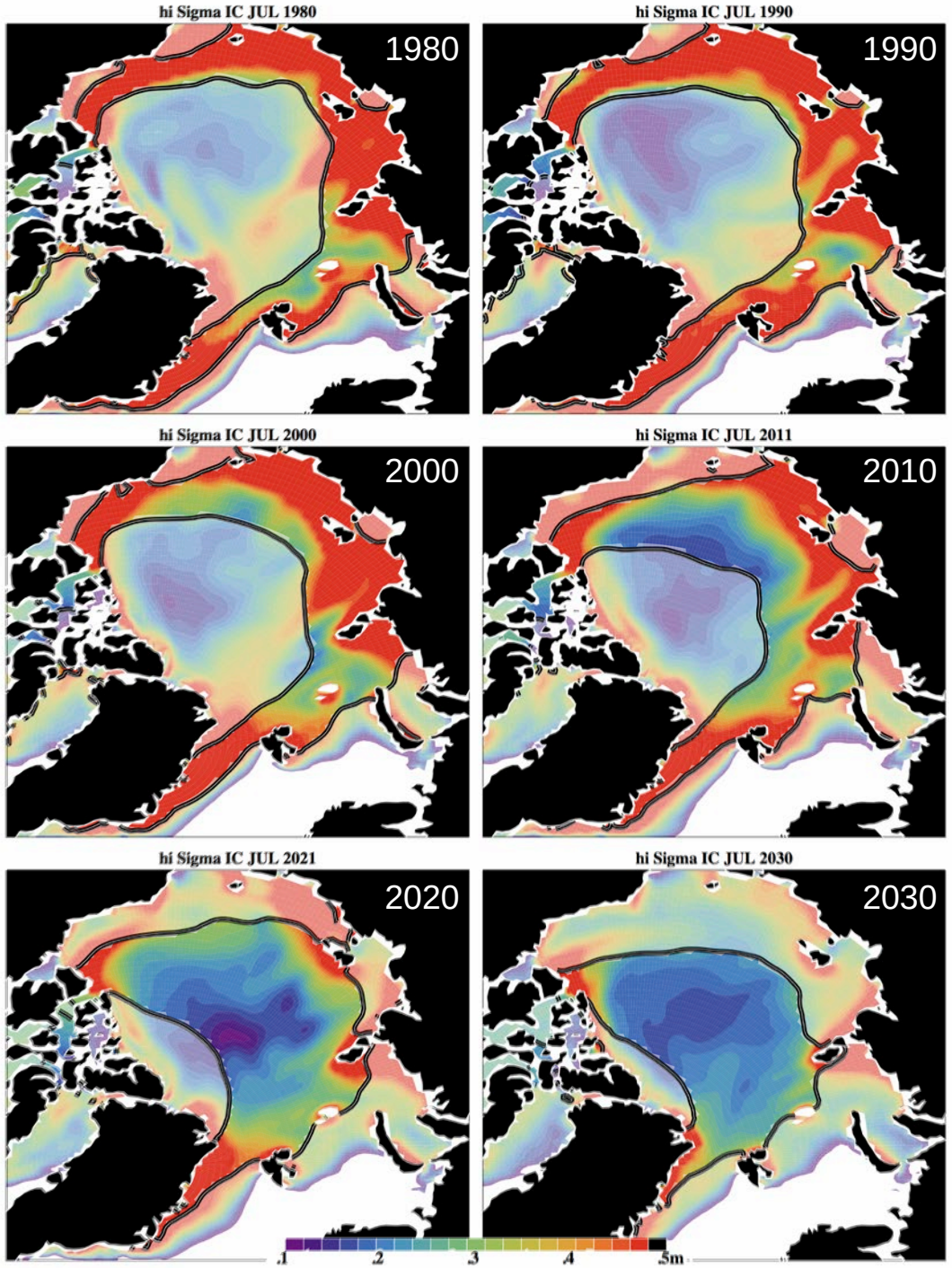


What causes ice area predictability to change?

