Should we expect a rebound of Arctic sea ice extent in coming years?

Initialized predictions of AMOC and sea ice extent using CCSM4

Steve Yeager

with thanks to Haiyan Teng and Gary Strand

COMMENTARY:

Influence of internal variability on Arctic sea-ice trends

Neil C. Swart, John C. Fyfe, Ed Hawkins, Jennifer E. Kay and Alexandra Jahn

Internal climate variability can mask or enhance human-induced sea-ice loss on timescales ranging from years to decades. It must be properly accounted for when considering observations, understanding projections and evaluating models.

Nature Climate Change (Jan 2015)

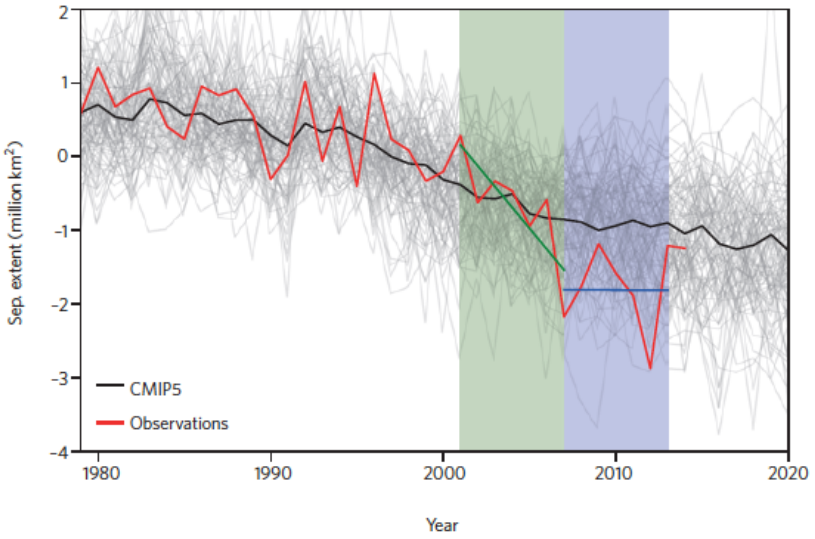


Figure 1 | Arctic September sea-ice extent anomalies. Sea-ice extent anomaly relative to 1980–2000 from observations (red) and 102 realizations from 31 CMIP5 models (grey), along with the CMIP5 ensemble mean (black). Linear trends are fitted to the observations over 2001–2007 (green) and 2007–2013 (blue). The CMIP5 ensemble mean is calculated such that each model has a weight of 1. Observations extend to 2014.

"It is … quite conceivable that the current period of near-zero sea-ice trend could extend for a decade or more due solely to internal climate variability masking the anthropogenically induced decline."

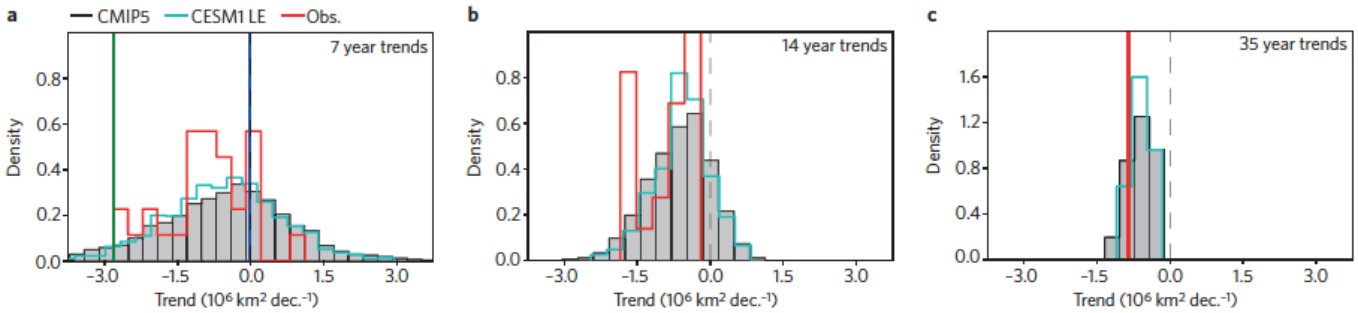
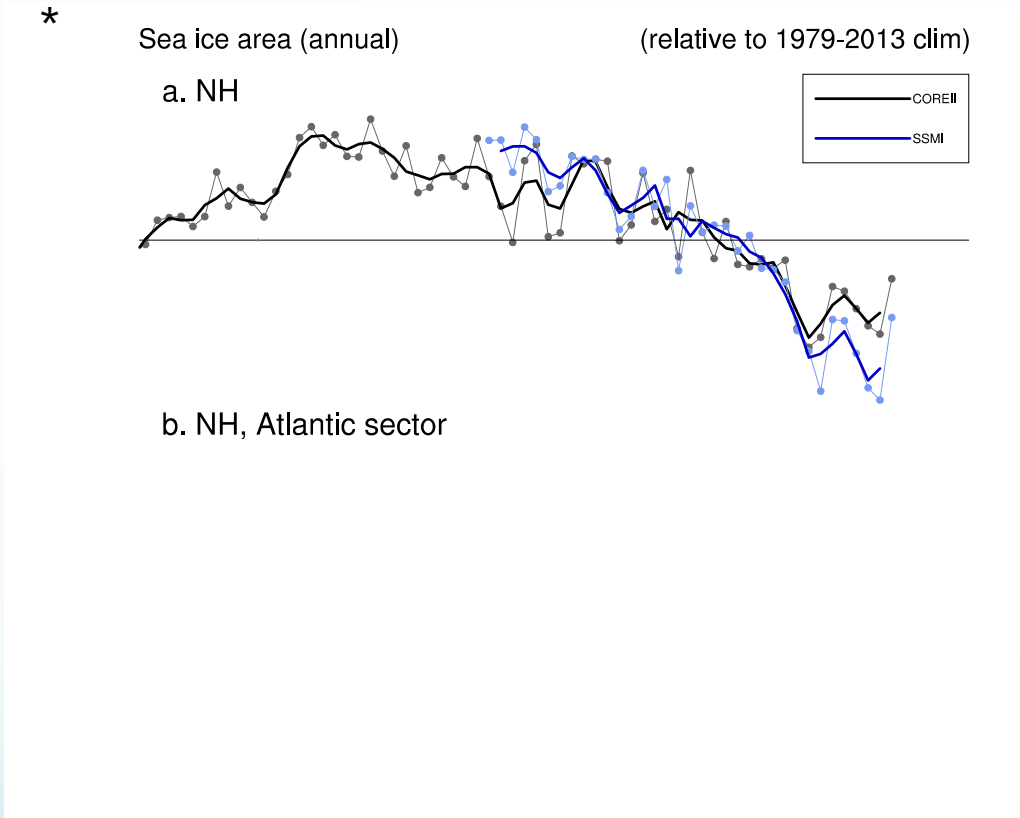
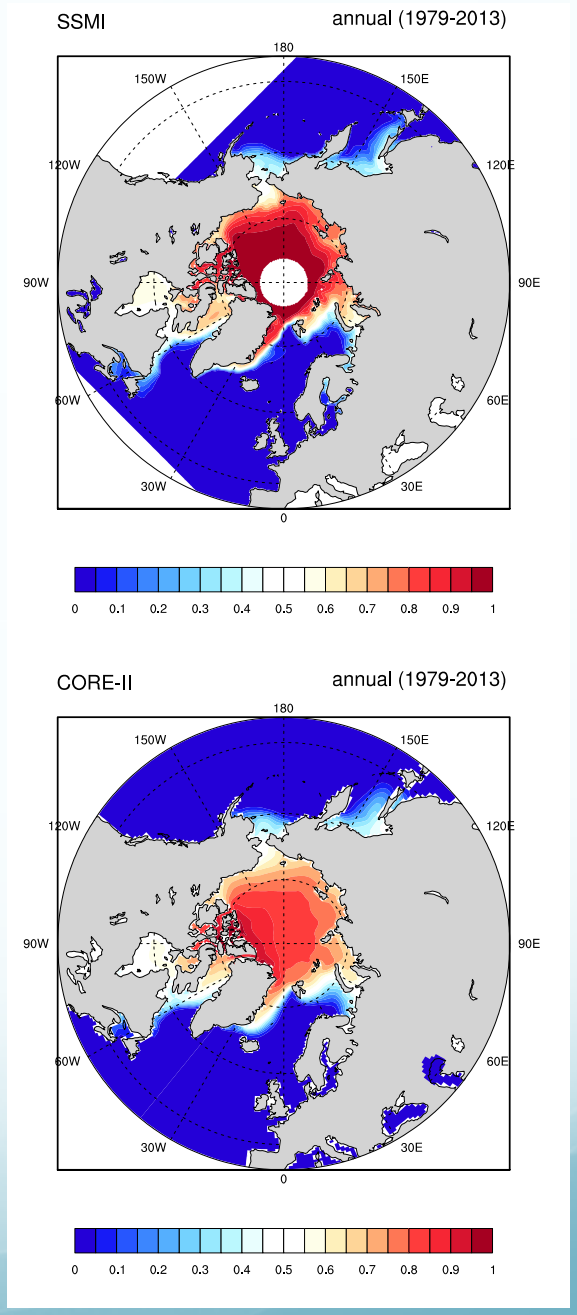


Figure 2 | Arctic September sea-ice extent trends. **a,** Distribution of all possible 7-year trends between 1979–2013 for observations (red), the CMIP5 realizations (grey) and the 30 CESM1 LE realizations (cyan). **b**, As in **a** but for 14 year trends. **c,** As in **a** but for 35 year trends. The solid green and blue lines in **a** are the observed linear trends from 2001 to 2007 and 2007 to 2013, respectively. Density implies that the area under each distribution equals one.

