Internal (atmospheric) variability and (the forcing of) 21st century (Arctic) sea ice loss

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Acknowledgments (in no particular order):
Marika Holland, Adam Phillips, Dennis Shea, Alex Jahn, Jen Kay, Matt Long, Dave Bailey, Gary Strand, Bob Thomas, Dave Schneider

using (mostly) NCAR CCSM3 (also CCSM4, obs.):

40-member coupled model ensemble 2000-2061

Forcing: SRES A1B greenhouse gas scenario

Initial conditions: identical except for slight perturbations to the atmosphere

No memory of initial conditions beyond ~ 1 decade

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Uncertainty in 21st century Arctic sea ice loss:
The role of internal climate variability

Differences in the amount of simulated (and observed)
21st century ice loss can be caused by 3 factors:

1) FORCING: GHGs, aerosols, etc.

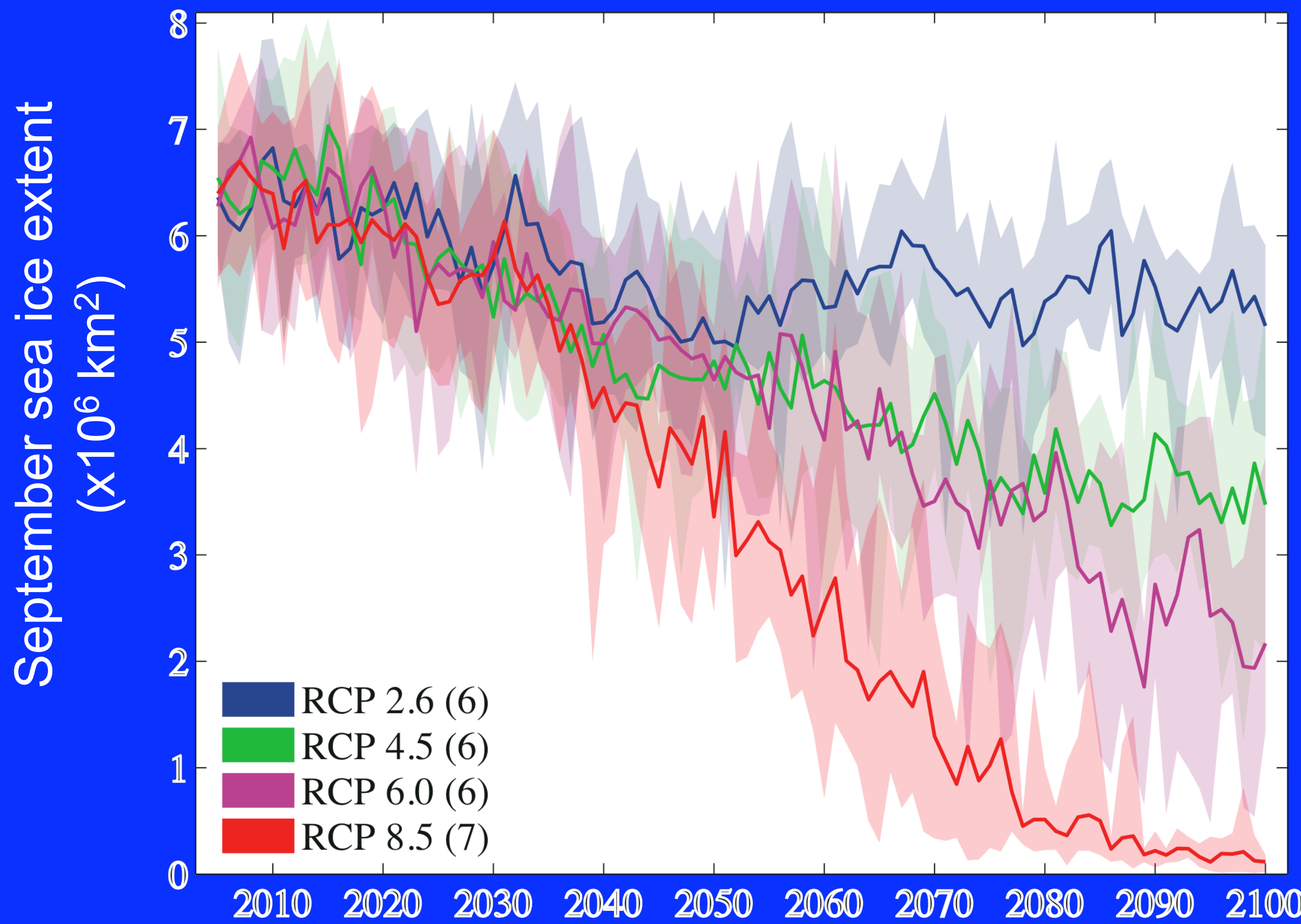
2) PHYSICS: Relative importance of dynamic vs. thermodynamic processes; model parameterization

3) VARIABILITY: coupled variability in ocean, ice, atmos, land…

Deser et al., 2012 (Climate Dynamics)

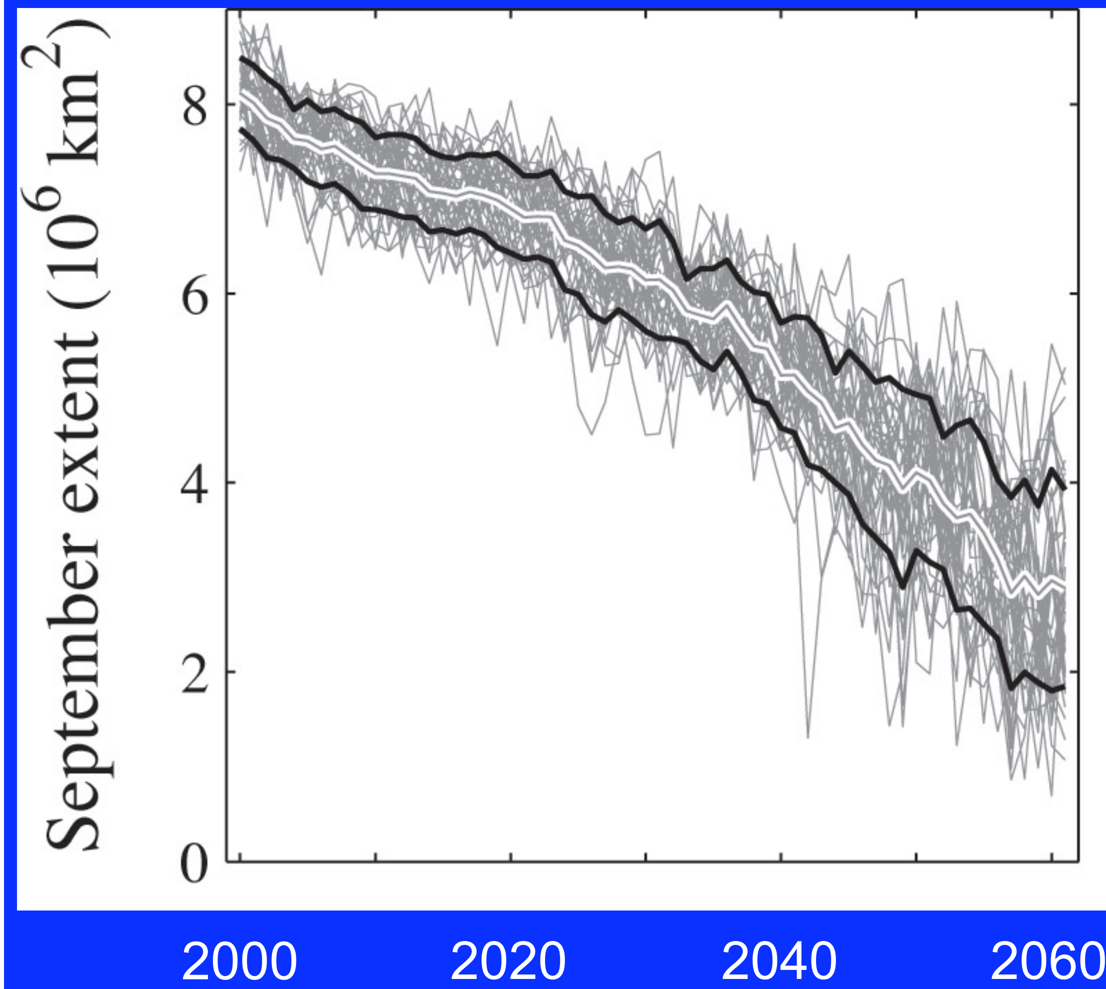
1) FORCING 2) Physics 3) VARIABILITY

CCSM4 simulations



see also: Kay et al., 2011 (GRL): trends / importance of internal variability

1) Forcing 2) Physics 3) VARIABILITY



NCAR CCSM3:

Unique large fully-coupled ensemble; CCSM3 has been used extensively in studies of Arctic sea ice; clean set of experiments to isolate and evaluate important physical relationships

39-member fully-coupled T42 ensemble

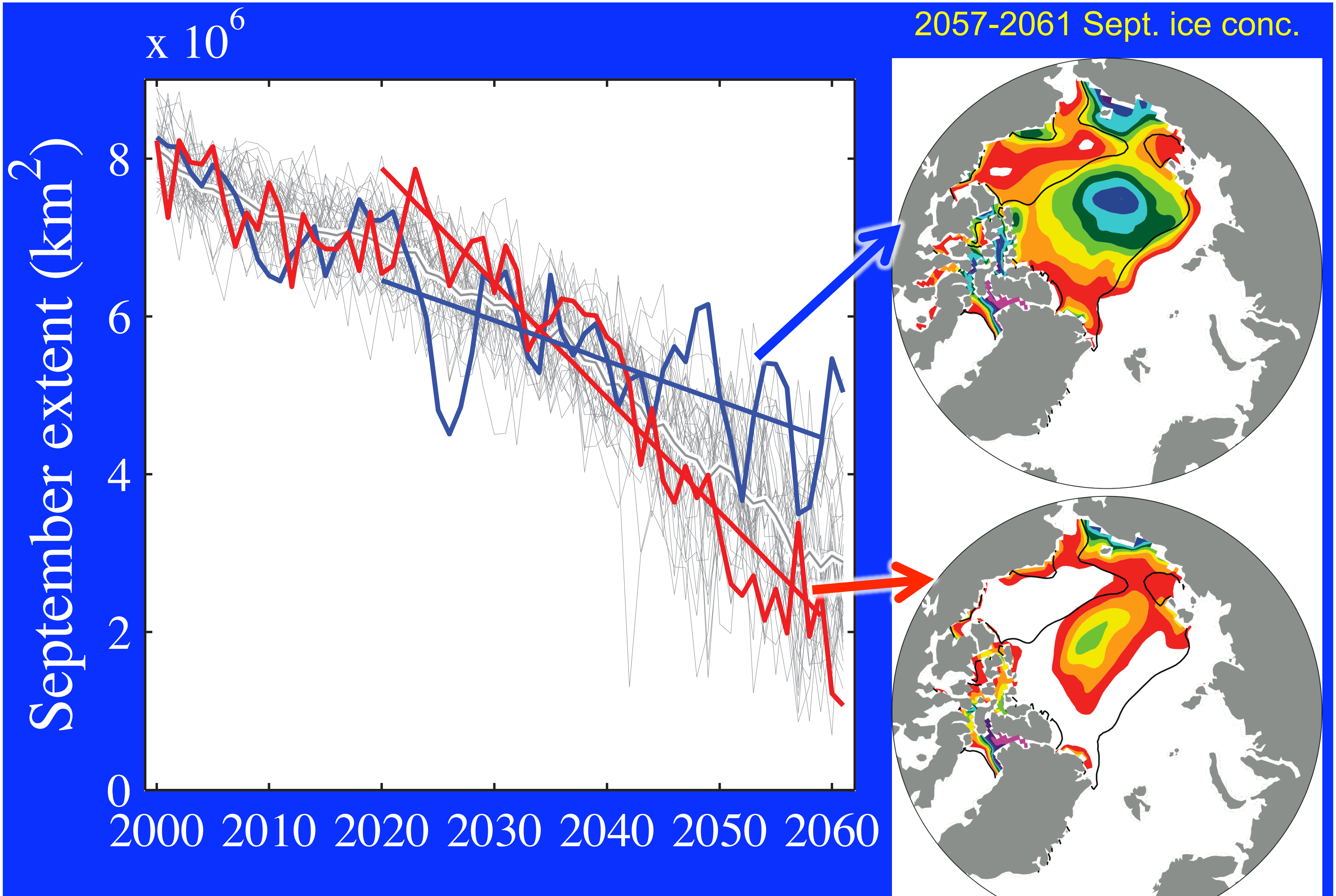
Simulations from 2000-2061 (62 years)

