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Mechanisms associated with predictable North Atlantic decadal variability

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Introduction

- Multiple lines of evidence from observations (?) & models (!) suggest that deep water formation through persistent North Atlantic Oscillation (NAO) forcing is the primary mechanism of decadal AMOC variability in modern times.

- Decadal prediction simulations (initialized coupled climate model simulations) show significant skill in the subpolar Atlantic at interannual-up-to-decadal lead times. This is generally attributed to the initialization of persistent ocean heat transport variations related to AMOC.

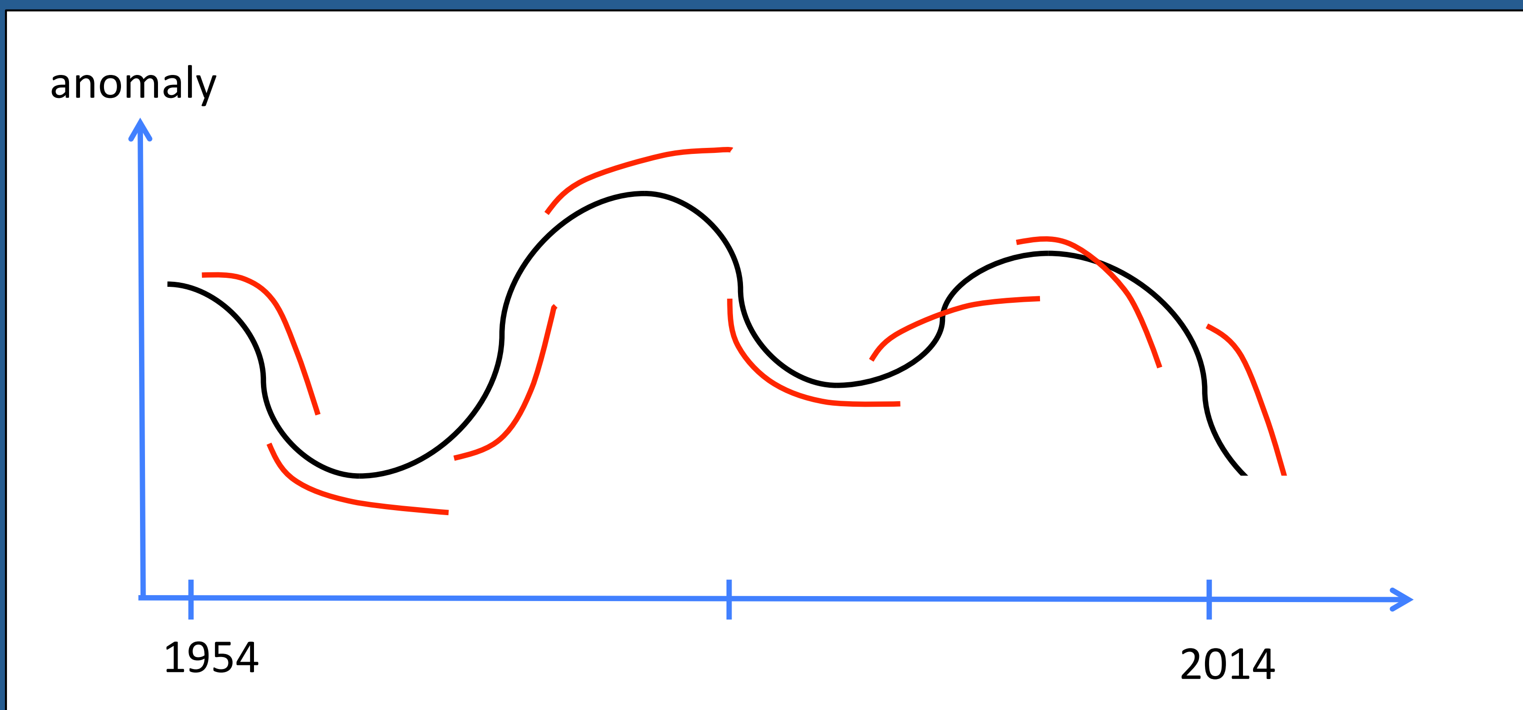
- What are the mechanisms underpinning skillful prediction of recently observed decadal changes in the North Atlantic? What role does AMOC play in predictions? Might gyre variations be more relevant for prediction than AMOC (at least on ~10-year timescales)?

