CPC Sea Ice Predictions

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Outline

1. Sea ice predictions at CPC

1) Challenges in sea ice forecasts from NCEP operational Climate Forecast System (CFS)
2) CPC experimental sea ice prediction system
3) CPC Sea ice initialization system (CSIS)
4) Sea ice predictions: Forecast configuration and Performance assessment
5) CPC Sea ice forecast products

2. Sea ice impacts on lower latitudes

1) Northern mid-latitude 2-m temperature trend
2) Northern mid-latitude 2-m temperature variability

1. Sea ice predictions at CPC

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1). Challenges in sea ice forecasts from operational CFS

- Model (CFSv2: GFS2007/MOM4)

  1) Excessive solar radiation at surface

  2) Unrealistic ocean-ice heat flux

- Initial conditions (CFSR)

  1) Too thick sea ice thickness

  2) Discontinuity in the time-series of sea ice extent

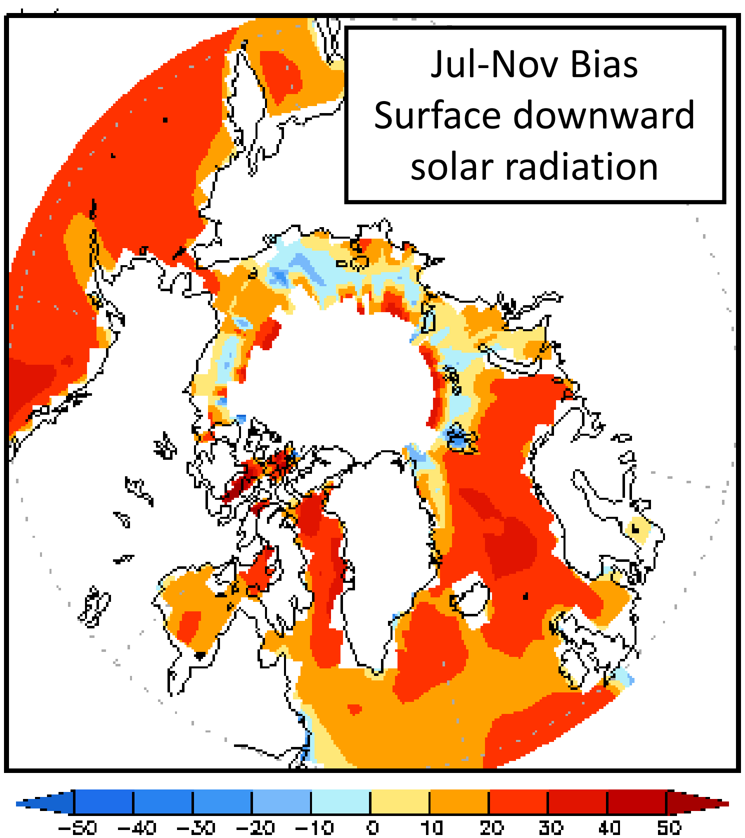
- Sea ice forecast from CFS

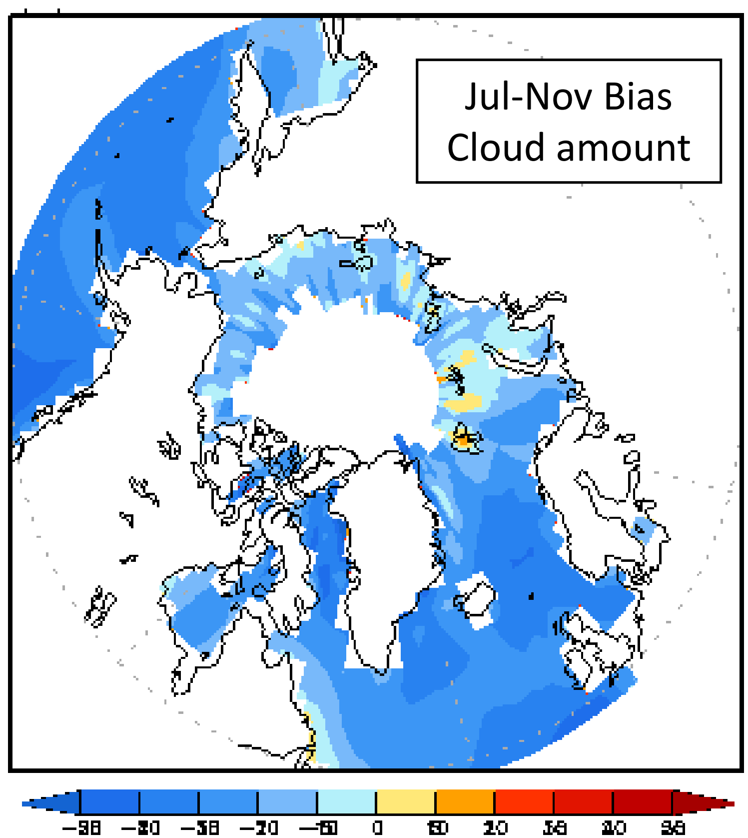
  1) Weaker seasonal cycle

  2) Large errors in predicted sea ice coverage

1). Challenges to sea ice forecasts from operational CFS

Excessive surface downward solar radiation flux in CFSv2

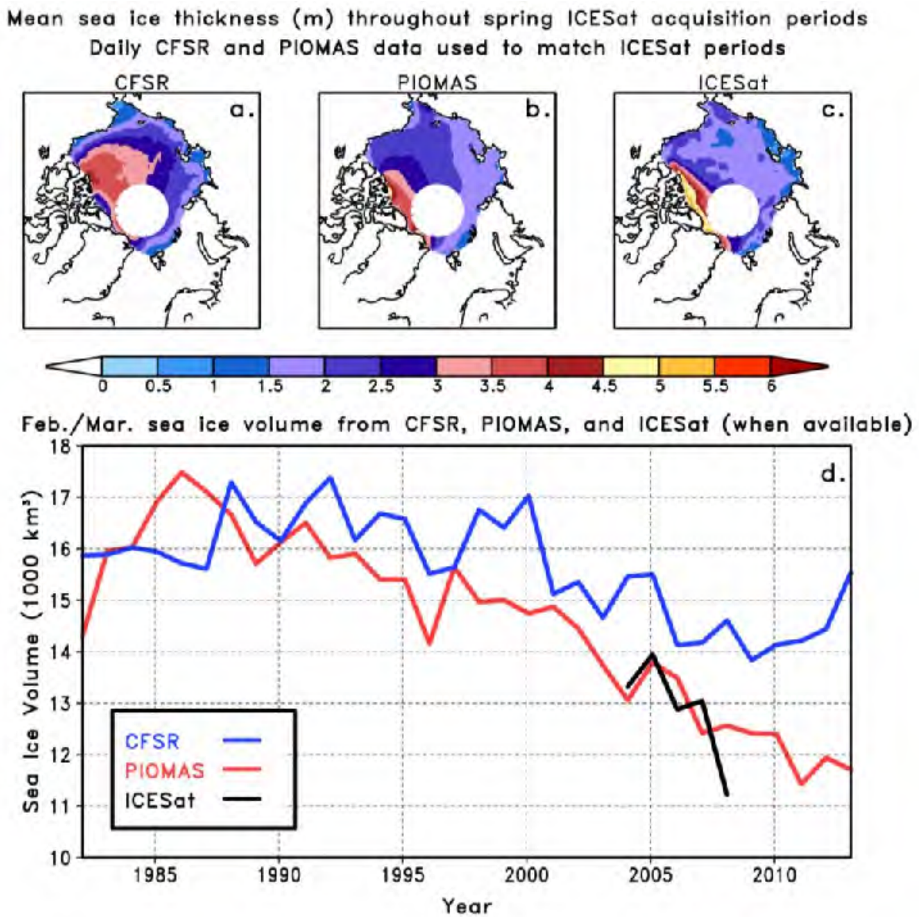




- Excessive surface solar radiation flux in CFSv2 due to negative bias in cloud amount

1). Challenges to sea ice forecasts from operational CFS

Unrealistic initial sea ice thickness in CFSv2

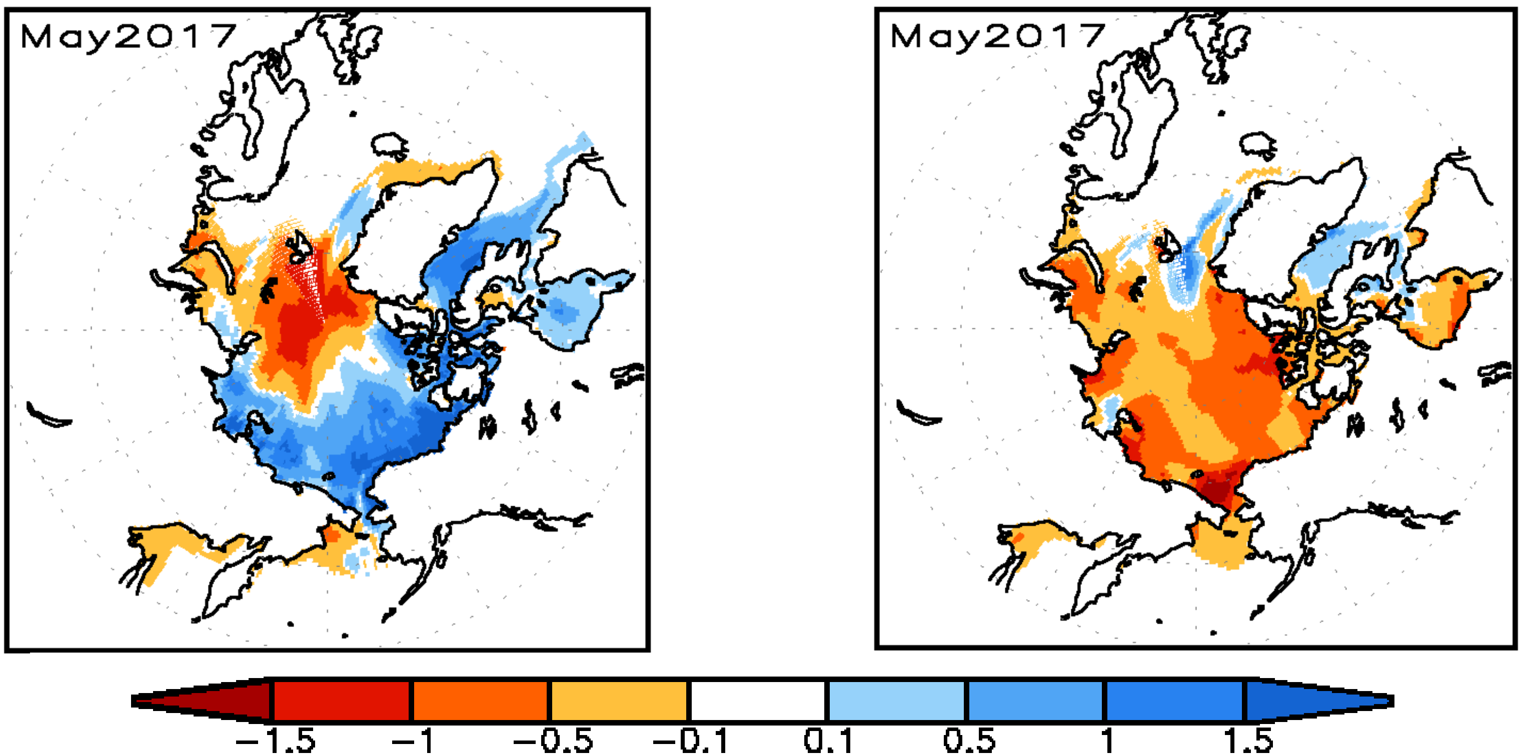


- PIOMAS sea ice thickness is more realistic than CFSR
- PIOMAS sea ice volume trend is more consistent with ICESat observations during the 2000s.

1). Challenges to sea ice forecasts from operational CFS

Sea ice thickness anomaly May 2017

CFSR PIOMAS



CFSR: Climate Forecast System Reanalysis

PIOMAS: Pan-arctic Ice/Ocean Modeling and Assimilation System

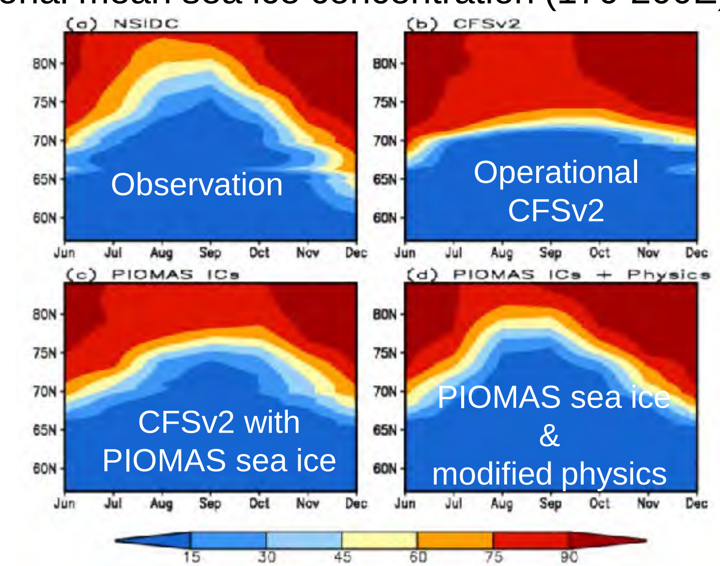
2). CPC experimental sea ice prediction system

- System used in 2015 – 2017 (CFSpp)
  - Model (CFS with two changes in physics)

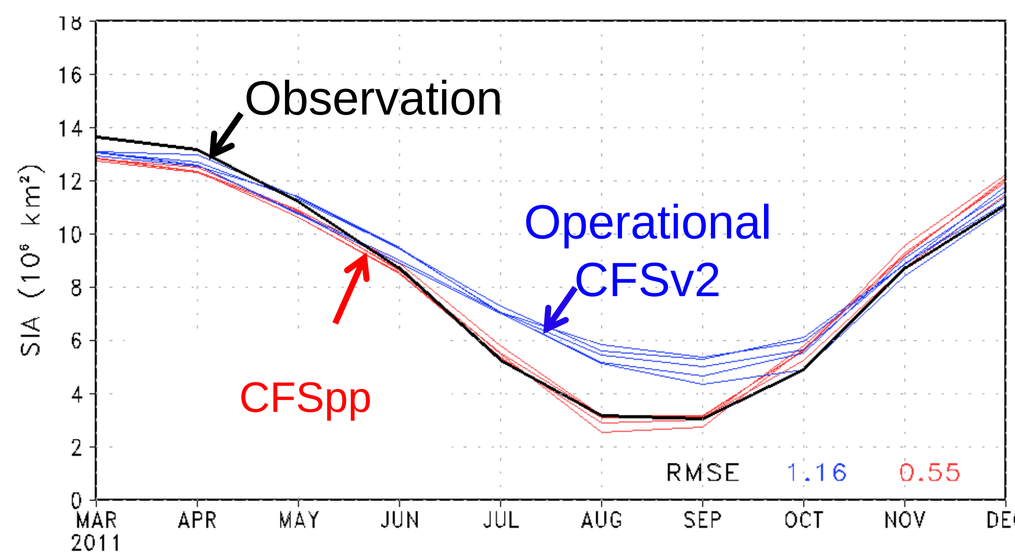
    Enable stratus cloud and remove ocean-ice heat flux constraint
  - Sea ice Initial conditions

    PIOMAS sea ice thickness

Zonal mean sea ice concentration (170-200E)



2011 sea ice area from March initial conditions



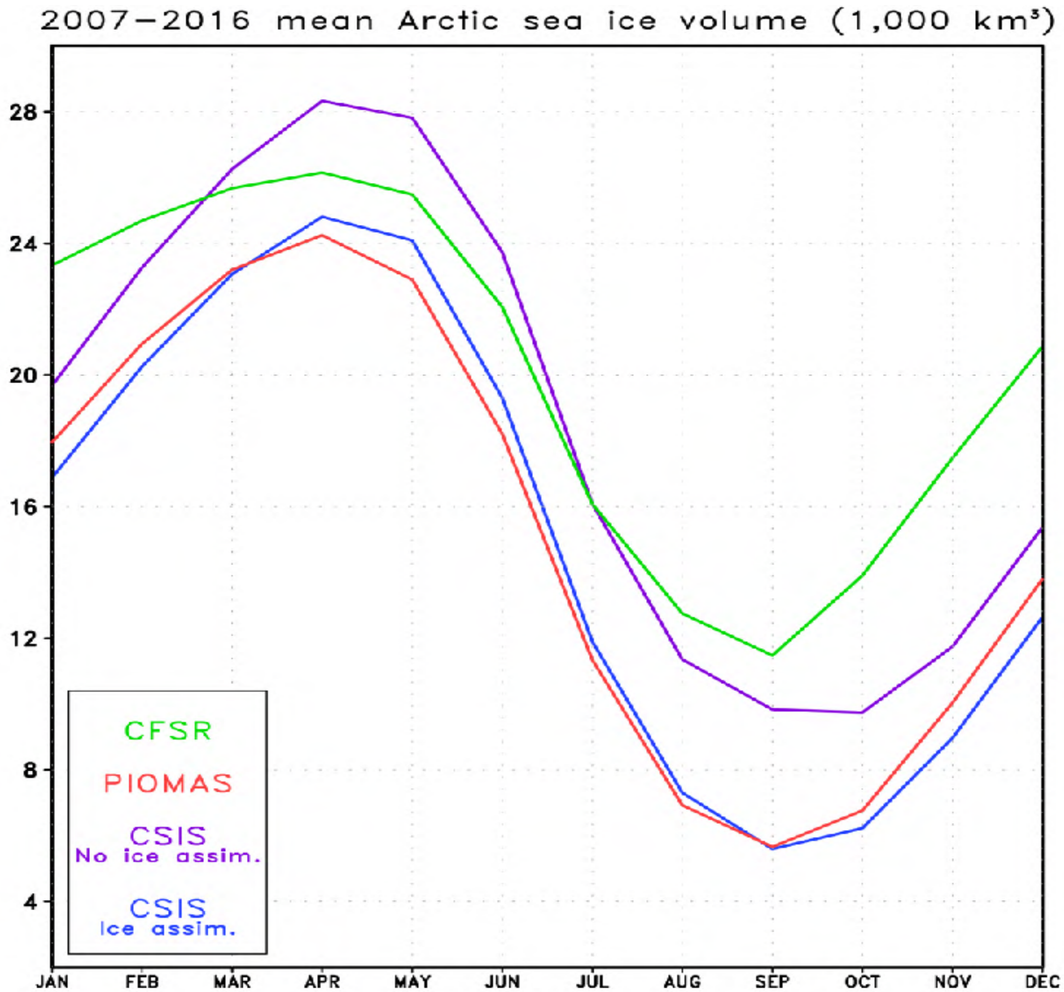
2). CPC experimental sea ice prediction system

- New system Used since 2018
  - Model (CFSm5)
    - Atmospheric component: GFS2015 (T126/L64)
    - Oceanic component: GFDL MOM5 (0.5X0.5/L40)
      GFDL SIS
  - Initial conditions
    1) Atmosphere: Climate Forecast System Reanalysis (CFSR)
    2) Ocean and sea ice: CPC Sea Ice initialization System (CSIS)