1. Growth of Ice Thickness Errors

- Ice thickness error growth changes due to the changing climate

July ice thickness standard deviation of prediction ensembles



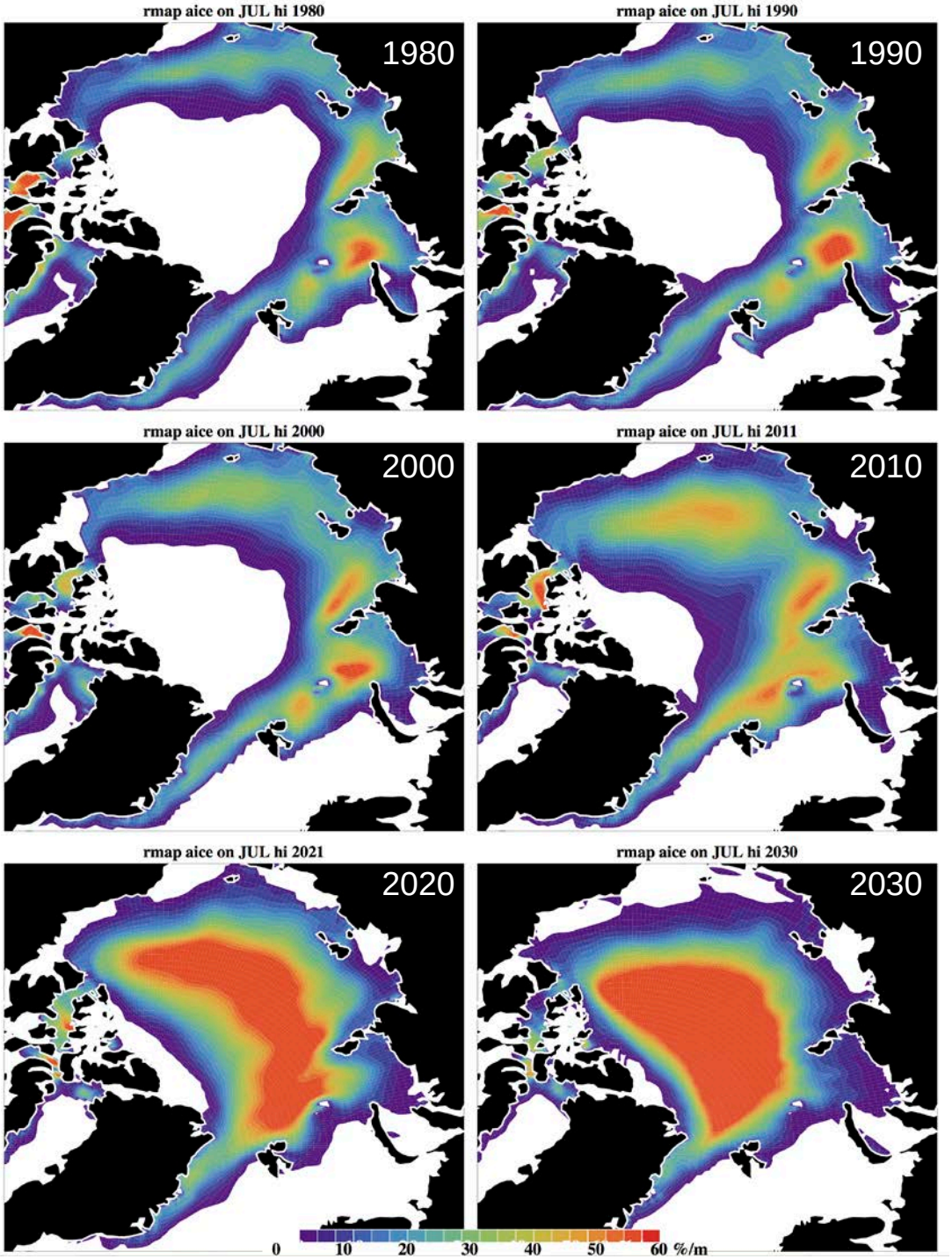
What causes ice area predictability to change?

1. Growth of Ice Thickness Errors

- Ice thickness error growth changes due to the changing climate
- The region of important ice thickness anomalies also changes in a warming climate

Earlier decades have larger growth in ice thickness errors in regions of high September ice area variability

July ice thickness standard deviation of prediction ensembles



What causes ice area predictability to change?

2. Influence of ice thickness "errors" on melt out

In a warmer climate, thickness anomalies in July drive larger variations in September ice area

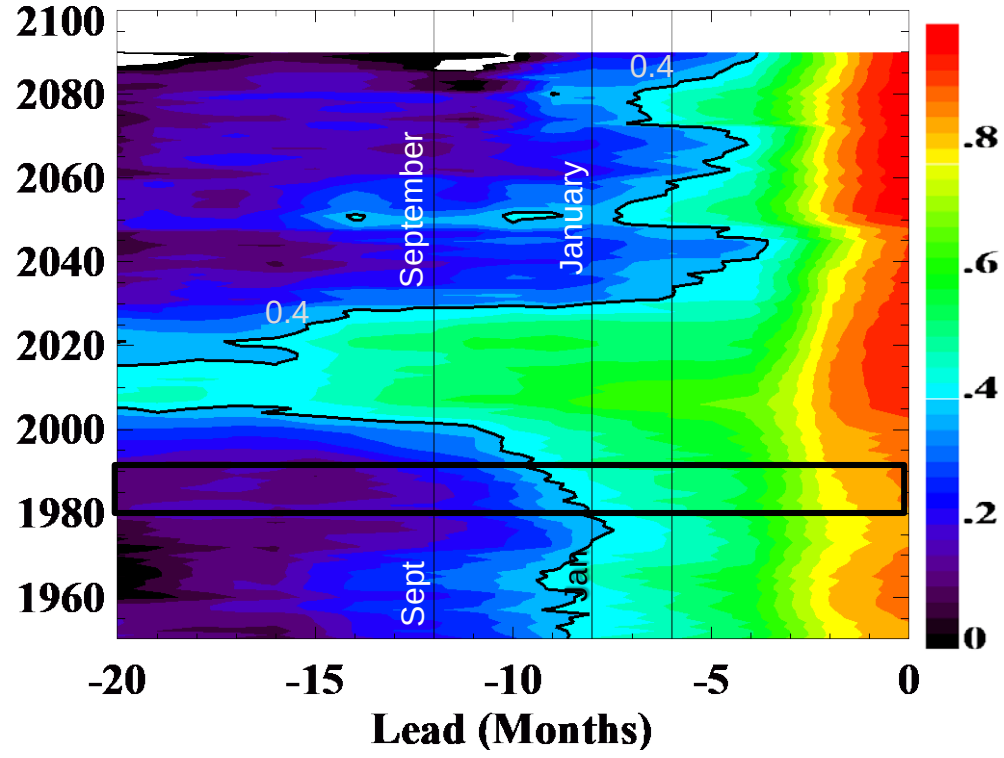
In our simulations, conditions in 2010 provide a "**sweet spot**" for summer ice area predictability