CESM Decadal Prediction (DP) Simulations

DP: 10-member ensemble of coupled CESM simulations initialized from…

HD: CORE-forced ocean—sea-ice hindcast simulation spanning 1948-2015

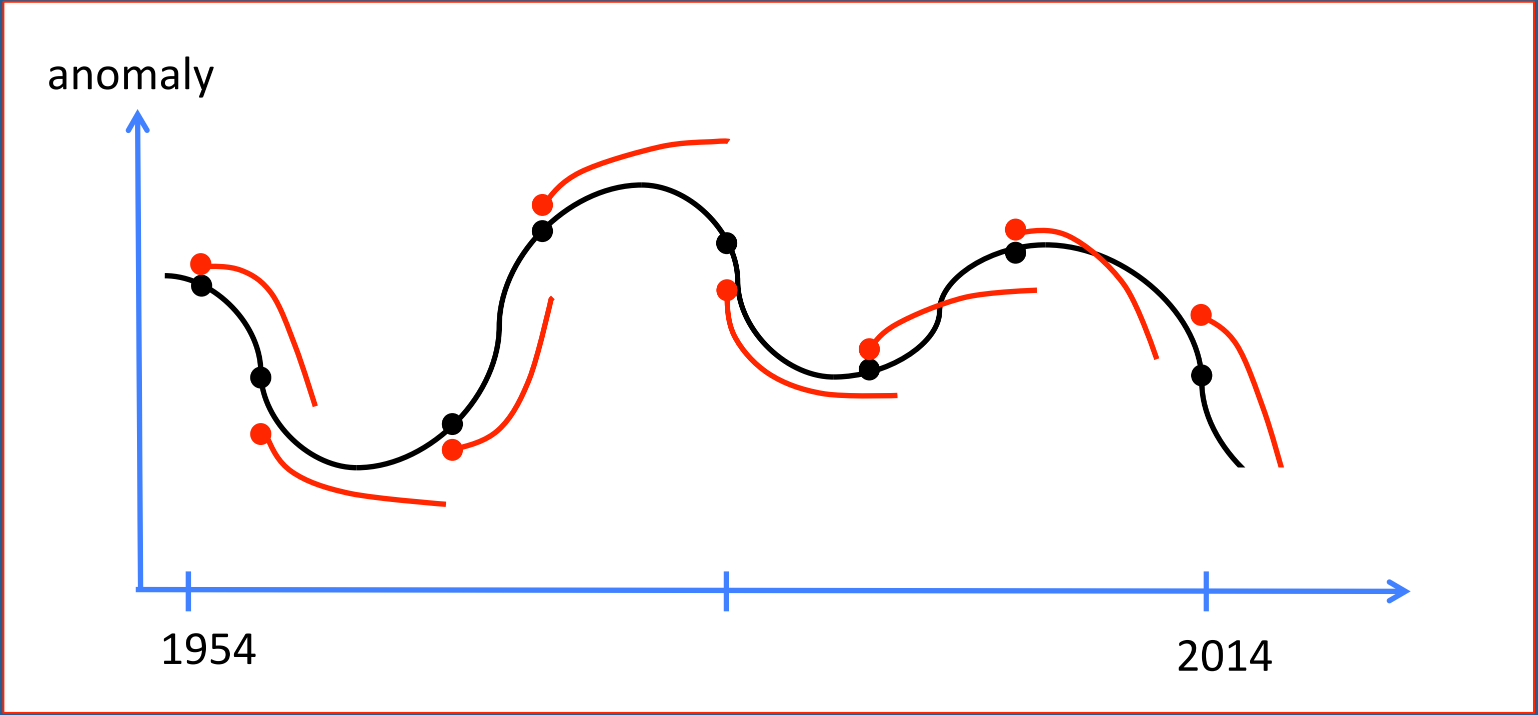
— **DP** ensemble average
— **HD** (“truth”)



CESM Decadal Prediction (DP) Simulations

— **DP** ensemble average
— **HD** ("truth")