A1B 21st century forcing

Identical initial conditions in the ocean, land and sea ice

Slightly different atmospheric initial conditions in each ensemble member

Caveat: some problems with initial ice amount and distribution



Large difference in ultimate ice
Little long-term ice memory

1) Forcing vs. 2) Physics vs. 3) Variability

CCSM4 ensemble mean spread, 2060 (forcing)	~ 2.6 x 10^6 km^2
CCSM4 ensemble member spread, 2060 (forcing + internal variability)	~ 5 x 10^6 km^2
Increase in 1 standard deviation range, 2000-2060 (IPCC AR4 ens.: Stroeve et. al 2007; physics and variability)	~ 1.7 x 10^6 km^2
1 standard deviation range in 39-member CCSM3 ensemble (internal variability)	~ 2 x 10^6 km^2

Key result:

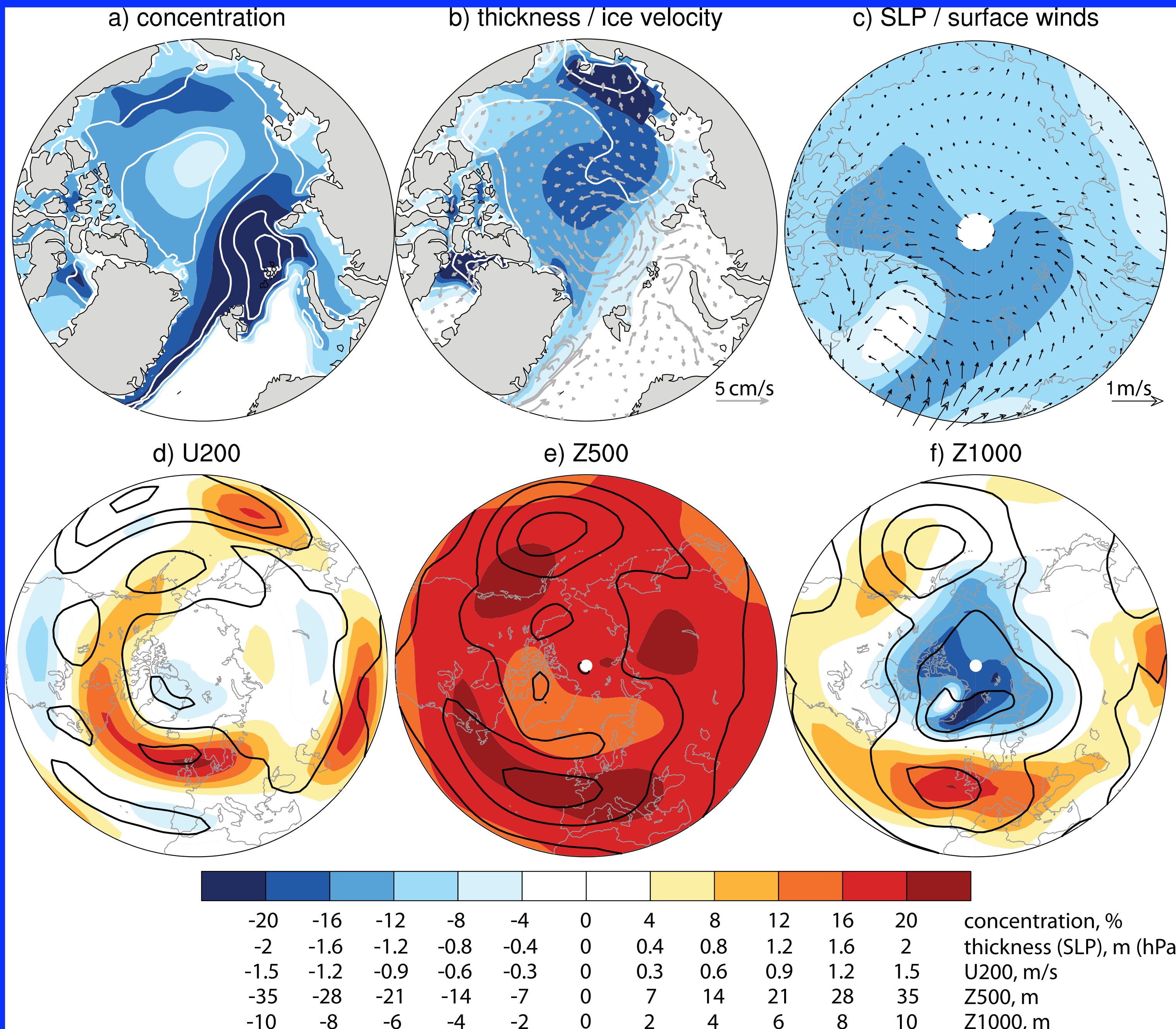
Internal variability is important.

The internal variability in the 25-member CCSM4 and 39-member CCSM3 ensembles is comparable to changes resulting from different forcing and different models in simulated mid-21st century sea ice loss.

What causes the different amounts of sea ice loss by 2060?

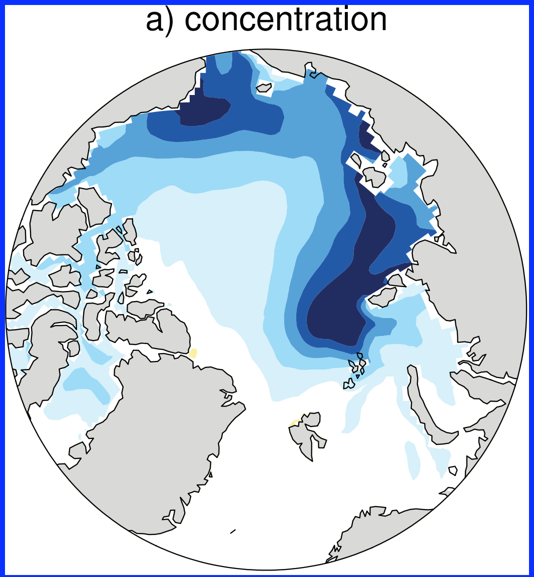
To address this question, we have looked at a broad suite of candidate ocean and atmospheric influences ("internal forcings" and "internal responses / feedbacks"). For simplicity, we'll focus on atmospheric forcing in the Arctic today…

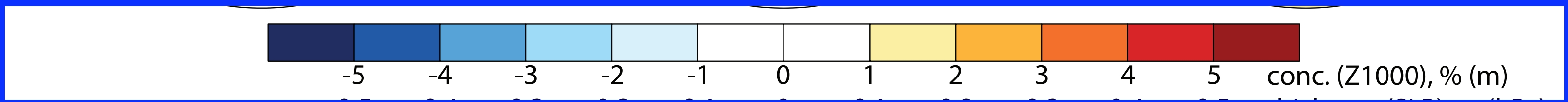
annual ens.-mean trends and trend standard deviations



Relationships to ensemble spread in Sep. ice loss

regressions of Oct-Sept 2020-2059 linear trends onto STD[2020-59 Sep extent trend]





loss of ice coverage
around the coast

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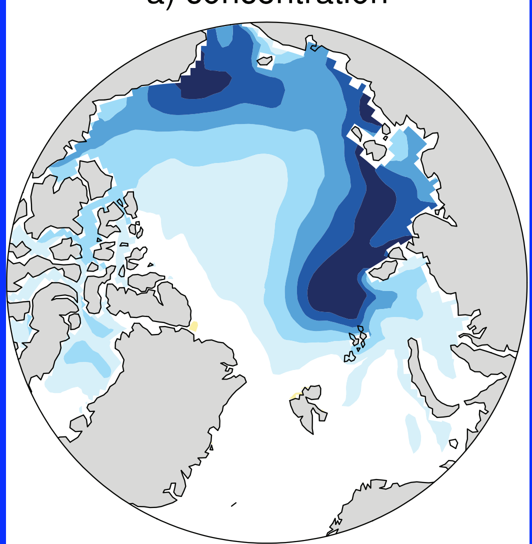

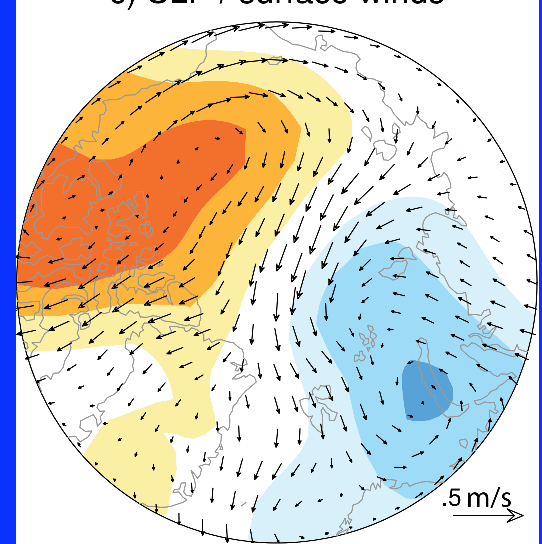

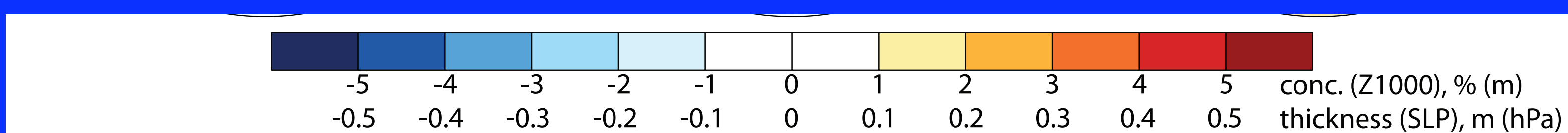

loss of ice coverage
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“Arctic Dipole” SLP pattern
transpolar drift / ice advection