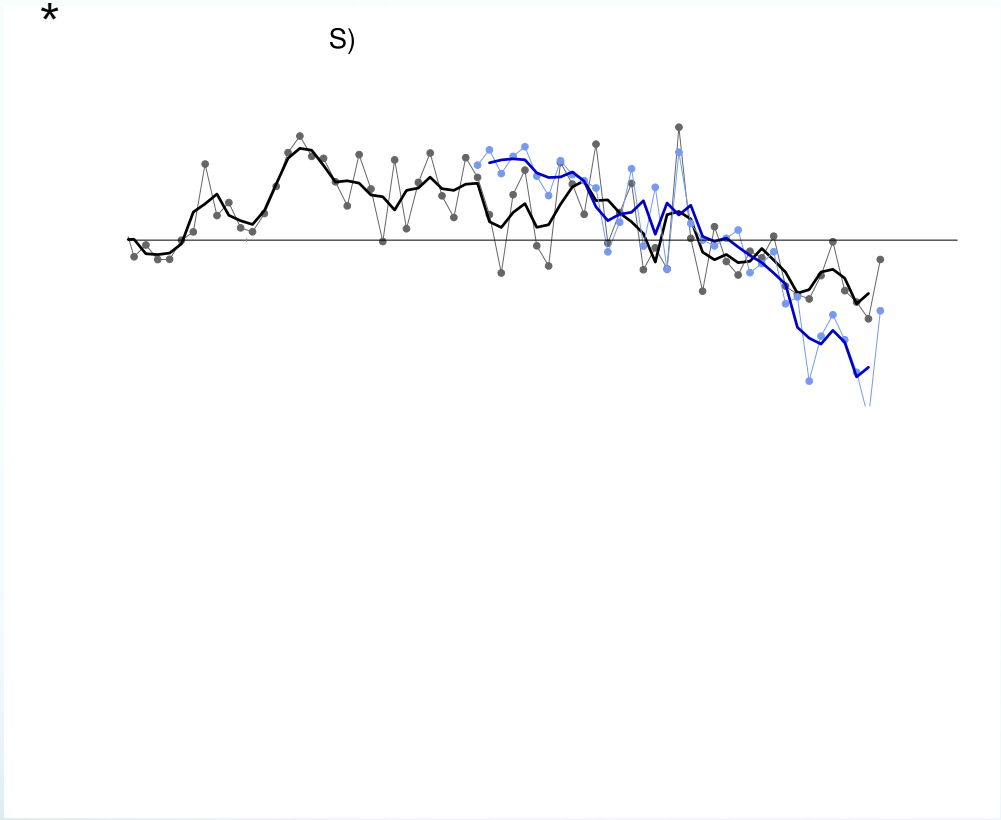
Annual NH sea ice extent

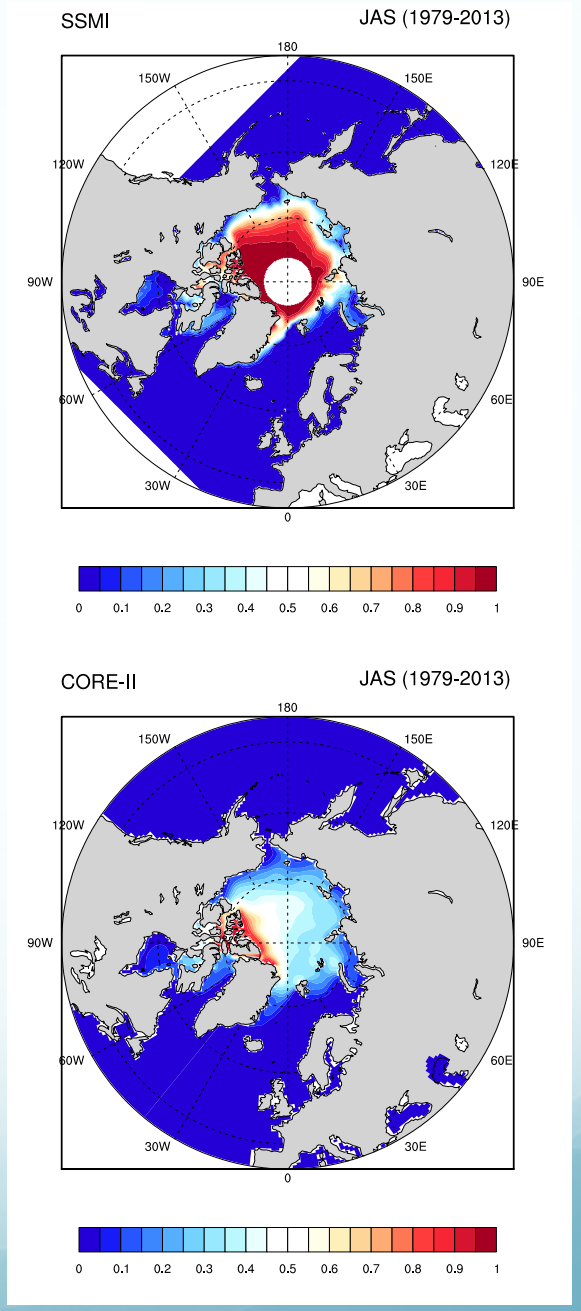




*40ºN-82ºN

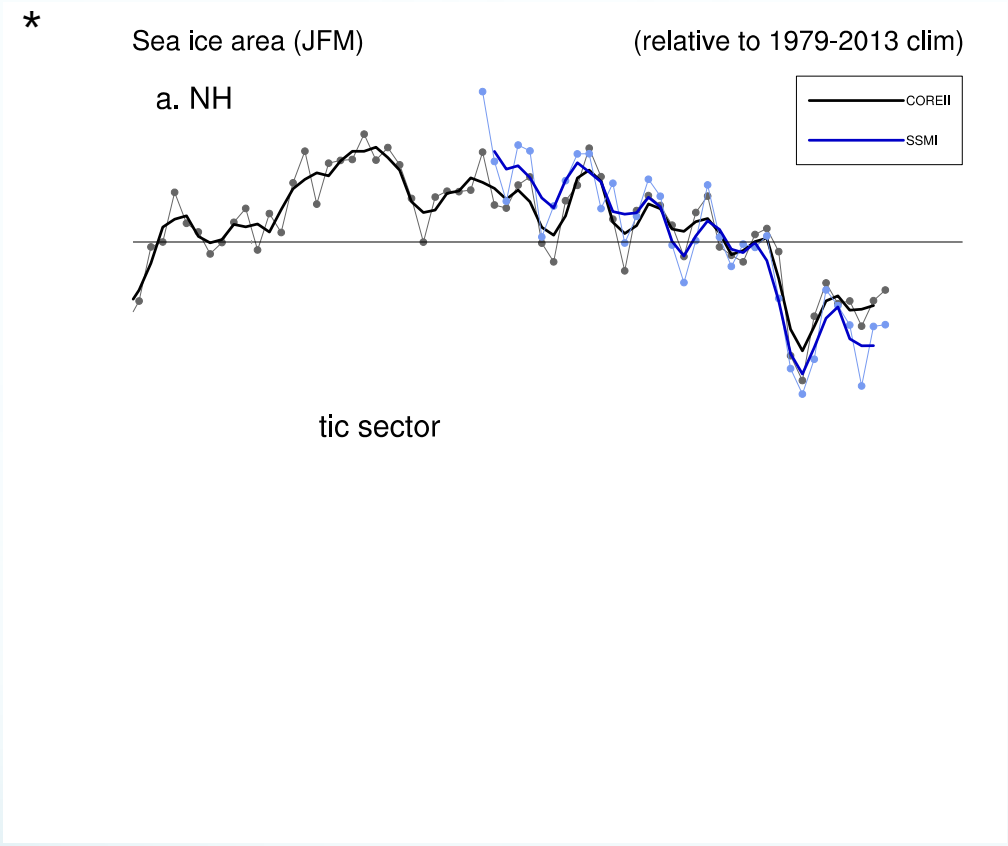
Summer NH sea ice extent

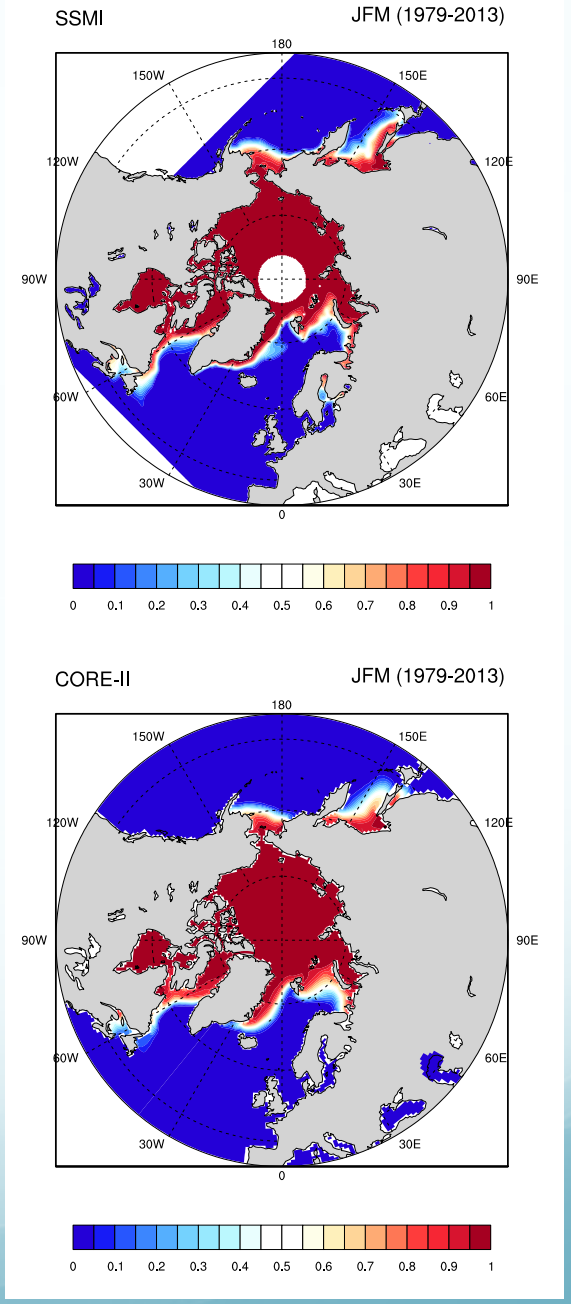




*40ºN-82ºN

Winter NH sea ice extent





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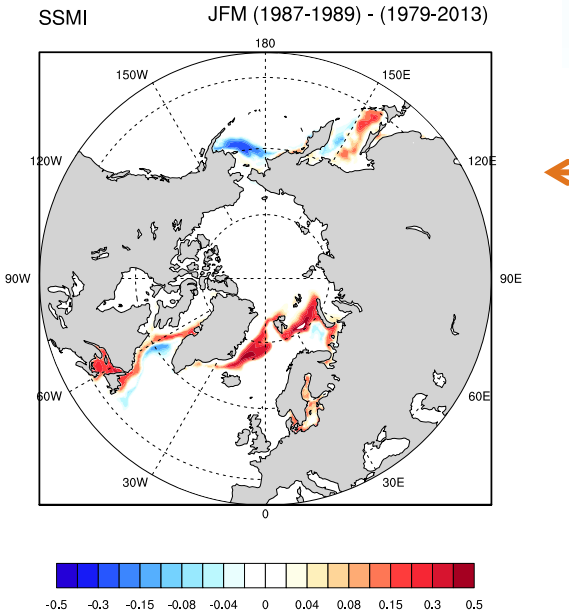
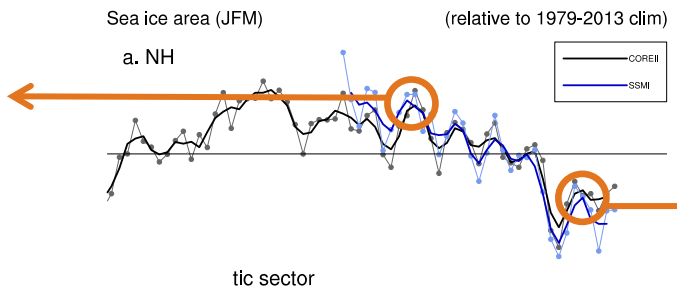
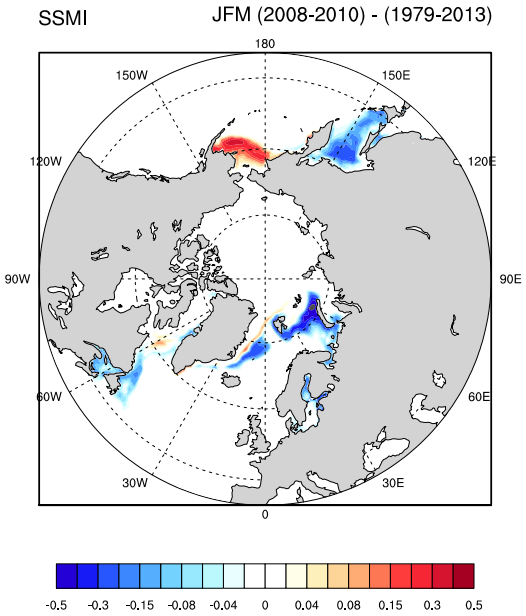
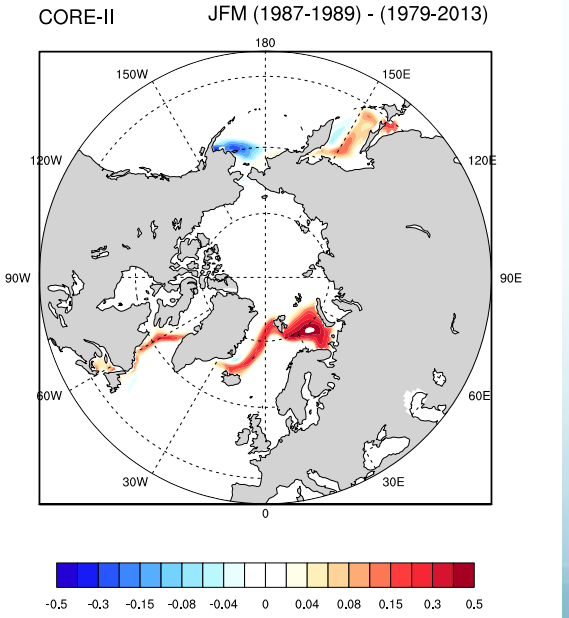
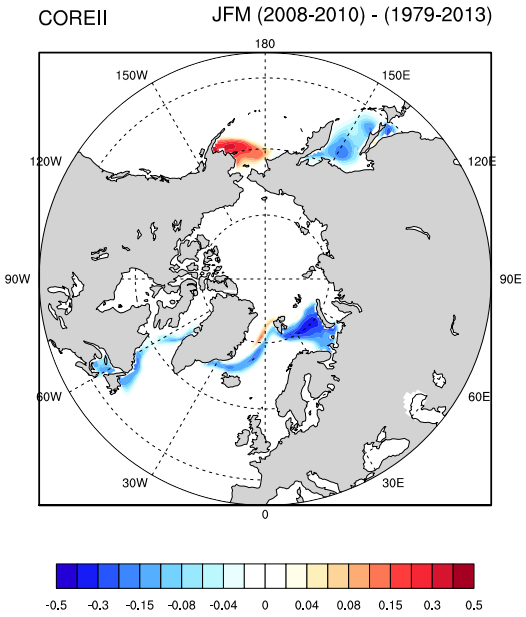
Winter NH sea ice extent



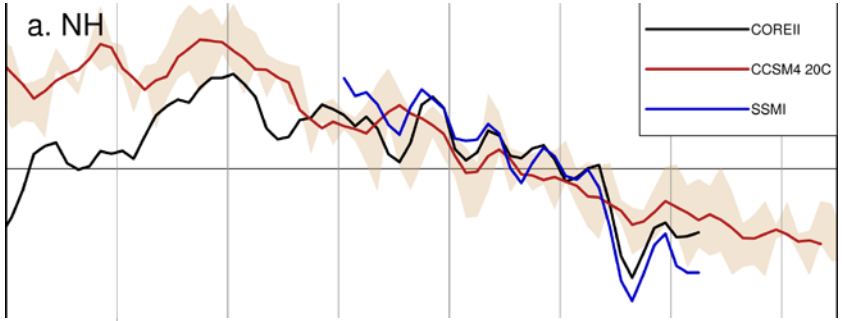


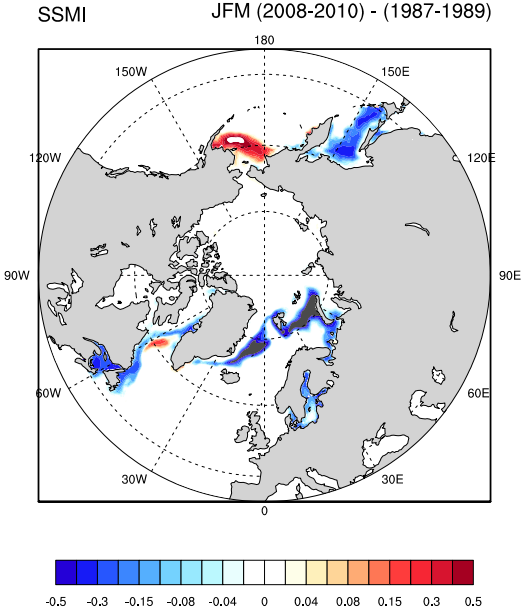


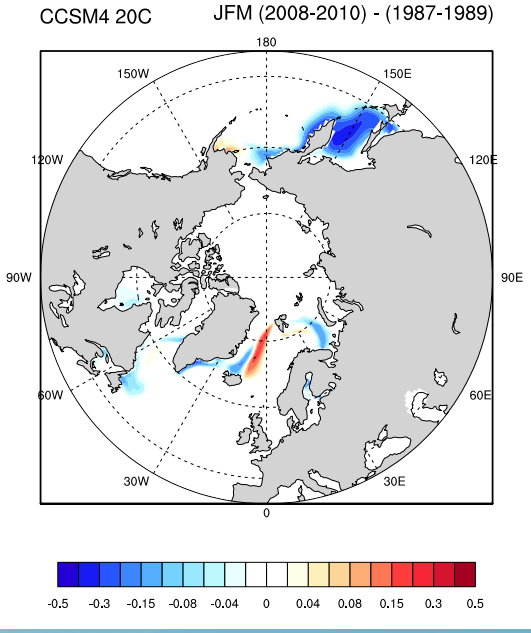




Role of external forcing?