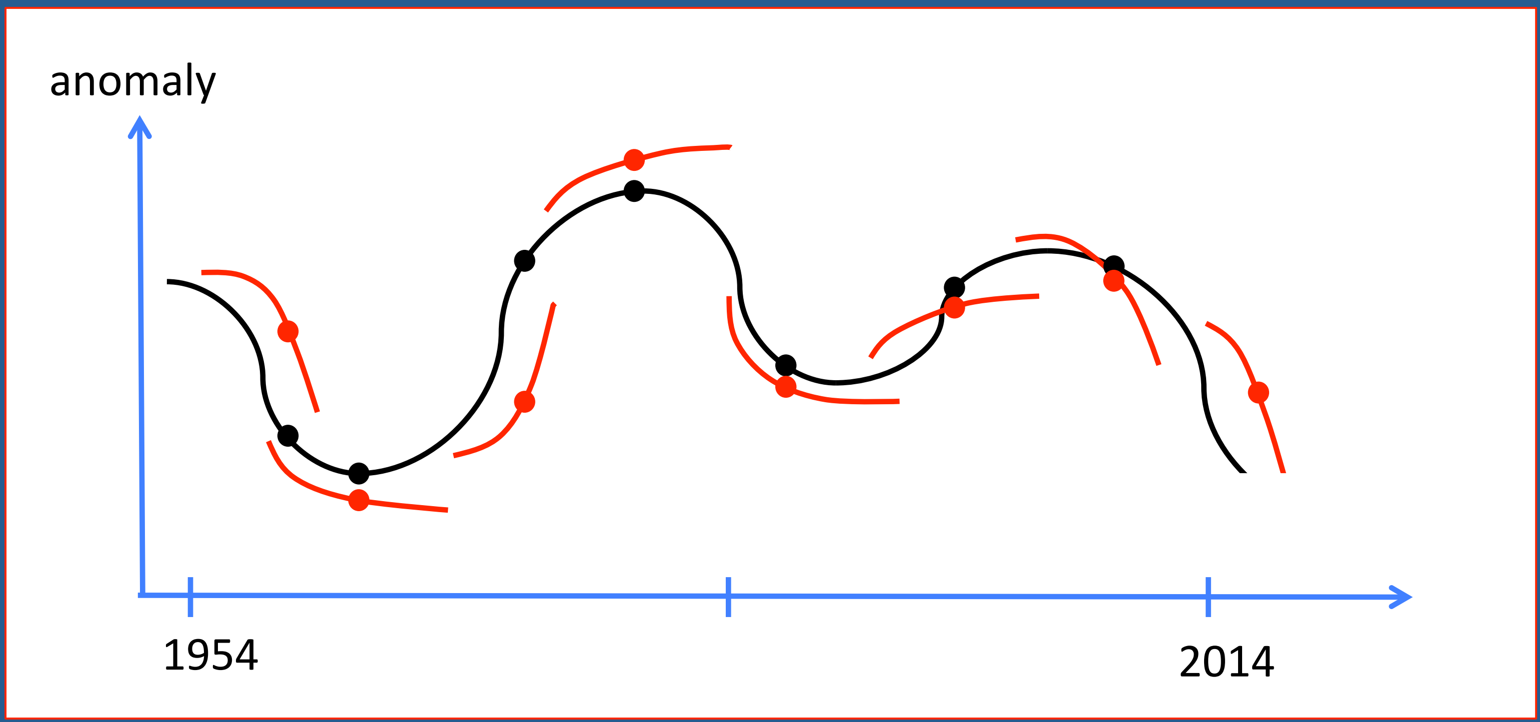
● lead year 1 forecast



CESM Decadal Prediction (DP) Simulations

— **DP** ensemble average
— **HD** (“truth”)

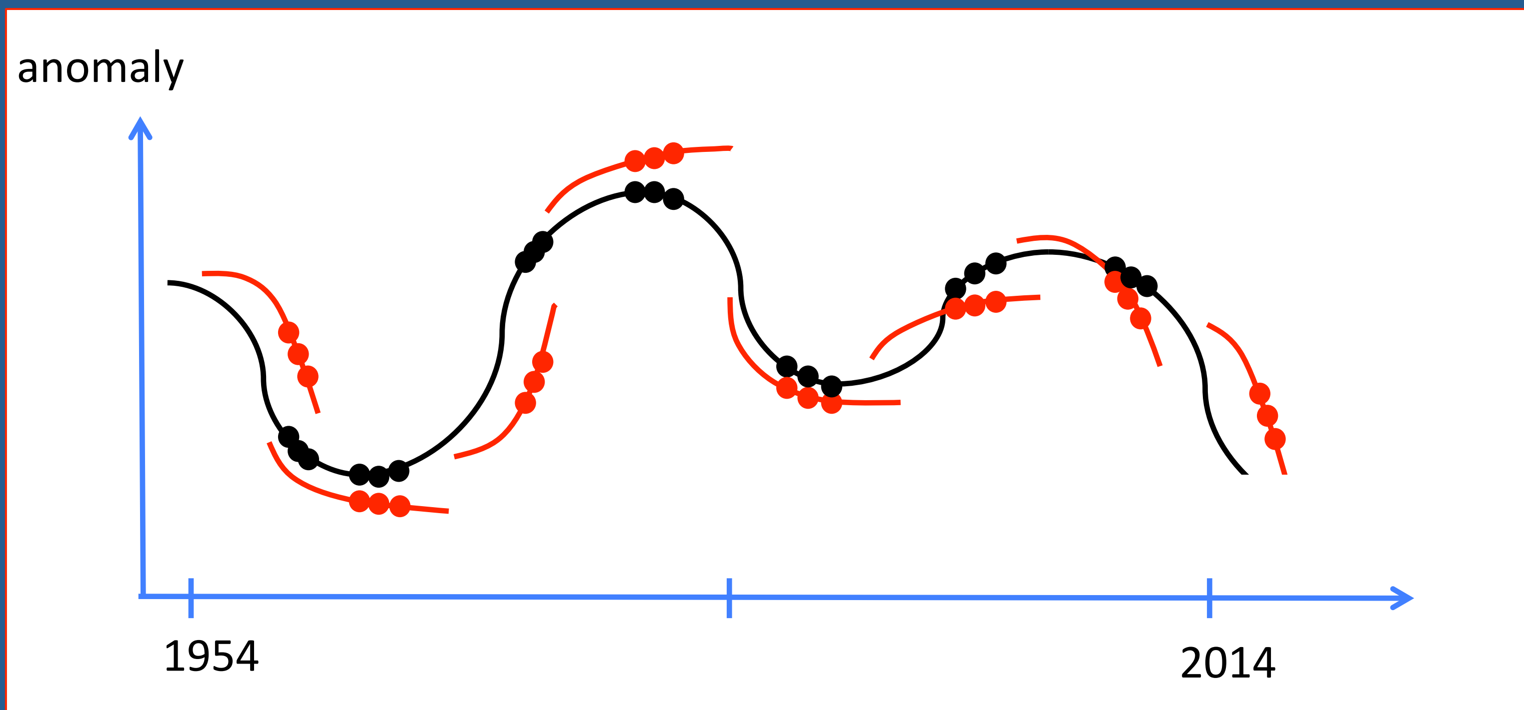
● lead year 5 forecast



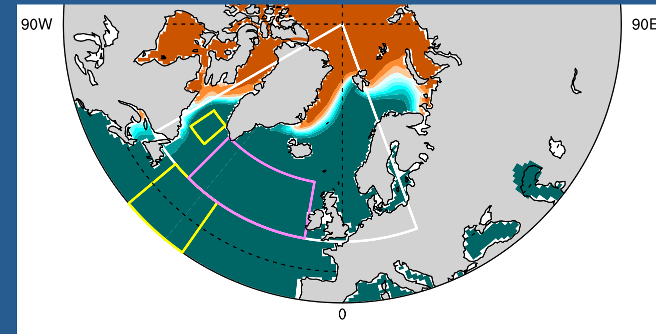
CESM Decadal Prediction (DP) Simulations