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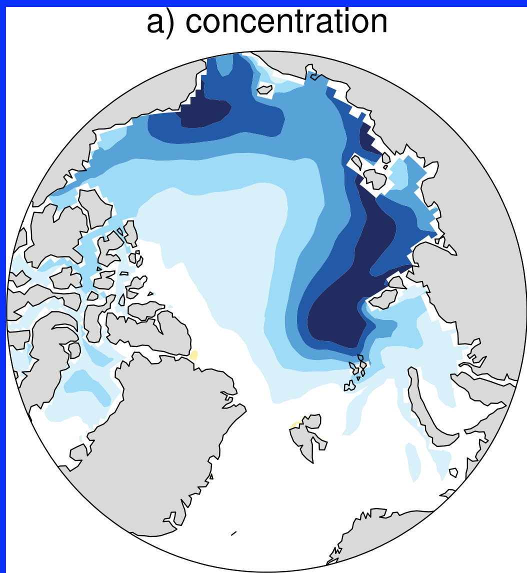

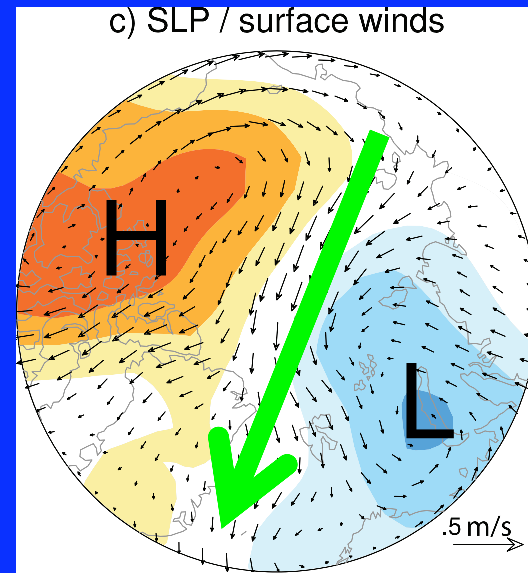

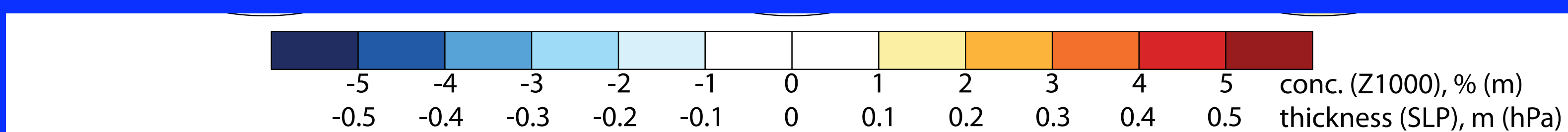

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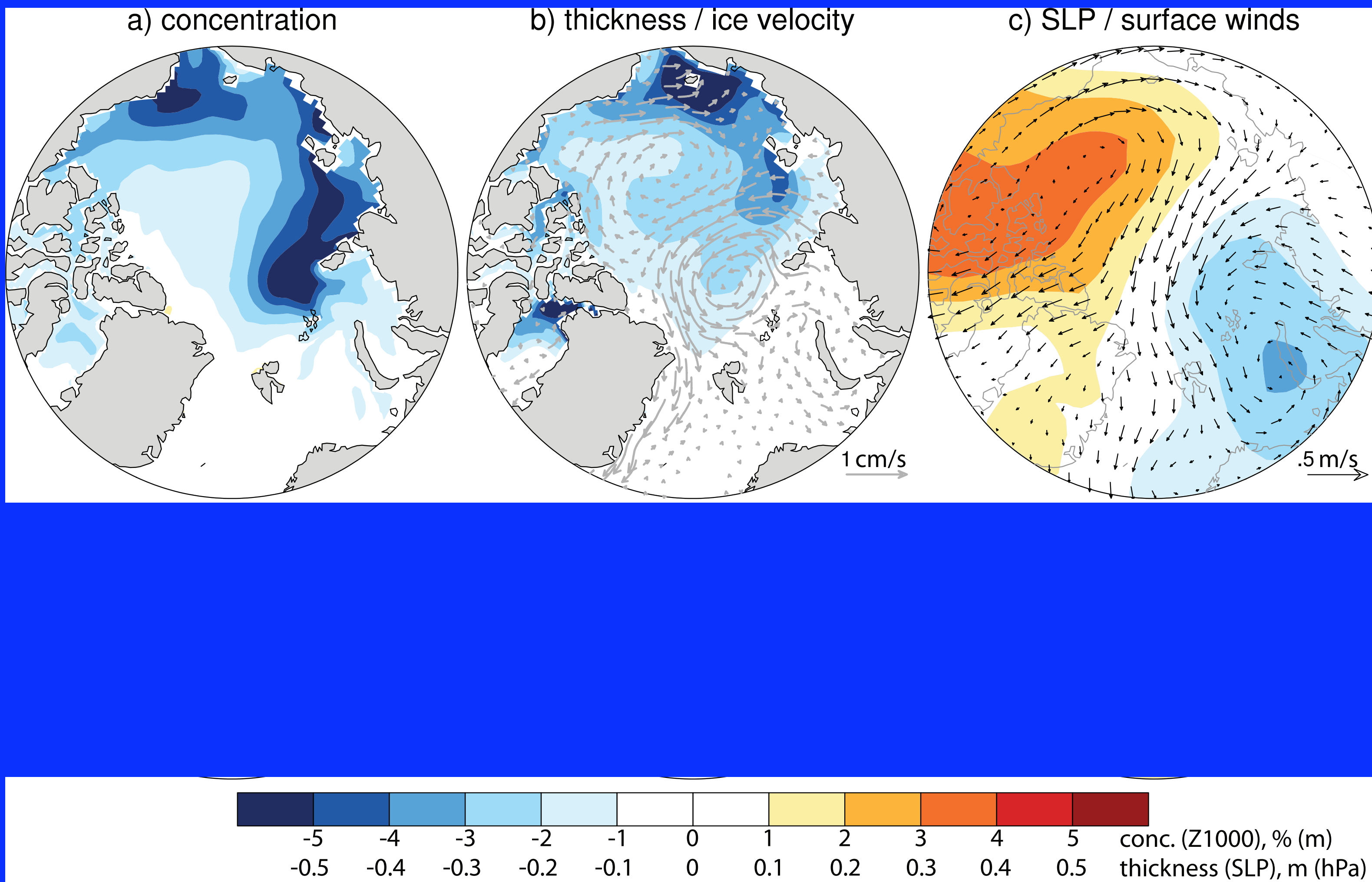
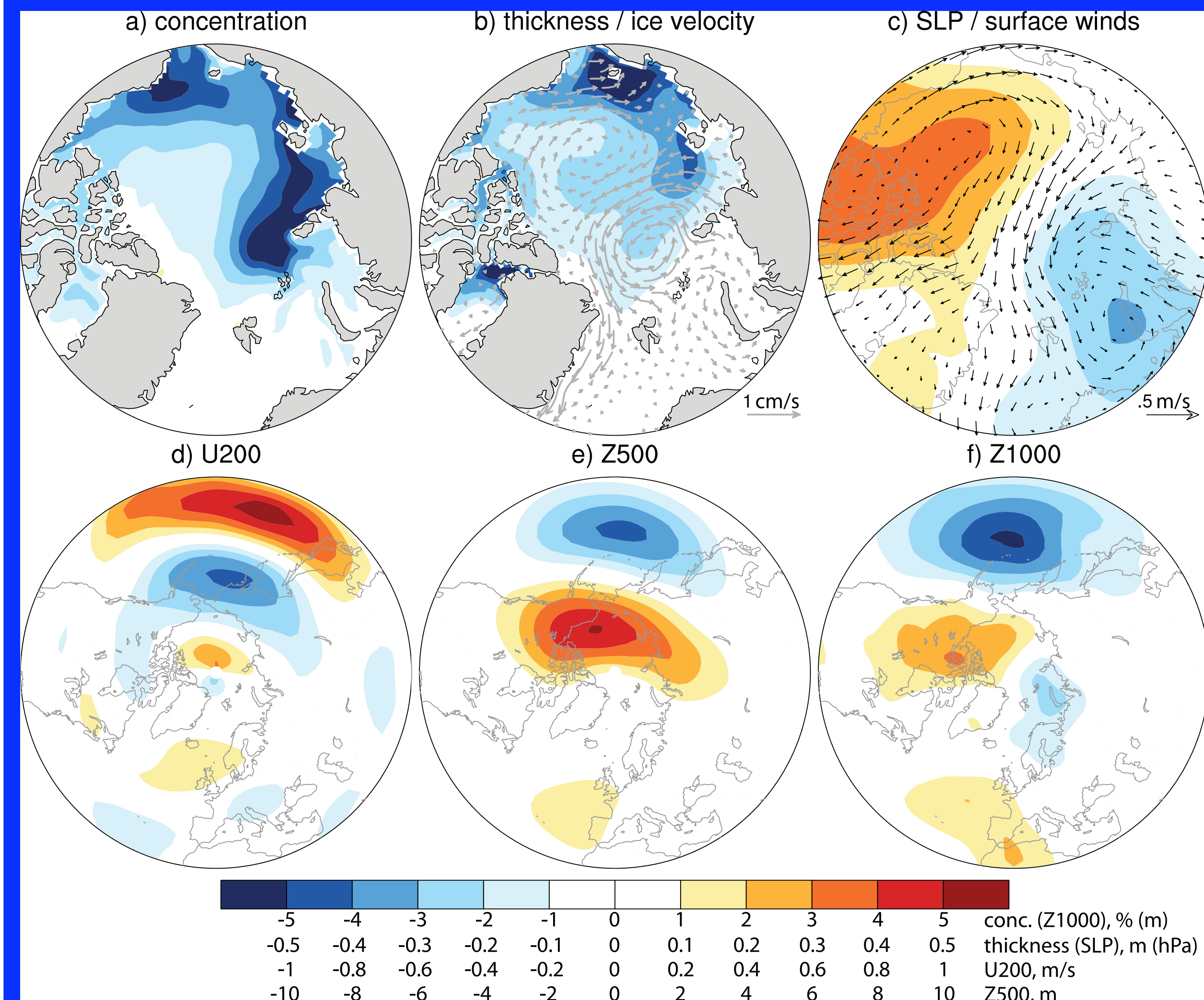