- Modest growth in ice thickness errors relative to earlier decades
- Modest influence of thickness errors on summer melt out relative to later decades

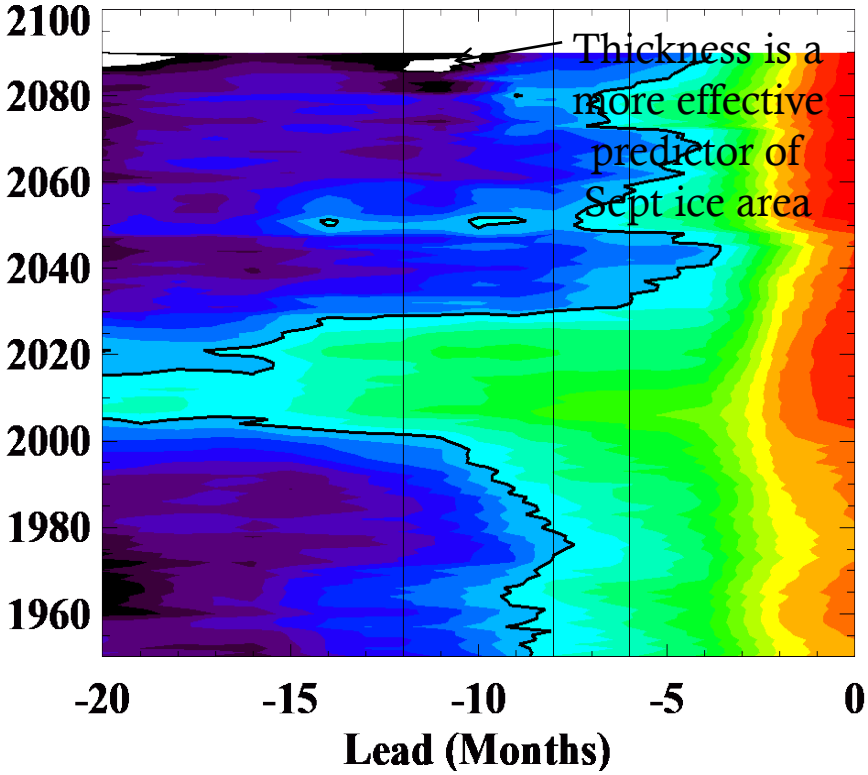
Regression of September ice concentration on July thickness anomalies

Changing Beaufort Sea summer ice predictability assessed from CESM-LE statistics

Assessing ice thickness as a predictor



Correlation of September ice area with prior ice thickness



Correlation of September ice area with prior Jan thickness

Using 10 year running windows

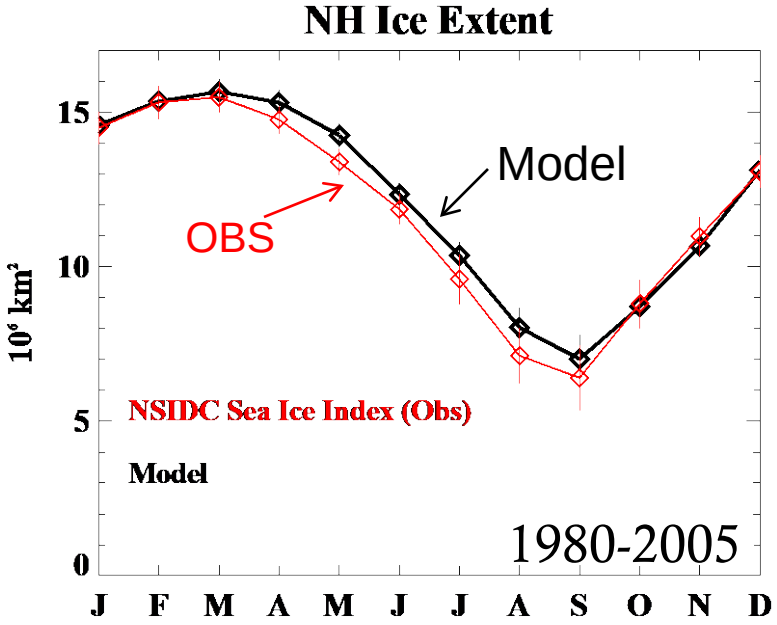
Final Thoughts

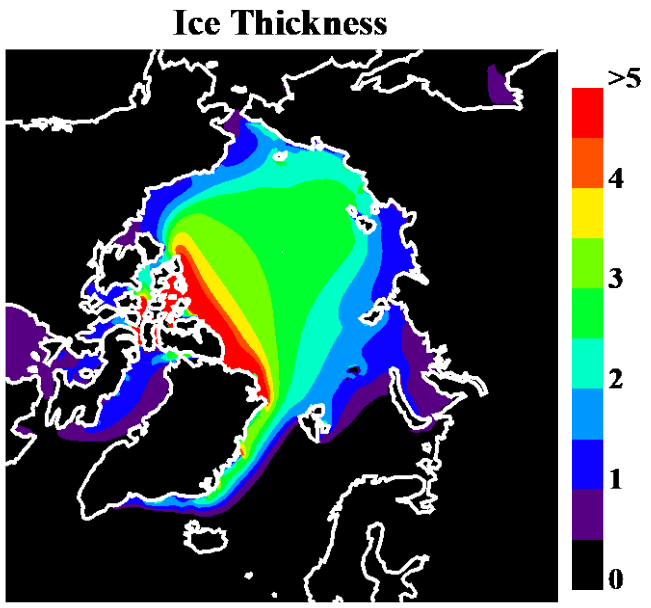
- Seasonal predictability of Arctic sea ice is likely to change with a warming climate
- Multiple factors affect summer ice predictability:
  - Growth of thickness errors in potential melt out regions
  - Influence of ice thickness anomalies on summer melt out
- From CESM experiments, we find
  - Growth of thickness errors relevant for Sept ice area predictability is larger in colder (late 20C) climate
  - Influence of ice thickness errors on summer melt out is larger in warmer climate
  - This results in a "sweet-spot" for predictability in early decades of the 21st century