3). CPC Sea ice initialization system (CSIS)

- **Model**: MOM5
- **Atmospheric forcing**: CFSR
- **Variables assimilated** (as in PIOMAS)**:**
  - **SST**: NCEI or OISST
  - **Ice concentration**: NASA Team

3). CPC Sea ice initialization system (CSIS)



Slide produced by Tom Collow

4). Sea ice predictions

- Forecast configuration

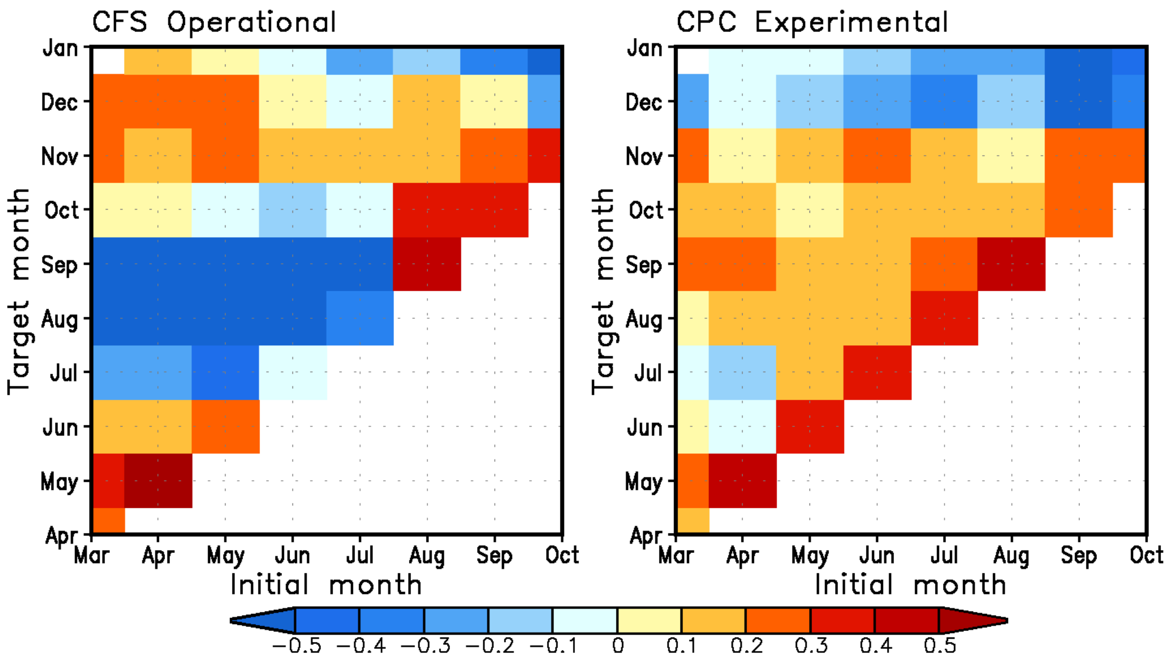
1) Forecast model: CFSm5 (GFS/MOM5)
2) Initialization: CFSR (atmosphere) and CSIS (Ocean/sea ice)
3) Sea ice predictions
   - **Seasonal**
     - Forecast frequency: Monthly
     - Initial dates: 21st-25th
     - Target 9 months
     - Hindcasts: Most recent 12 years
   - **Week 3-4**
     - Forecast frequency: Weekly
     - Initial dates: Sunday
     - Target 45 days
     - Hindcasts: 2012-2018

4). Sea ice predictions

- performance evaluation

Seasonal predictions

Sea ice existence Heidke Skill Score (HSS)
(Mar-Oct 2015-2018 forecasts)



$$HSS = \frac{AC - AC_e}{AT - AC_e}$$

AC: Area of correct forecast
AC_e: Area of expected correct forecast
AT: Area of total forecast grid boxes
(Sea ice exists if SIC > 15%)

- Overall improvements in CPC experimental system in predicting sea ice melt over CFSv2
- Forecasts for summer (Jul-Sep) sea ice melt in CFSv2 is not useful
- CPC experimental system has difficulties in predicting sea ice freeze-up.

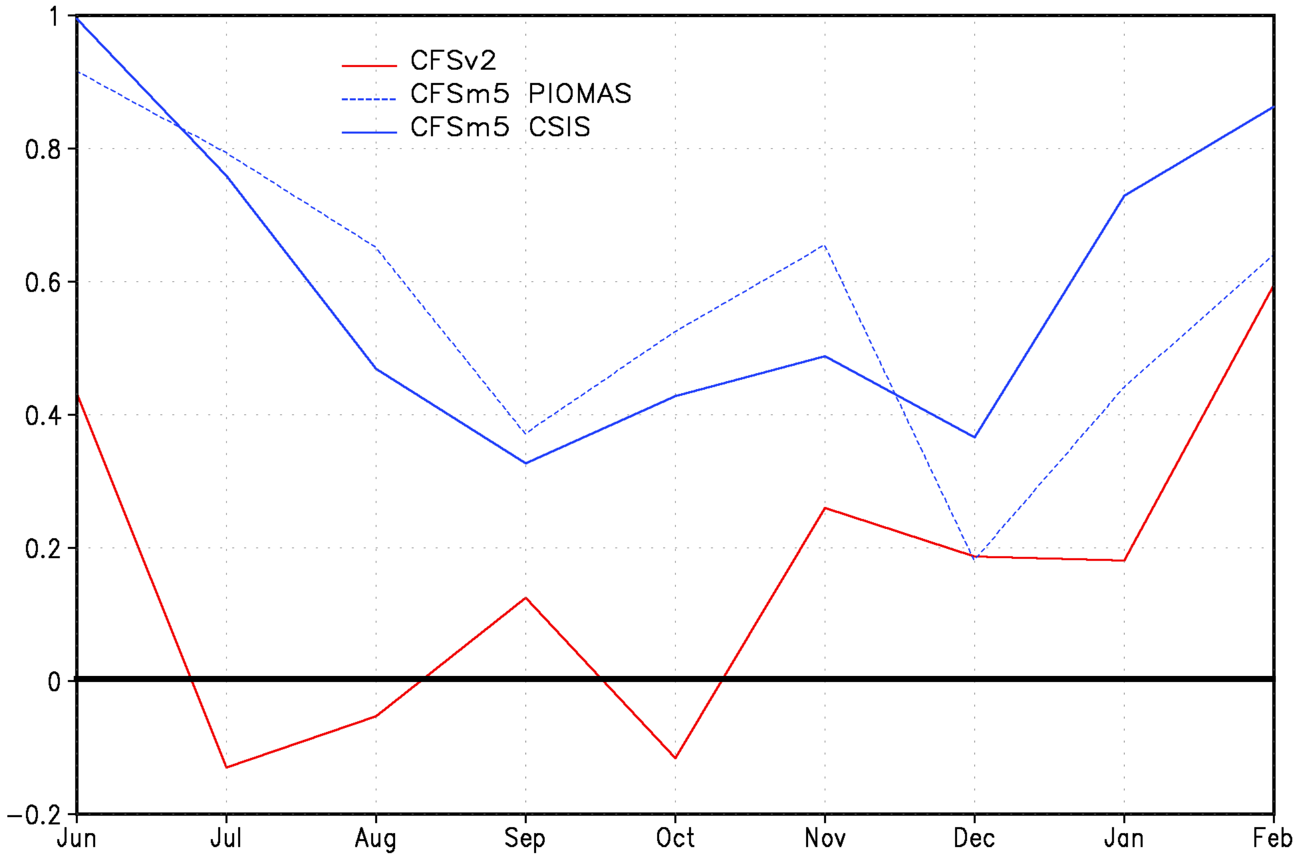
4). Sea ice predictions

- performance evaluation

Seasonal predictions

SIE ACC from seasonal predictions

(May initial conditions, 2006-2017)