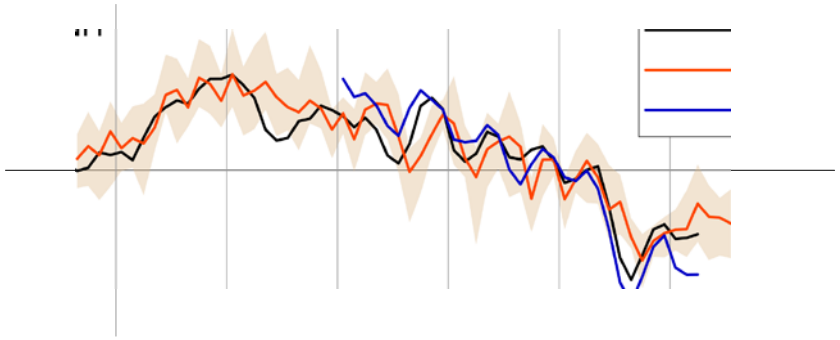




CCSM4 initialized decadal predictions

- Fully-coupled CCSM4 (fv0.9^{o}x1.25^{o} CAM4; 1^{o} ocean) 20th-century simulations extended past 2005 with RCP4.5
- 10-member ensembles initialized every Jan 1st between 1955-2014, integrated 10 years (= 6000 sim. yrs)
- Historical ic's used for ocn/ice components come from COREII
  - ocean/sea-ice hindcast spanning 1948-2013
  - COREII atmospheric state (NCEP, GISS, GPCP + adjustments)
- Full field initialization (➔ bias-corrected by subtracting lead-time-dependent climatology)
- Ensembles generated by altering atm/lnd ic's and/or "pertlim"
- Contrast with 6-member uninitialized CCSM4 20C ensemble (+ RCP4.5)

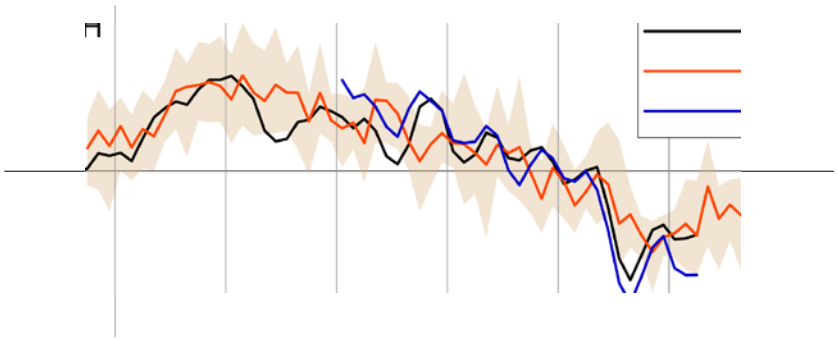
CCSM4 initialized decadal predictions



Forecast years 1-3

(3-yr mean JFM anomalies forecasted 1.12 years in advance)

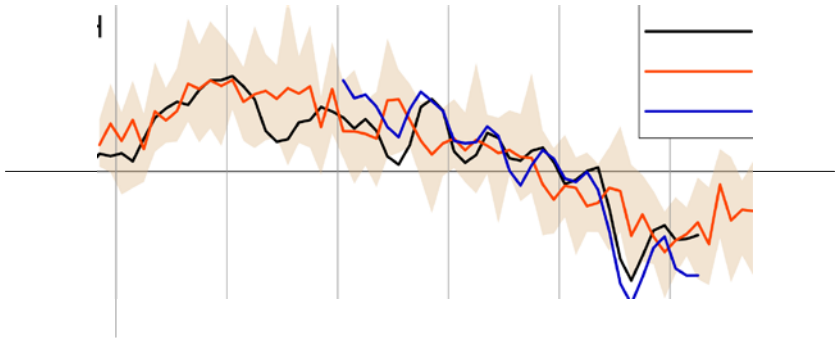
CCSM4 initialized decadal predictions



Forecast years 2-4

(3-yr mean JFM anomalies forecasted 2.12 years in advance)

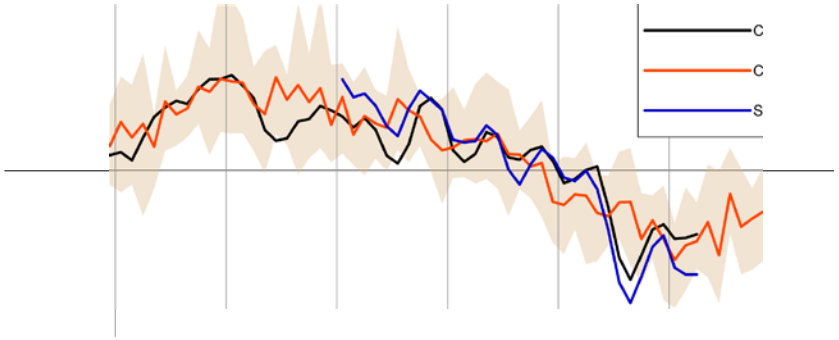
CCSM4 initialized decadal predictions



Forecast years 3-5

(3-yr mean JFM anomalies forecasted 3.12 years in advance)

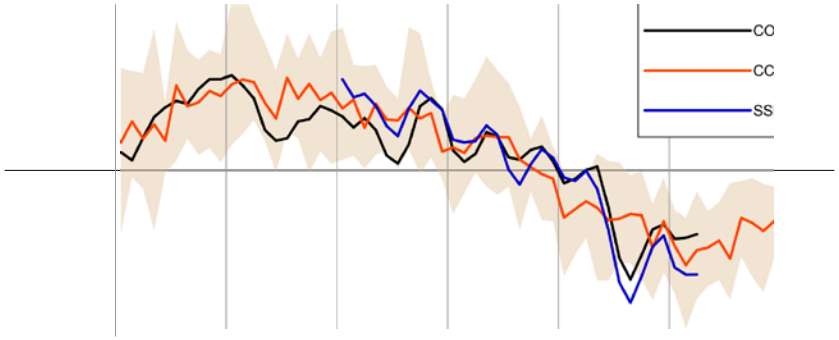
CCSM4 initialized decadal predictions



Forecast years 4-6

(3-yr mean JFM anomalies forecasted 4.12 years in advance)

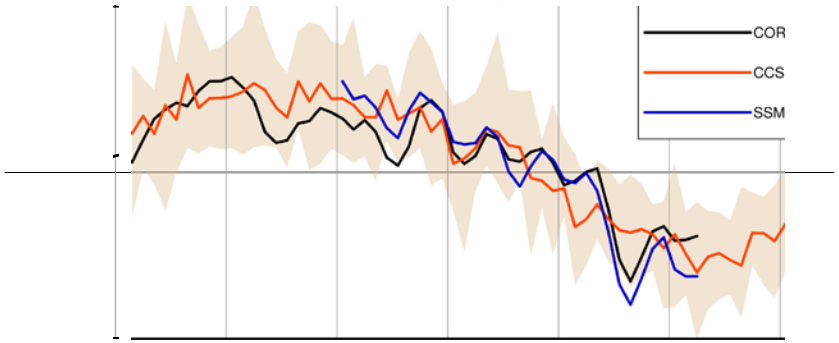
CCSM4 initialized decadal predictions



Forecast years 5-7

(3-yr mean JFM anomalies forecasted 5.12 years in advance)

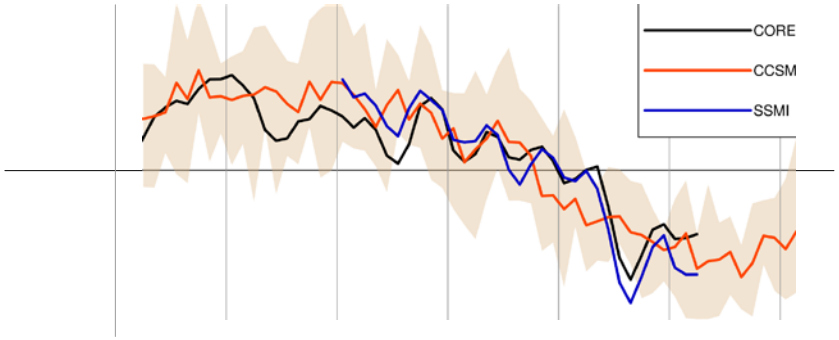
CCSM4 initialized decadal predictions



Forecast years 6-8

(3-yr mean JFM anomalies forecasted 6.12 years in advance)

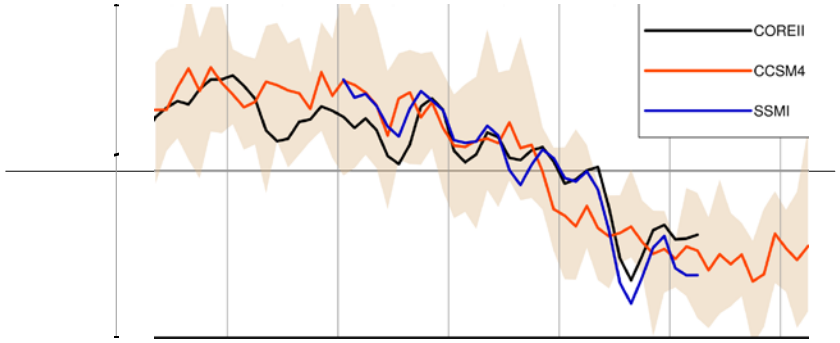
CCSM4 initialized decadal predictions



Forecast years 7-9

(3-yr mean JFM anomalies forecasted 7.12 years in advance)

CCSM4 initialized decadal predictions

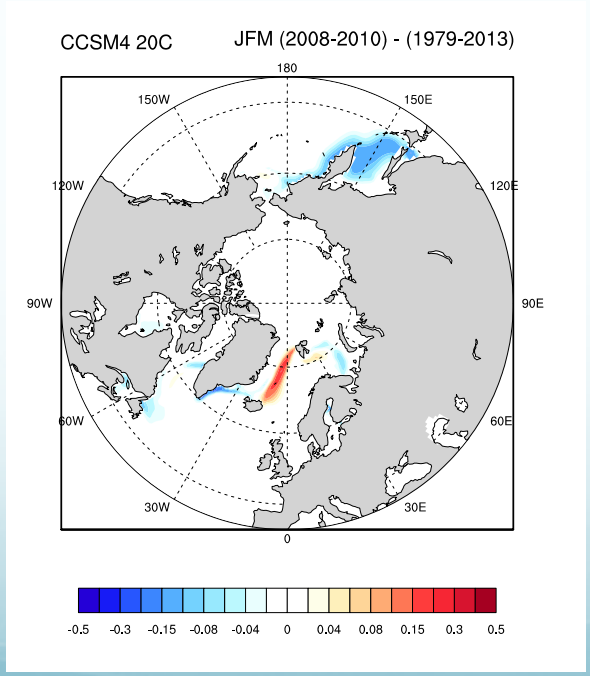


Forecast years 8-10

(3-yr mean JFM anomalies forecasted 8.12 years in advance)

CCSM4 initialized decadal predictions

Consider a forecast of future conditions undertaken in early 2004. What will 2008-2010 winter sea ice look like relative to long-term climatology?



CCSM4 initialized decadal predictions

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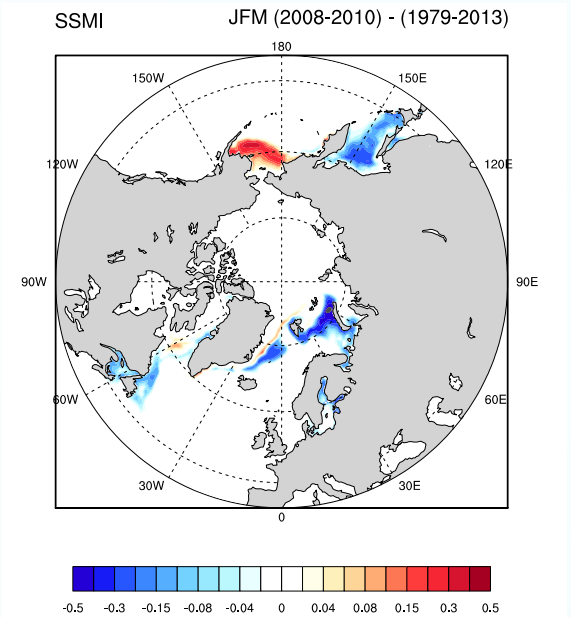
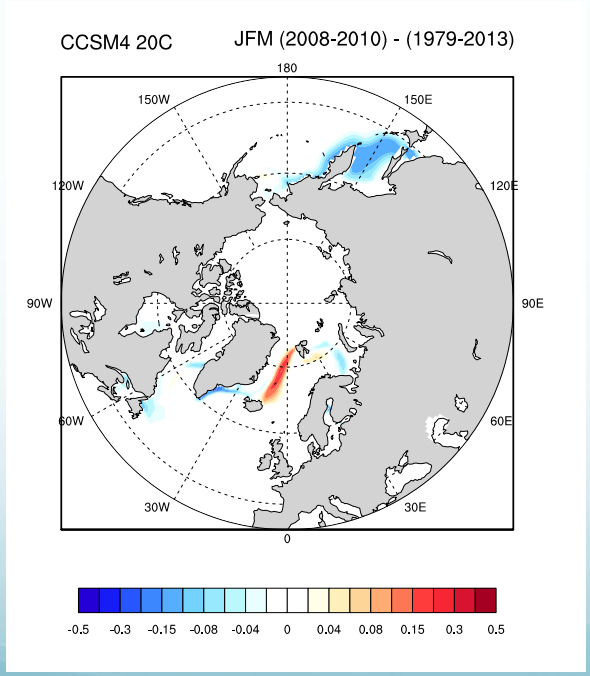
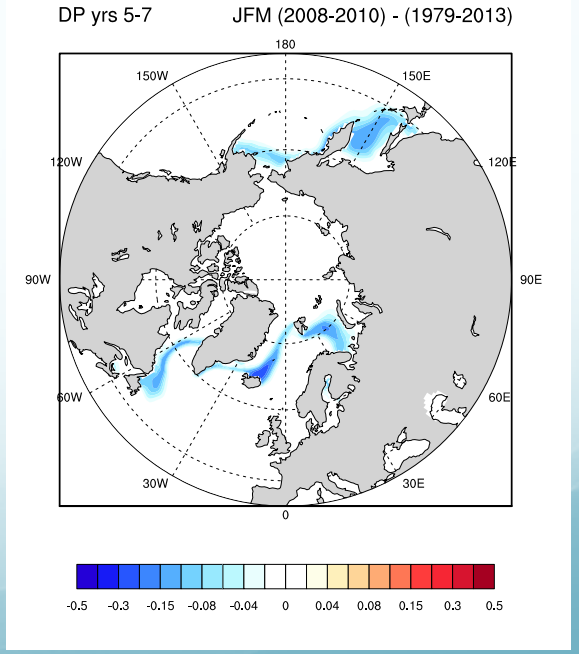
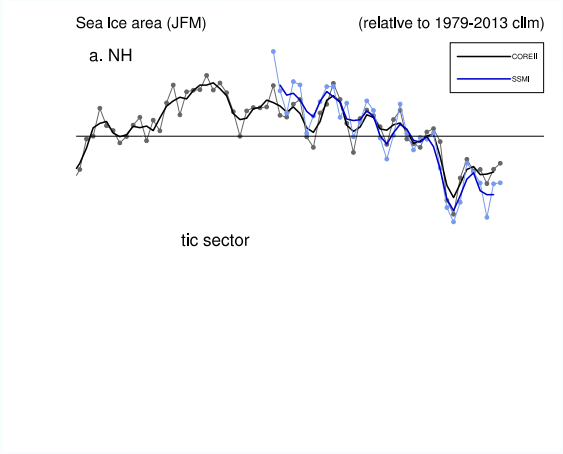






Winter sea ice trends



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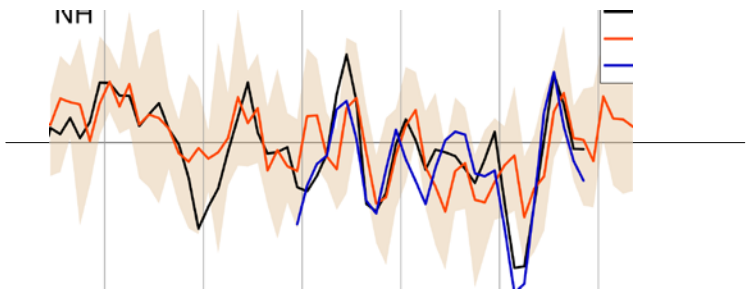