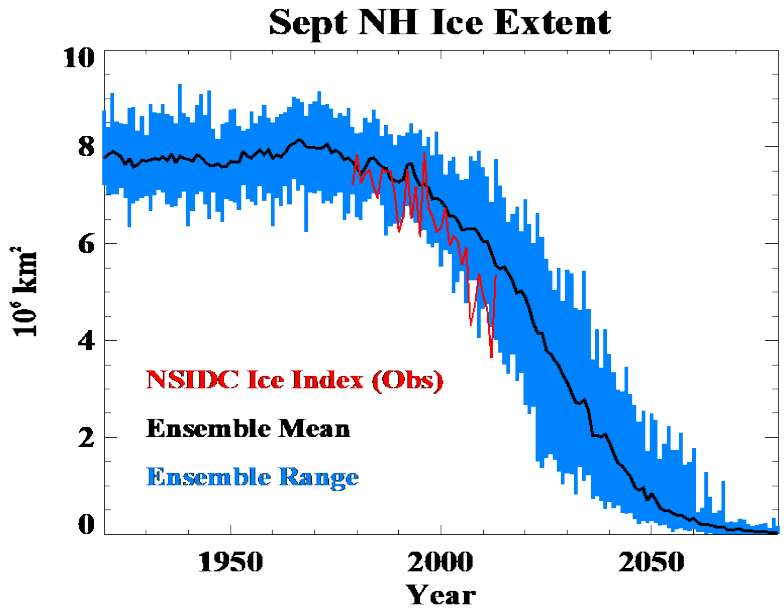
Questions?