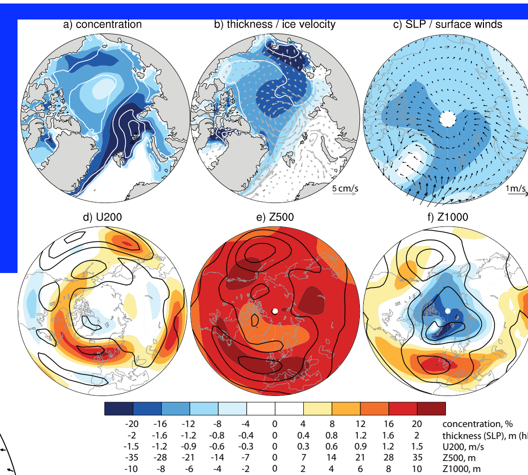
loss of ice coverage around the coast

evidence of ice advection

"Arctic Dipole" SLP pattern transpolar drift / ice advection

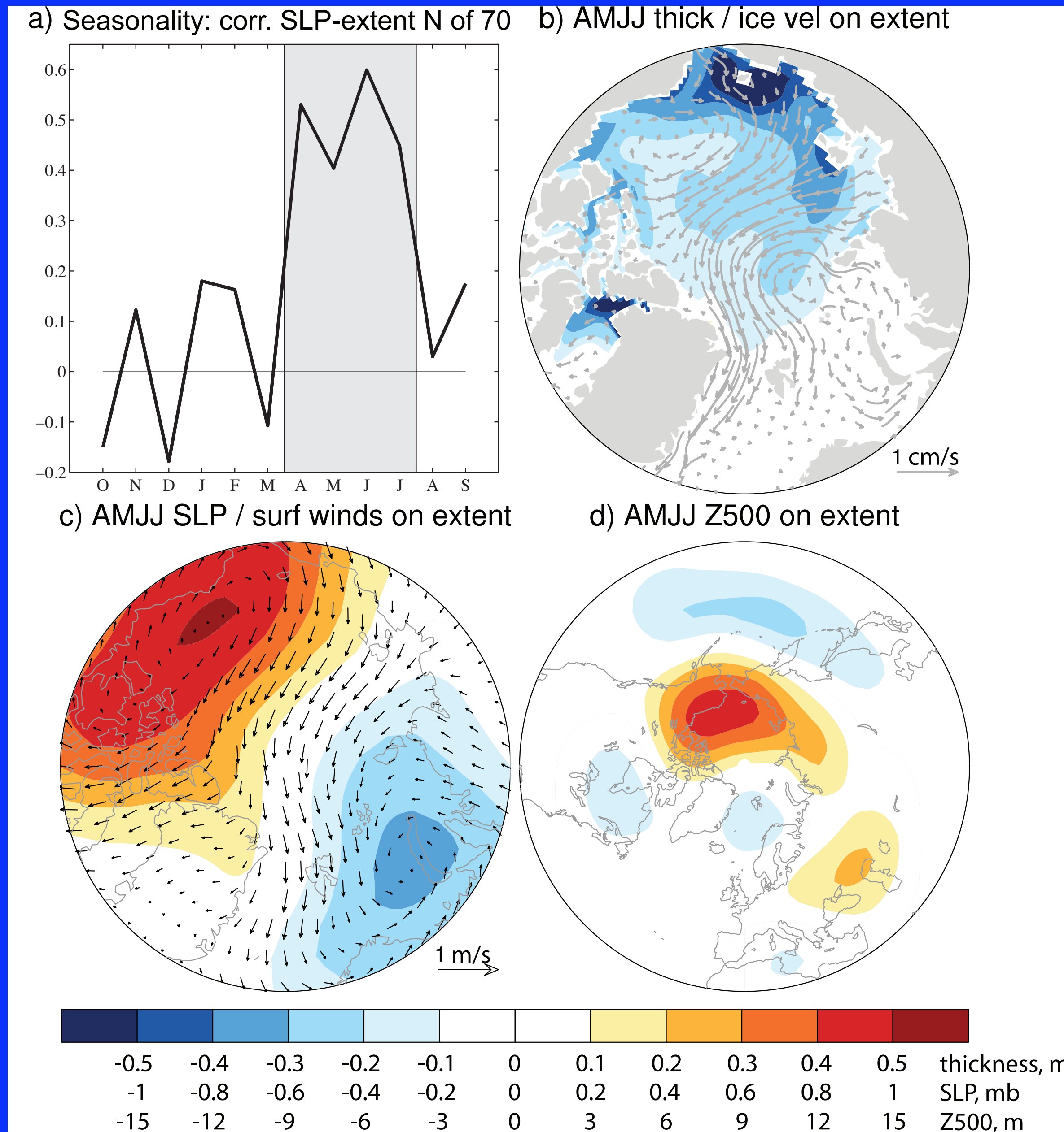
Regressions onto ensemble spread in September ice extent loss