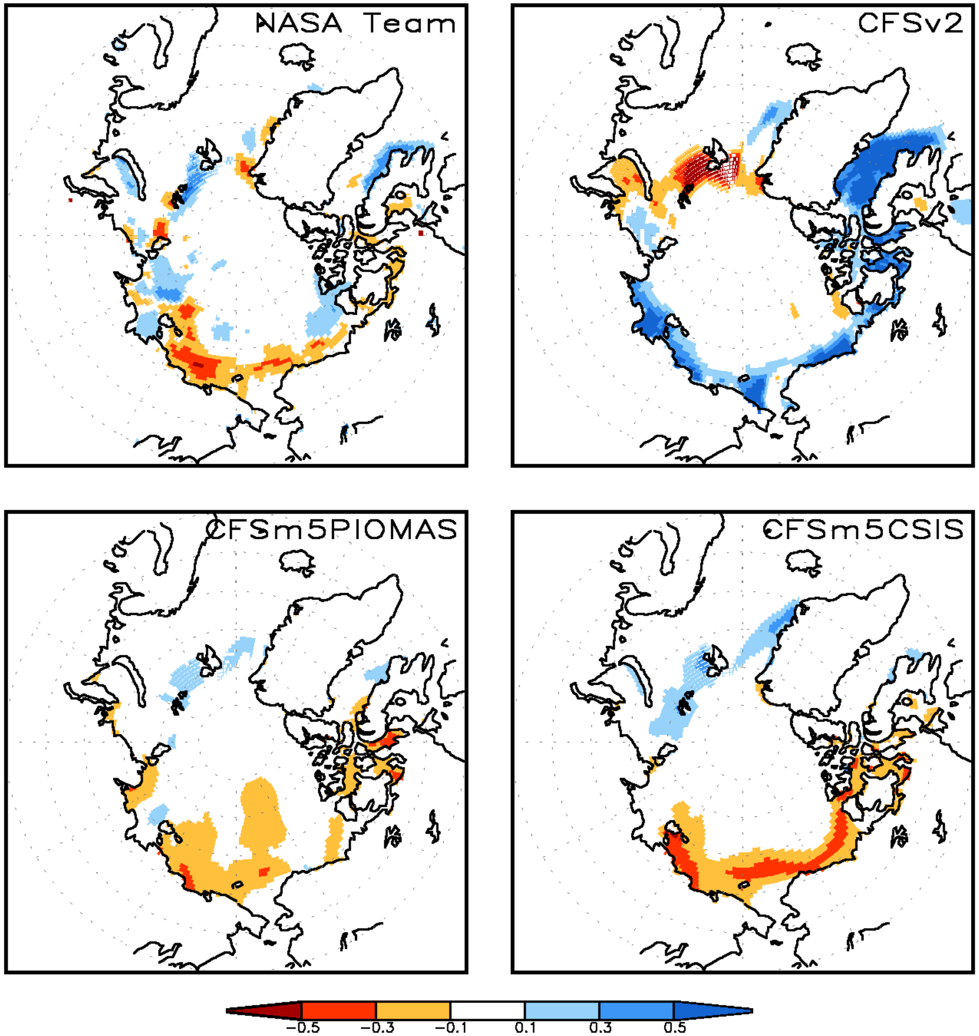
4). Sea ice predictions

- performance evaluation

Seasonal predictions

Jul 2017 sea ice concentration anomalies

May 2017 initial conditions



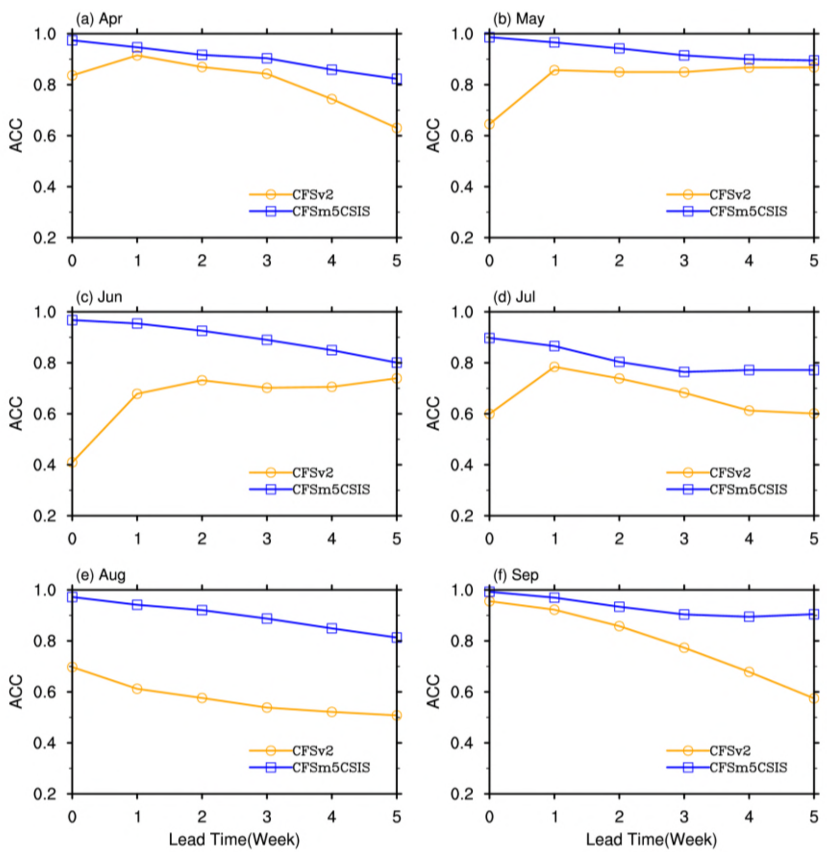
4). Sea ice predictions

- performance evaluation

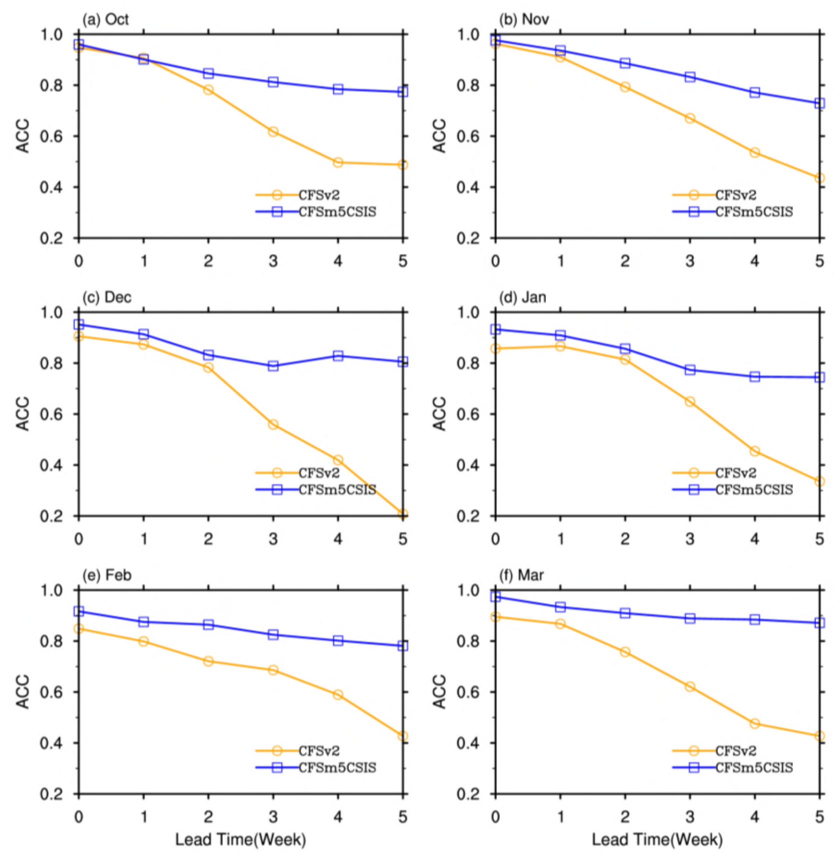
Week-3/4 predictions

Arctic SIE ACC, 2012-2018

Melt season



Freeze-up season



4). Sea ice predictions

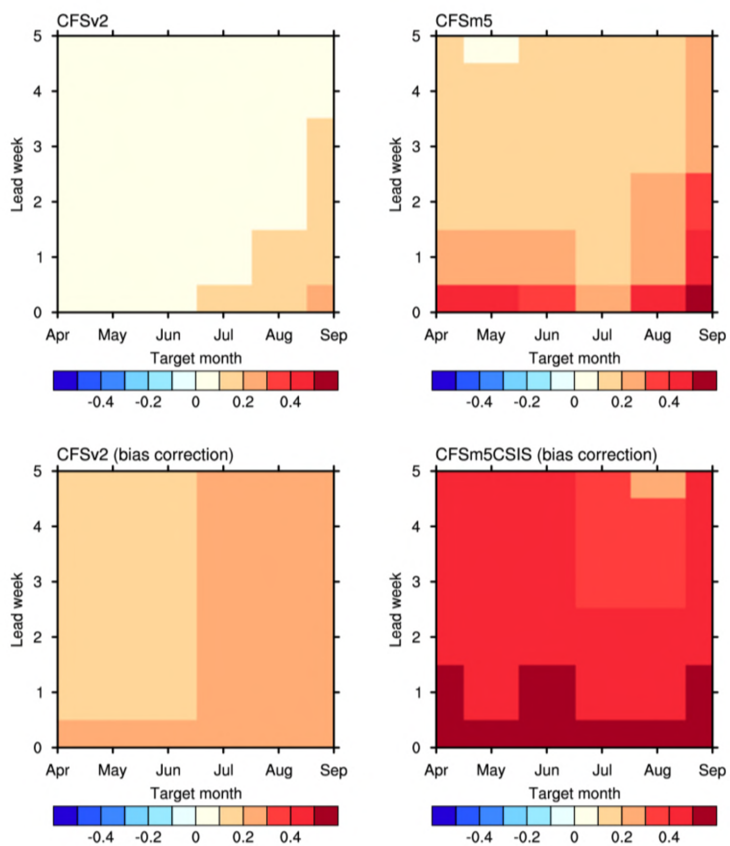
- performance evaluation

Week-3/4 predictions

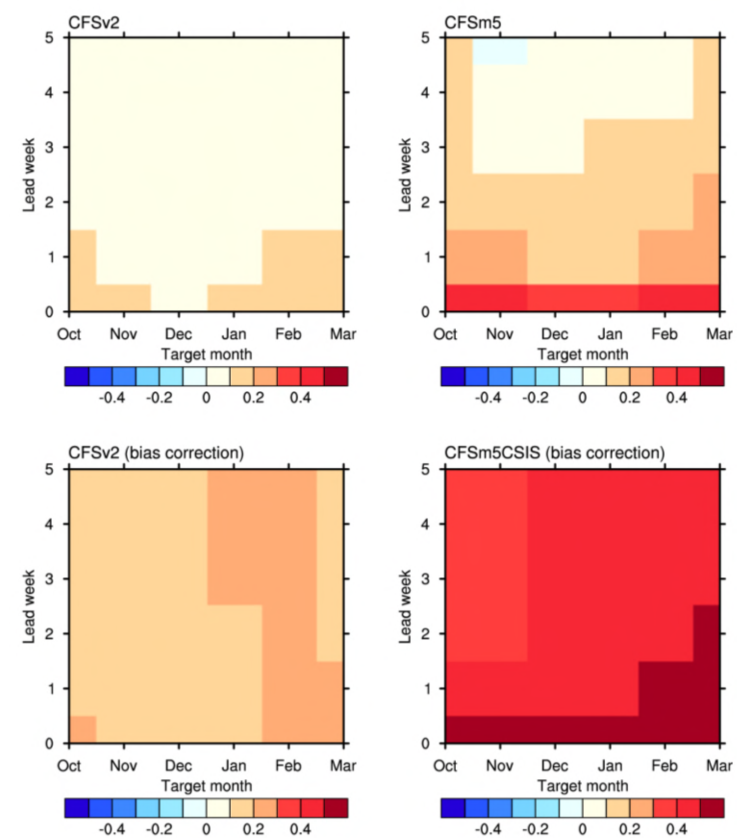
Heidke Skill Score, 2012-2018

$$HSS = \frac{AC - AC_e}{AT - AC_e}$$

Melt season



Freeze-up season

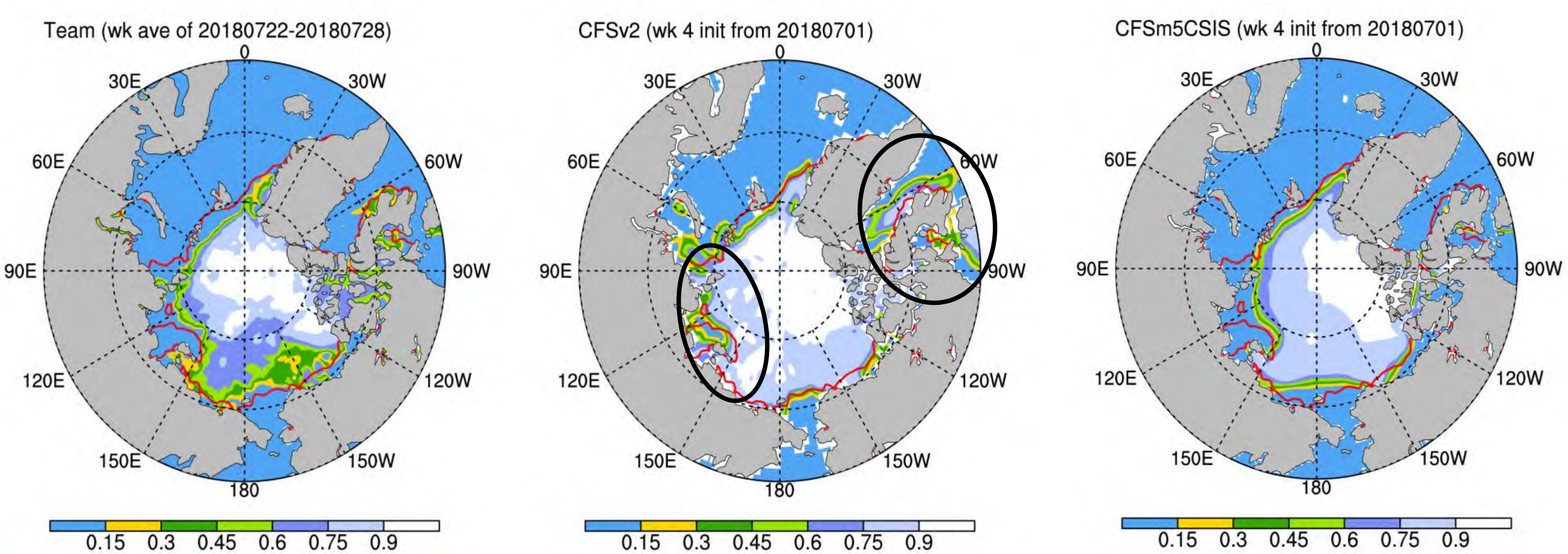


4). Sea ice predictions

- performance evaluation

Week-3/4 predictions

Week 4 (Jul 22-28) forecast from 20180701



- CFSv2: Too much sea ice in Kara Sea, Laptev Sea, Hudson Bay, Baffin Bay
- CFSv2 and CFSm5: Too much sea in Beaufort Sea

5). CPC Sea ice forecast products

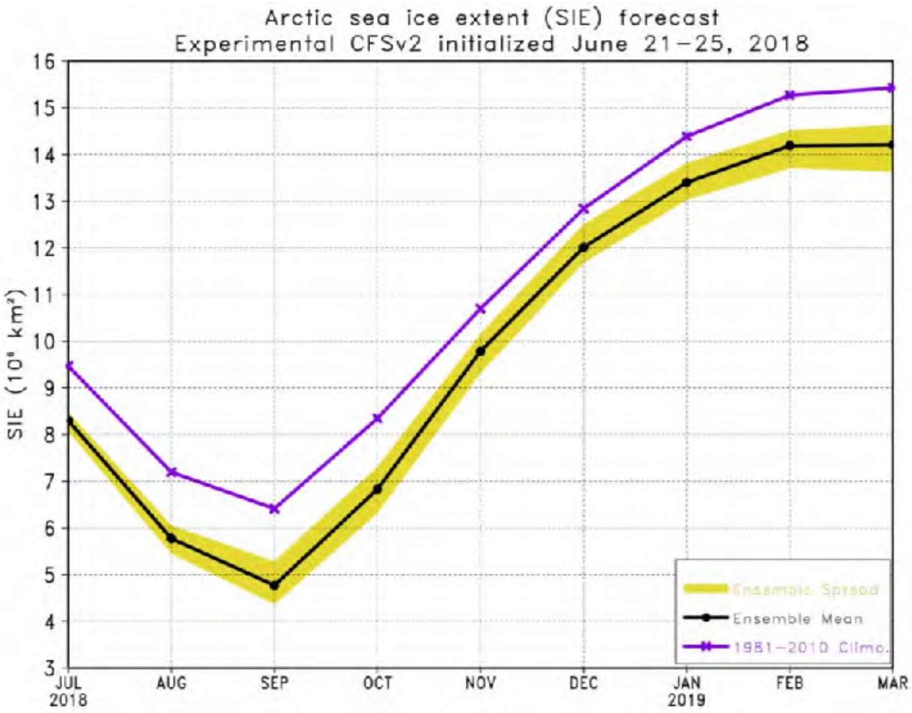
Seasonal Sea Ice prediction

- Monthly mean ice extent
- Monthly mean sea ice concentration
- Probability of monthly mean sea ice
- First ice melt day (IMD) and ice freeze day (IFD)

5). CPC Sea ice forecast products

<u>Seasonal Sea Ice prediction</u>

- Monthly mean ice extent
  - Total area of grid boxes where monthly mean sea ice concentration is greater than 15%
  - Ensemble mean and ensemble spread

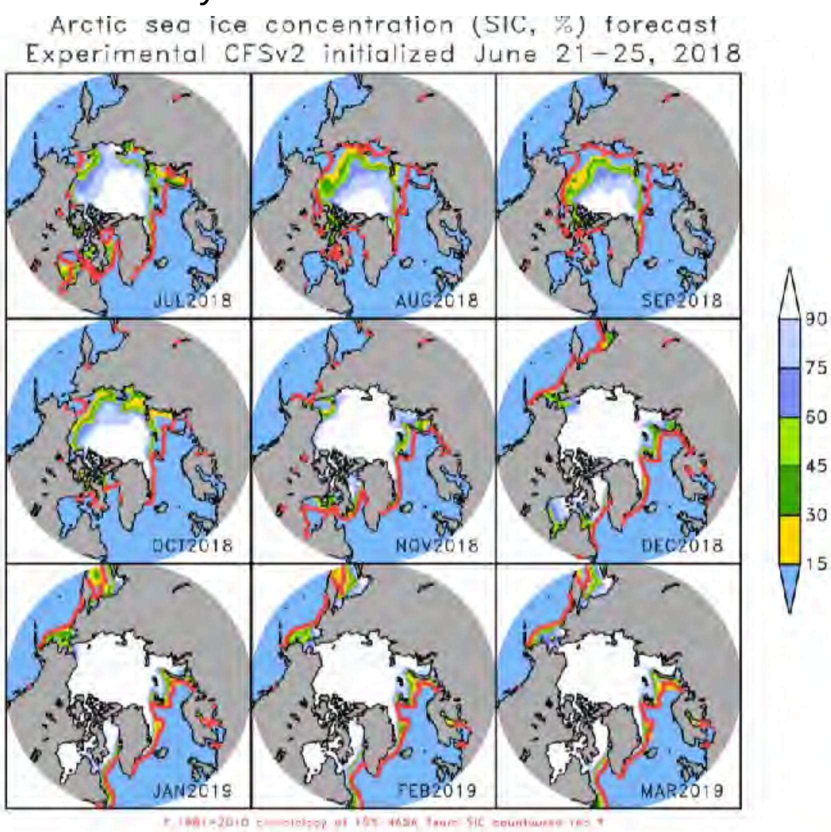


5). CPC Sea ice forecast products

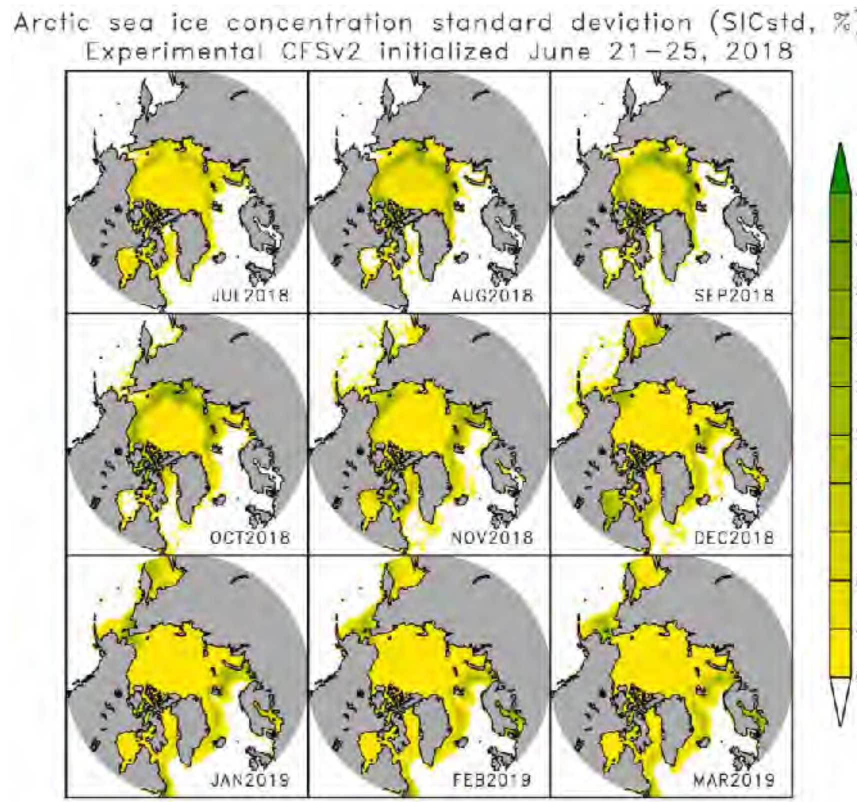
Seasonal Sea Ice prediction

- Monthly mean sea ice concentration
  - Ensemble mean and spread

Monthly mean sea ice concentration



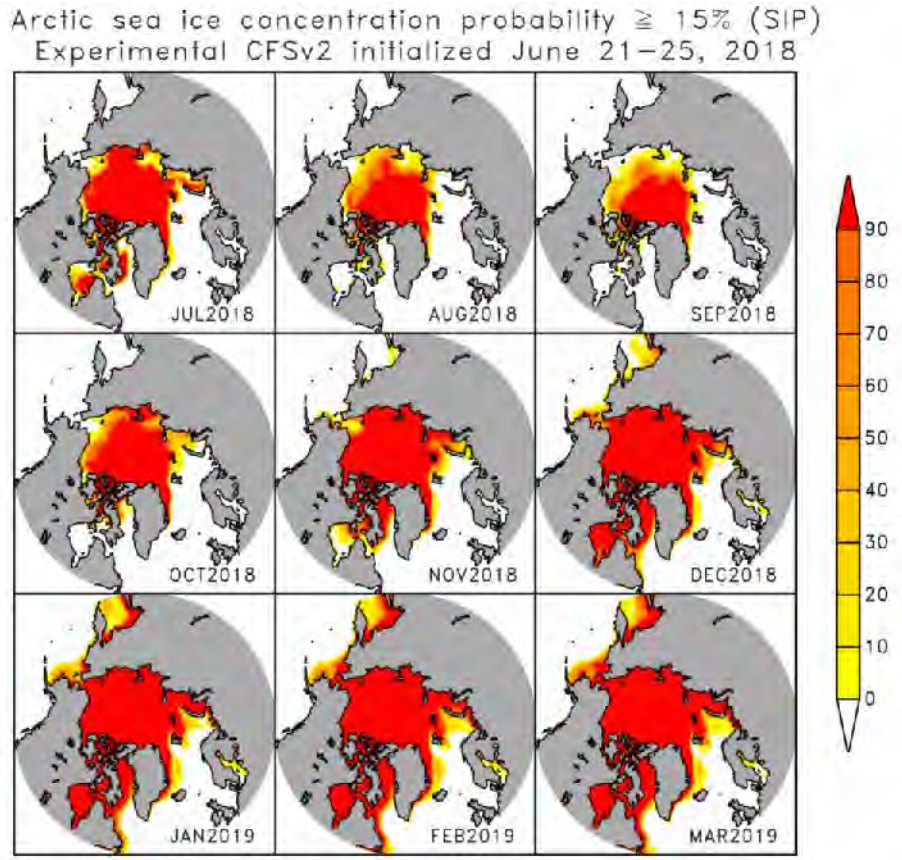
Monthly sea ice concentration spread



5). CPC Sea ice forecast products

Seasonal Sea Ice prediction

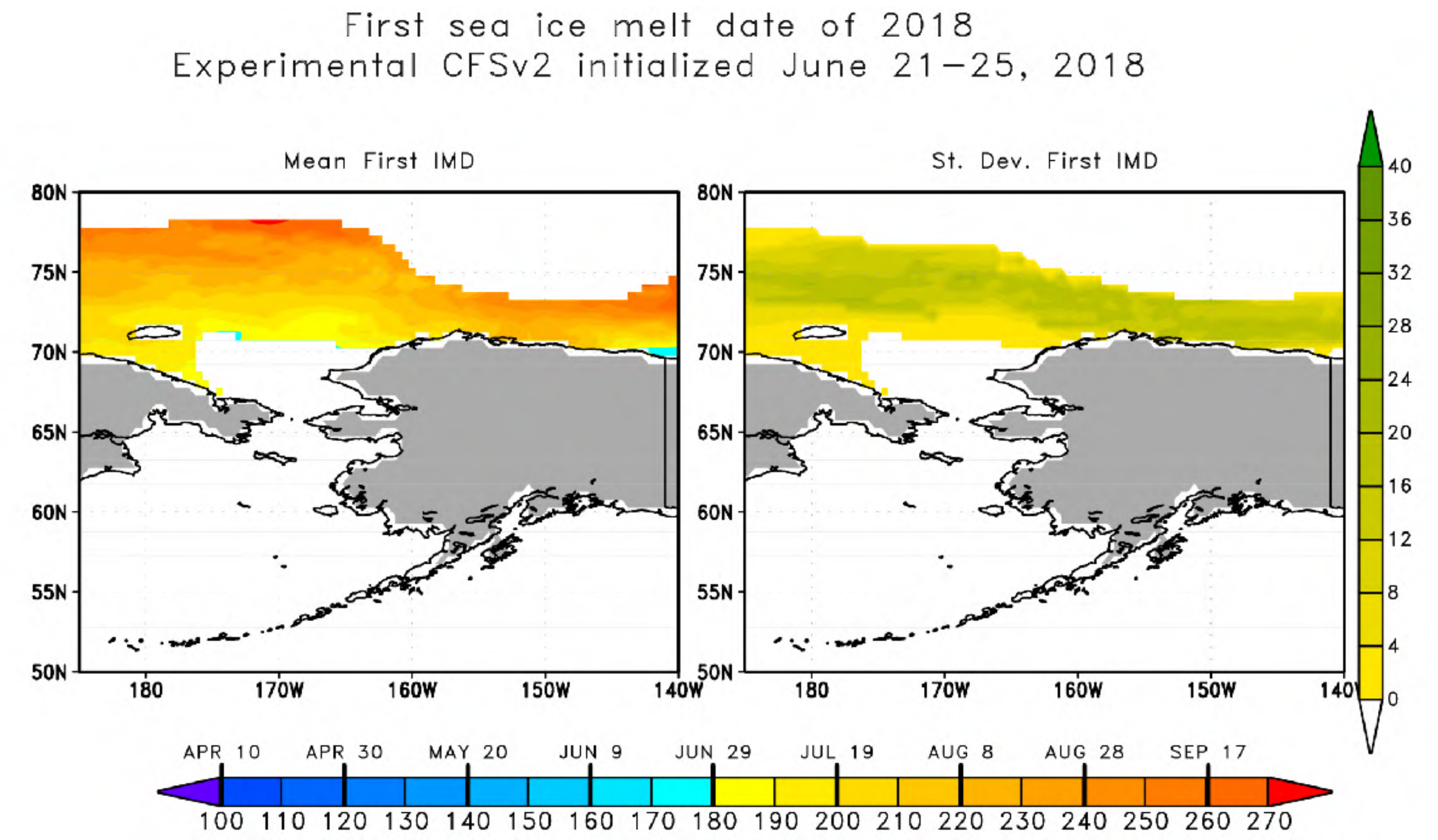
- Probability of monthly mean sea ice
  - Concentration greater than 15%