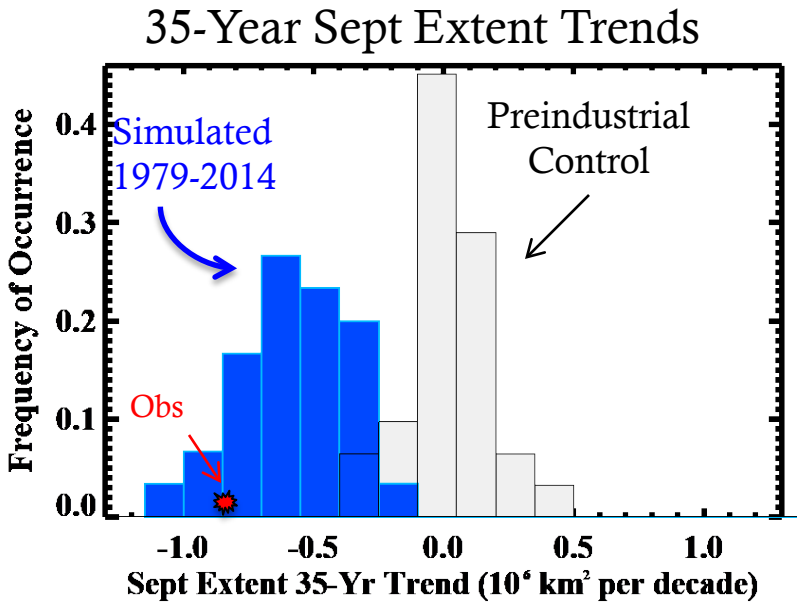
Extra Slides

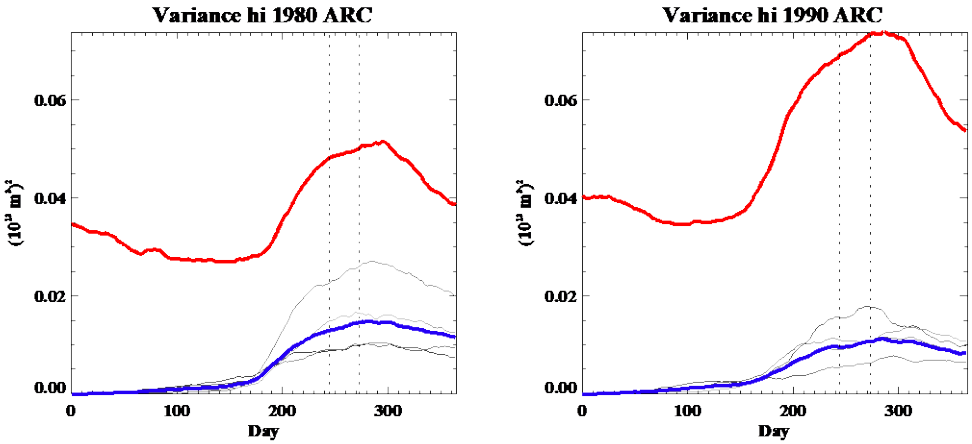
CESM-LE Simulated Climatology



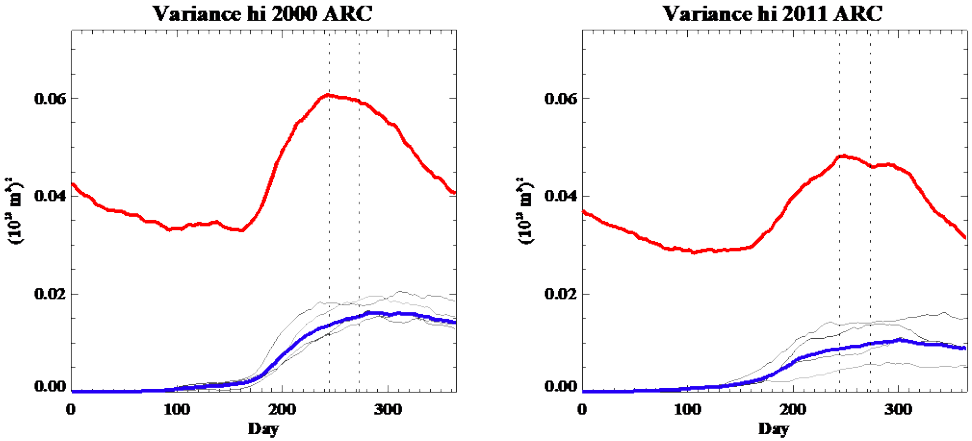







Variance hi 1980 ARC
0.06
0.04
0.02
0.00
(10^12 m^2)^2
0
100
200
300
Day

Variance hi 1990 ARC
0.06
0.04
0.02
0.00
(10^12 m^2)^2
0
100
200
300
Day


Variance hi 2000 ARC
0.06
0.04
0.02
0.00
(10^12 m^2)^2
0
100
200
300
Day

Variance hi 2011 ARC
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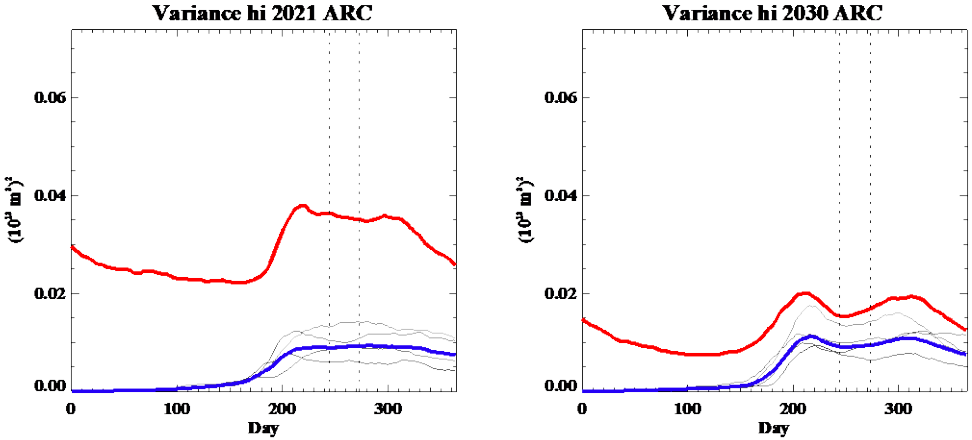
0.04
0.02
0.00
(10^12 m^2)^2
0
100
200
300
Day


Variance hi 2021 ARC
0.06
0.04
0.02
0.00
(10^12 m^2)^2
0
100
200
300
Day

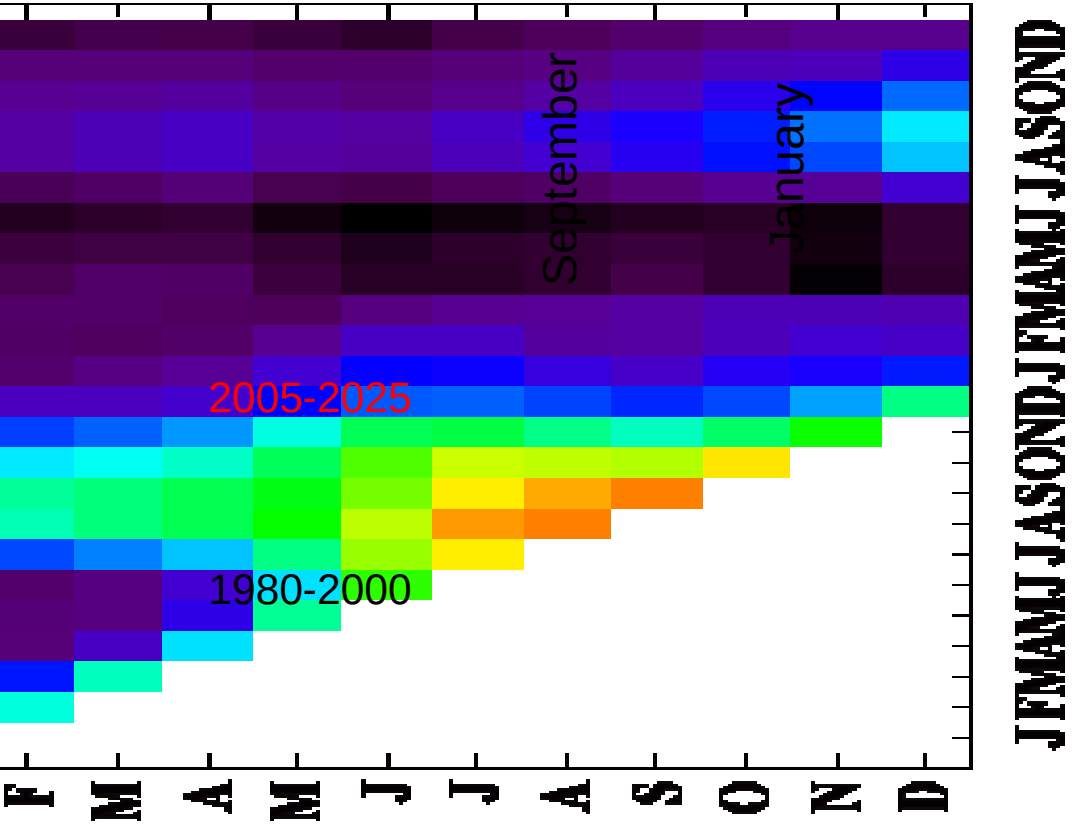
Variance hi 2030 ARC
0.06
0.04
0.02
0.00
(10^12 m^2)^2
0
100
200
300
Day