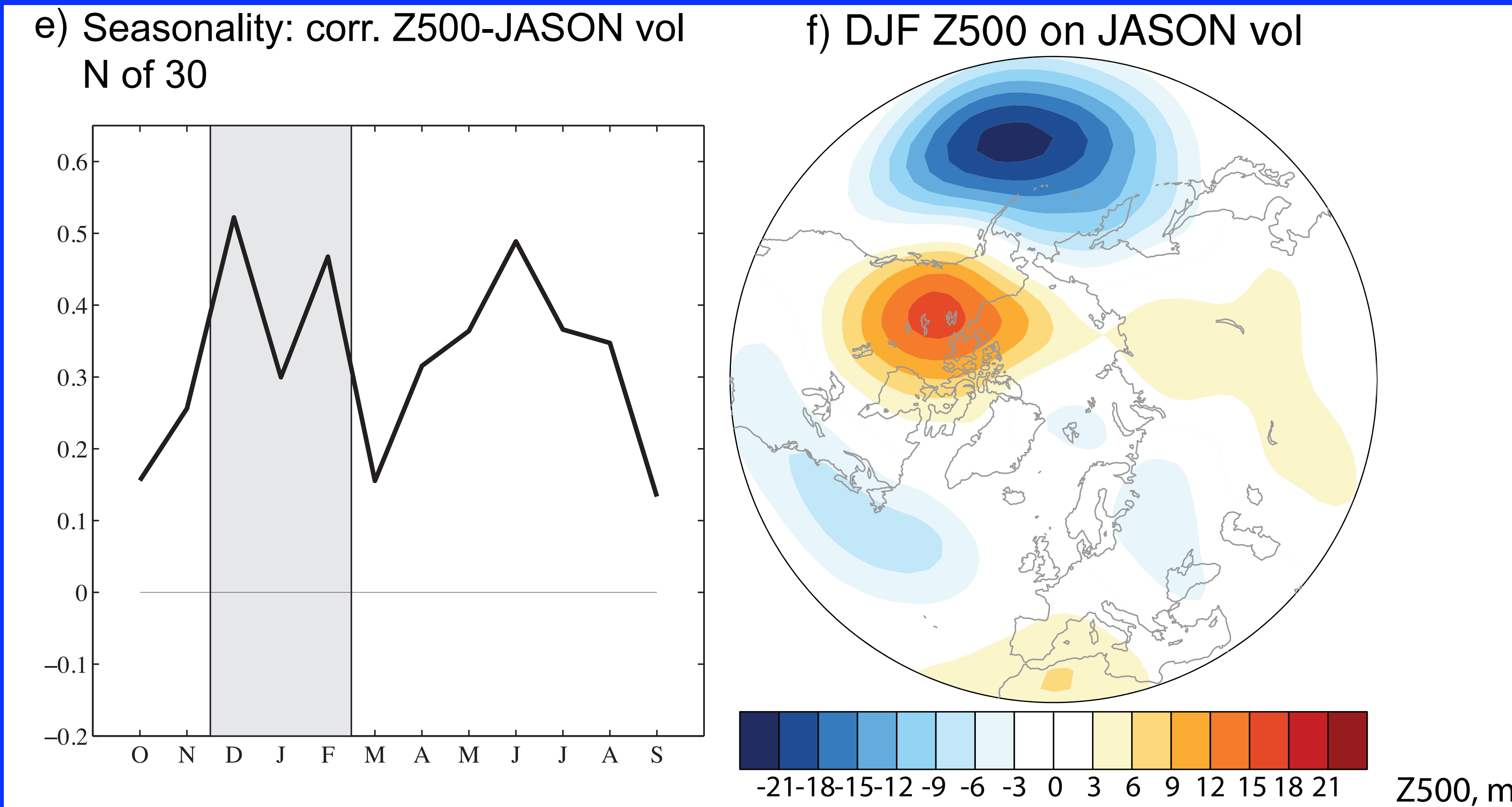


ensemble-mean trends

seasonality: AMJJ

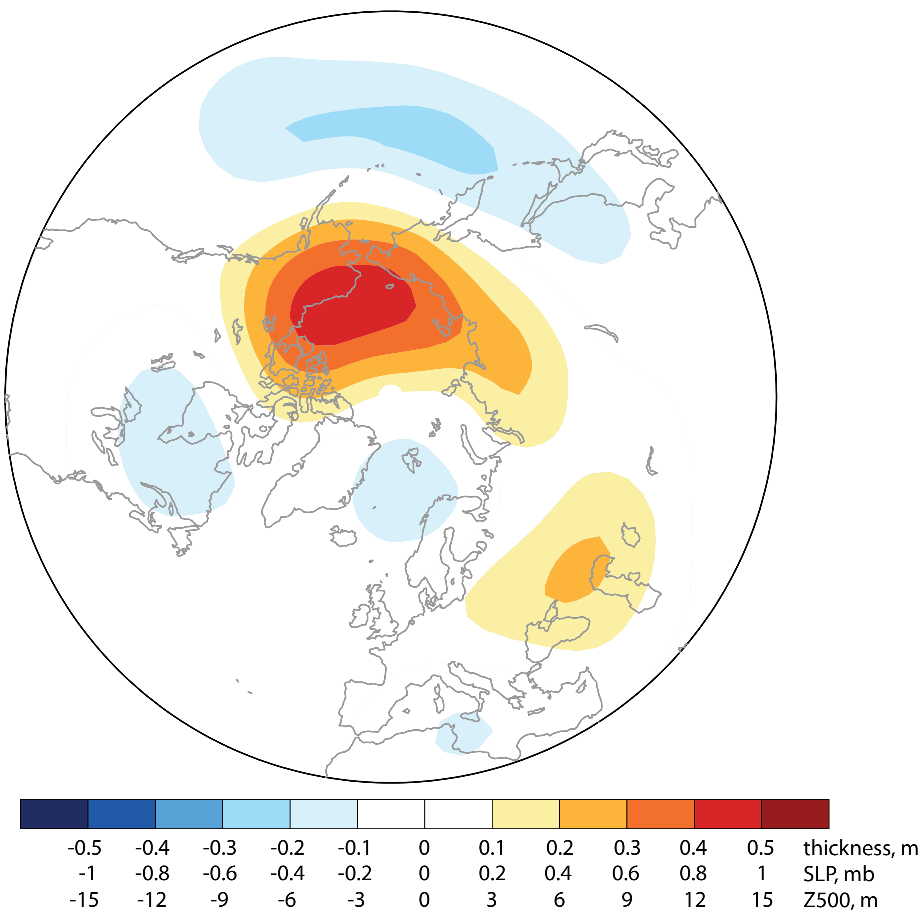


seasonality: DJF

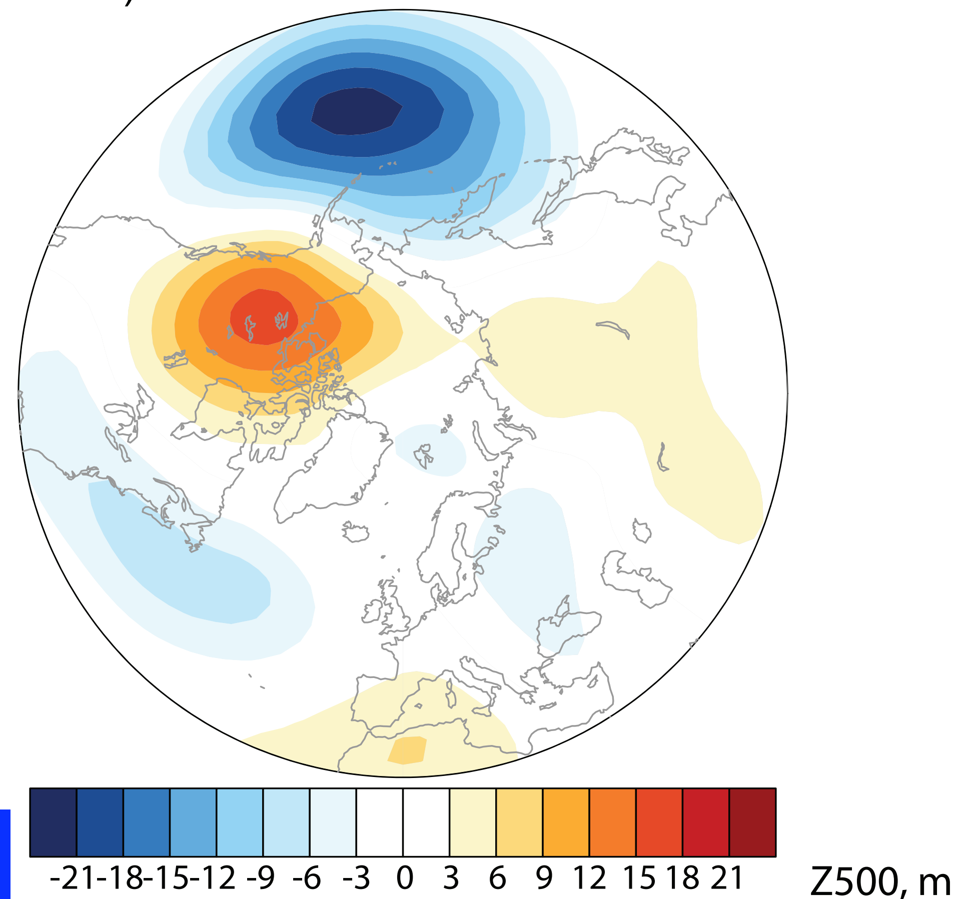


seasonality: AMJJ vs. DJF

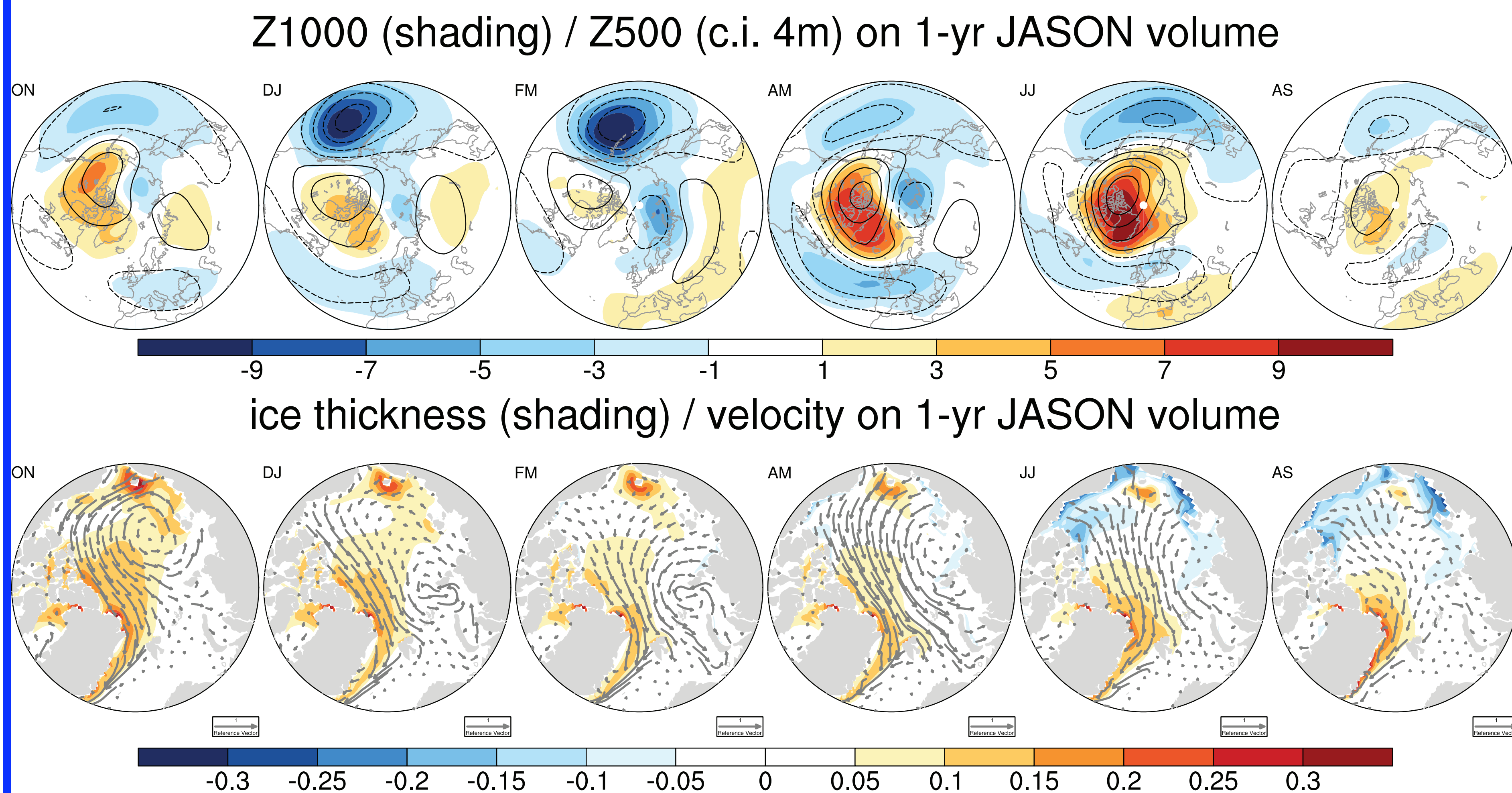
d) AMJJ Z500 on extent

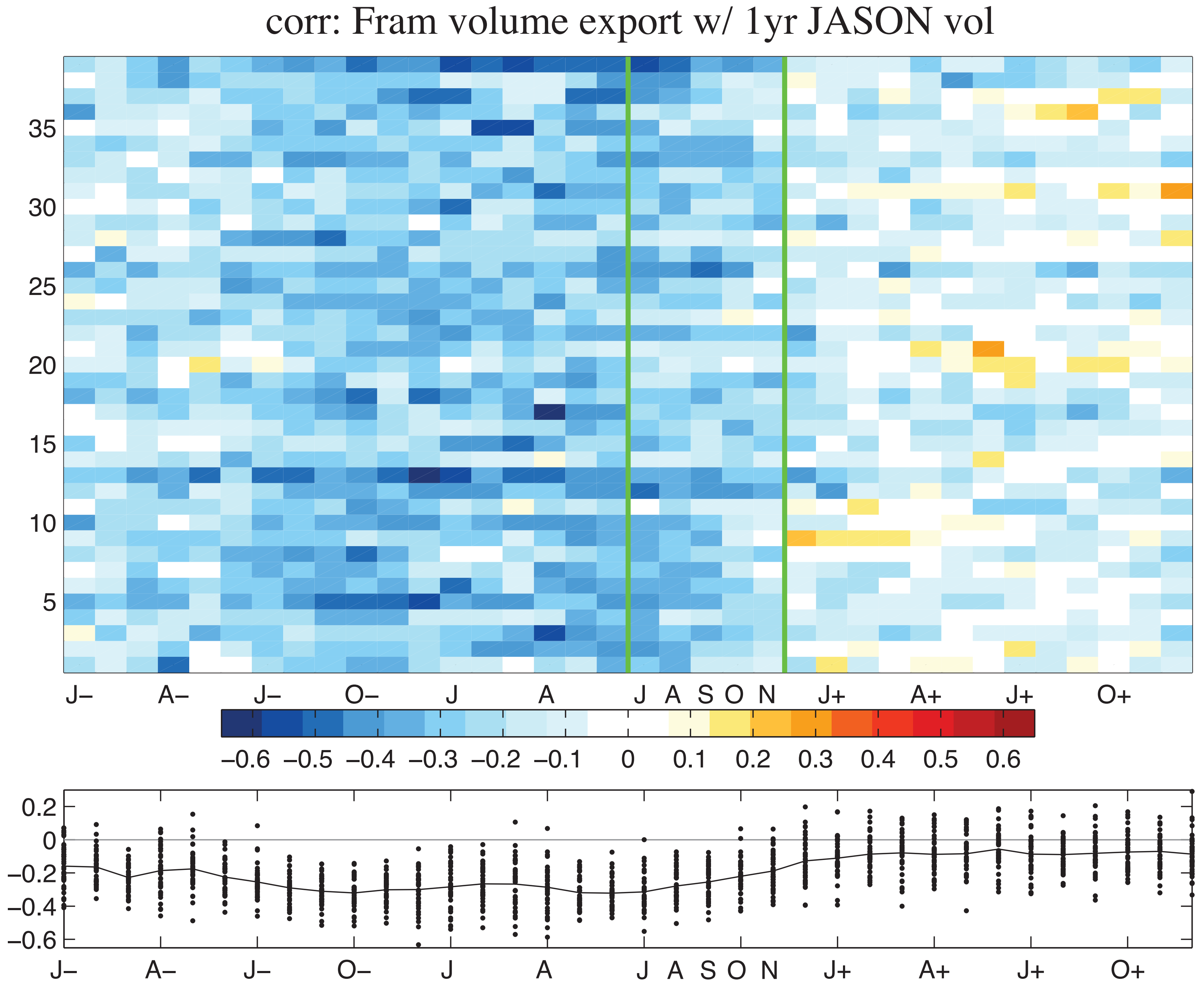


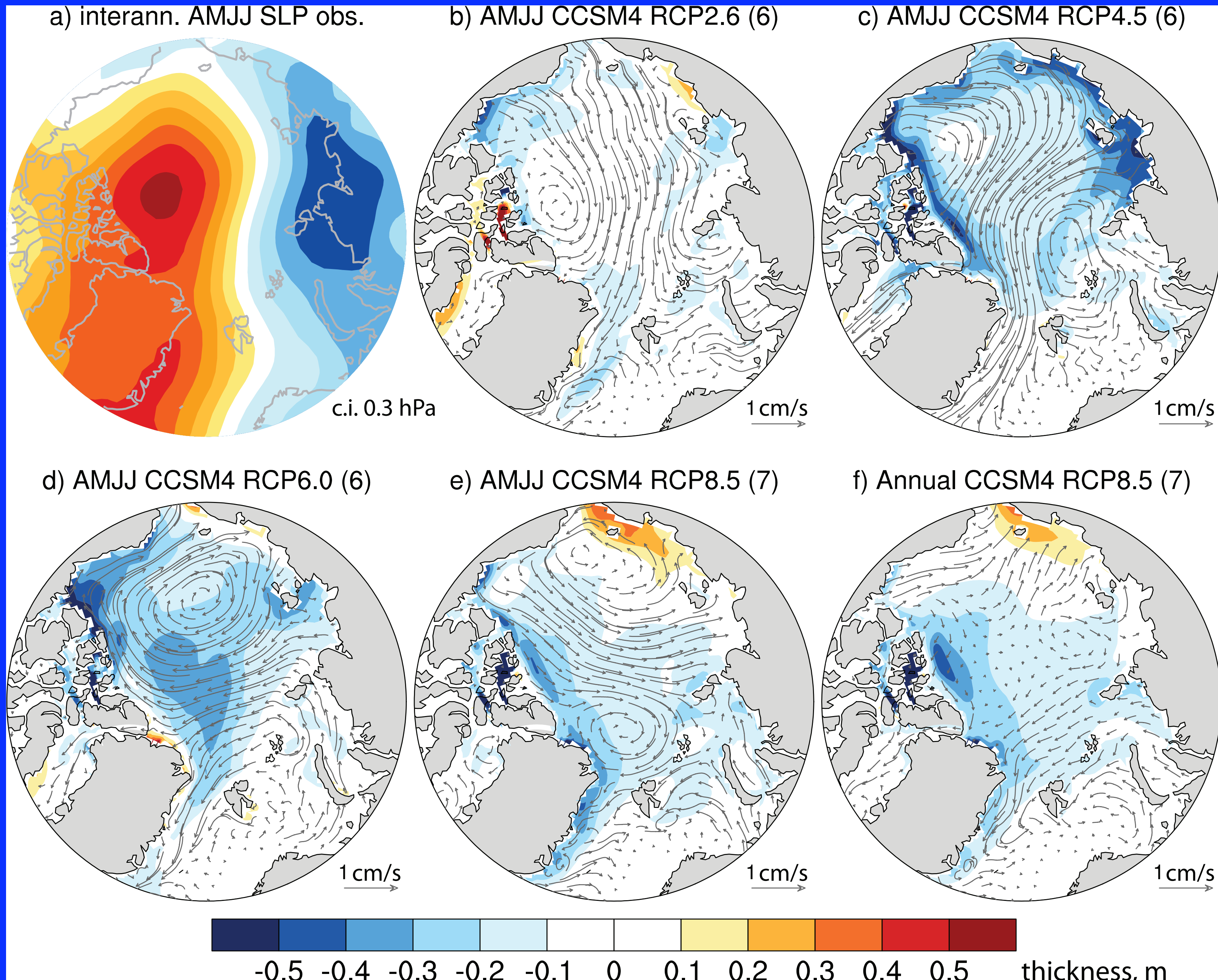
f) DJF Z500 on JASON vol

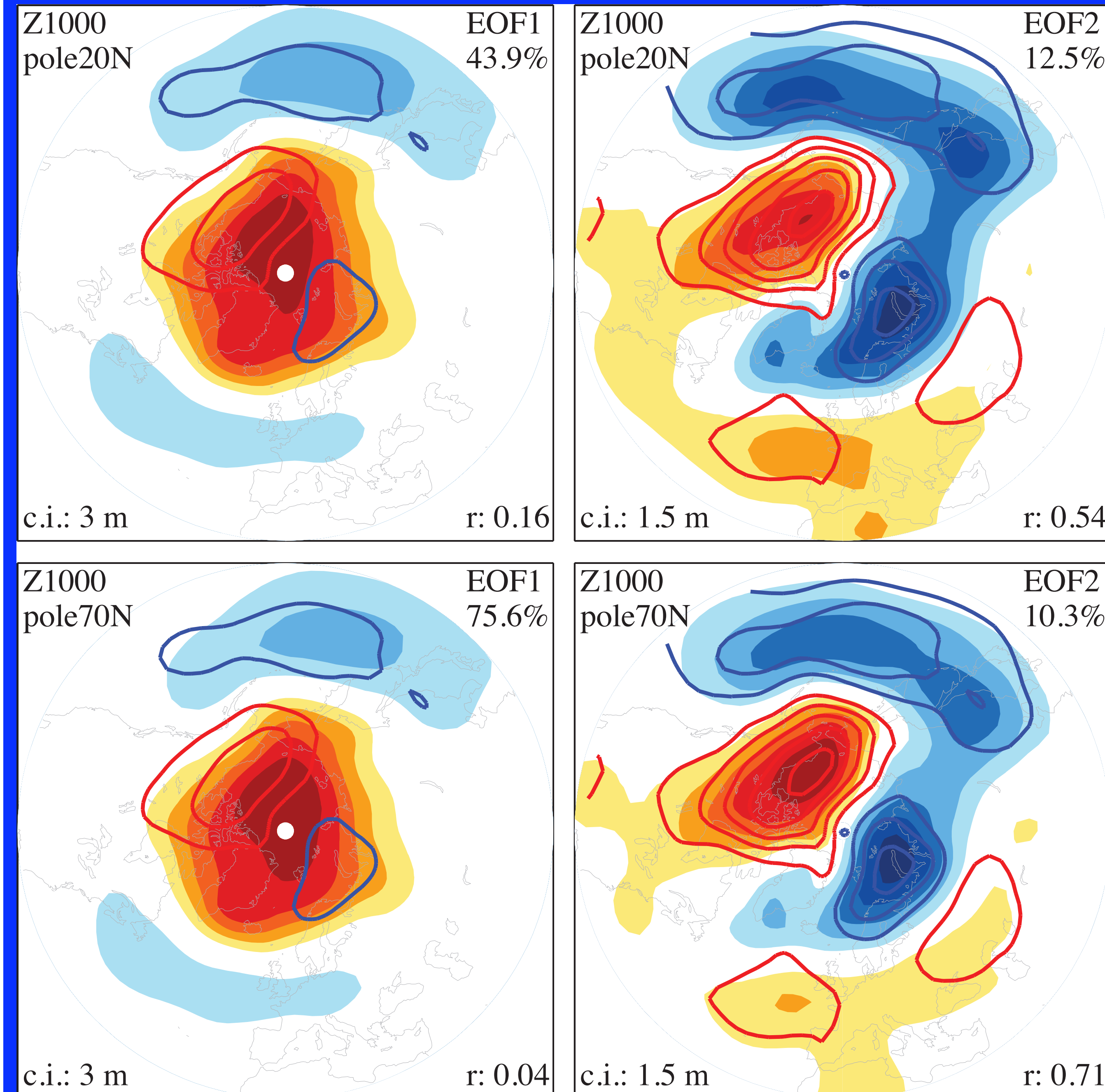


interannual (high-frequency) variability