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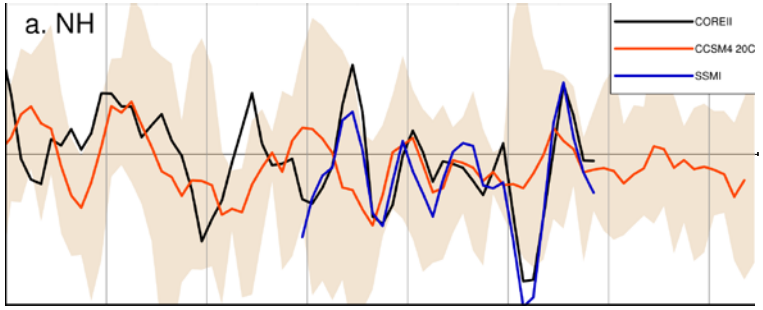
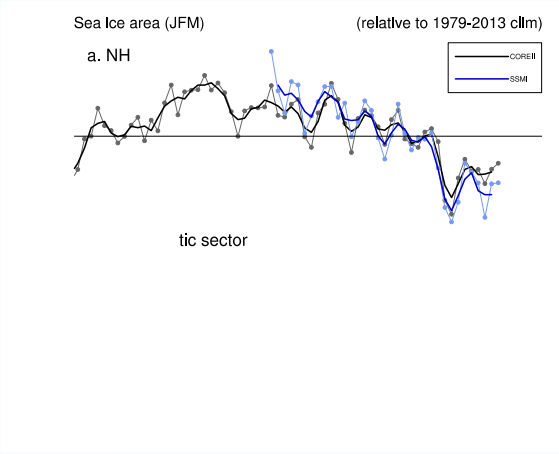


Winter sea ice trends



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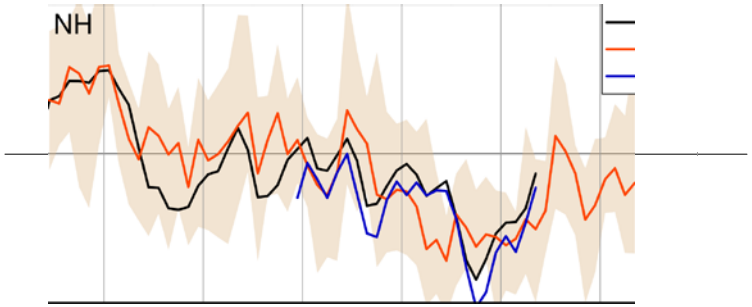

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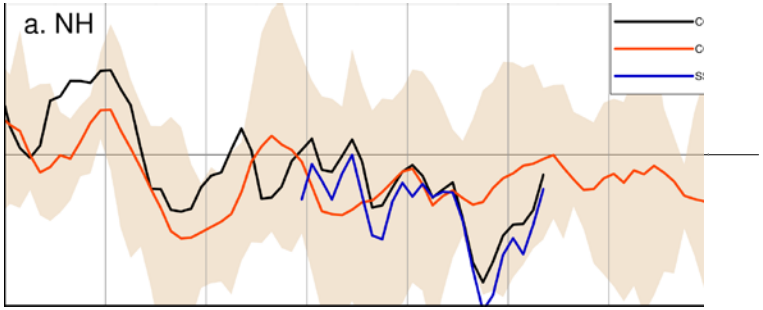
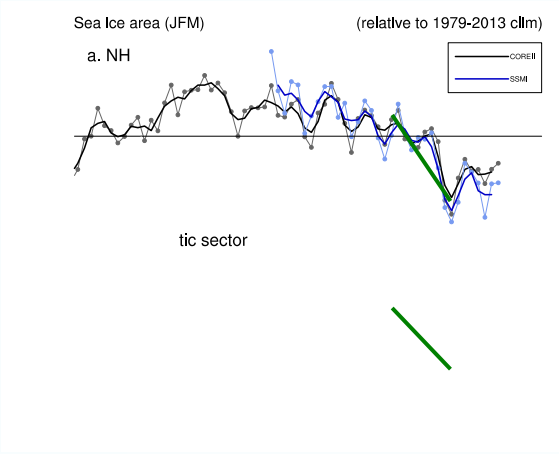


Winter sea ice trends



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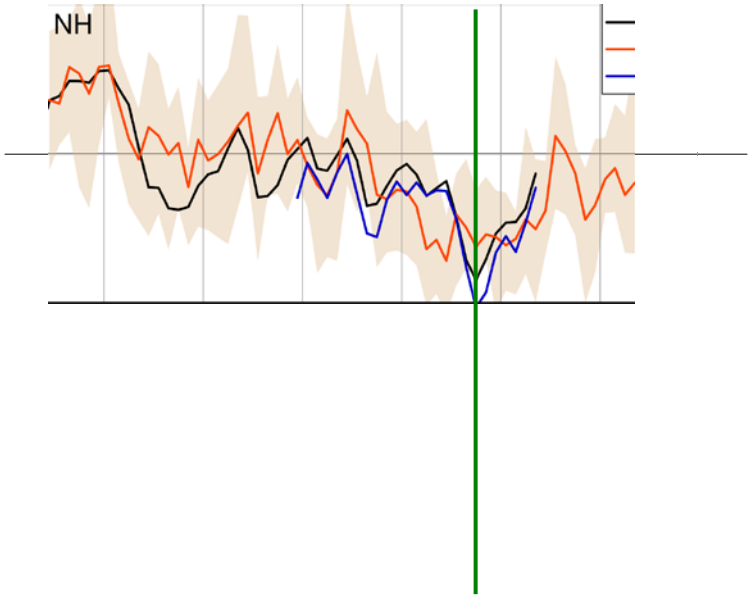

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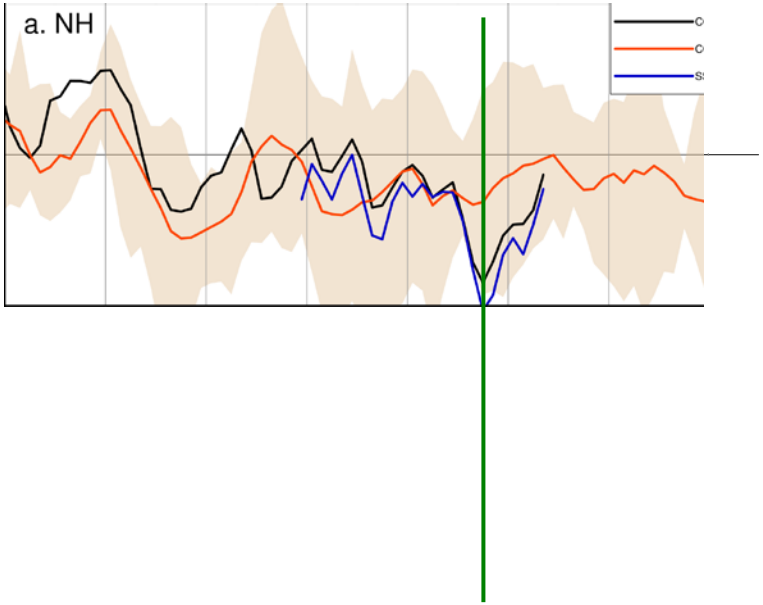
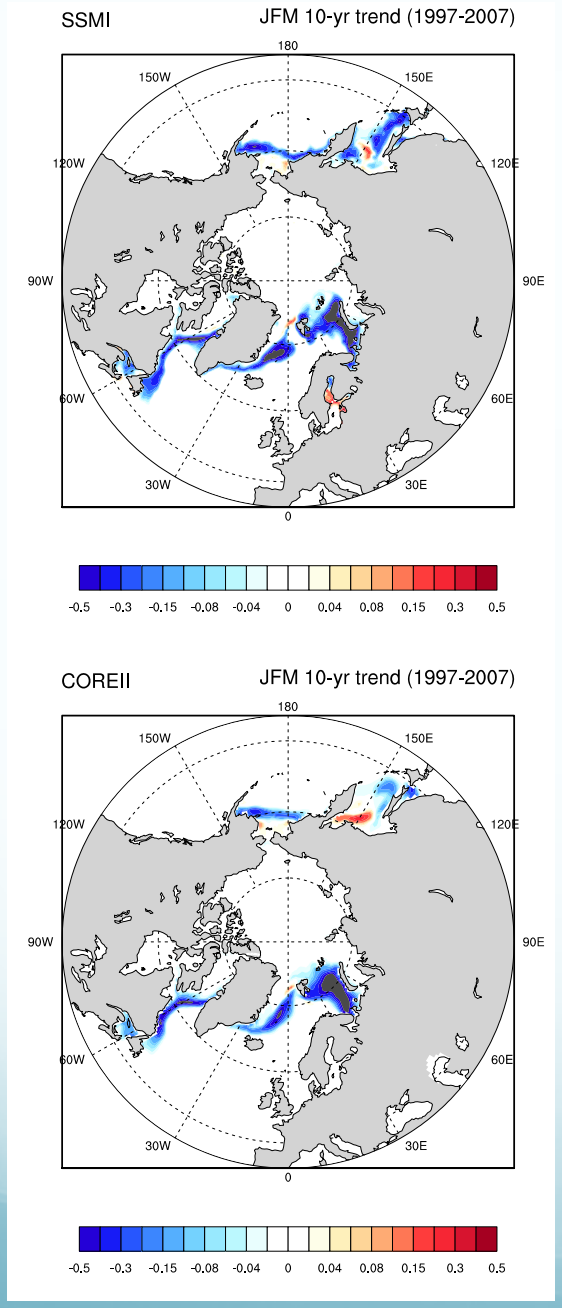
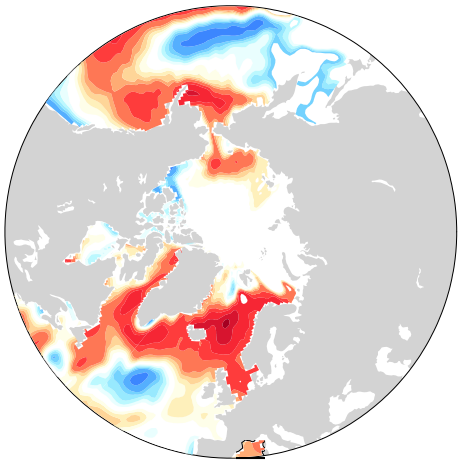


Winter sea ice trends

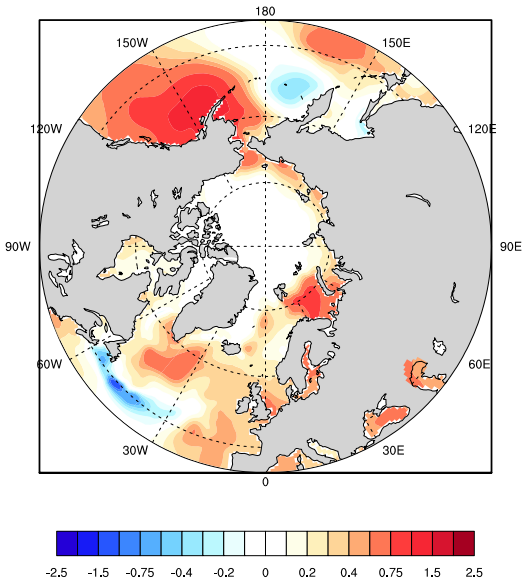


Annual SST trends

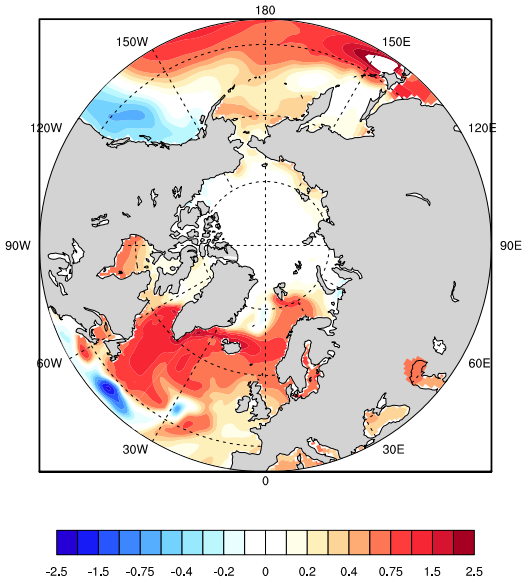


0.4 0.75 1.5 2.5

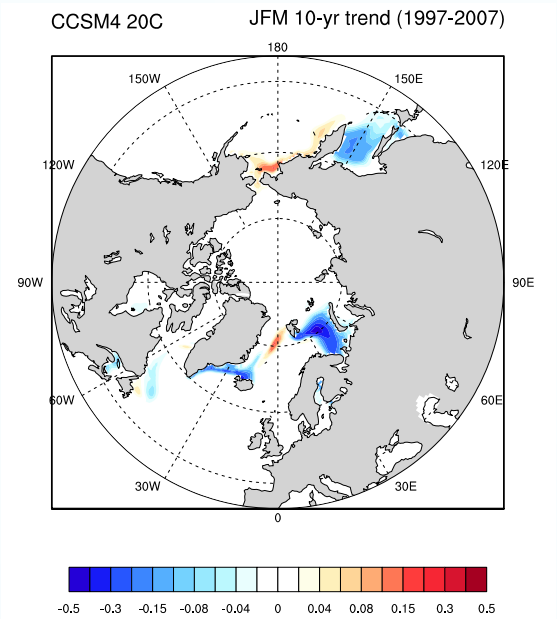
CCSM4 20C annual 10-yr trend (1995-2005)