Changing Beaufort ice predictability in a warming climate

For 2005-2025 period

Ice thickness becomes a more effective predictor of summer sea ice

Correlation – Sept Ice Area and Prior Ice Thickness

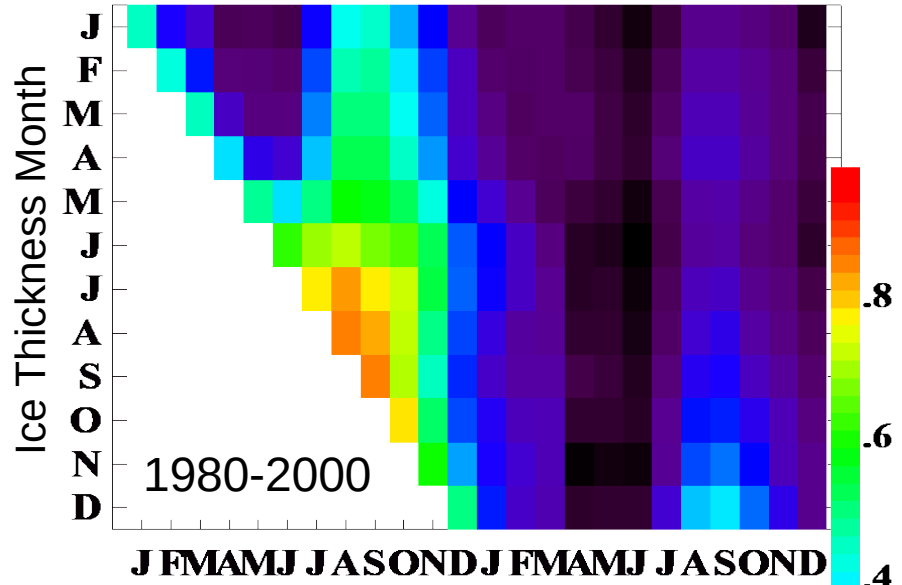


For 2005-2025

- Beaufort Sea ice thickness anomalies are longer lived
- Winter thickness has larger influence on summer open water formation
- Partly caused by a decreased role of ice dynamics

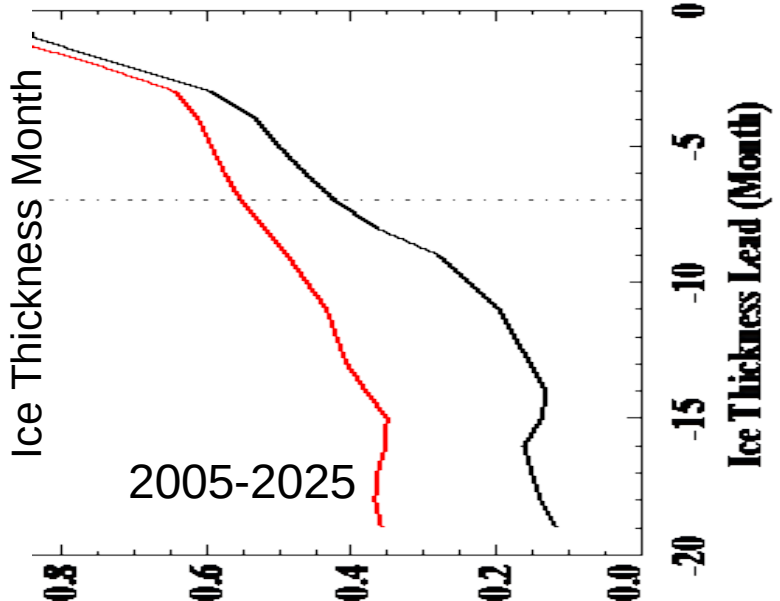
Changing Beaufort ice predictability in a warming climate