corr: Fram volume export w/ 1yr JASON vol
35
30
25
20
15
10
5
J– A– J– O– J A J A S O N J+ A+ J+ O+
−0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5 0.6
0.2
0
−0.2
−0.4
−0.6
J– A– J– O– J A J A S O N J+ A+ J+ O+

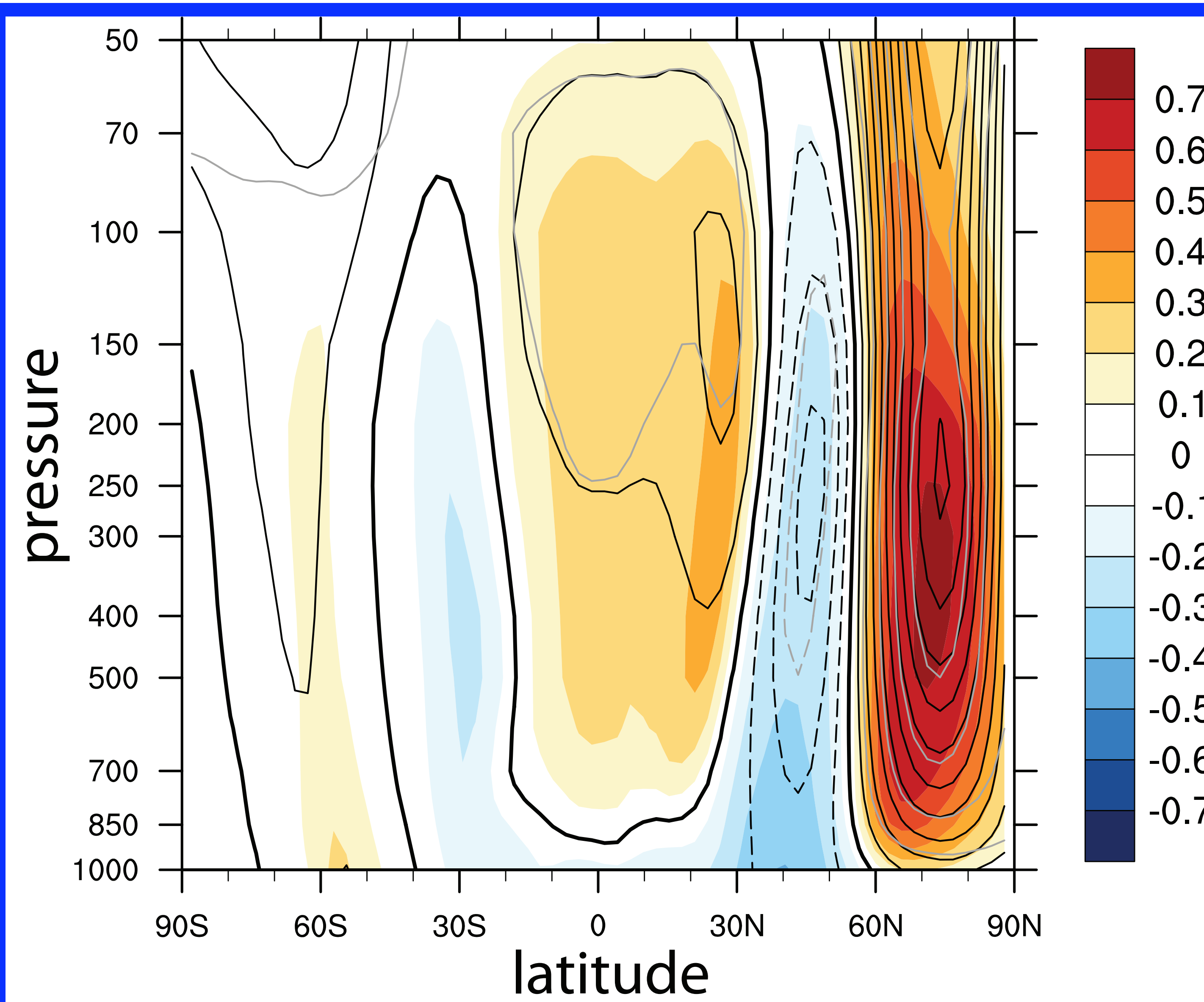

a) interann. AMJJ SLP obs.
c.i. 0.3 hPa
b) AMJJ CCSM4 RCP2.6 (6)
c) AMJJ CCSM4 RCP4.5 (6)
d) AMJJ CCSM4 RCP6.0 (6)
e) AMJJ CCSM4 RCP8.5 (7)
f) Annual CCSM4 RCP8.5 (7)
1 cm/s
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5
thickness, m