5). CPC Sea ice forecast products

Seasonal Sea Ice prediction

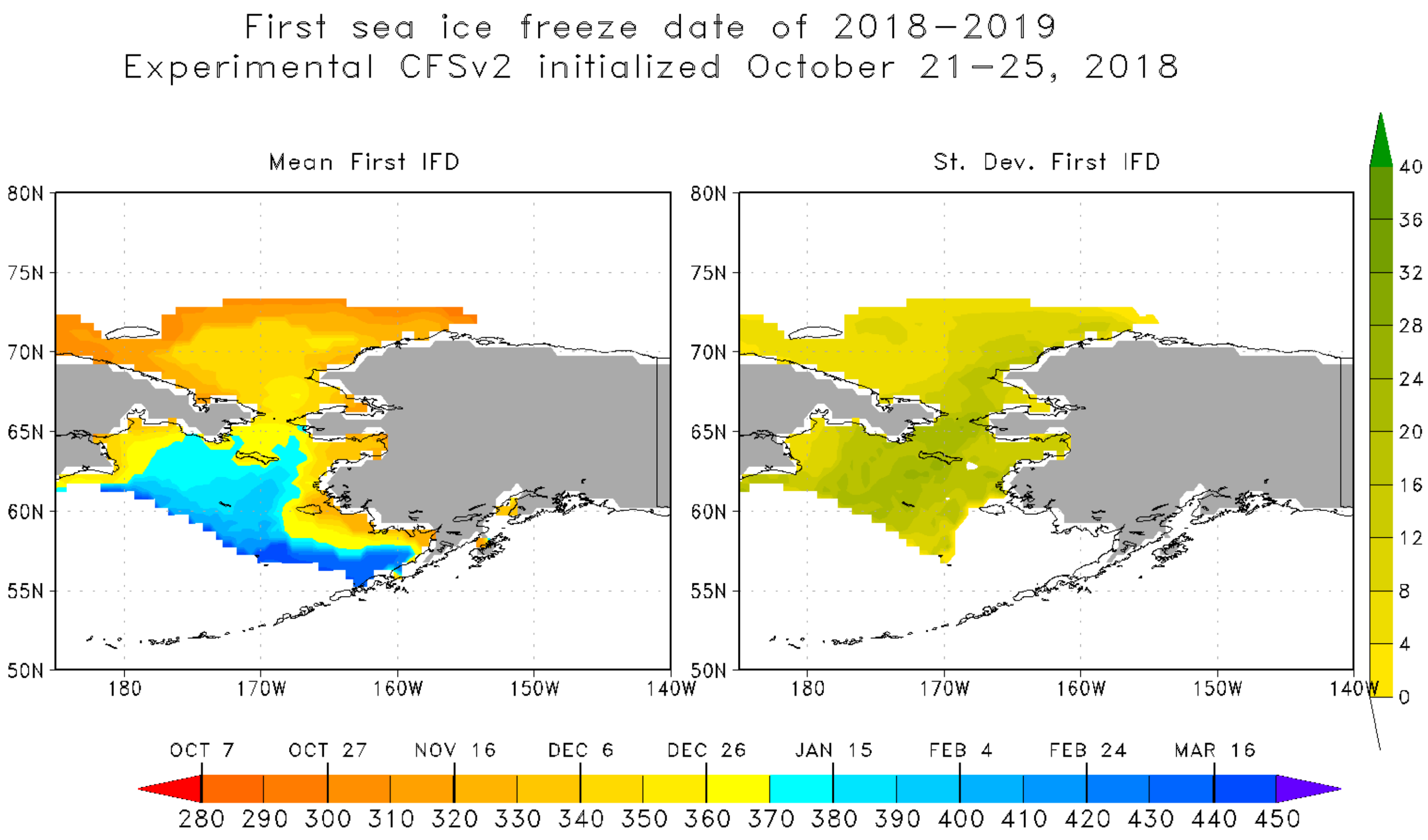
- First ice melt day (IMD) and ice freeze day (IFD)
  - Ensemble mean and spread



5). CPC Sea ice forecast products

<u>Seasonal Sea Ice prediction</u>

- First ice melt day (IMD) and ice freeze day ([IFD](IFD))
  - Ensemble mean and spread



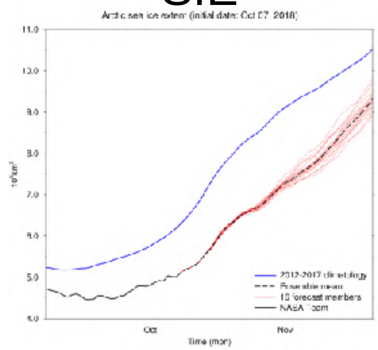
5). CPC Sea ice forecast products

Weekly Sea Ice prediction

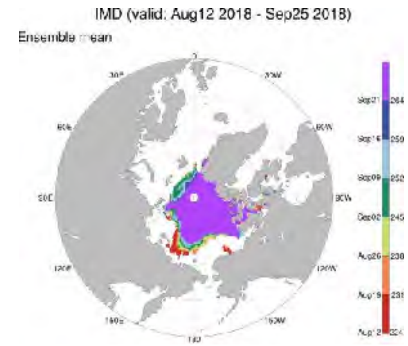
- **Forecast Model**
  - **CFSm5**: GFS (T126,L64)
  - MOM5 (0.5x0.5, L40)
- **Initialization**
  - **Sea ice**: CSIS (CPC Sea ice Initialization System)
  - **Ocean**: CSIS
  - **Atmos.**: CFSR
- **Forecast**
  - **Target**: Weeks 1-6 target
  - **Update**: weekly
- **Products**
  - **SIE**: Sea ice extent
  - **SIC**: Sea ice concentration
  - **IMD**: Sea ice melt date
  - **IFD**: Sea ice freeze-up date

http://www.cpc.ncep.noaa.gov/products/people/wwang/seaice_wk34

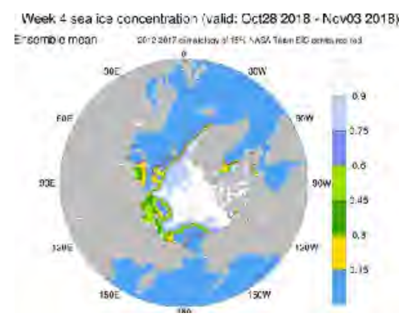
SIE



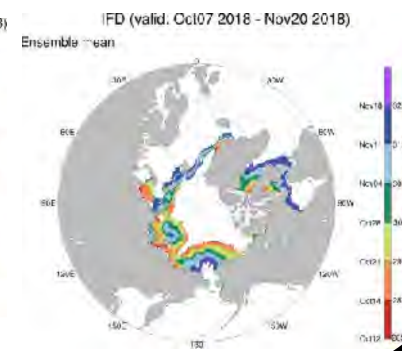
IMD



SIC



IFD



Part 1 Summary

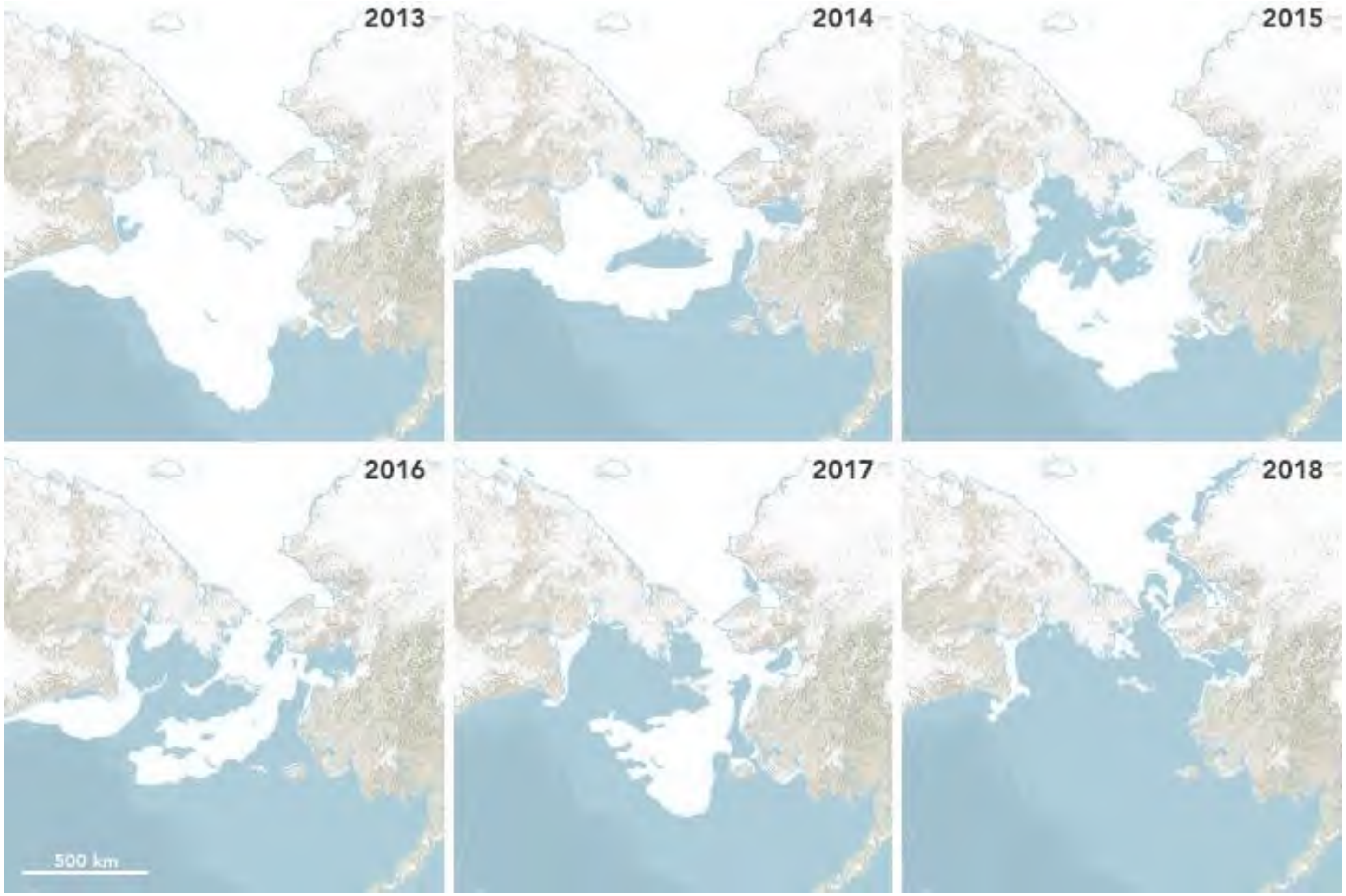
- Substantial errors in the NCEP operational climate forecast system (CFSv2)
- Significant improvement in CPC experimental sea ice predictions for both week 3/4 and seasonal time scales
- CPC provides week 3/4 and seasonal sea ice forecast products routinely
- Additional work is required to further reduce model bias in winter season

A forecast case assessment

Record-low Bering Sea sea ice extent in 2018 spring

Record-low Bering Sea sea ice extent in 2018 spring

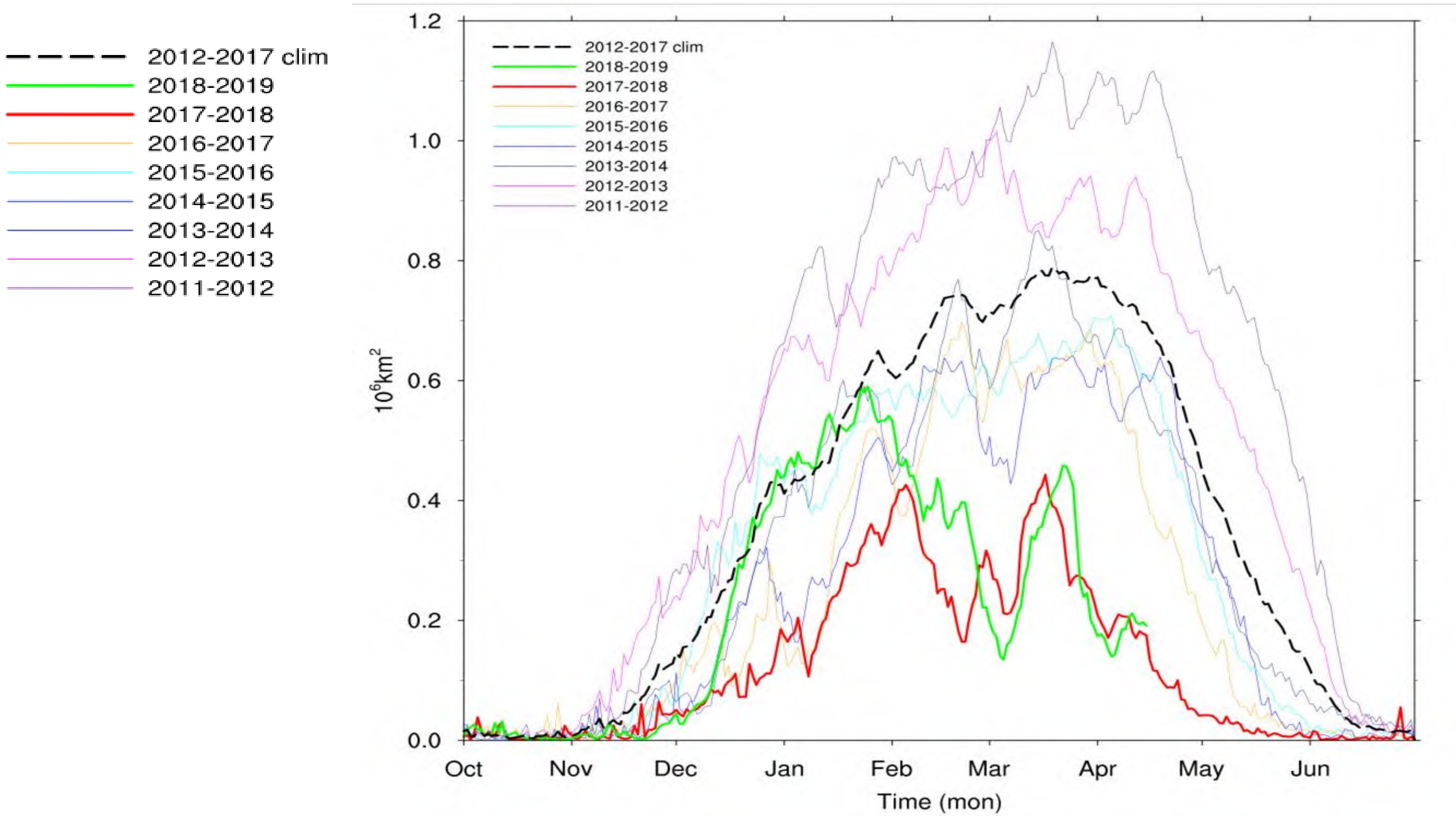
Sea ice coverage on April 30, 2013-2018



https://climate.nasa.gov/news/2726/historic-low-sea-ice-in-the-bering-sea/

Record-low Bering Sea sea ice extent in 2018 spring

Bering Sea daily SIE



Record-low Bering Sea sea ice extent in 2018 spring

The report said the Bering Sea's record-low 2018 ice cover was due to two factors:

(1) Warmer temperatures ice/albedo feedback

(2) **Increased storms**.

Warmer air and water temperatures have interacted with lower ice levels over the past four winters to create a feedback loop leading to even greater melting.
"Open water absorbs heat more than ice-covered water. Less sea ice means warmer ocean water, and warmer ocean water generally means less and thinner sea ice," the report said.
The winter of 2018 also saw more storms than usual in the region, meaning that when ice did form, it was broken up again.

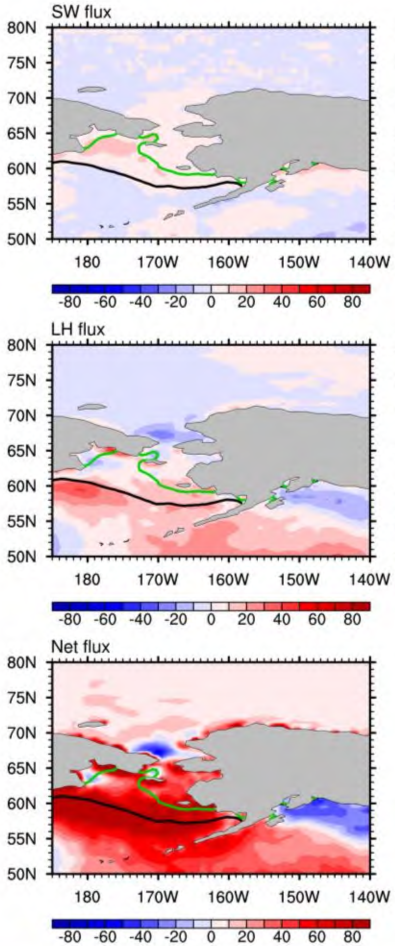
According to The Washington Post, Bering Sea ice took a major hit during an arctic heatwave in February, when one third of it melted in a week. While ice cover increased during March, it was reversed again by storms from the south beginning March 21, leading to a low-ice spring, the IARC report said.

"Communities need to prepare for more winters with low sea ice and stormy conditions. Although not every winter will be like this one, there will likely be similar winters in the future. Ice formation will likely remain low if warm water temperatures in the Bering Sea continue," the report concluded.

Record-low Bering Sea sea ice extent in 2018 spring

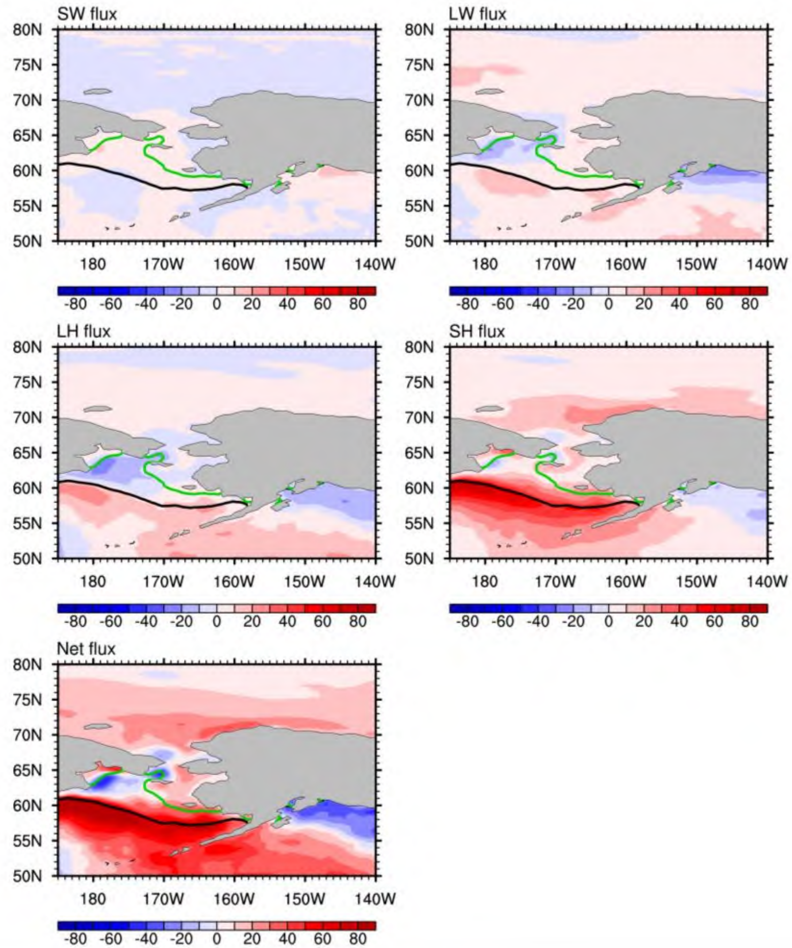
Feb 2018 surface heat flux anomalies

CFSR



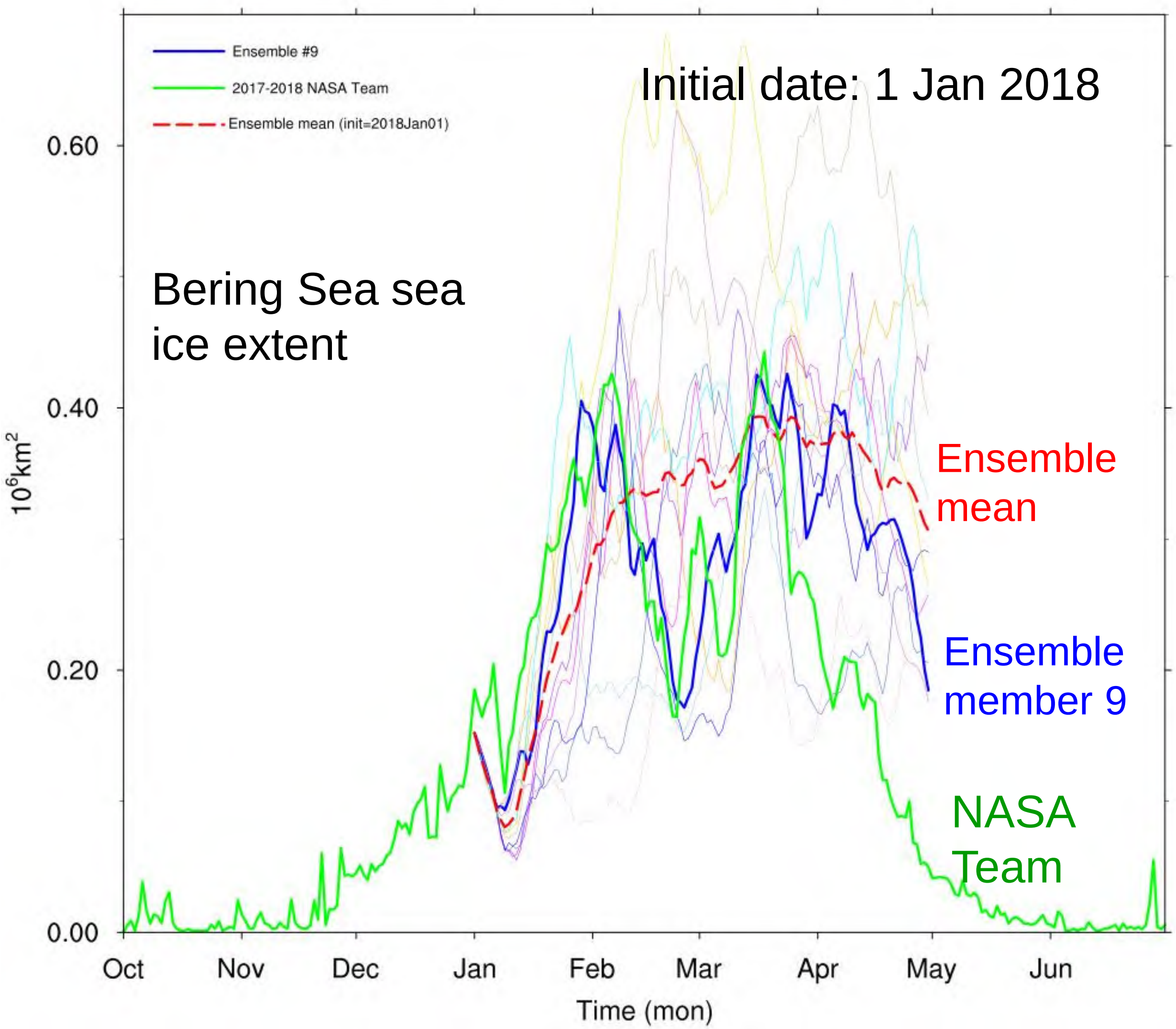
Increased sensible heat flux appeared to be the primary cause of the anomalous sea ice melt