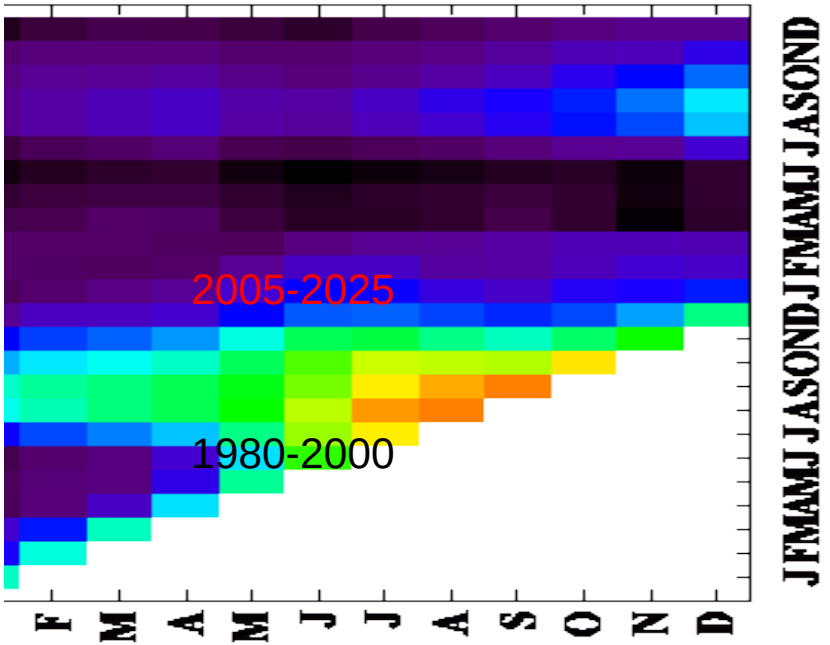
Correlation – Ice Thickness with Following Ice Area



<u>For 2005-2025 period</u>

Ice thickness becomes a more effective predictor of summer sea ice





Changing Beaufort ice predictability in a warming climate

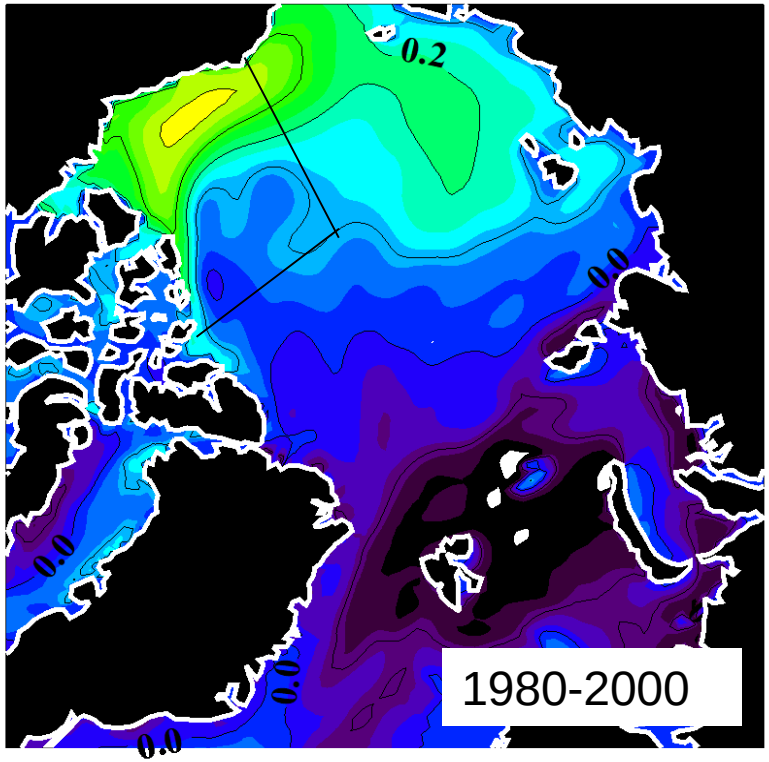
For 2005-2025 period

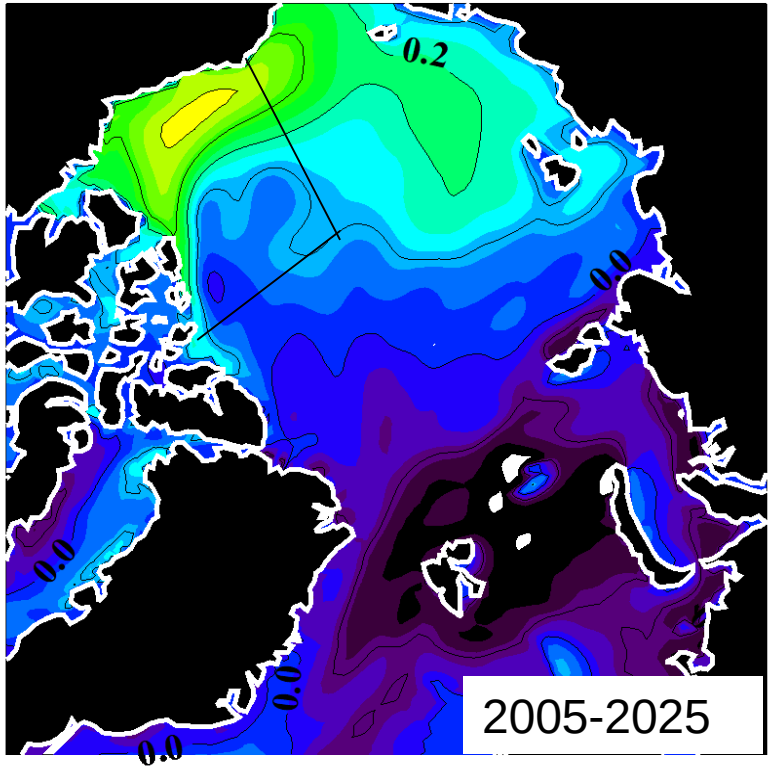
Ice thickness becomes a more effective predictor of summer sea ice