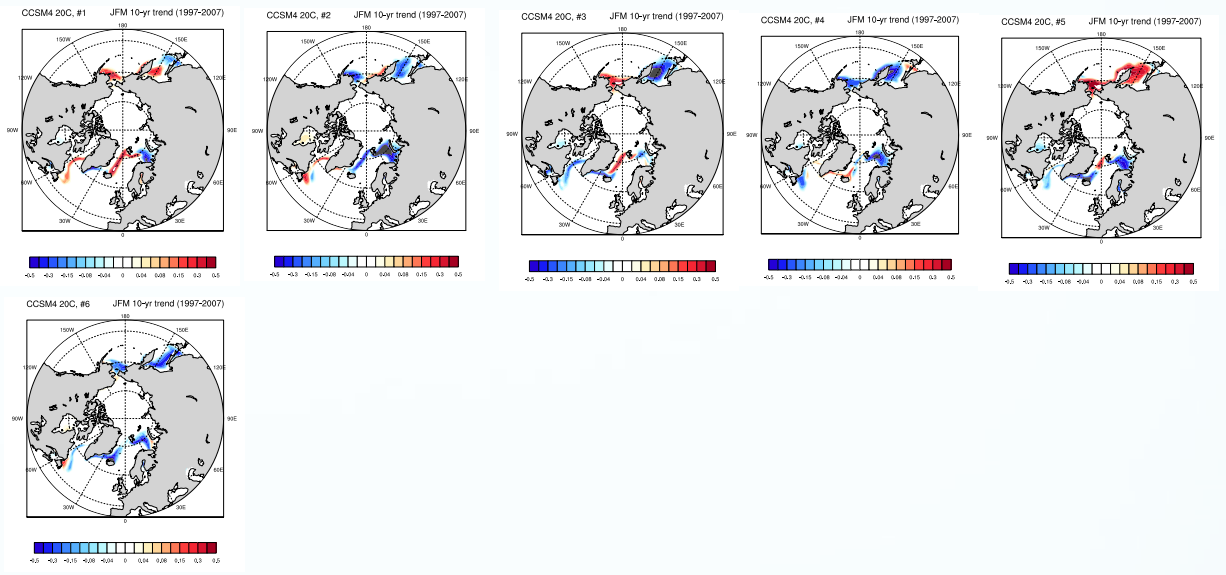


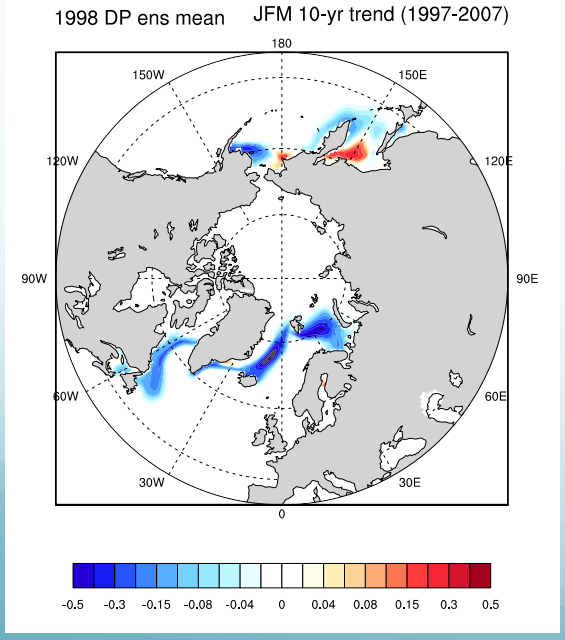
1996 DP ens mean annual 10-yr trend (1995-2005)

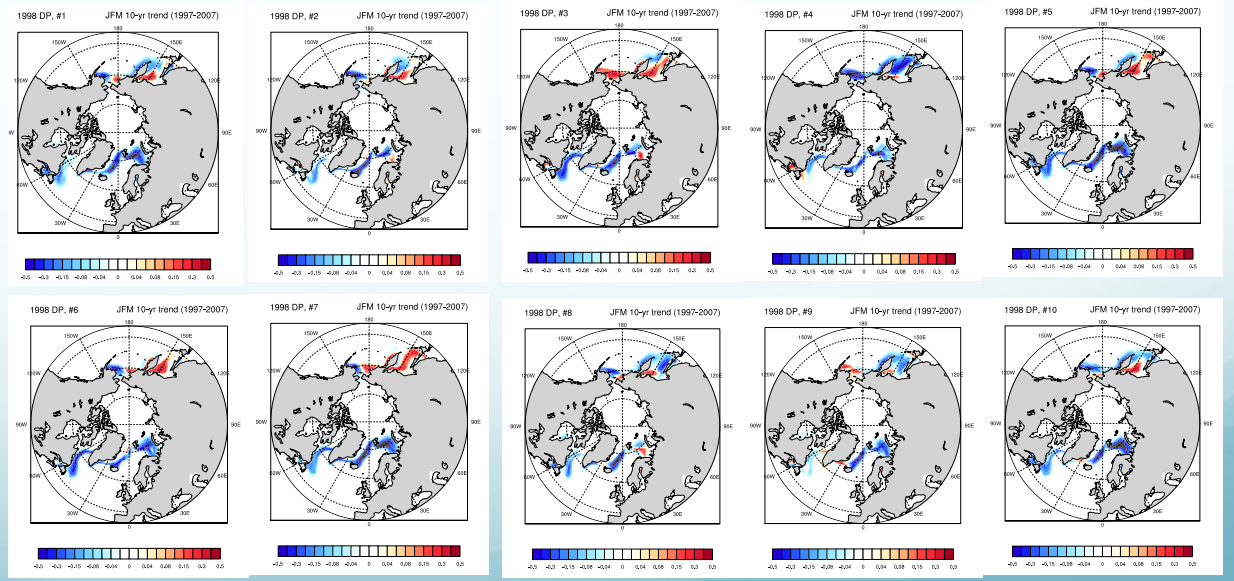


Winter sea ice trends



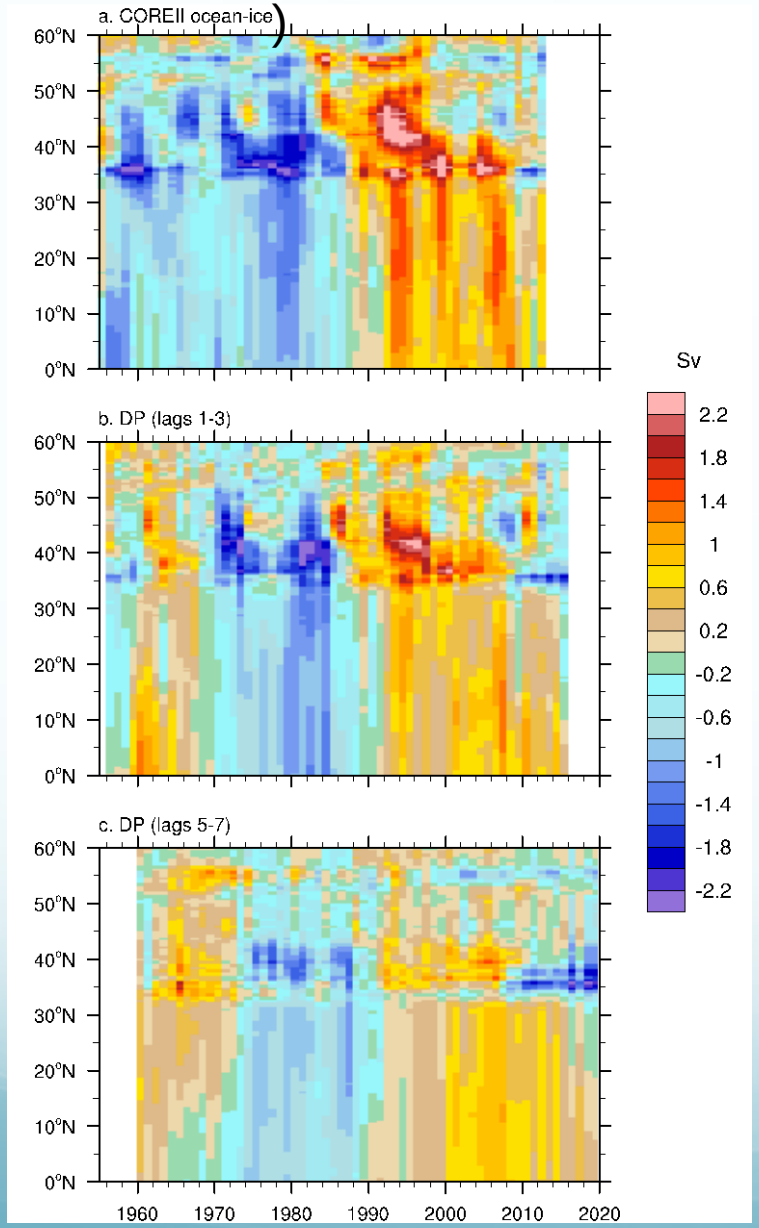




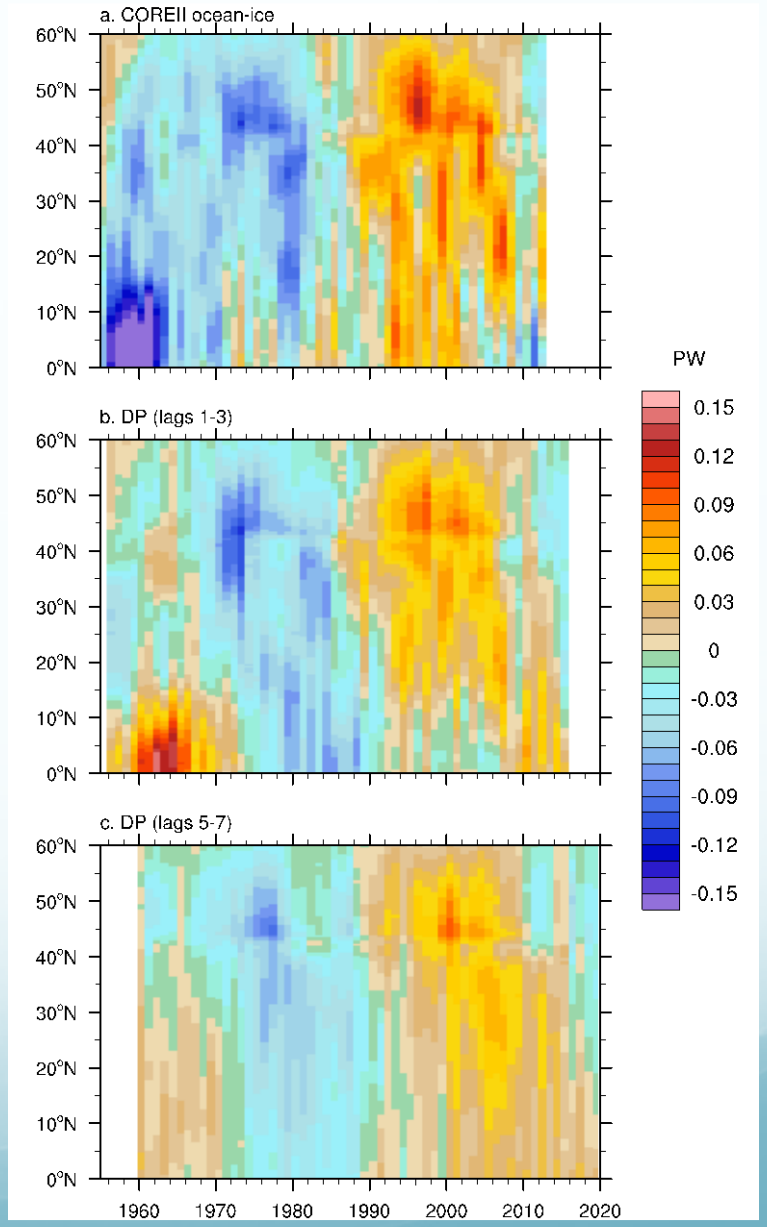


Mechanism

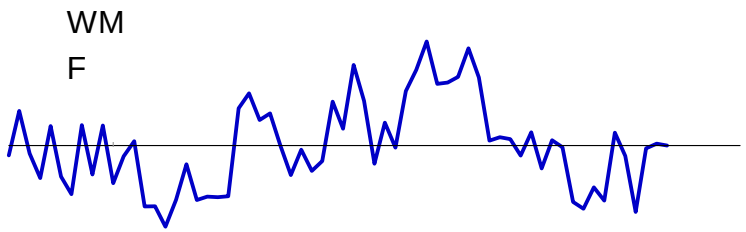
MOC(z)



Poleward Heat Transport



Mechanism



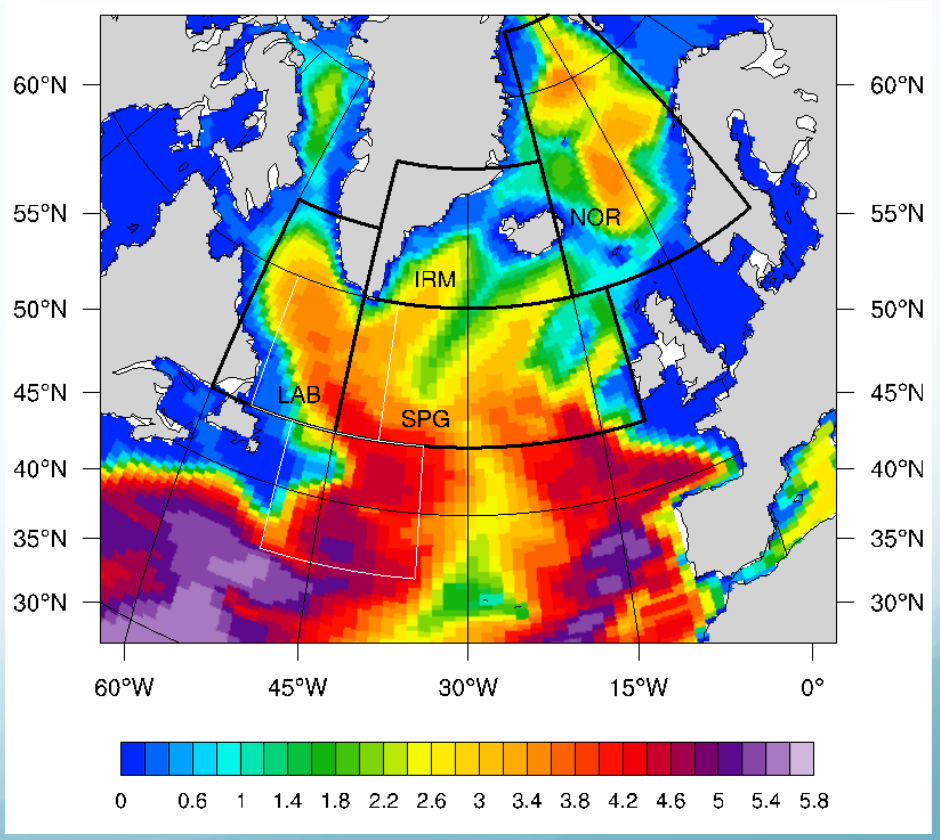
• Annual water mass formation rate (WMF in Sv) anomaly time series computed from monthly COREII surface fluxes over LAB+IRM+SPG regions:

$$D_{as} = -\alpha \frac{Q_{as}}{C_p} - \beta F_{as} \frac{SSS}{1-SSS}$$

$$\mathrm{WMT}(\rho) = \frac{1}{\Delta\rho} \int_{outcrop} D_{as}\, dA \qquad \Delta\rho = 0.1 \frac{kg}{m^3}$$

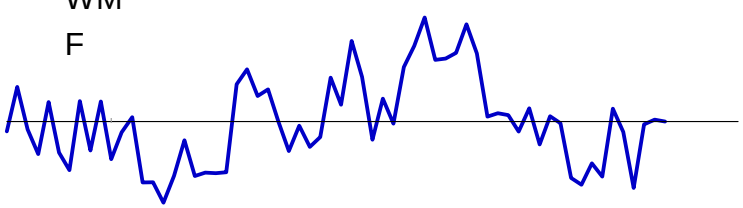
$$\mathrm{WMF}(\rho) = -\frac{\partial(\mathrm{WMT})}{\partial\rho}$$

• In the adiabatic limit, gives anomalous subduction rate of NADW → buoyancy-driven AMOC