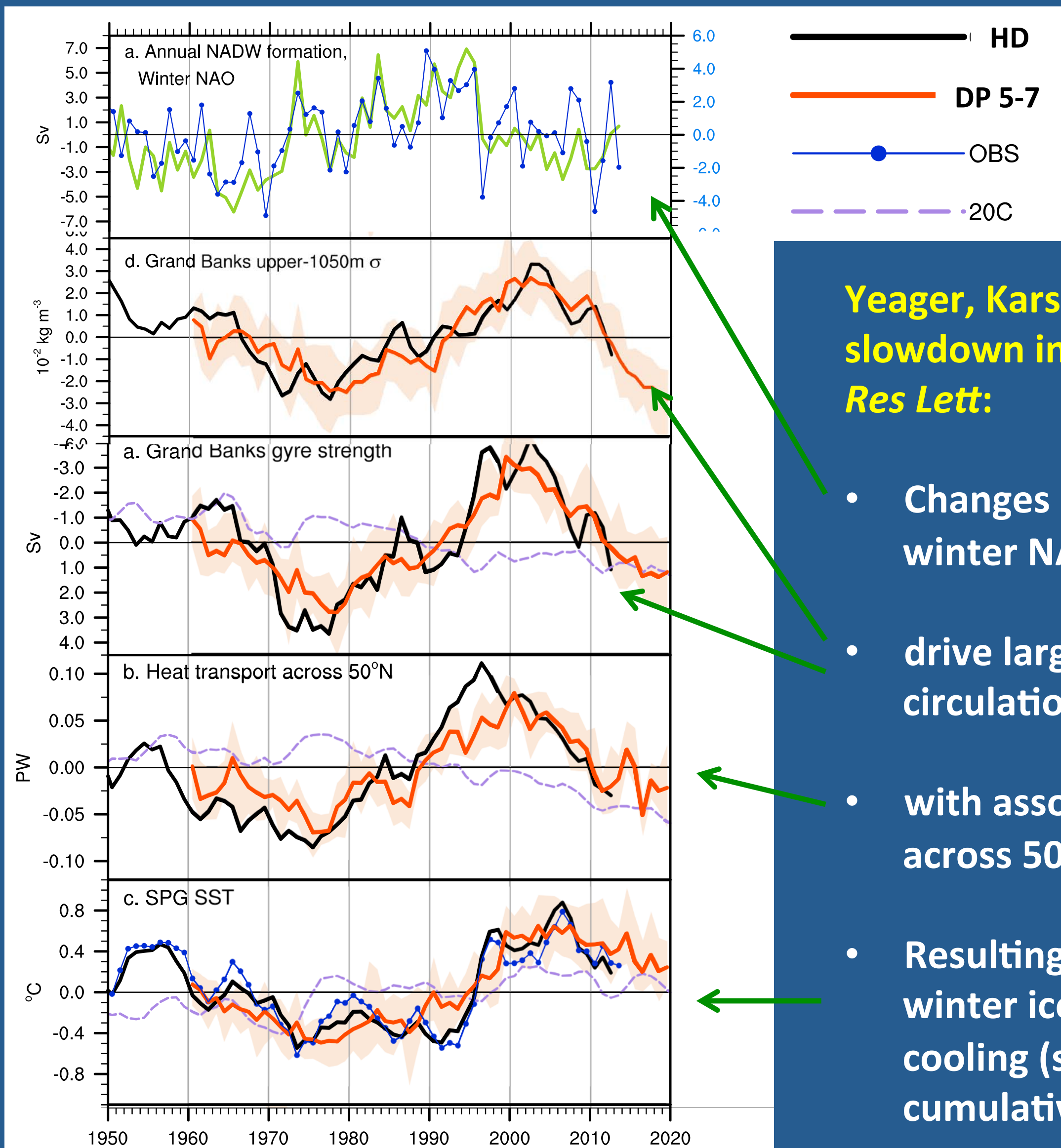
— **DP** ensemble average
— **HD** (“truth”)

● lead years 5-7 forecast



Skillful North Atlantic Prediction





Yeager, Karspeck, & Danabasoglu, 2015: Predicted slowdown in the rate of Atlantic sea ice loss, *Geophys Res Lett*:

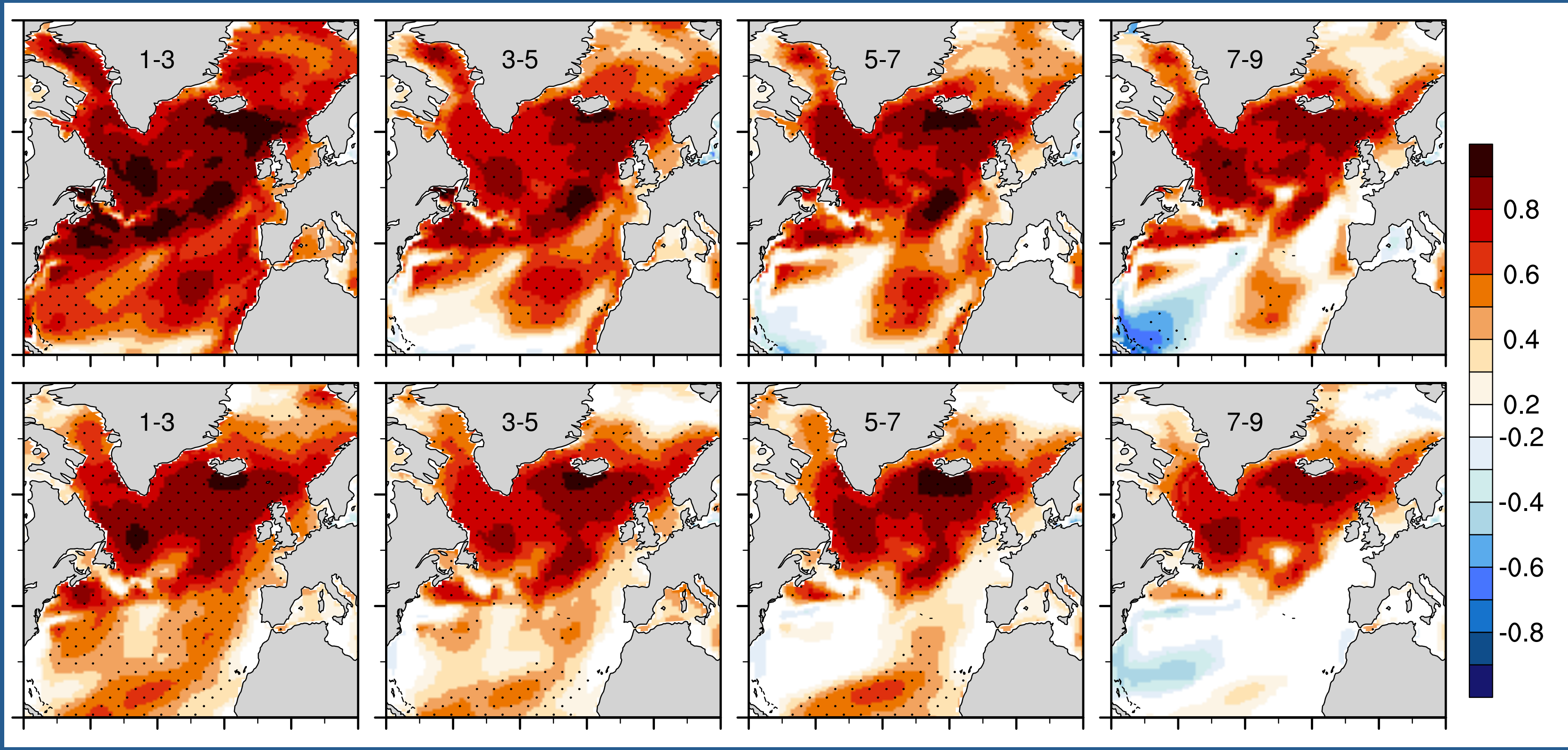
- **Changes in surface formation of NADW linked to winter NAO…**
- **drive large-scale density and thermohaline circulation (THC) changes east of Grand Banks…**
- **with associated decadal heat transport changes across 50°N…**
- **Resulting in predictable subpolar gyre (SPG) SST and winter ice extent (not shown) changes. Future SPG cooling (slowdown in winter ice loss) linked to cumulative deficit of NADW since ~1996.**

Upper Ocean Heat Content & SST

correlation(DP,HD)

T295:

SST:



(3-year mean detrended time series)