Location of important ice thickness anomalies changes

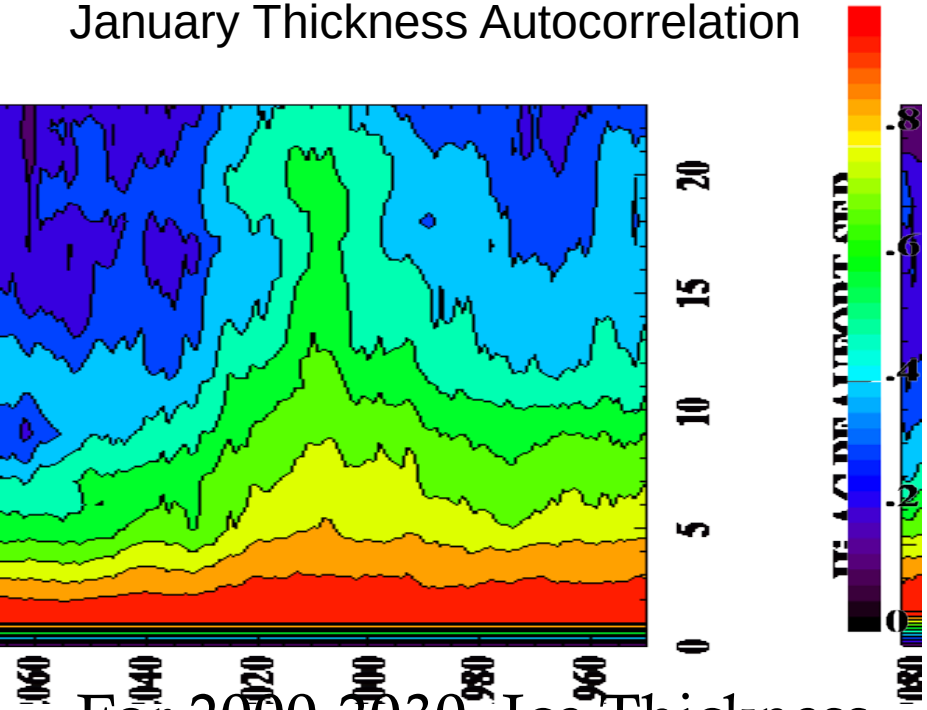
Correlation:

Jan Thickness & Sept Ice Area





How does Beaufort sea summer ice predictability change with a warming climate?



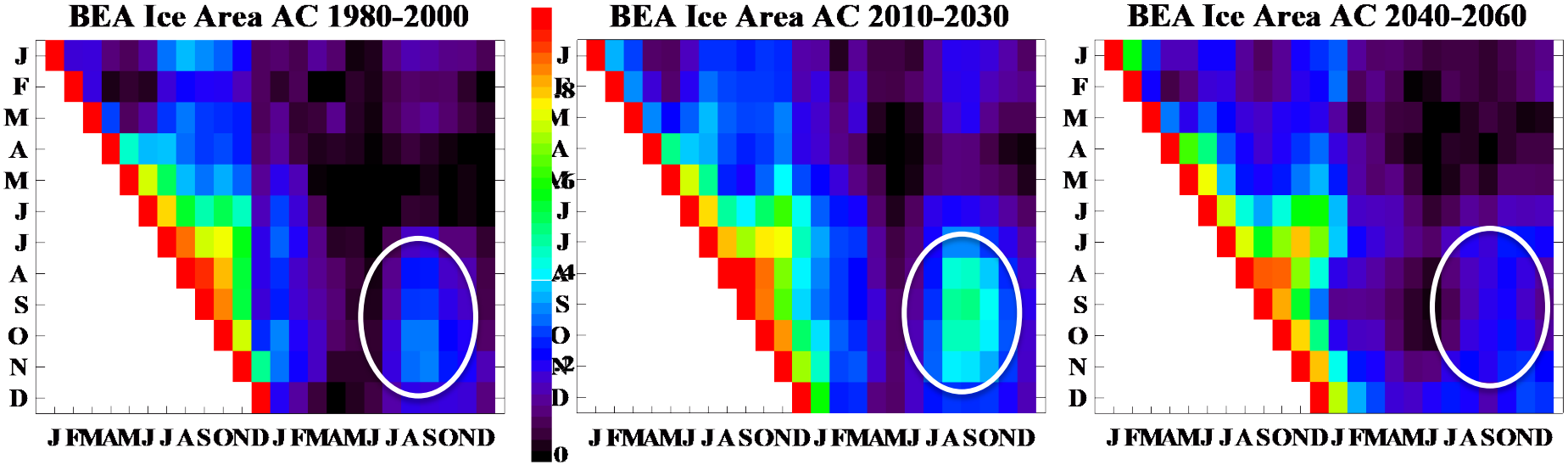
For 2000-2030, Ice Thickness Anomalies are more persistent

Correlation of Jan Ice Thickness and Following Summer Ice Area Change

Summer ice area predictability

- Prior ice thickness affects ice area anomalies the following summer
- This is influenced by
  - Longevity of thickness anomalies
  - How effectively thickness anomalies modify summer melt out

Changing Predictability in a Changing Arctic



Beaufort Sea Ice
Area Autocorrelation

Summer-to-summer re-emergence changes with time (Memory source = ice thickness)