MERRA2



Record-low Bering Sea sea ice extent in 2018 spring

CPC experimental prediction with CFSm5

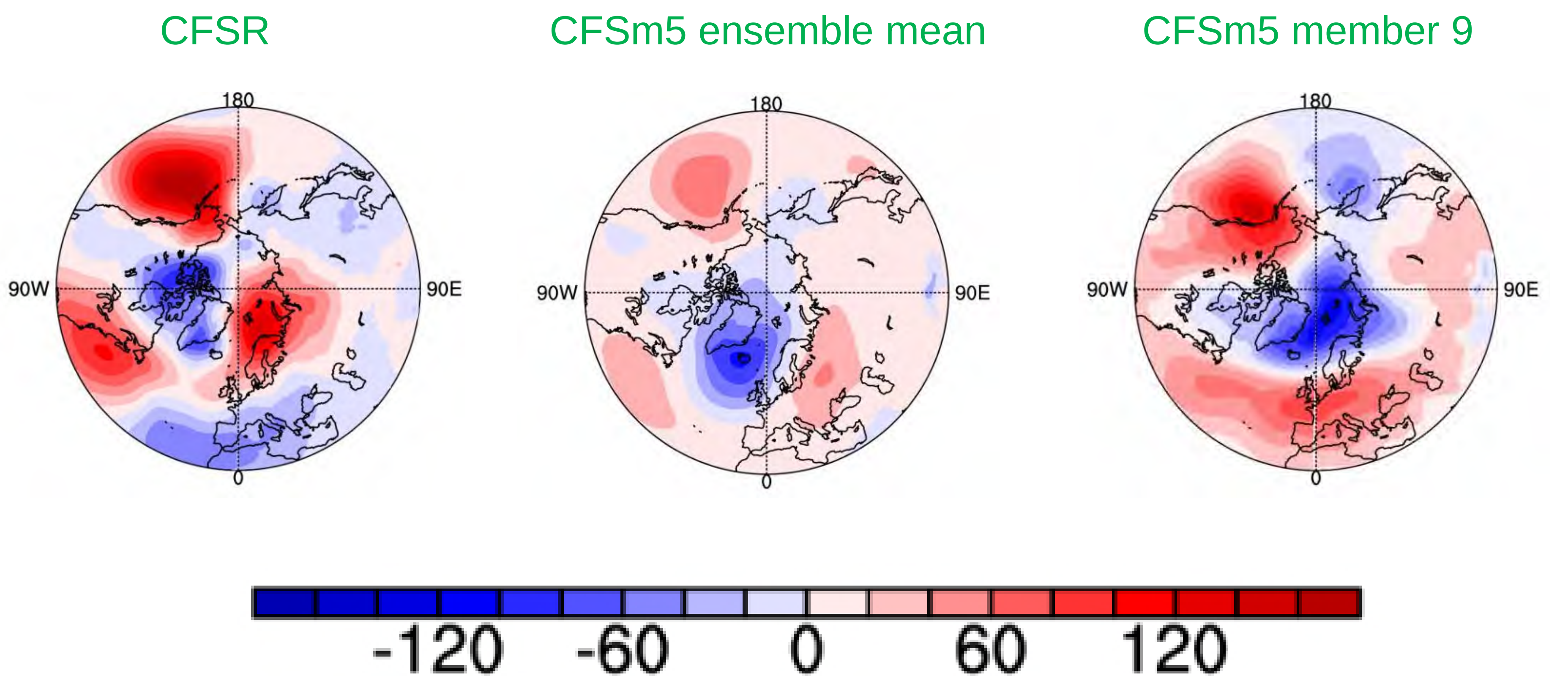


- Reasonable prediction for the first month
- Unable to capture sub-monthly variations beyond one month.
- Observed variations were replicated in some members (e.g., ensemble member 9)

Record-low Bering Sea sea ice extent in 2018 spring

CPC experimental prediction with CFSm5

Feb 2018 850hPa Geopotential Height Anomalies



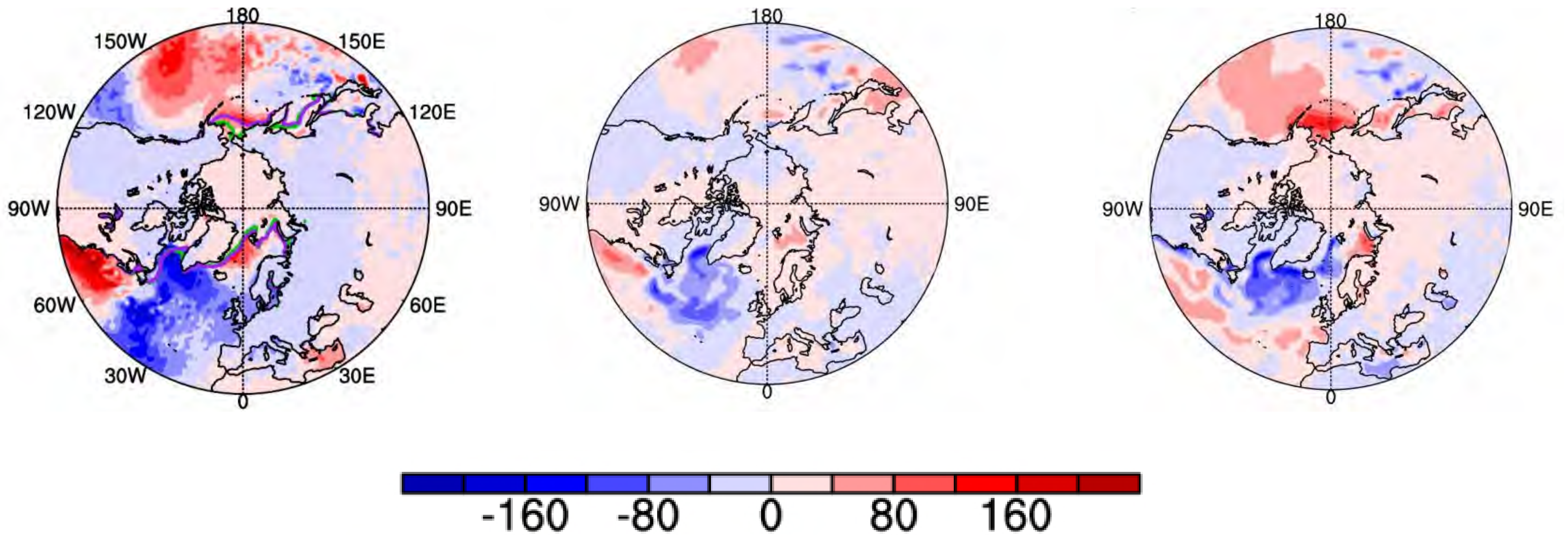
- CFSm5 capture the pattern in ensemble mean but with weaker amplitude
- Member 9 is similar to observed pattern with comparable amplitude

Record-low Bering Sea sea ice extent in 2018 spring

CPC experimental prediction with CFSm5

Feb 2018 sensible Heat Flux Anomalies

CFSR | CFSm5 ensemble mean | CFSm5 member 9



- CFSm5 capture the pattern in ensemble mean but with weaker amplitude
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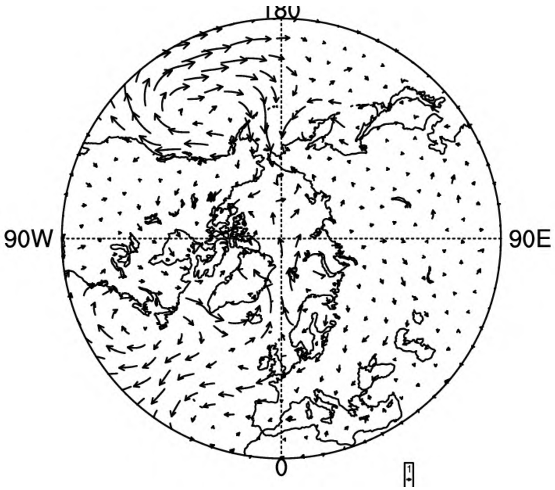
Record-low Bering Sea sea ice extent in 2018 spring

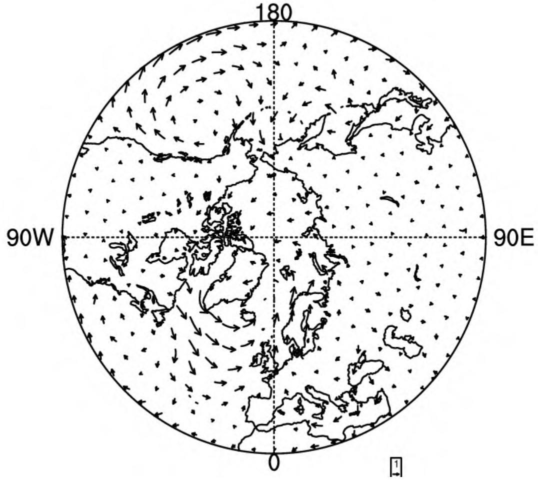
CPC experimental prediction with CFSm5

Feb 2018 10m Wind Anomalies

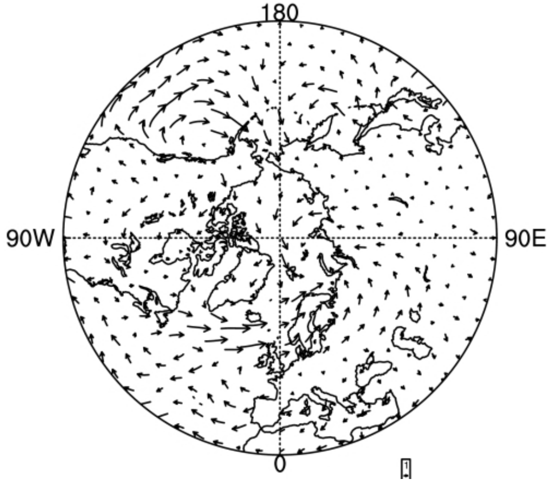
CFSR



CFSm5 ensemble mean



CFSm5 member 9



- CFSm5 capture the pattern in ensemble mean but with weaker amplitude
- Member 9 is similar to observed pattern with comparable amplitude

Record-low Bering Sea sea ice extent in 2018 spring

CPC experimental prediction with CFSm5

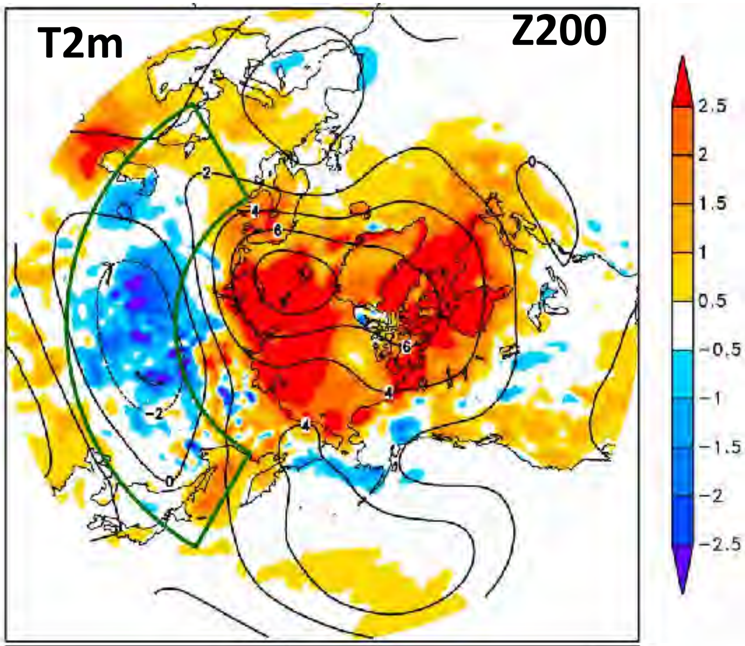
- CFSm5 is capable of reproducing observed patterns with weaker amplitude for February 2018
- Observed patterns were captured more realistically in certain ensemble members
- The CFSm5 forecasts suggest that the observed 2019 Bering Sea sea ice extent anomalies resulted from combination of low frequency (period > 1 month) and high-frequency (period < 1 month) variability.

2. Sea ice impacts on lower latitudes

1) Northern mid-latitude 2-m temperature trend

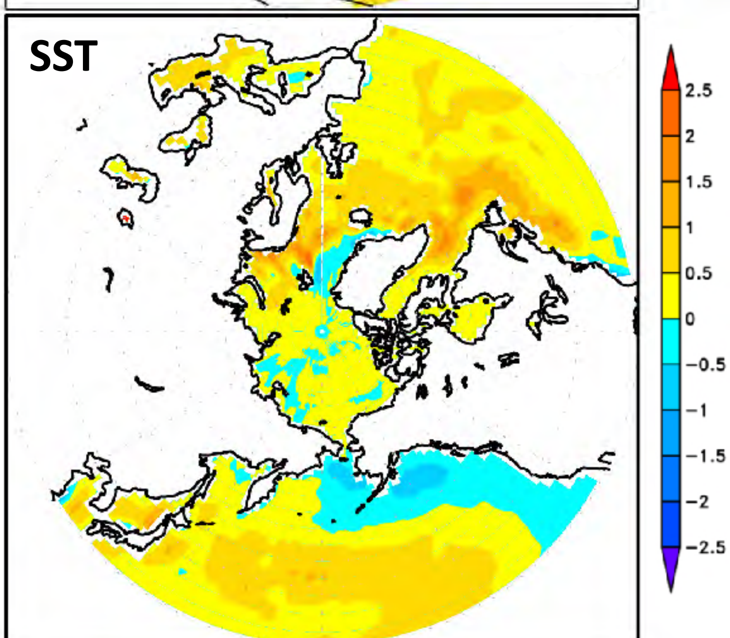
2) Northern mid-latitude 2-m temperature variability

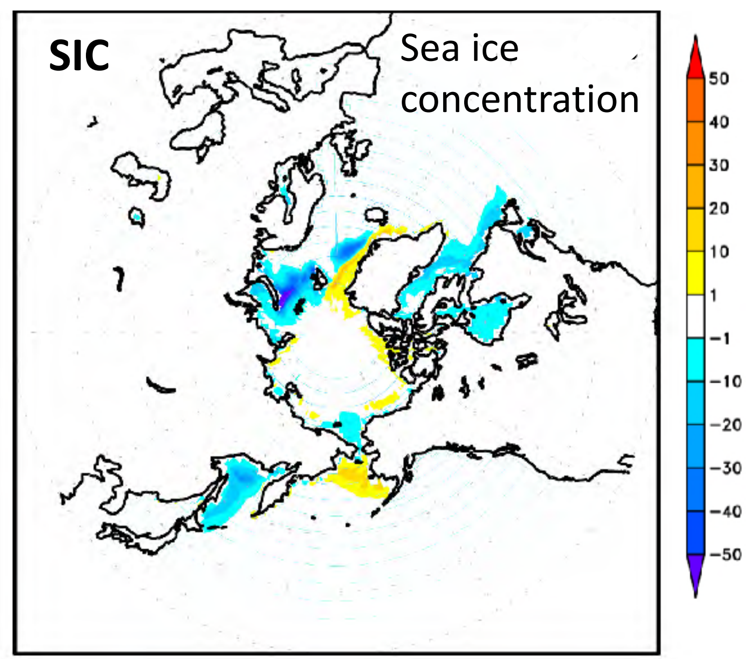
Dec-Jan-Feb changes (2005-2014 minus 1981-1990)



Observations during the past a few decades

- Cooling temperature trend in Eurasia; warming in Arctic region
- Global warming in SST
- Decreasing coverage in Arctic sea ice





Was the Eurasian cooling trend a result of sea ice decrease?

Yes:

Honda et al. 2009 Liu et al. 2012 Mori et al. 201
Nakamura et al. 2014 Kug et al. 2015 Screen 2017
......

No:

Kumar et al. 2010 Screen et al. 2013 Gerber et al. 2014
Pelwitz et al. 2015 Li et al. 2015 Sun et al. 2016
McCusker et al. 2016 Blackport et al. (2019) ......

Questions to address

- Was the DJF Eurasian temperature trend a response to the observed sea ice and SST changes or a result of atmospheric internal variability?

- Was the Eurasian cooling trend predictable in initialized seasonal predictions?