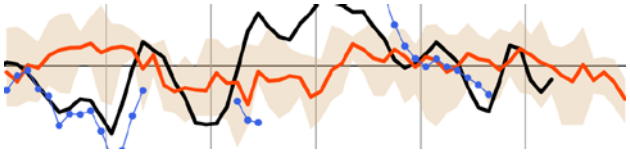


Mechanism

WM
F

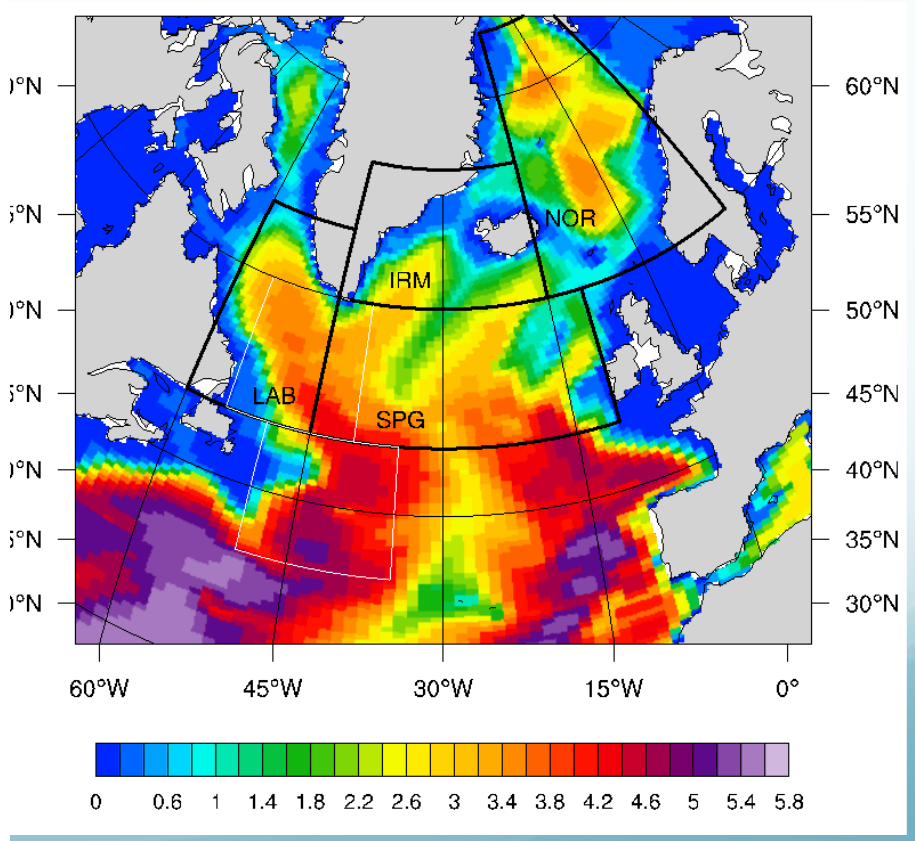


Lab Sea σ’ (0-1000m)



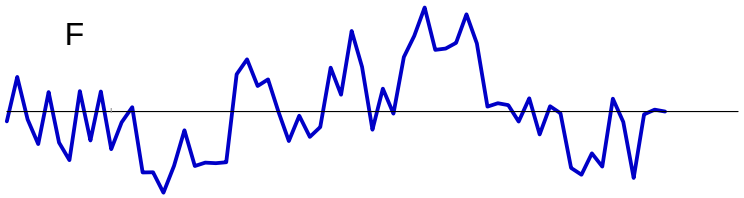
Grand Banks σ’ (0-1000m)

Grand Banks BSF

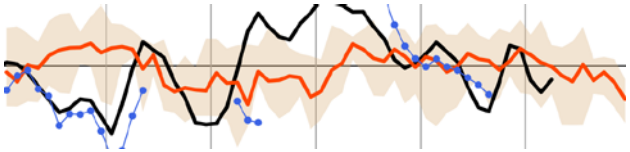


Mechanism

WM
F



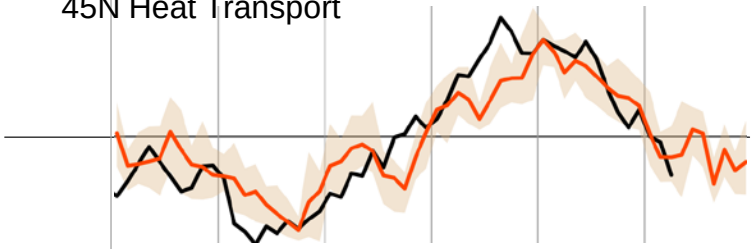
Lab Sea σ’ (0-1000m)



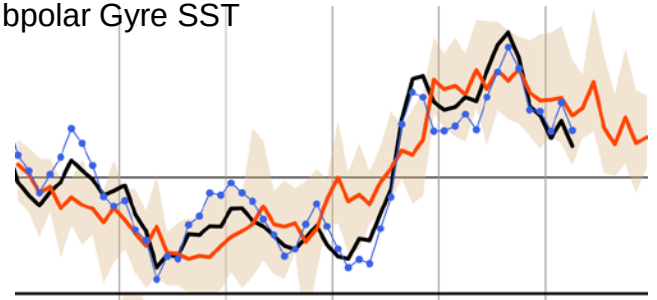
Grand Banks σ’ (0-1000m)

Grand Banks BSF

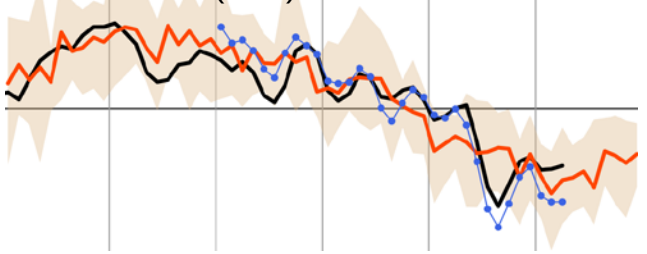
45N Heat Transport



Subpolar Gyre SST

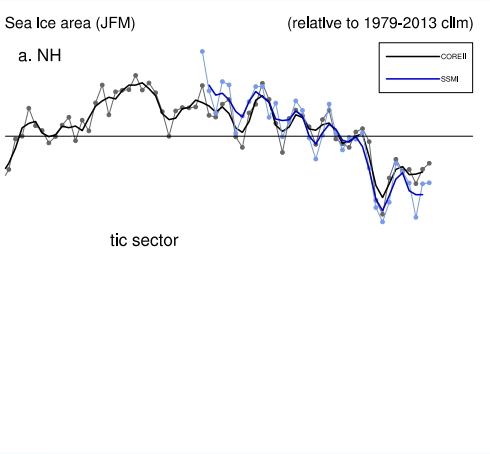


NH sea ice extent (JFM)



NH Atlantic sea ice extent (JFM)

Winter sea ice trend predictions



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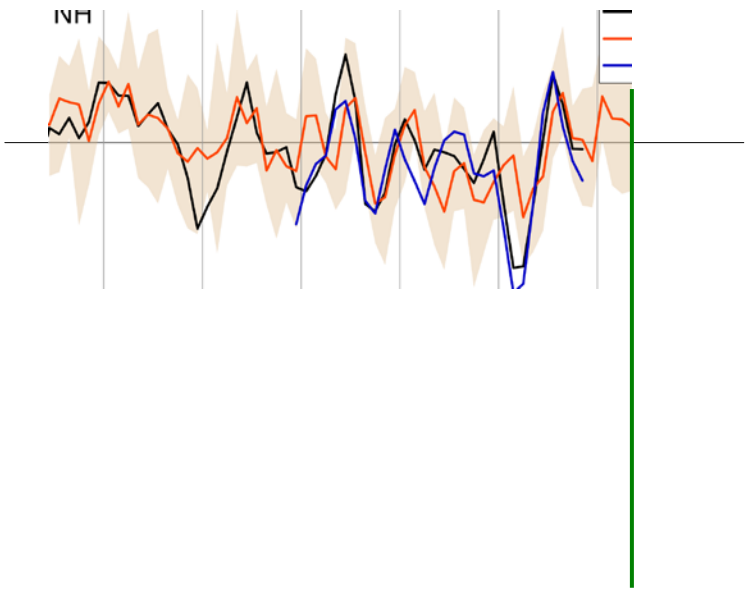

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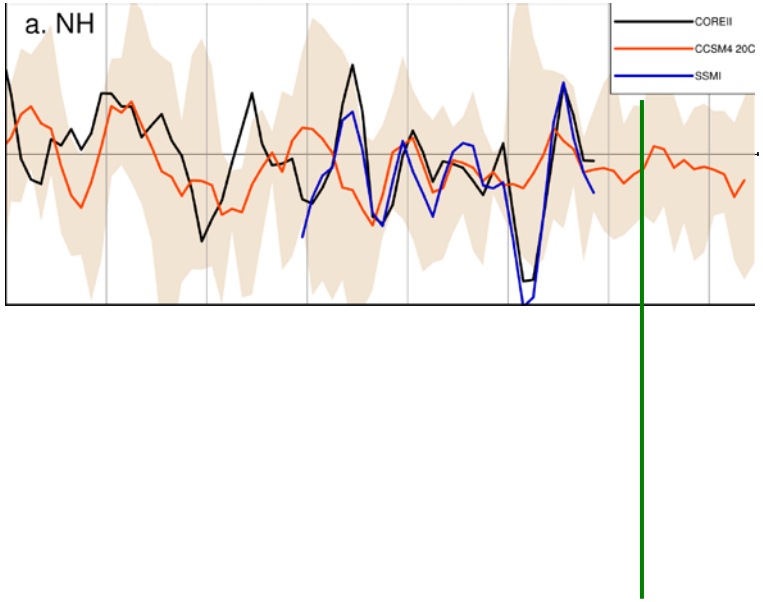
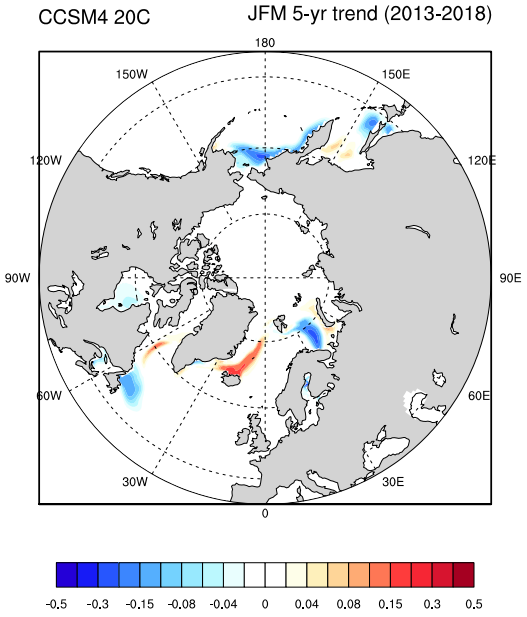
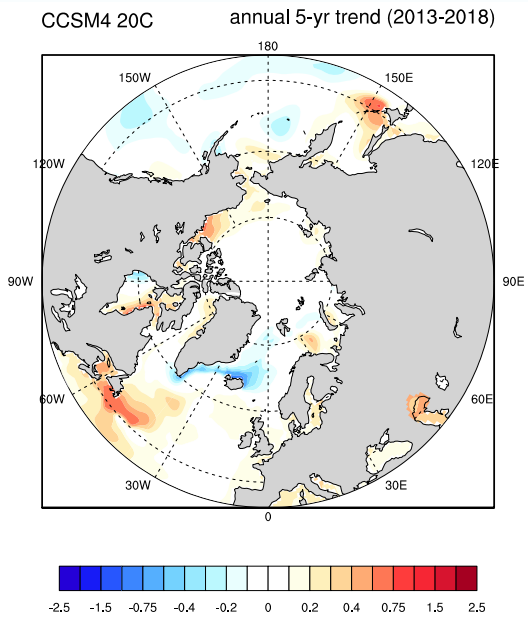
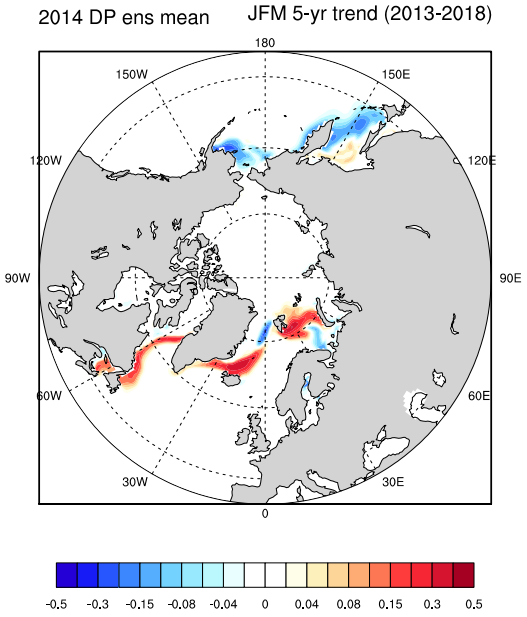


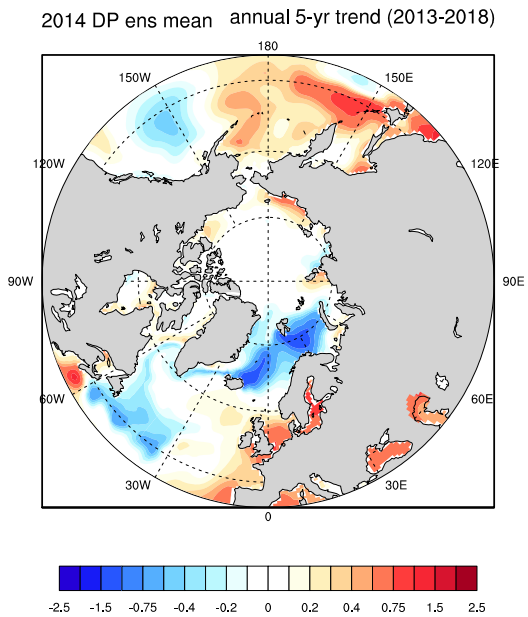
5-yr trends: Winter sea ice annual SST





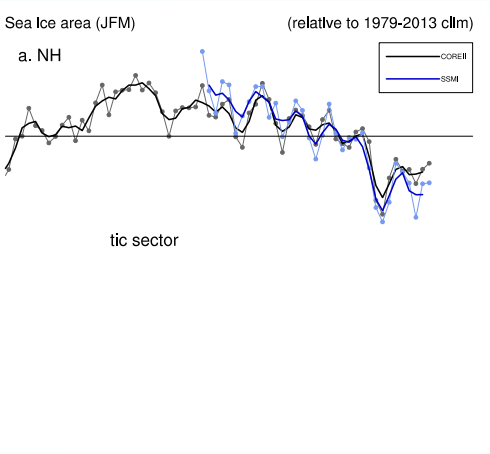
20C





DP

Winter sea ice trend predictions



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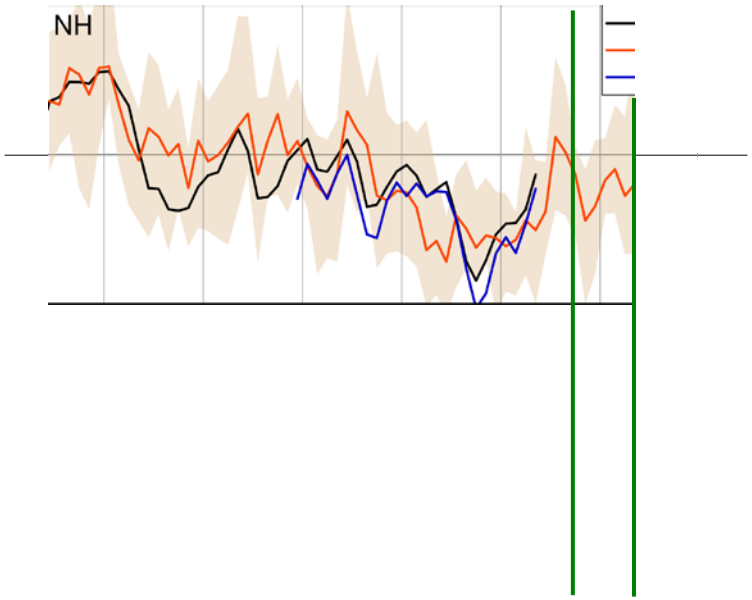