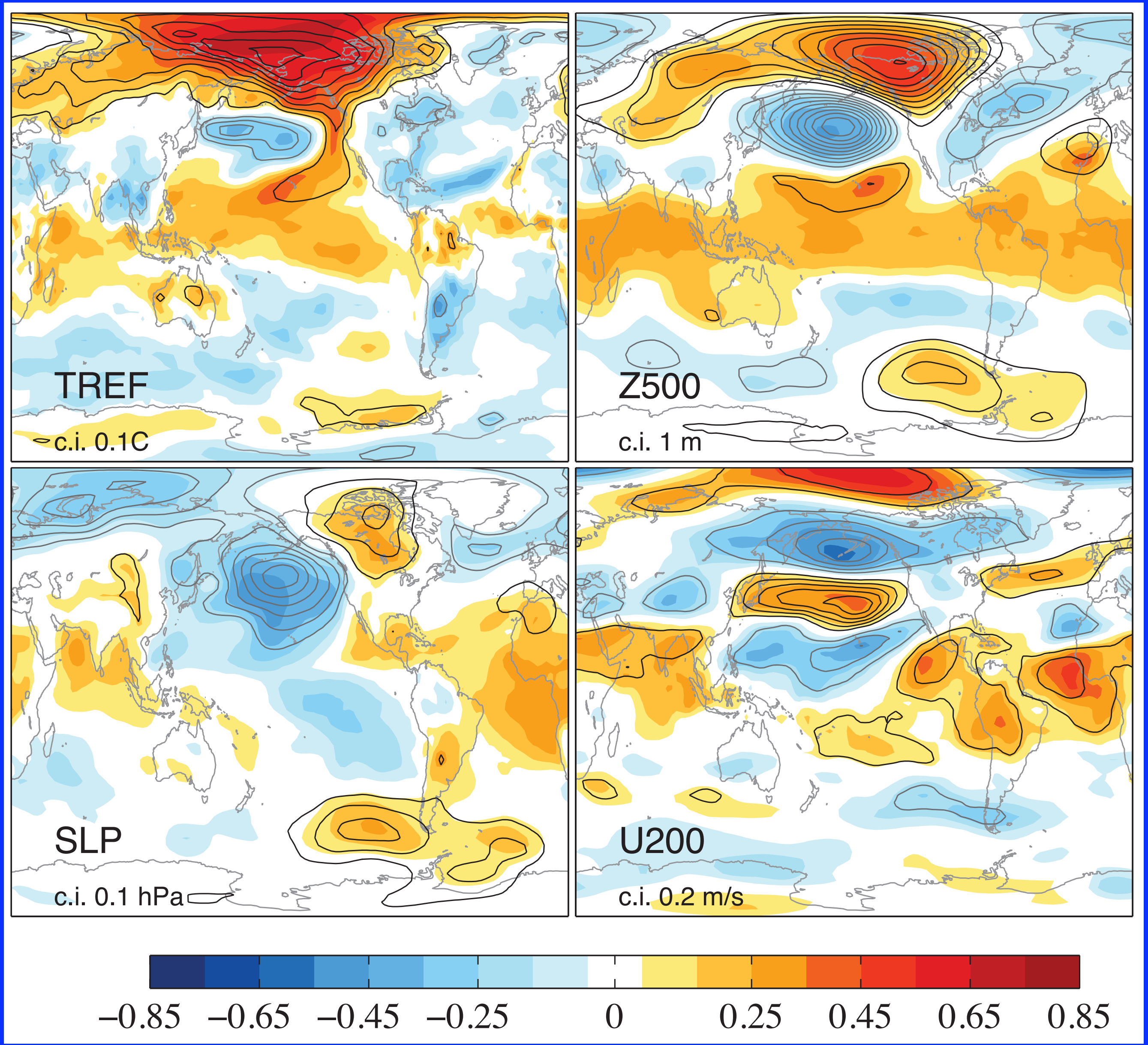
Compare:

1) AMJJ Z1000 regressions onto ensemble spread in Sept. extent loss; contours

2) EOFs 1 (left) and 2 (right) of AMJJ Z1000 trends poleward of 20N (top) and 70N (bottom); shading



Geopotential height regressions onto (contours) and correlations with (shading) ensemble spread in Sept. extent trend



Correlations (shading) and regressions (contours) of annual avg. (Oct.-Sept.) atmospheric variables with ens. spread in ice vol loss

Conclusions

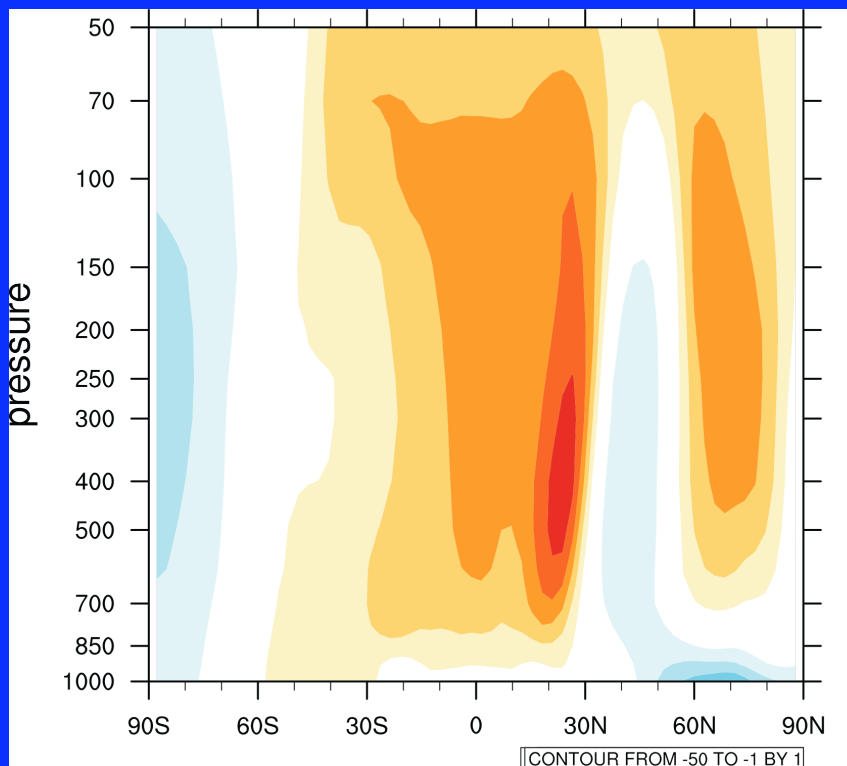
(based on CCSM3 A1B 40-member ensemble, for now…)

- Internal variability is large and an important factor in 21st century Arctic sea ice evolution (+/- 1 std in 2060 ~ 2 x 10^6 km^2)
- Ensemble spread in ice loss (Sep. extent) is associated with an "Arctic Dipole" in SLP and ice advection from the central Arctic
  - *similar to CCSM4 and interannual variability in observations and CCSM3*
- The "Arctic Dipole" SLP association is strongest in April-July, similar to previous observational studies (e.g., Screen, 2011)
  - Development from PNA-like wave train in DJF > A-D in AMJJ
- "Arctic Dipole" is associated with large-scale Pacific circulation and fundamental features of the atmos. general circulation
  - *qualitative similarity with interannual obs. (noisy / degrees of freedom)*
- Ensemble spread (internal variability) in Arctic sea ice loss is, to first order, not predictable