Upper Ocean Heat Content & SST

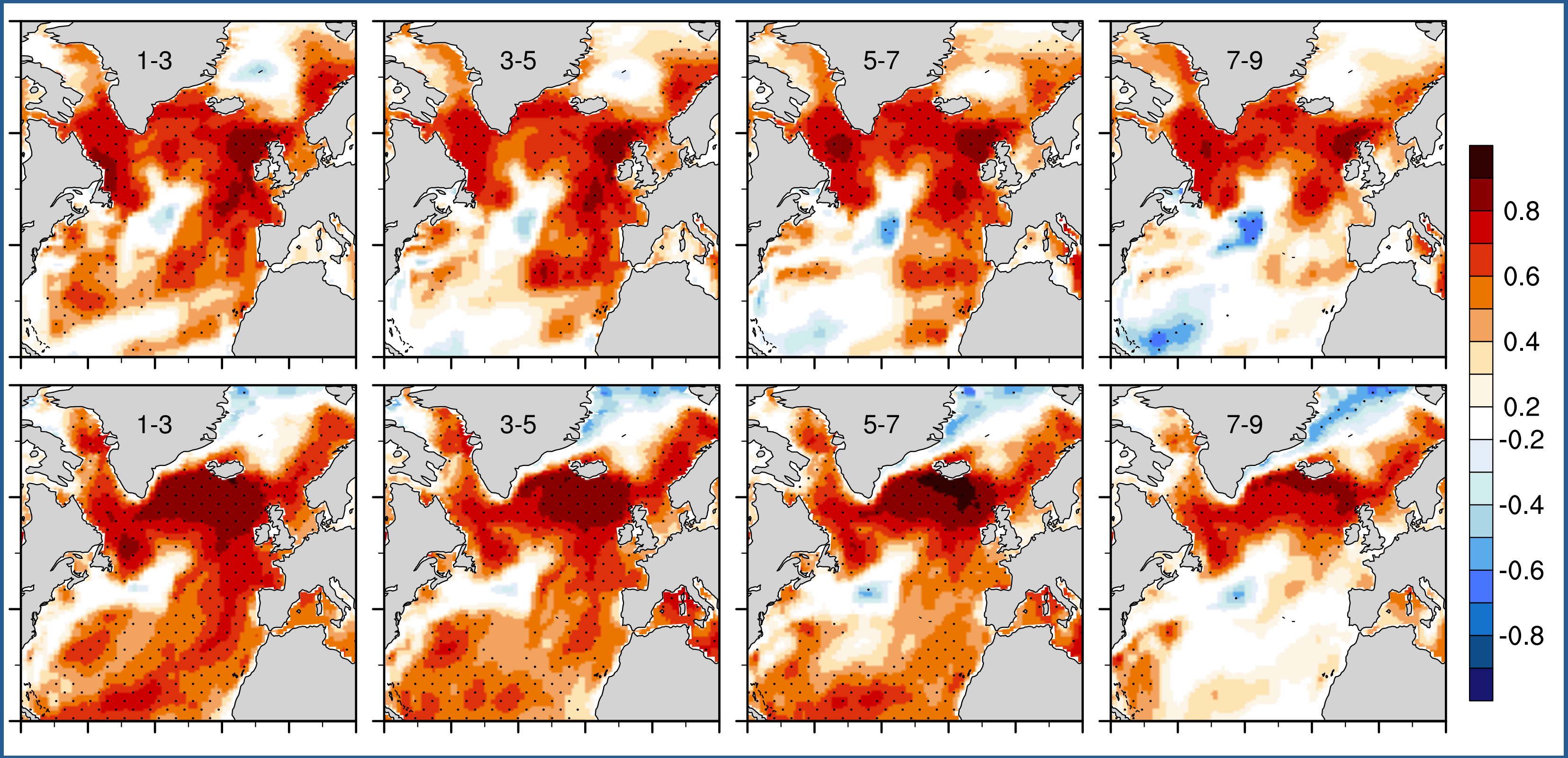
correlation(DP,OBS*)

T295:

*EN4

SST:

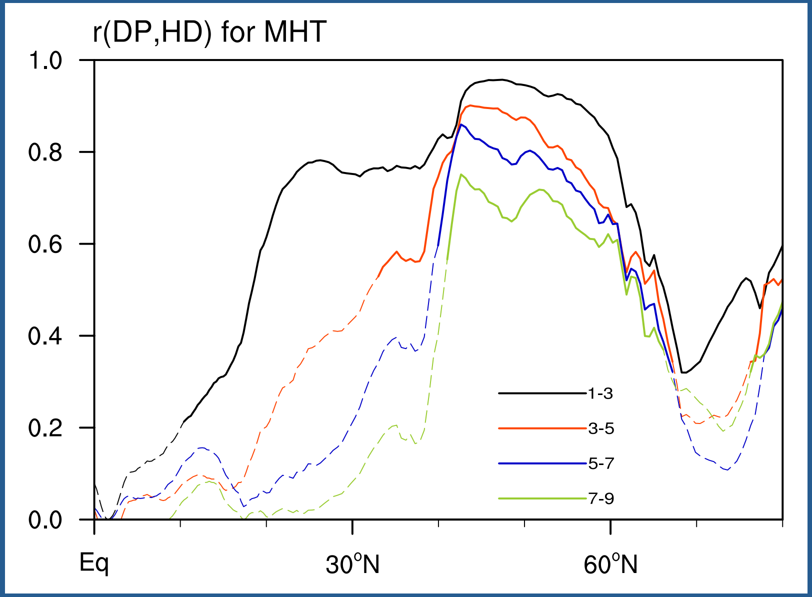
*HadISST



(3-year mean detrended time series)

How does it work?

- **Key mechanism : high skill at predicting ocean heat transport variations at long lead times (north of 40^{o}N)**