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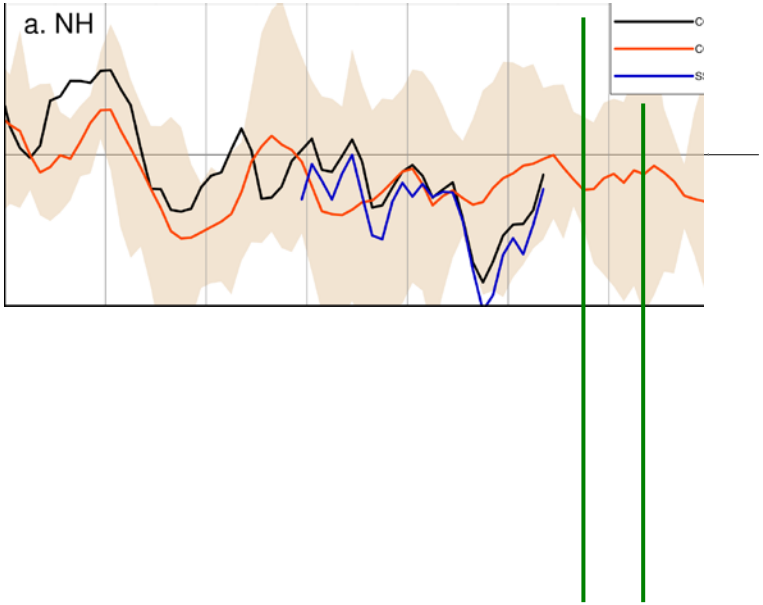
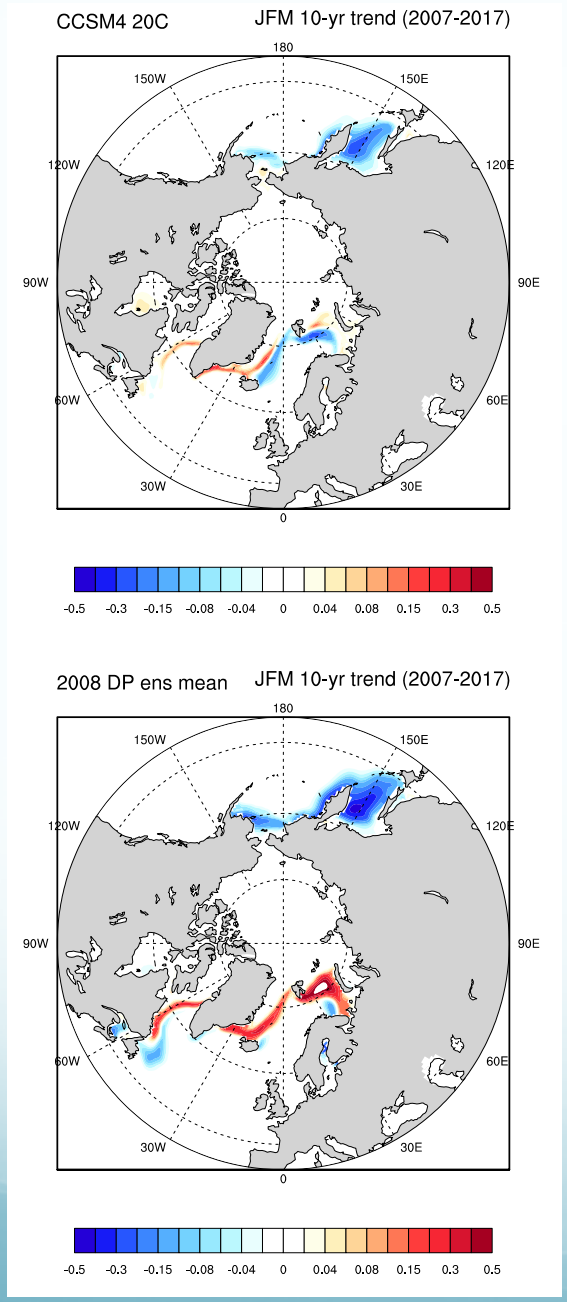
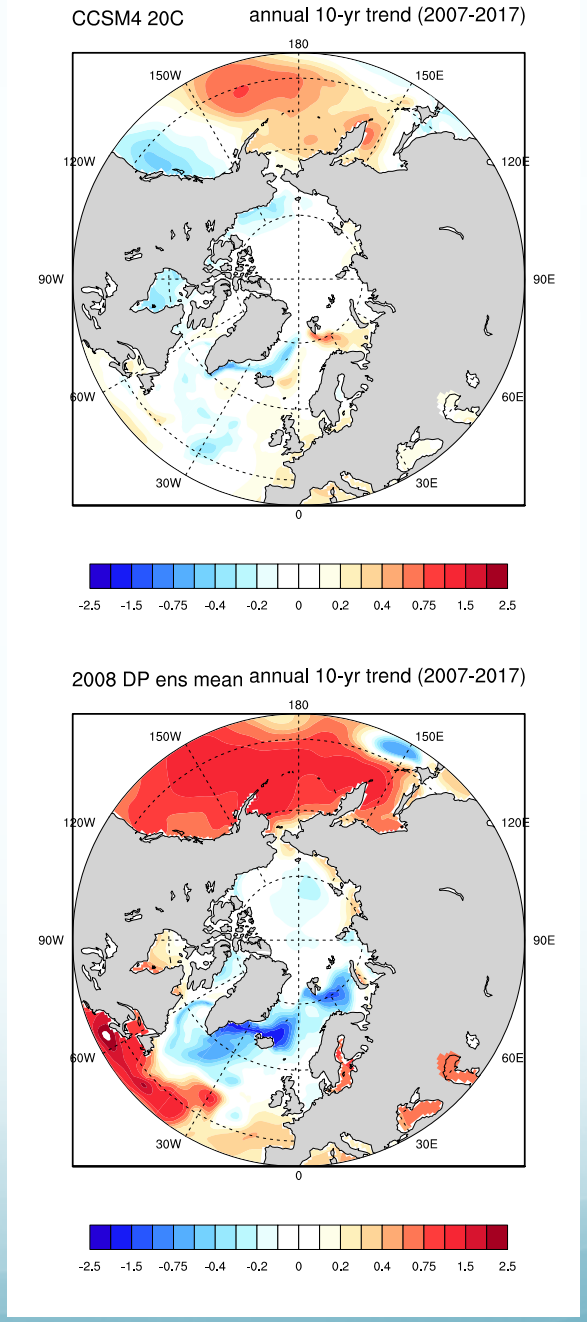