Approach

1. ***Atmosphere-only model*** **simulations forced with specified 10-year mean SIC and SST of 1981-1990 and 2005-2014**

   Differences between simulations are taken as the atmospheric response to changes in *SST* or *SIC*, or *SST* and *SIC*

2. ***Coupled-model*** **initialized seasonal predictions for 1982-1990 and 2005-2013**

   Differences between the two periods are considered as the impacts of *SST* and *SIC*, as well as *atmospheric initial conditions*

Models

1. Atmosphere-only model

NCEP CFSv2: NCEP CFSv2 atmospheric component GFS

2. Coupled models (NMME - North American Multi-Model Ensemble)

- CFSv2: NCEP GFS/ GFDL MOM4
- CMC1: Third Generation Canadian Coupled Global Climate Model
- CMC2: Fourth Generation Canadian Coupled Global Climate Model
- NASA: Goddard Earth Observing System version 5 (GEOS5)
- CCSM: The NCAR Community Climate System Model (CCSM4)
- GFDL: Geophysical Fluid Dynamics Laboratory

Atmosphere-only simulations - impacts of

- Sea ice
- SST
- Sea ice + SST

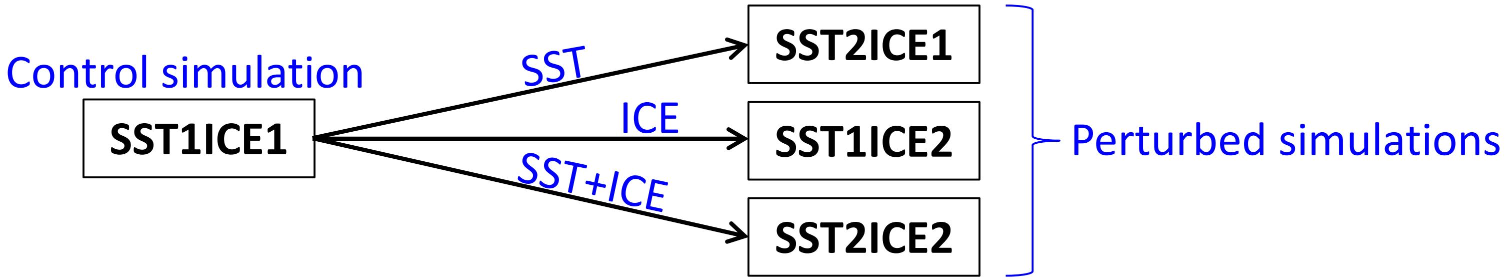
Simulations (CFSv2 Atmosphere-only)

- Surface conditions (Hurrell et al., 2008)
  - **SST1**: 1981-1990 average SST
  - **ICE1**: 1981-1990 average sea ice concentration
  - **SST2**: 2005-2014 average SST
  - **ICE2**: 2005-2014 average sea ice concentration

- Simulations (100 years with repeating SST and ice)
  - SST1ICE1
  - SST2ICE1
  - SST1ICE2
  - SST2ICE2

Analysis

- Mean impact of SST, ICE, SST+ICE (100-year average)



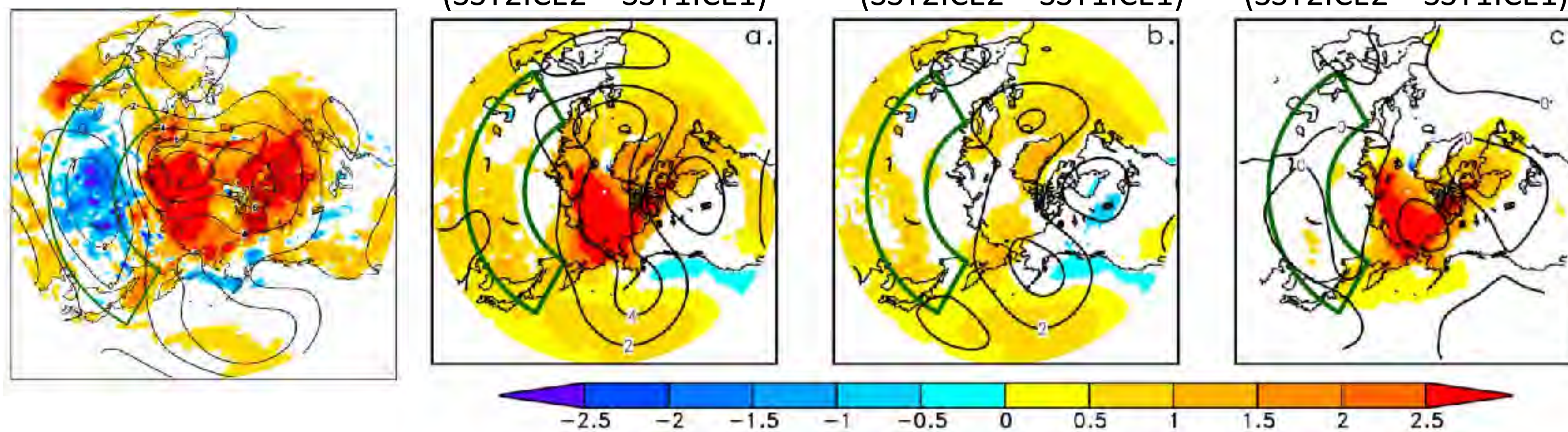
- Differences in 10-year average between simulations
  - 100 combinations of 10-year average differences
  - Distribution of 10-year-average differences
  - Extremeness of 10-year-average differencesd

100-year mean response

DJF T2m (shading) and Z200 (contour)

Observation — **Simulation**

ERA-I	SST + ICE (SST2ICE2 – SST1ICE1)	SST (SST2ICE2 – SST1ICE1)	ICE (SST2ICE2 – SST1ICE1)



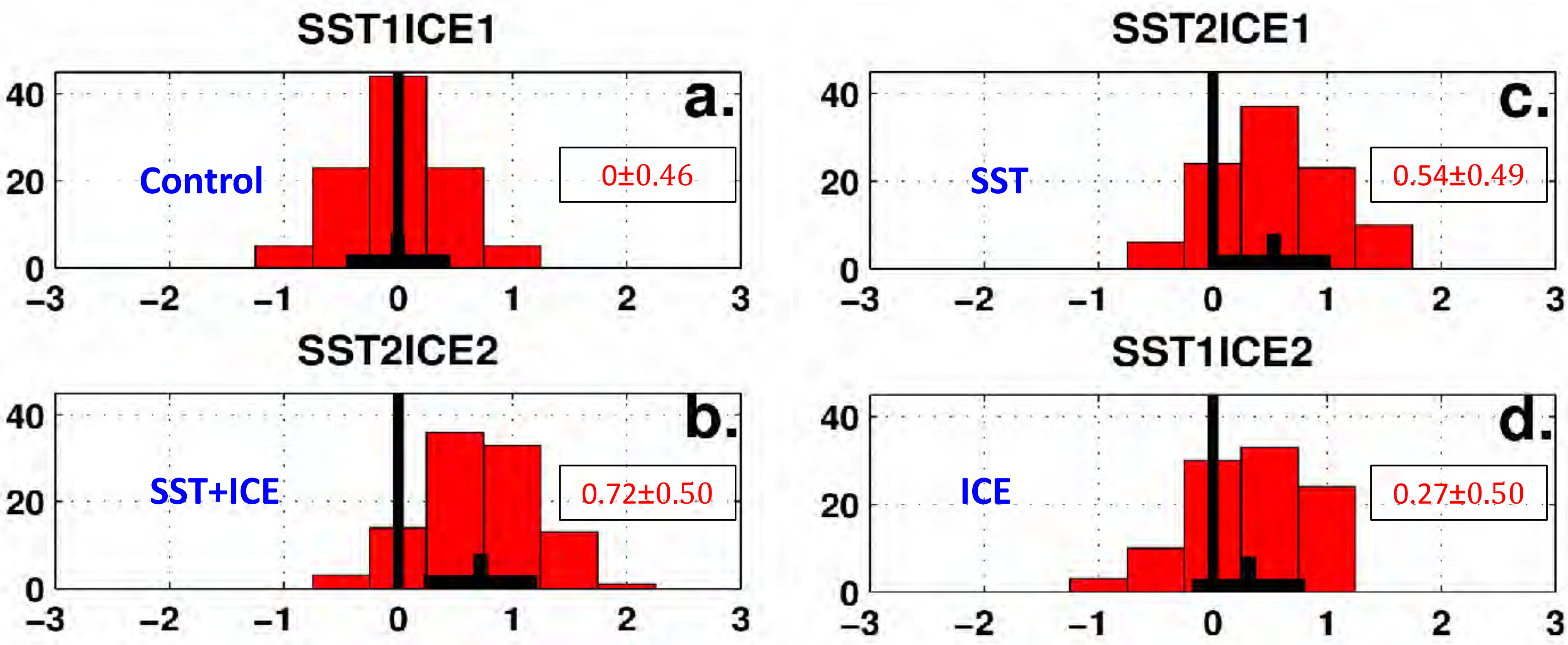
Eurasian average:	-0.27	0.72	0.54	0.27

- **ICE perturbation**: Large Arctic warming; very weak warming in lower latitudes
- **SST perturbation**: Weaker but uniform warming over the globe
- **SST+ICE perturbations**: Large Arctic warming ; weaker warming at lower latitudes.

No Eurasian cooling in the mean response in all perturbed simulations

Distribution of 10-year-mean temperature change over the *Eurasian domain*

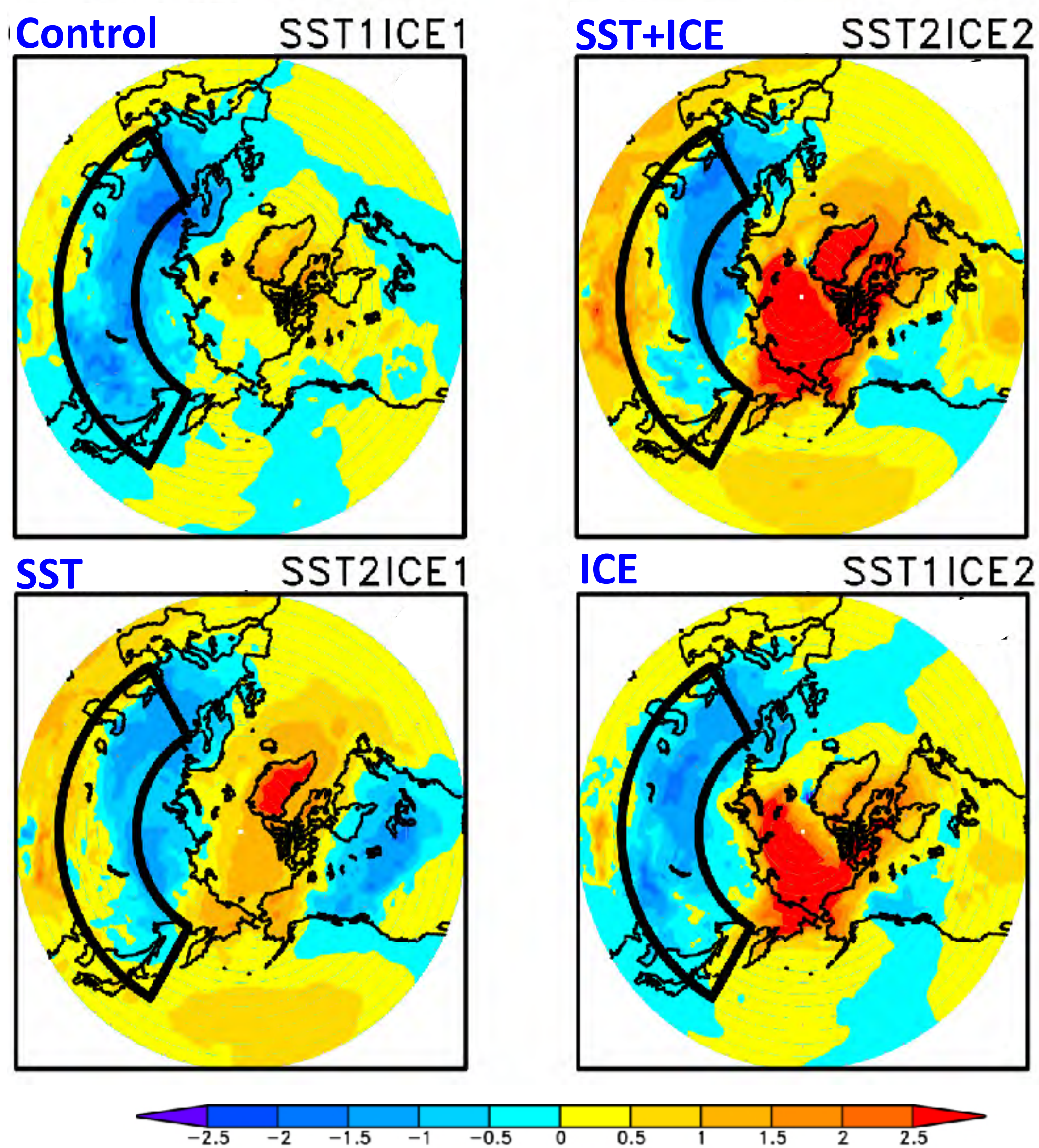
(100 combinations of differences relative to SST1ICE1)



- **NO perturbation:** Normal distribution
- **Perturbations**: (1) Positive mean shift.
  (2) Increased probability of warm extremes
  (3) Reduced probability of cold extremes

Extreme temperature differences

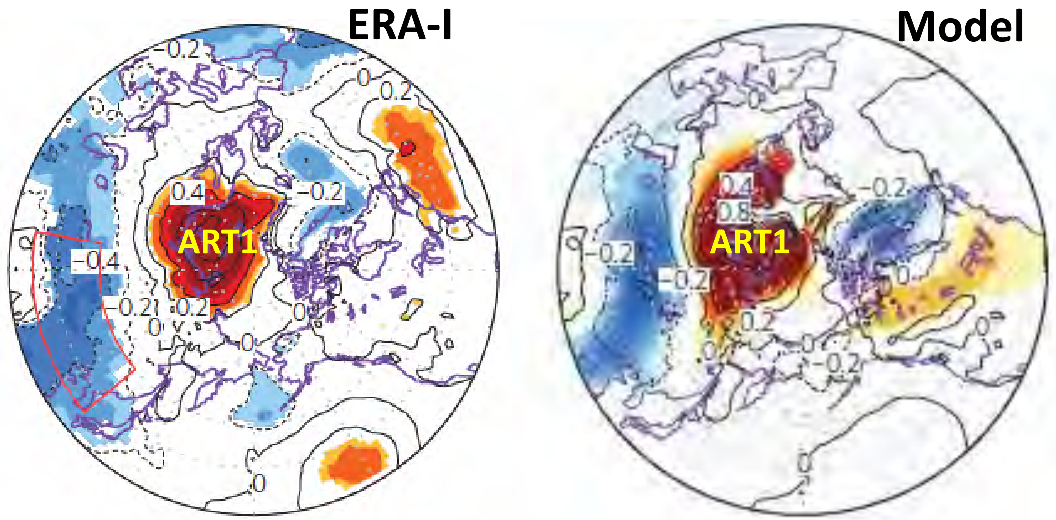
- Each panel is average of **10** coldest Eurasian combinations.
- Cold extremes can be simulated in each of the simulations.
- Warmer Arctic with ice perturbation.
- Warmer open ocean with SST perturbation.



Relationships between Arctic temperature Index and SAT over NH

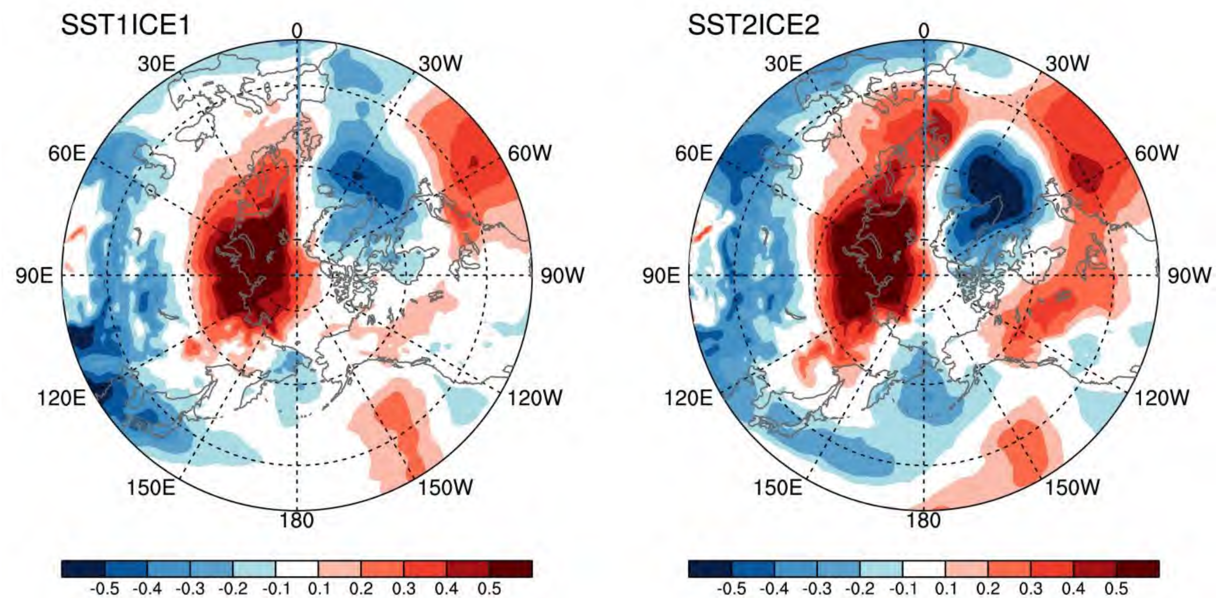
(Courtesy Kug et al. 2015)

ART1: SAT Barents-Kara Sea
(30E-70E, 70N-80N)



- Observed pattern correlation can be well reproduced with constant sea ice and SST
- "Warm Arctic – cold continent" pattern does not necessarily indicate the impact of Arctic sea ice