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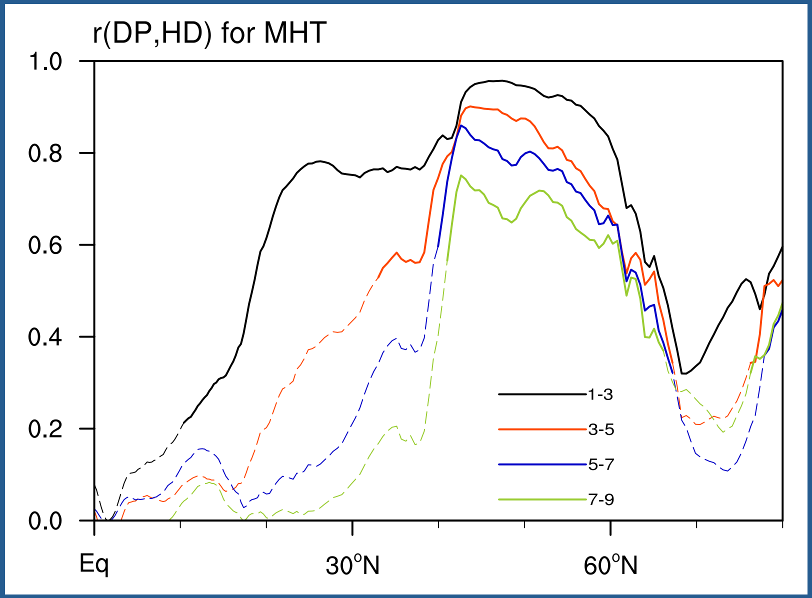
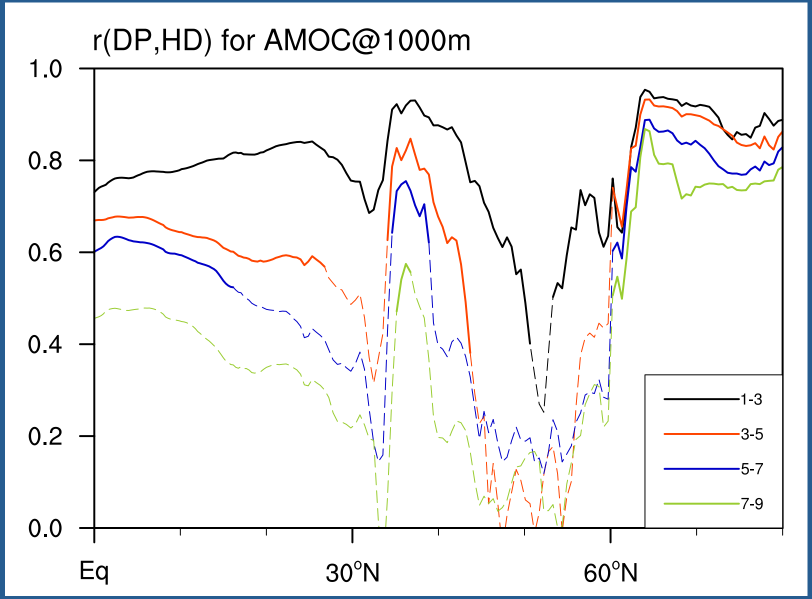


- **Despite low skill at predicting AMOC maximum transport !**



★ **Thermohaline gyre is more important for long lead (O(10-year)) predictions than AMOC**

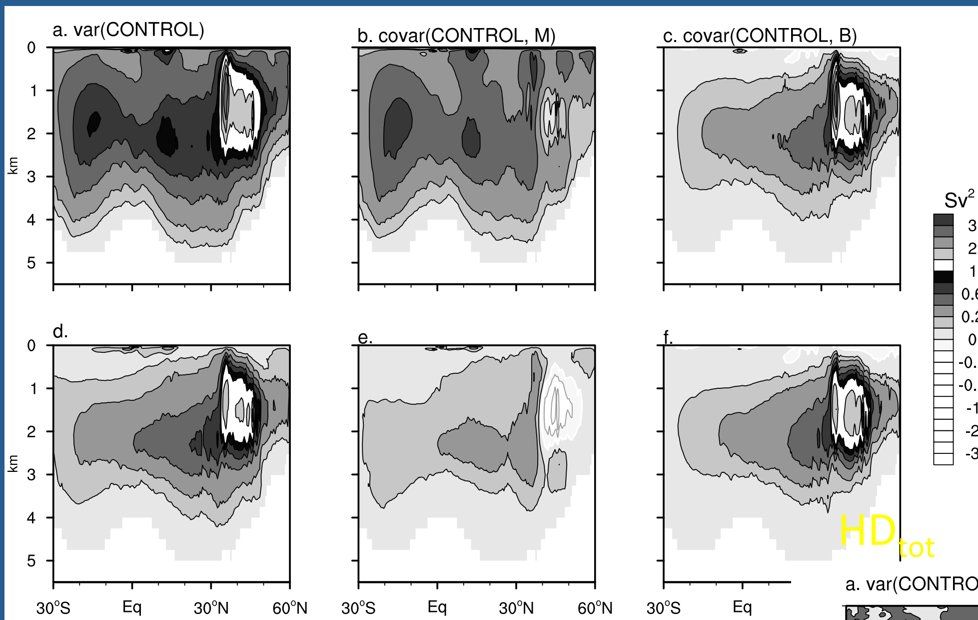
(3-year mean detrended time series)