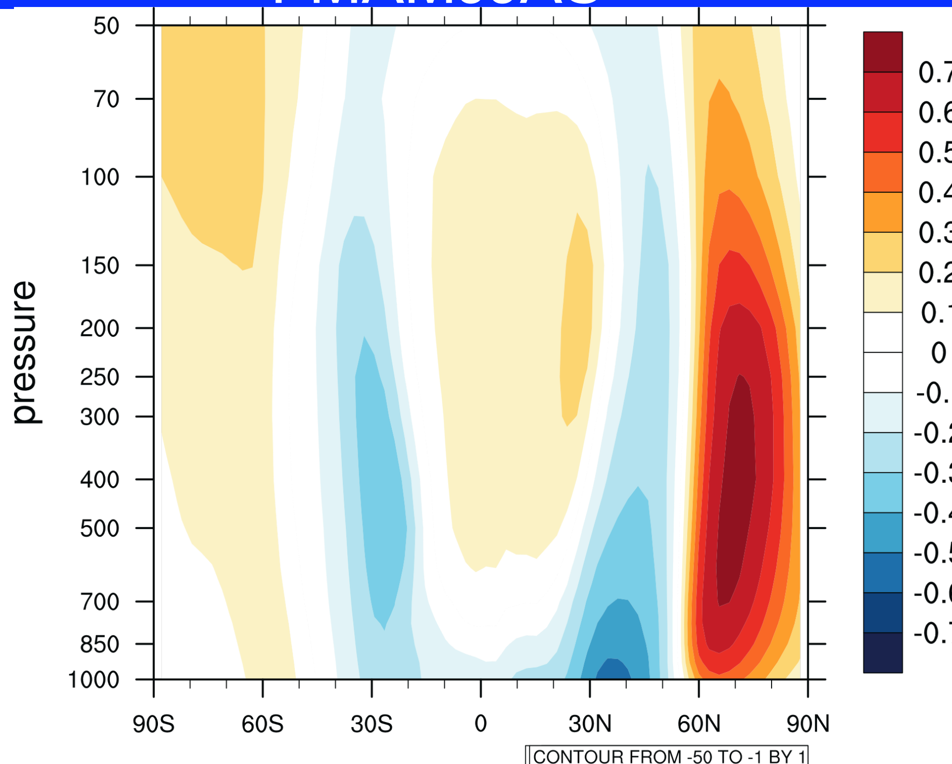
extra slides

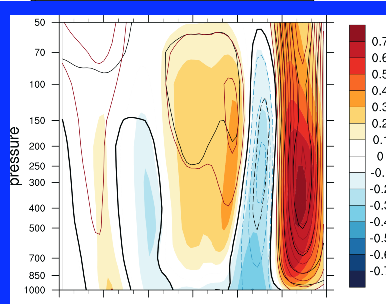
seasonality and baroclinicity

ONDJ



FMAMJJAS

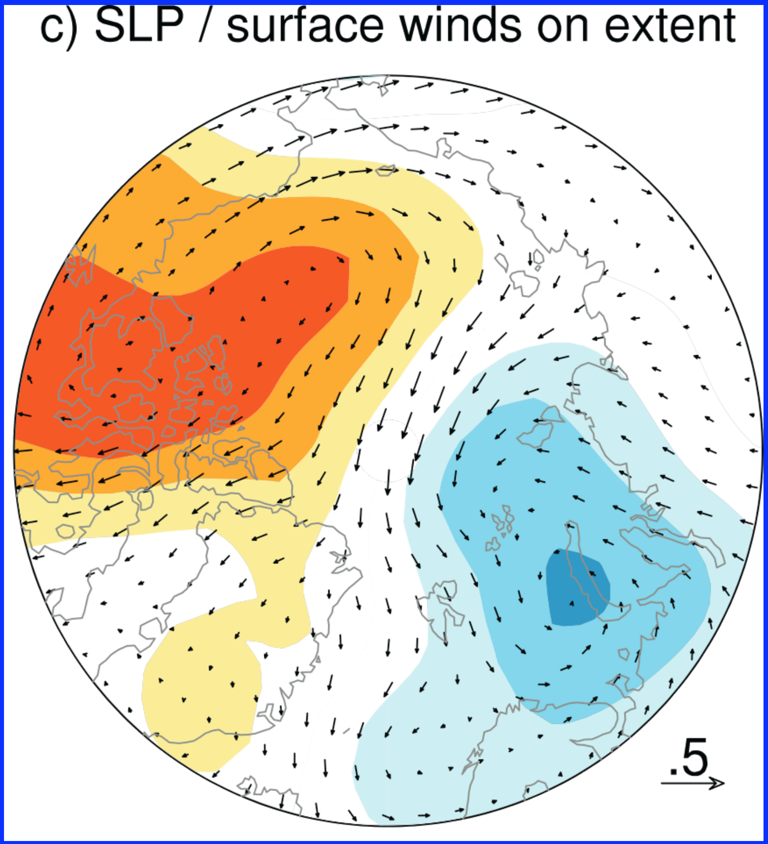




annual

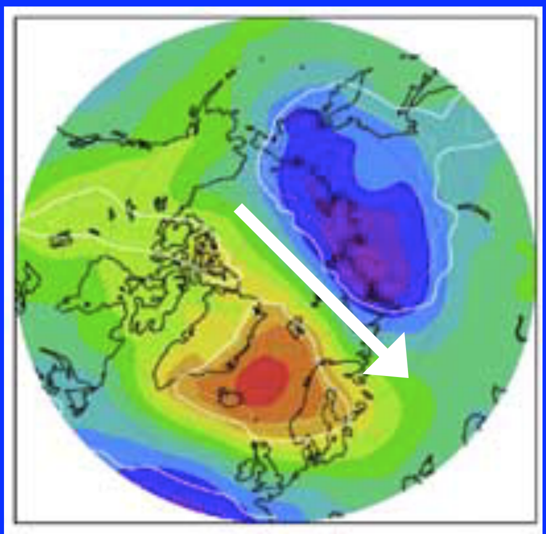
zonal-mean geopotential height regressions correlations (shading) on 2020-2059 ice extent trends

3) a proposed physical relationship

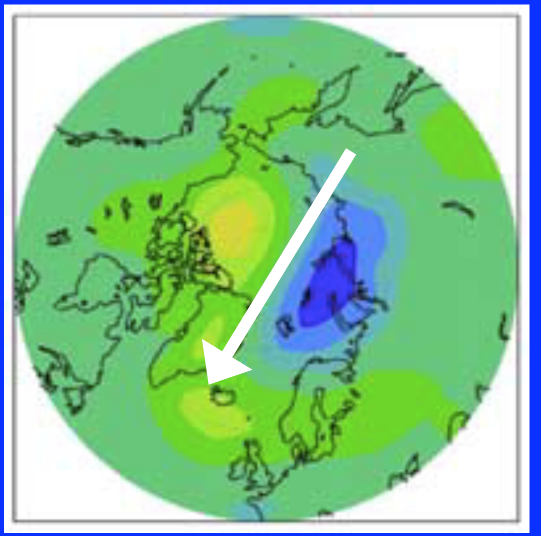


regressions on ensemble spread in CCSM3 ice extent

Wang et al., 2009 EOF2→ice loss



DJF

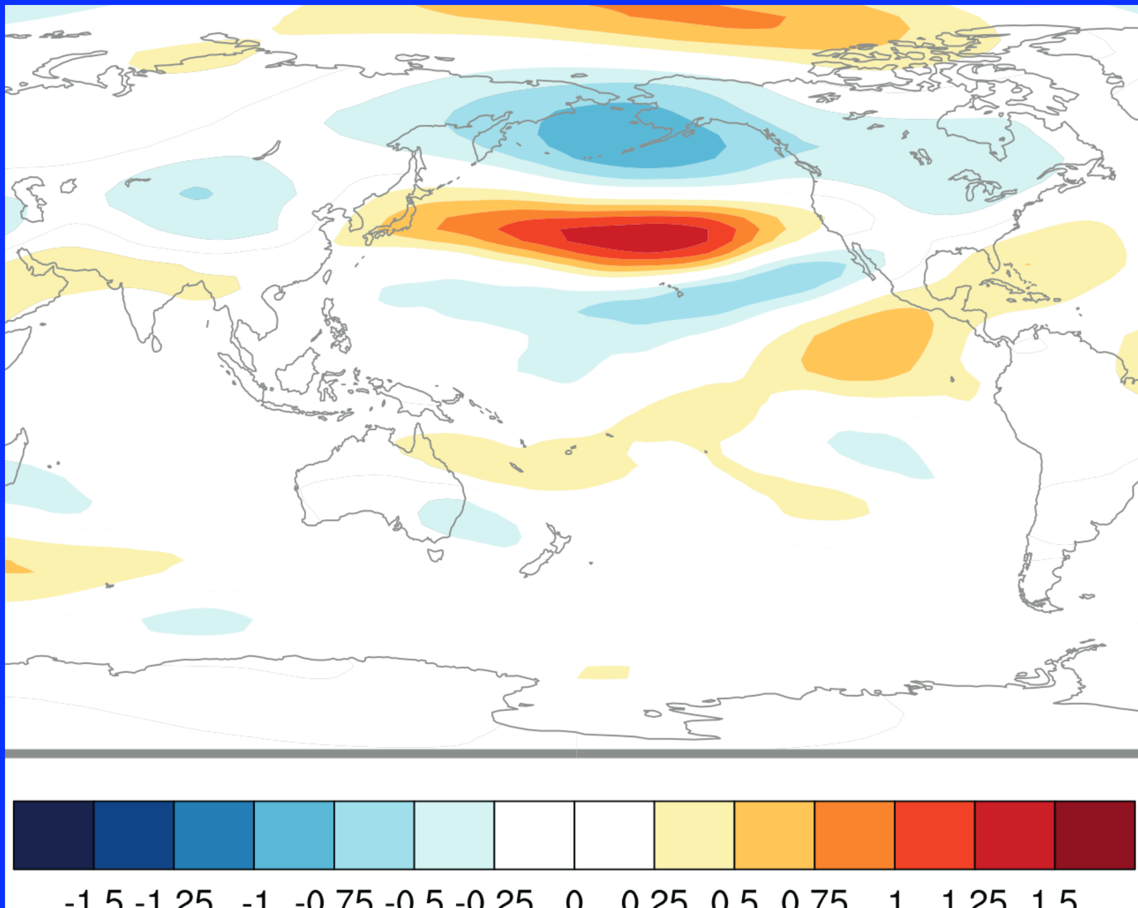


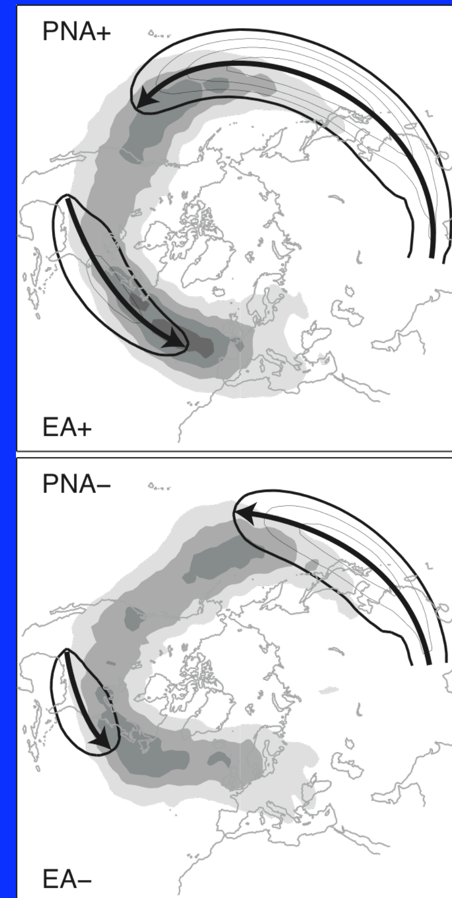
JJA

Observed relationship between the "Arctic Dipole" and interannual sea ice loss, related to the trans-polar drift and ice export

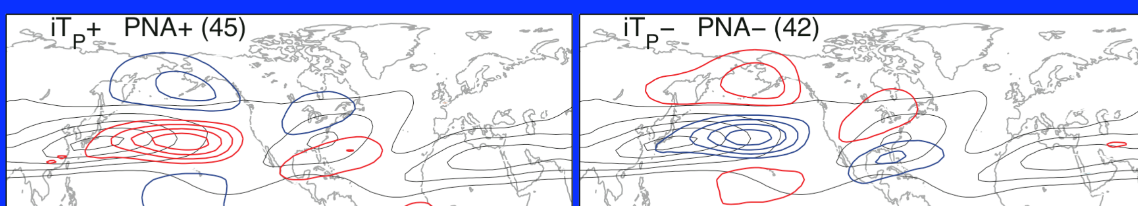
Also seen in Ogi and Wallace, 2007
Overland and Wang, 2010

3) A (little) broader perspective





Wettstein and Wallace, JAS 2010



Li and Wettstein, in press J. Clim.