CFSv2 atmosphere-only runs

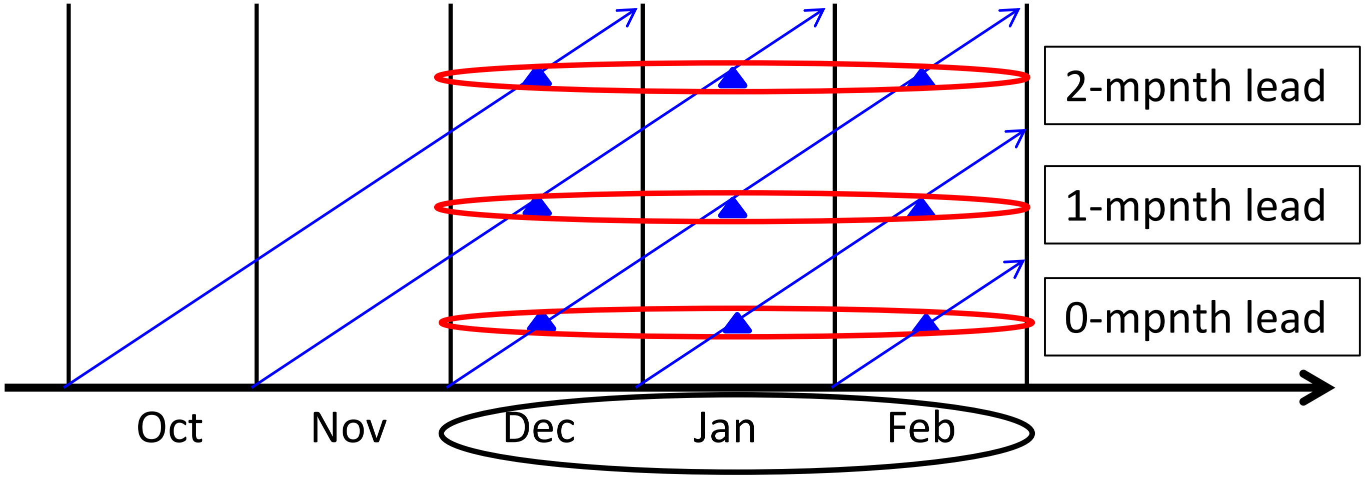


Coupled predictions - impacts of

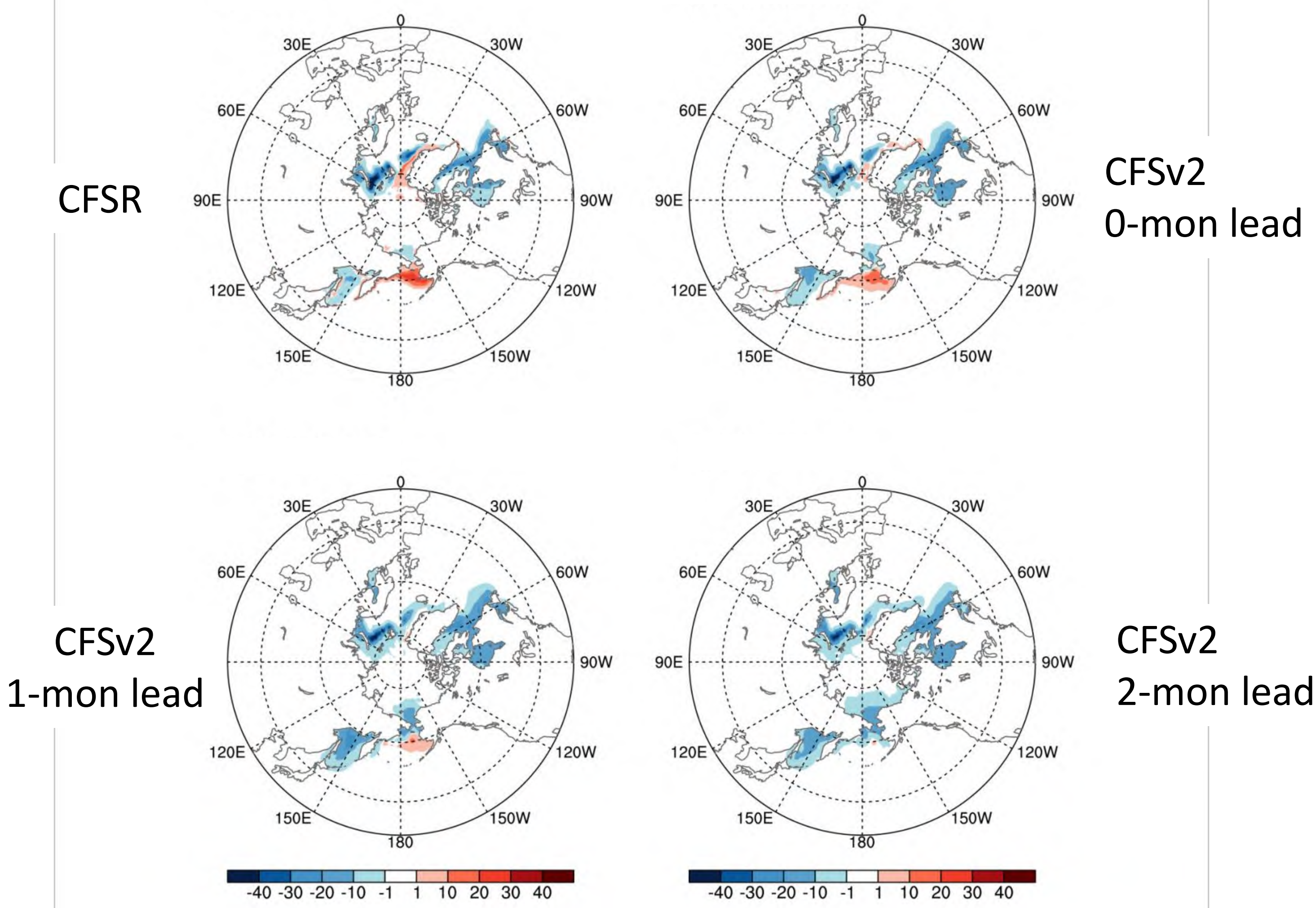
- Sea ice + SST + Atmospheric ICs
- Forecast lead time dependence

Coupled predictions (CFSv2)

- **Initial conditions**: Climate Forecast System reanalysis (CFSR)
- **Ensemble size**: 4
- **Initial time**: Beginning of each month
- **Target season**: Dec-Jan-Feb (reconstructed from each month at same lead time)
- **Forecast history**: 1982-2013
- **Analysis**: (2005-2013 average) — (1982-1990 average)



DJF SIC difference between 2005-2013 and 1982-1990

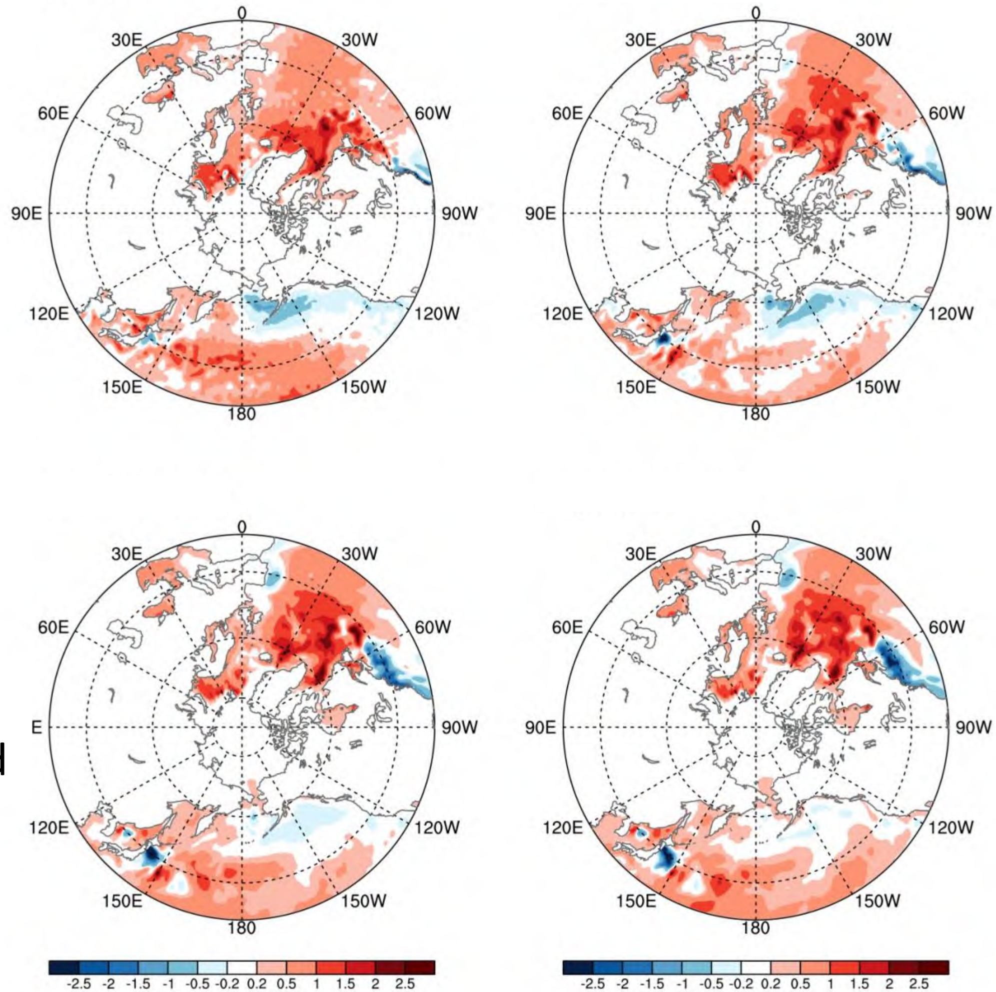


- Overall SIC decrease in NCEP CFSR, except Bering Sea and Western Greenland Sea
- CFSv2 captured the observed SIC decrease at 0, 1, & 2 month lead

DJF SST difference between 2005-2013 and 1982-1990

CFSR

lead

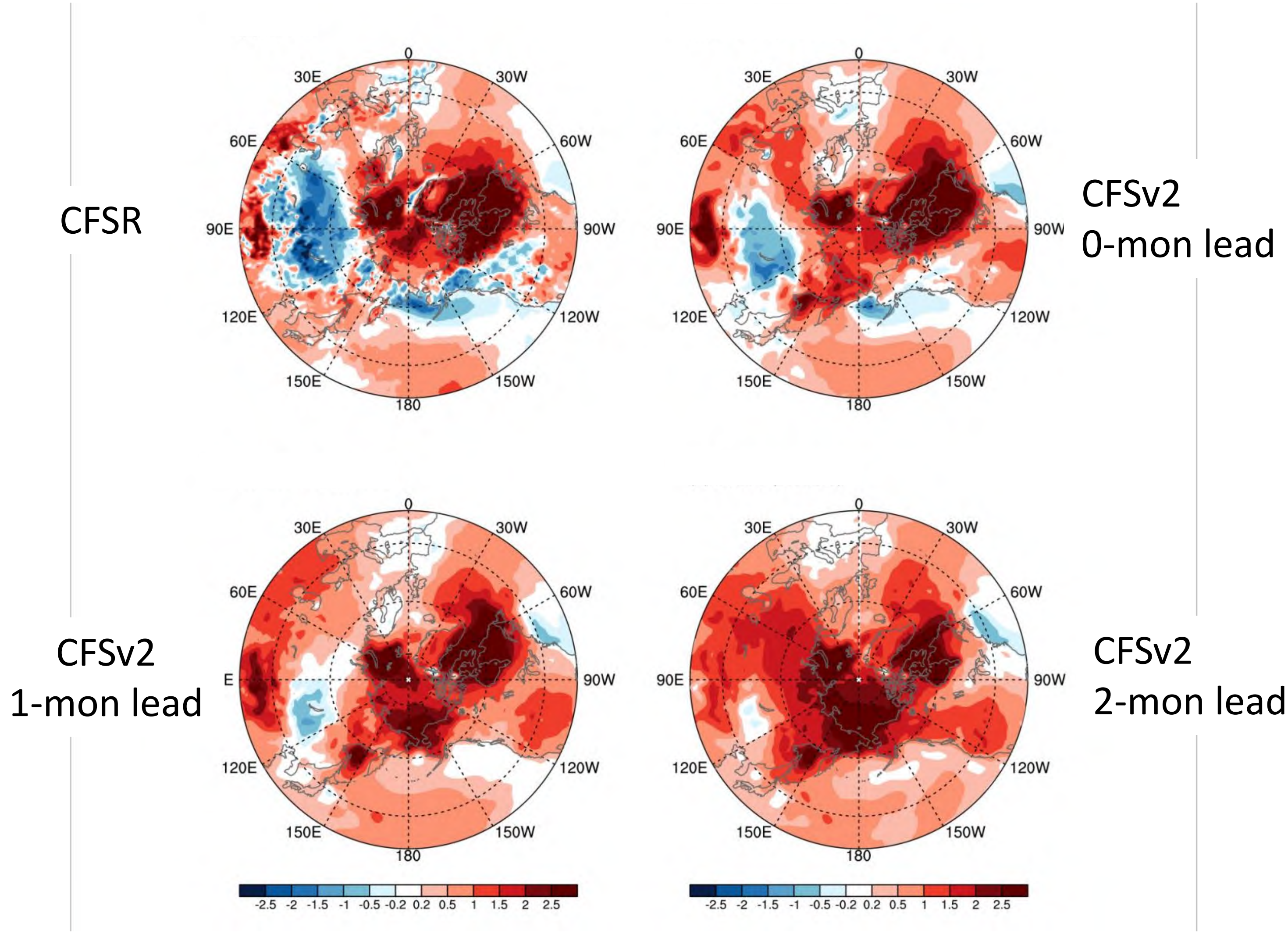


CFSv2
1-mon lead

CFSv2
2-mon lead

- Overall warming in NCEP CFSR, except Bering Sea areas
- CFSv2 captured observed SST warming at 0, 1, & 2 month lead

DJF T2m difference between 2005-2013 and 1982-1990



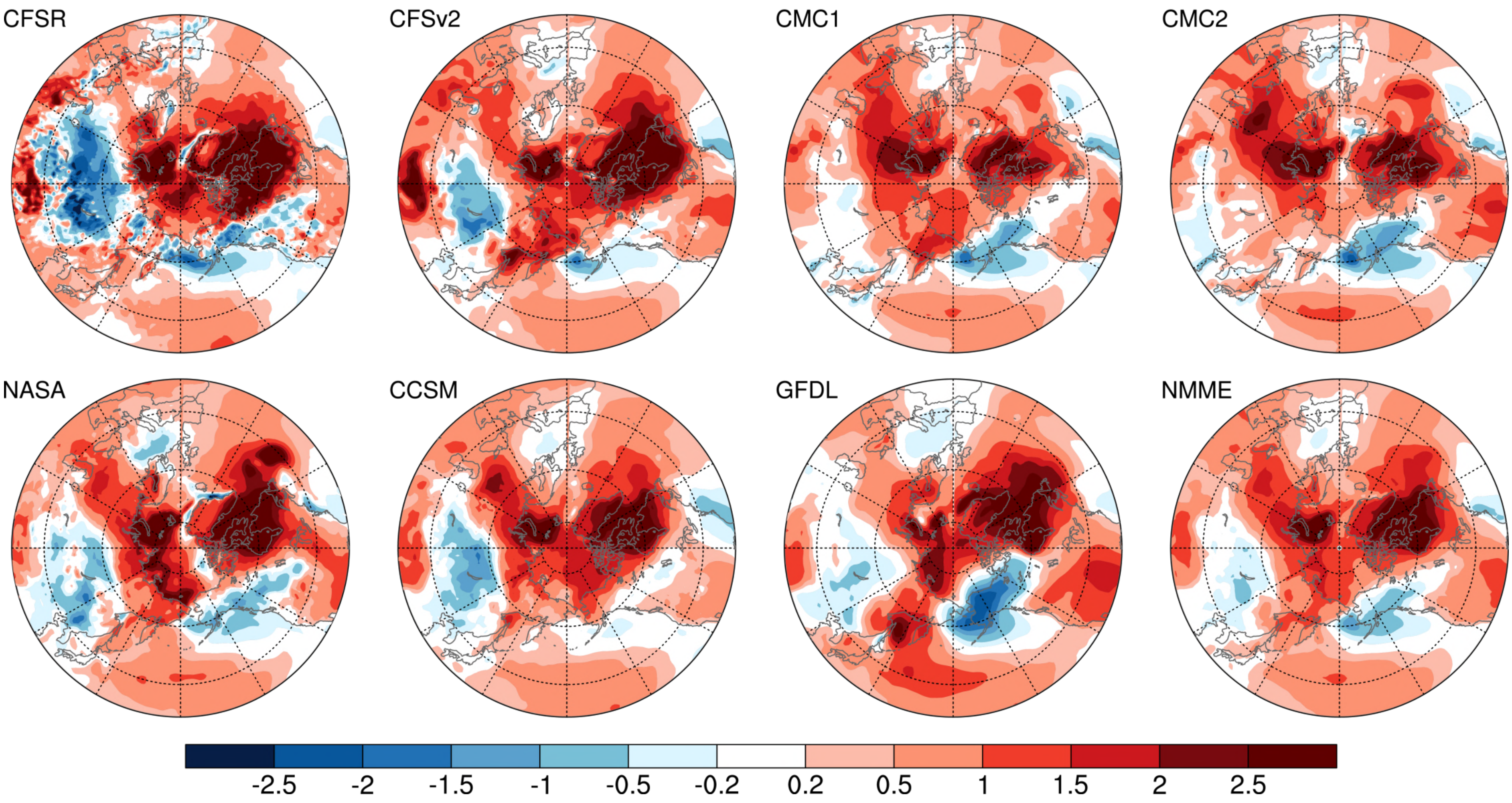
- Observation: Cooling over Eurasia and Bering Sea areas; Overall warming
- Forecast: Weak Eurasian cooling at 0-m lead, disappearing at 1-m and 2-m lead

Coupled prediction (NMME)

- **Models**: CFSv2, CMC1, CMC2, NASA, CCSM4, GFDL
- **Initial conditions**: Respective assimilation systems
- **Ensemble size**: Different among models (4 to 10)
- **Initial time**: Beginning of each month
- **Target season**: Dec-Jan-Feb (reconstructed from each month at same lead time)
- **Forecast history**: 1982-2013 (http://www.cpc.ncep.noaa.gov/products/NMME/data.html)
- **Analysis**: 2005-2013 average minus 1982-1990 average

DJF T2m change (2005-2013 minus 1982-1990)

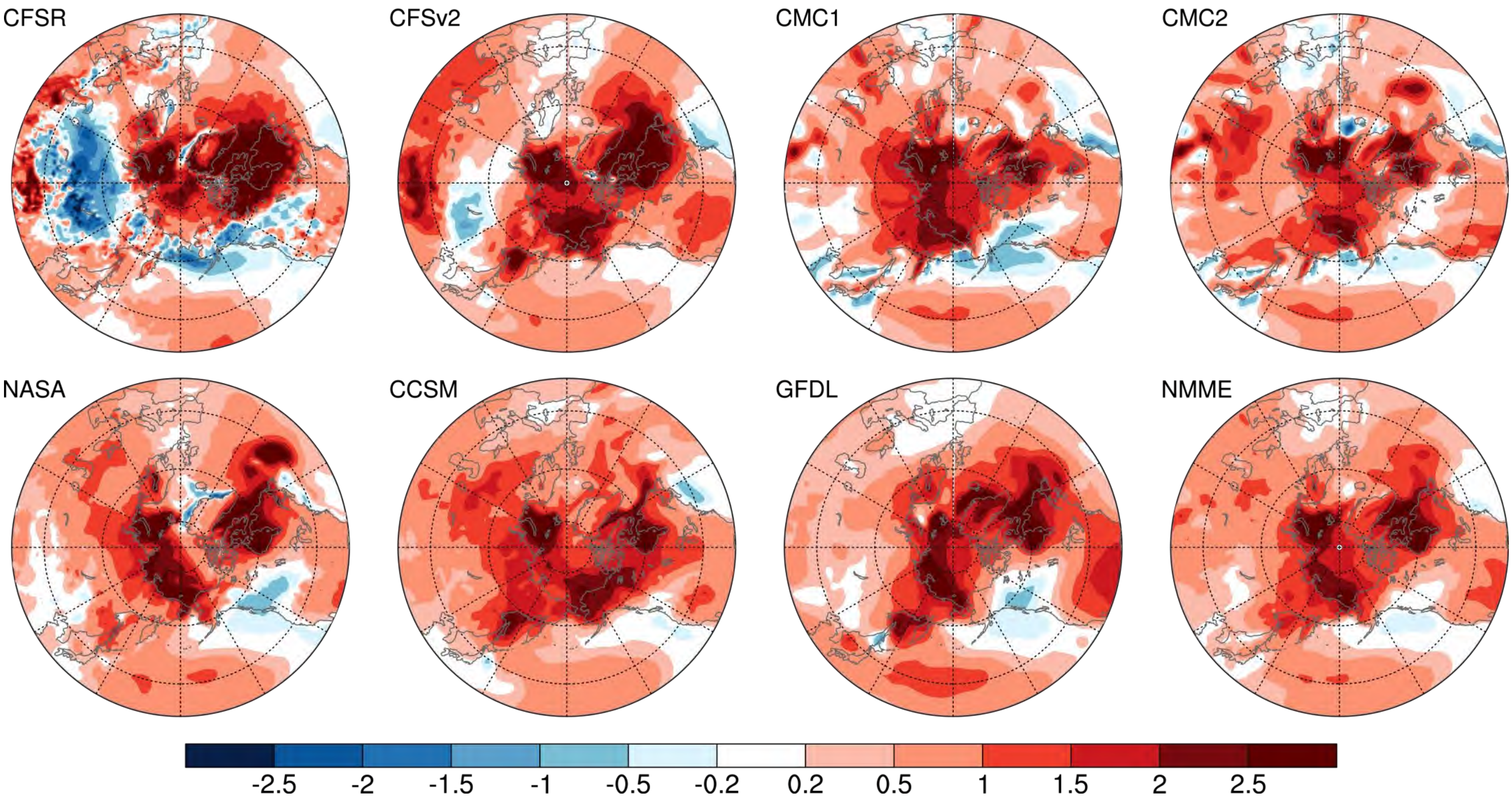
0-month lead



- Individual models captured Eurasian cooling to varying degrees
- Weak Eurasian cooling signal in NMME mean. (More realistic cooling in Bering Sea)