10-yr trends: Winter sea ice



annual SST

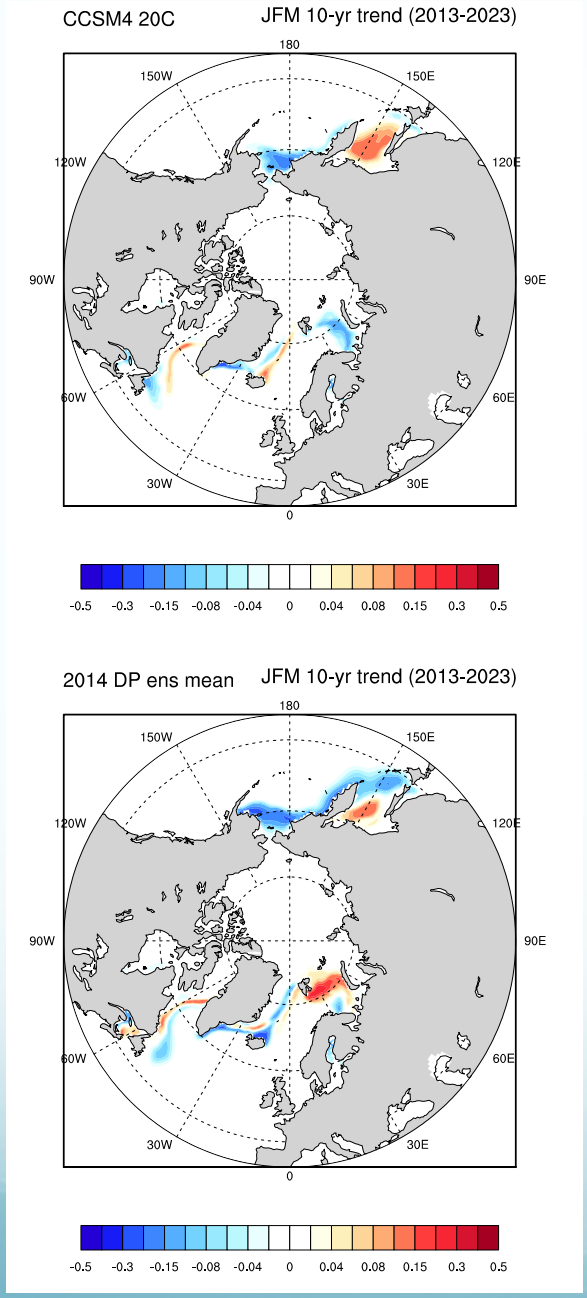


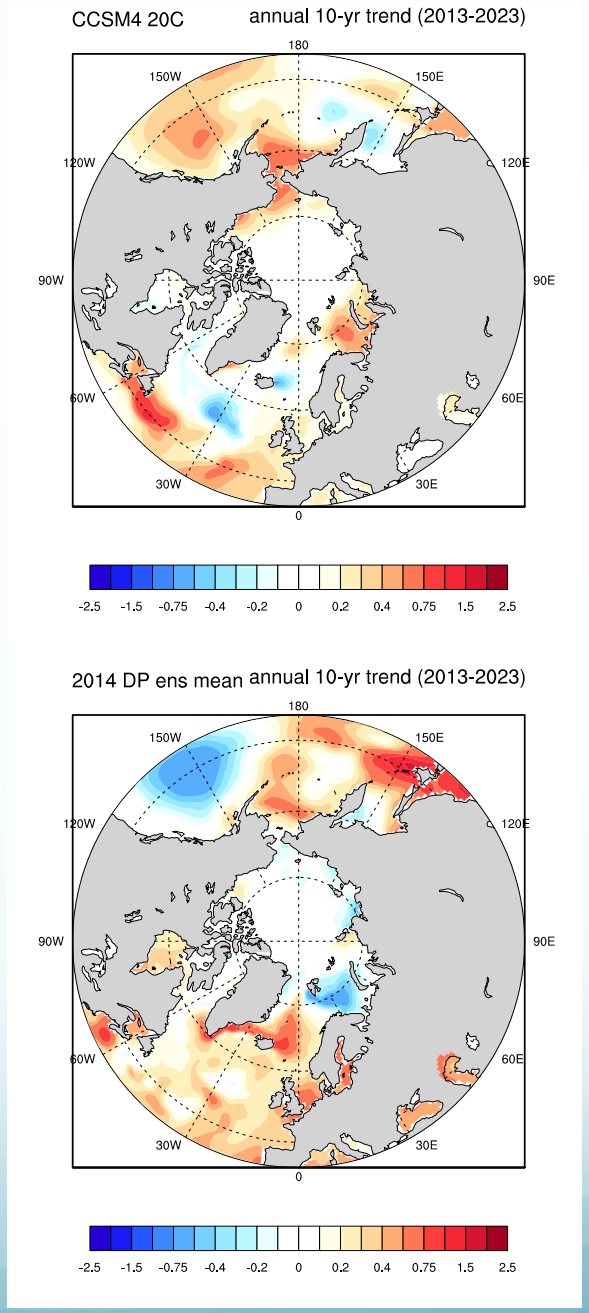
20C

DP

10-yr trends: Winter sea ice

annual SST



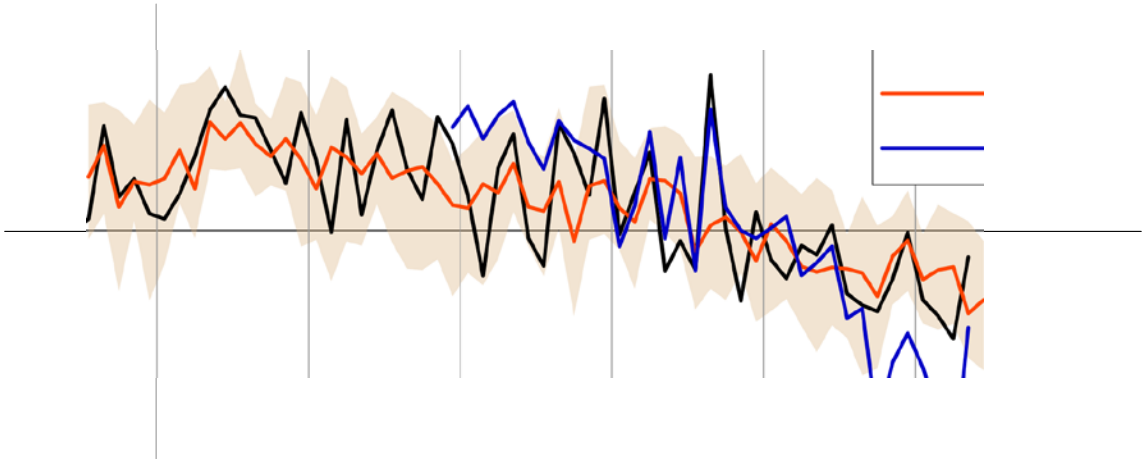


20C

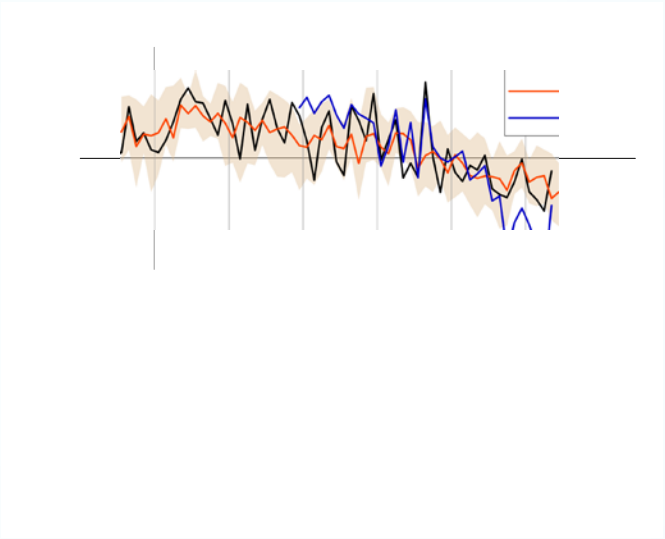
DP

Summer sea ice trend predictions

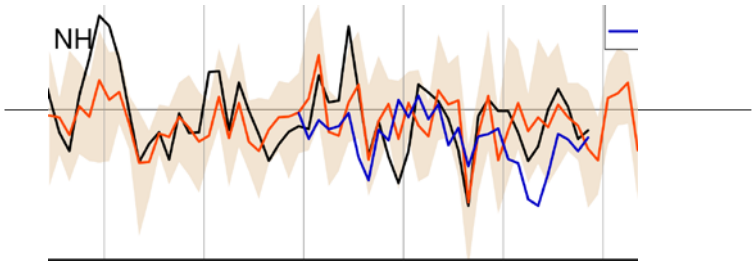
Lead time 7.5 mos



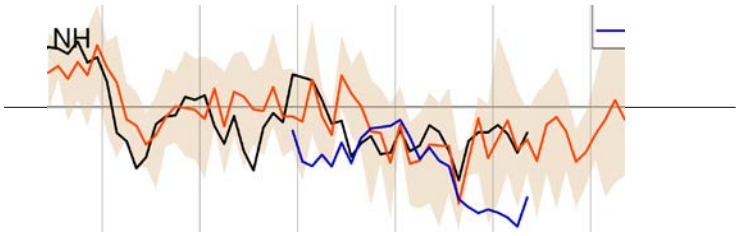
Summer sea ice trend predictions



5-yr trend



10-yr trend



Conclusions

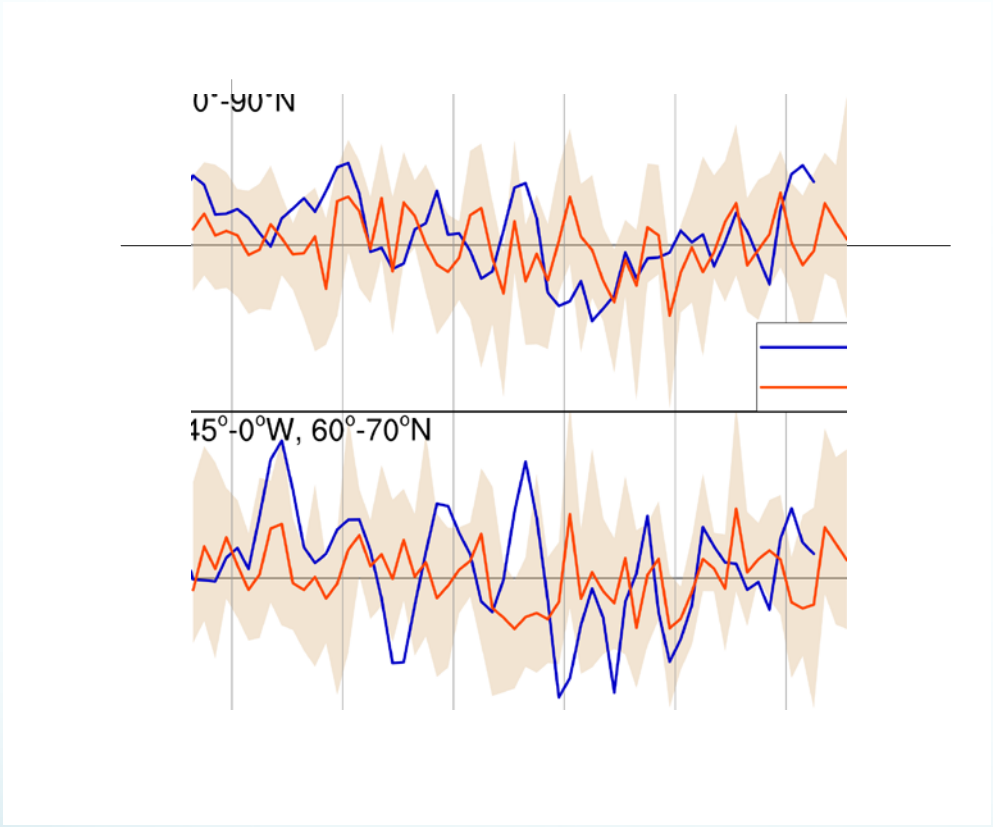
- COREII forced ocean/sea-ice hindcasts are able to reproduce observed Arctic winter sea ice extent variations with high accuracy; large errors in summer.

- CCSM4 initialized prediction ensembles show remarkable skill at forecasting multi-year trends in Arctic winter sea ice extent. Hints that forecasting summer sea ice trends may be feasible with improved historical state estimation.

- The spatial pattern and magnitude of the large negative sea ice trends observed in the 1990s were predictable in advance. The anomalously high rate of sea ice loss was driven by ocean heat transport in the Atlantic sector--a lagged response to the positive 1960-1995 NAO trend.

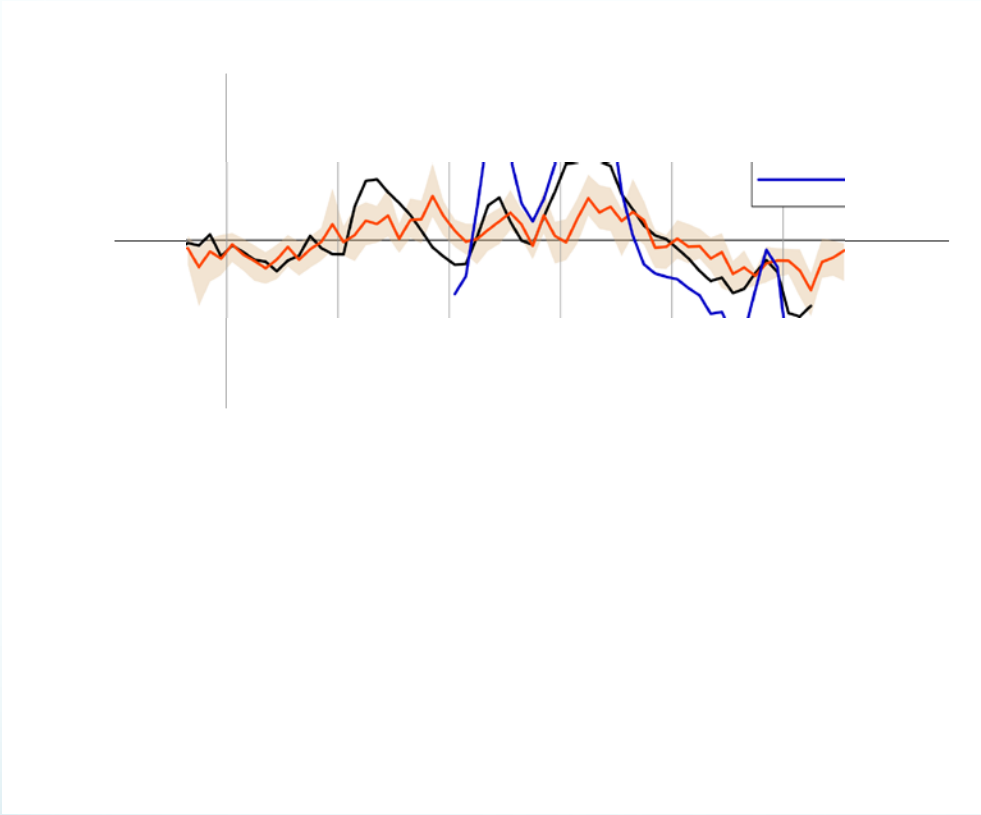
- Spin-down of the large-scale Atlantic circulation (high latitude gyre & AMOC) since ~2005 are associated with negative oceanic heat transport trends➔ likely winter sea ice re-growth in the Atlantic sector

CCSM4 initialized decadal predictions

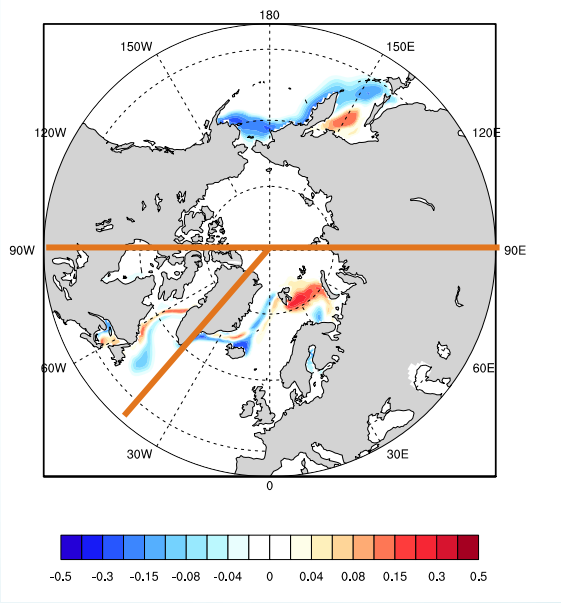


Forecast years 1-3

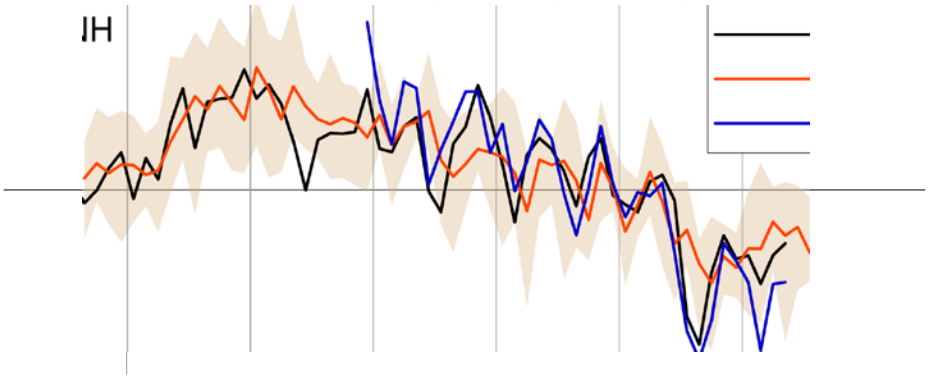
CCSM4 initialized decadal predictions



Forecast years 1-3

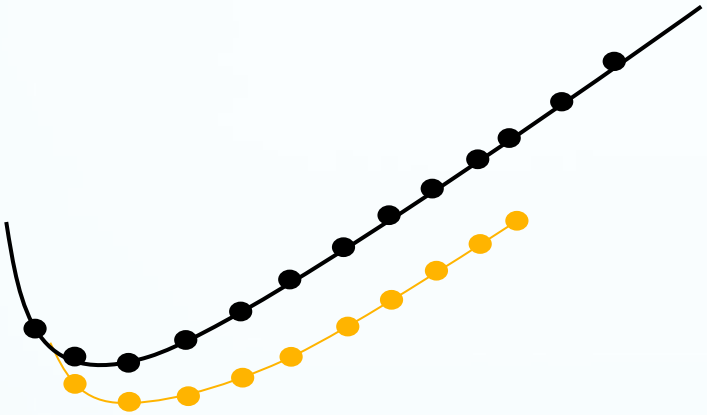


CCSM4 initialized decadal predictions



Lead time 1.12yrs
(no smoothing)

CCSM4 initialized decadal predictions



Regions

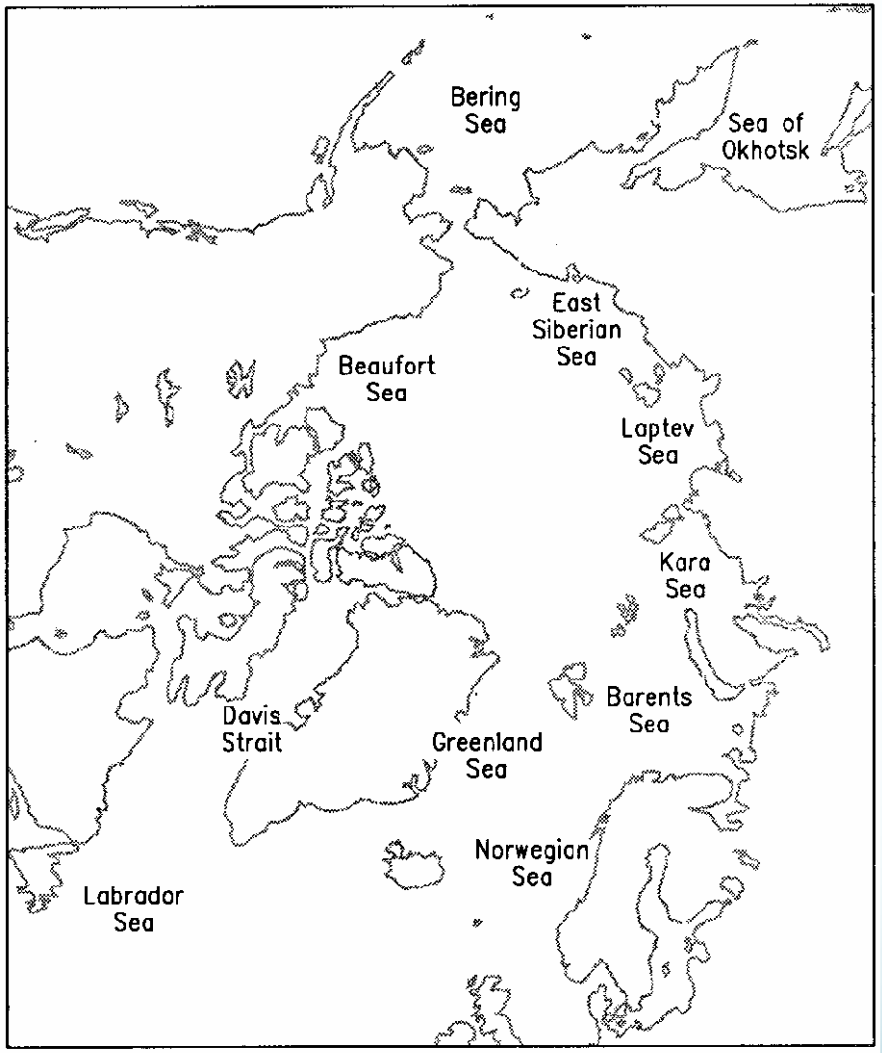


FIG. 1. Map of the Arctic Seas.