DJF T2m change (2005-2013 minus 1982-1990)

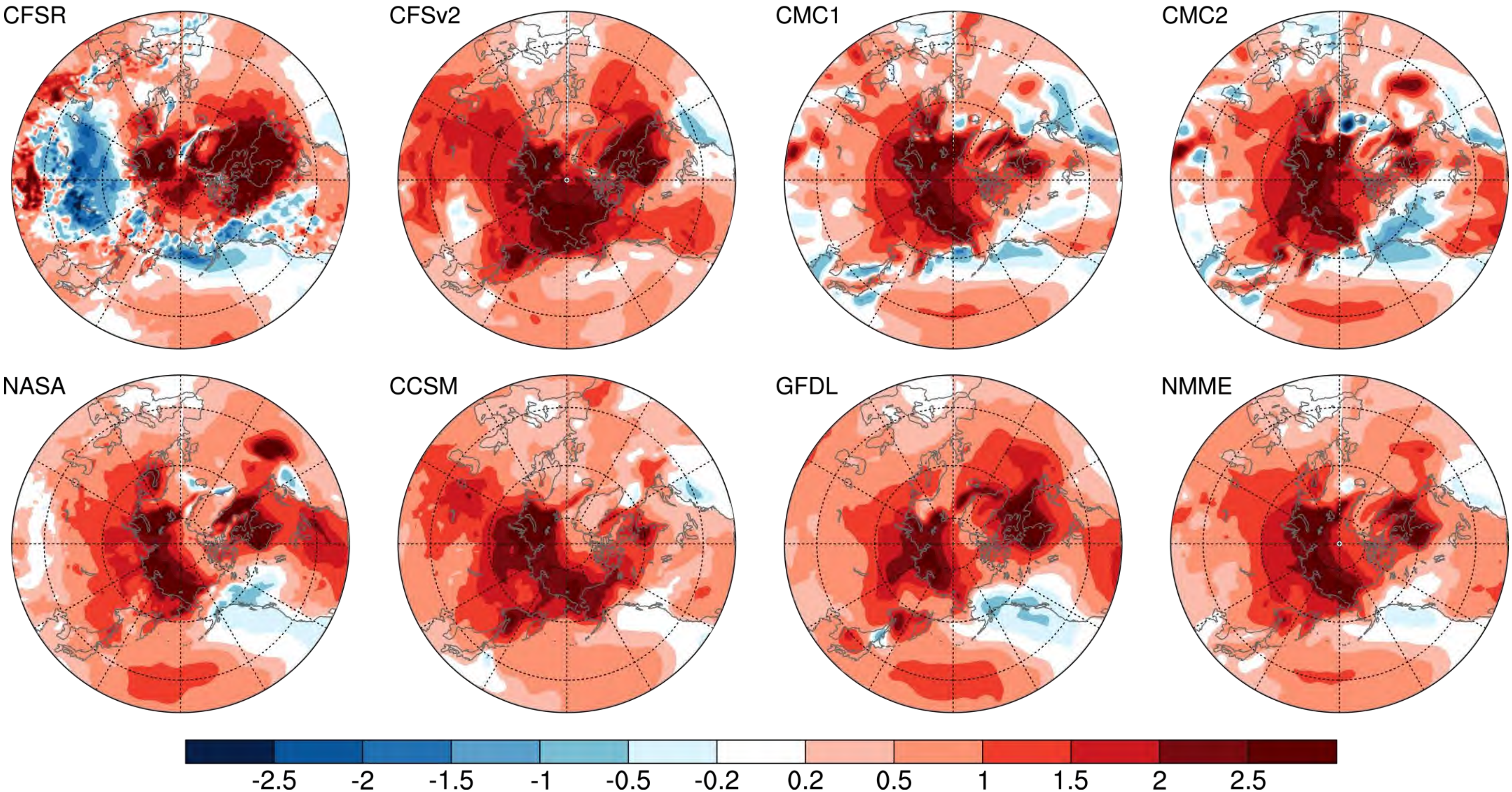
1-month lead



- Eurasian cooling not present in most models
- No Eurasian cooling signal in NMME average

DJF T2m change (2005-2013 minus 1982-1990)

2-month lead



- No Eurasian cooling signal in individual models
- No Eurasian cooling signal in NMME average

Part 2.1 Summary

- Atmosphere-only simulations show a mean warming response over Eurasia due to SST changes but little response to changes to sea ice.
- Atmosphere-only individual runs simulate cooler periods over Eurasia.
- These results suggest that the internal variability is the primary cause of the Eurasian cooling in the CFSv2.
- The Eurasian cooling is *predictable only in month one* in the current seasonal climate prediction systems.

2. Sea ice impacts on lower latitudes

1) Northern mid-latitude 2-m temperature trend

2) Northern mid-latitude 2-m temperature variability

Does the loss of Arctic sea ice result in more weather extremes?

Yes: Francis and Vavrus (2012, 2015)

- Sea ice loss
- ➔ Reduced the north-south temperature gradient
- ➔ Weakened the zonal jet stream
- ➔ Greater likelihood of extreme events

No: Screen (2014), Screen et al. (2015), Blackport and Kushner (2016; 2017)

- Sea ice loss
- ➔ Decreased temperature gradients
- ➔ Reduced temperature variability
- ➔ Decrease of likelihood of North American cold extremes

Questions to address in this analysis

- 1) Can the AMIP simulations represent the observed changes in the variability of northern mid-latitude temperatures?
- 2) How is the overall intraseasonal temperature anomaly distribution impacted due to the different forcings?

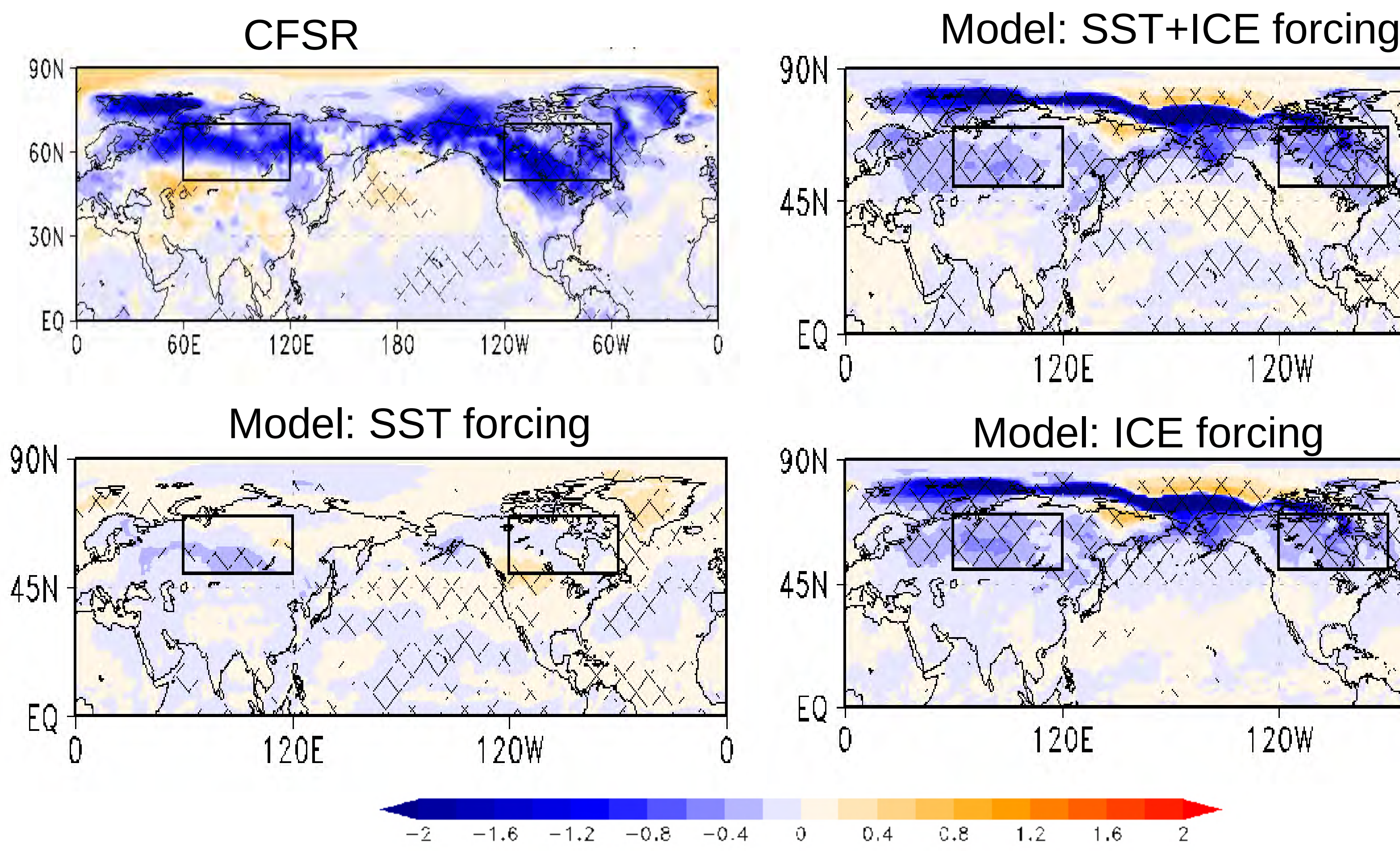
Simulations (CFSv2 Atmosphere-only)

- Surface conditions (Hurrell et al., 2008)
  - **SST1**: 1981-1990 average SST
  - **ICE1**: 1981-1990 average sea ice concentration
  - **SST2**: 2005-2014 average SST
  - **ICE2**: 2005-2014 average sea ice concentration

- Simulations (100 years with repeating SST and ice)
  - SST1ICE1
  - SST2ICE1
  - SST1ICE2
  - SST2ICE2

T2m Intraseasonal standard deviation (K)

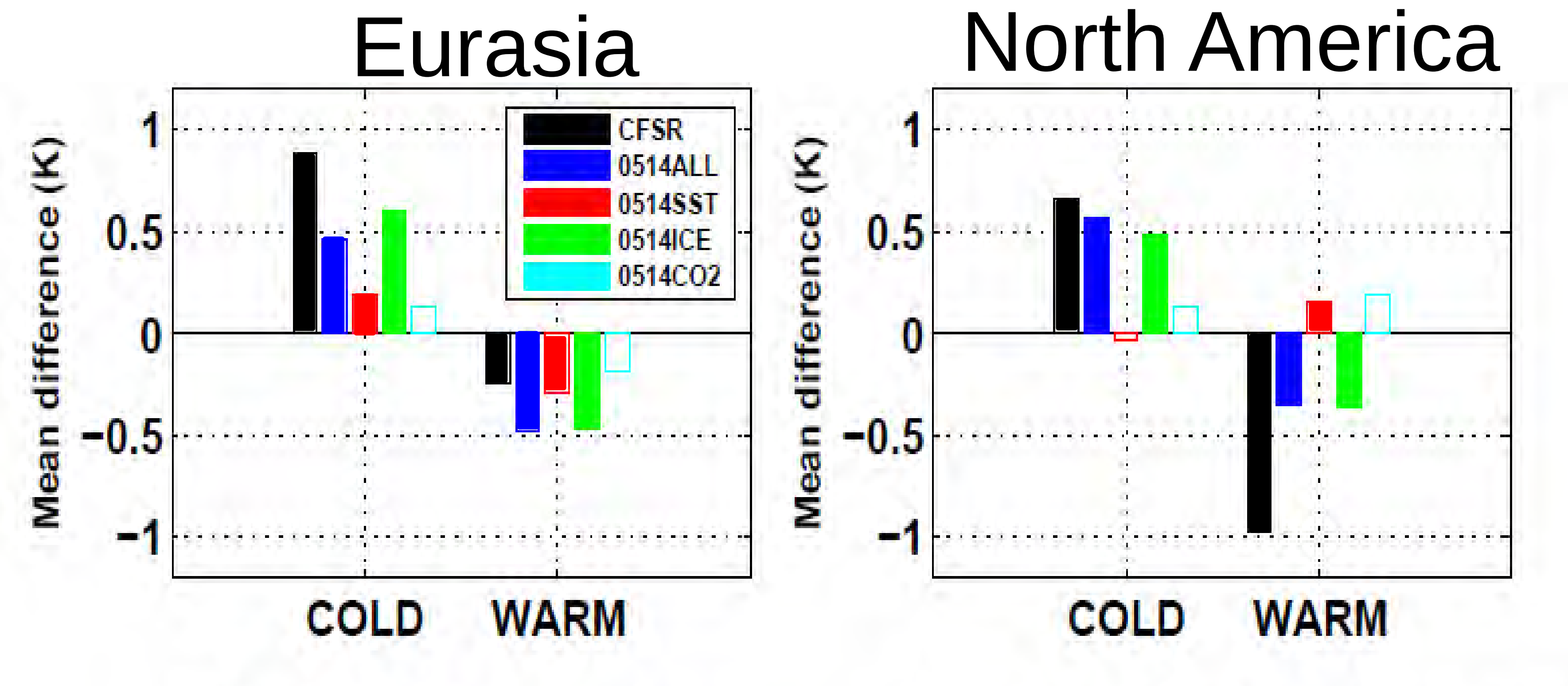
2005-2014 minus 1981-1990



- Significant decrease in intraseasonal variability in CFSR
- Model can reproduce observed pattern of variability change
- The change intraseasonal variability is largely due to sea ice loss

Change in T2m extreme (top/bottom 10%) amplitude

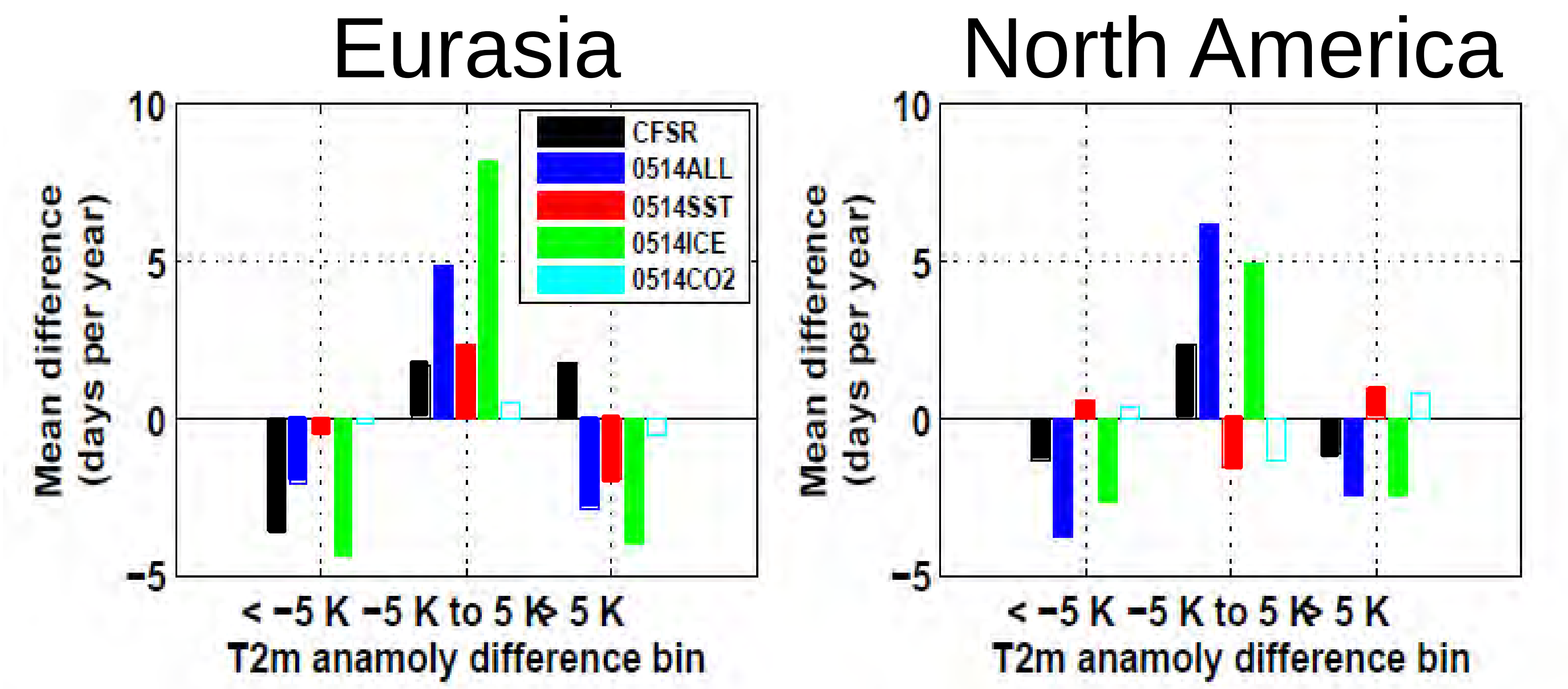
2005-2014 minus 1981-1990



- Decease in both cold and warm extreme amplitude in CFSR
- These features are captured in the model when sea ice change is included

Change T2m extreme frequency

2005-2014 minus 1981-1990



- Decrease (increase) in frequency of cold and warm extremes (non-extremes) in CFSR, except for Eurasian warm extreme
- These features are captured in the model when sea ice change is included

Part 2.2 Summary

- Observational reanalysis (CFSR) indicated a decrease in intraseasonal T2m variability, reduced amplitude and frequency of T2m extremes

- Model simulations showed that these features are related to the loss of Arctic sea ice

謝謝 ！

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