Large-Scale Circulation Variability in HD

$HD_{tot} \approx HD_M + HD_B$

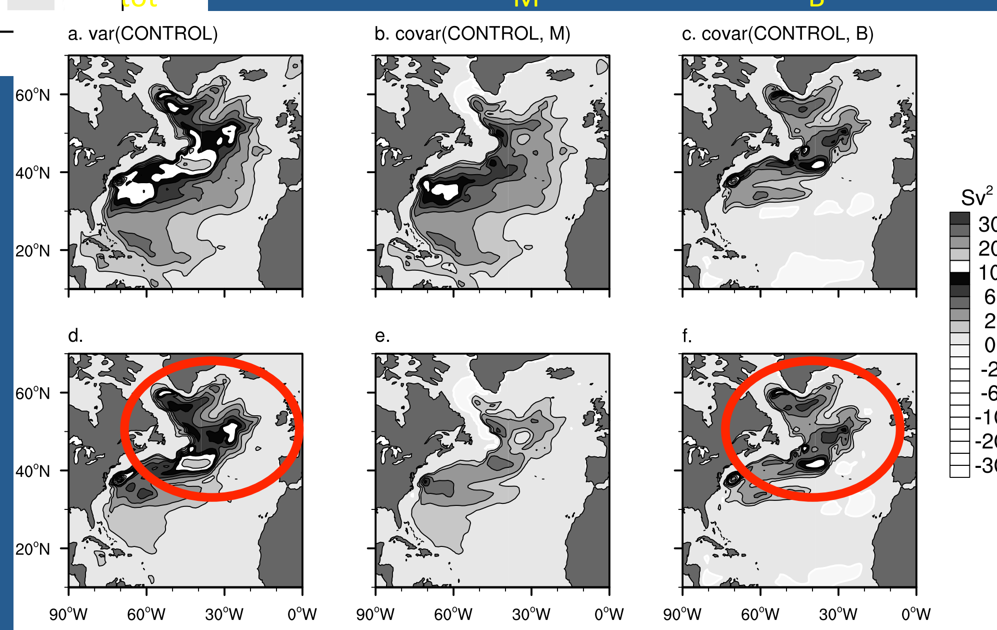
Raw

Decadal



🡐 AMOC variability in HD ≈ sum of momentum and buoyancy forced variations ($HD_M + HD_B$)

$HD_{tot} \approx HD_M + HD_B$



🡒 Gyre variability largely decadal/buoyancy-forced in HD; vorticity balance via bottom pressure torque

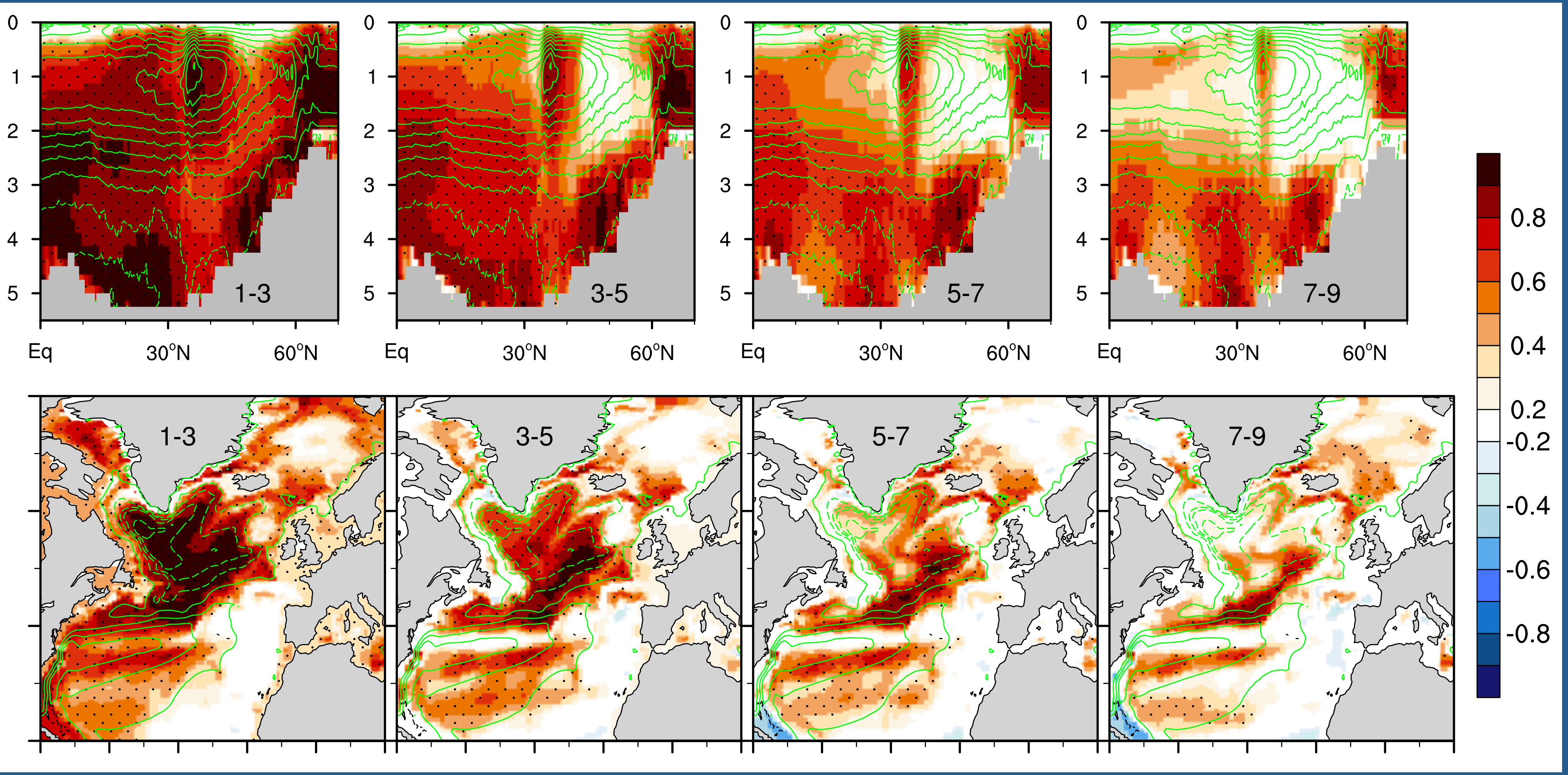
Zhang & Vallis (2007)
Yeager (*JPO* 2015)

Predicting the Large-scale Circulation

correlation(DP,HD)

MOC:

BSF:



- Rapid loss of $AMOC_{max}$ skill
- Good skill at predicting deep AMOC

(3-year mean detrended time series)

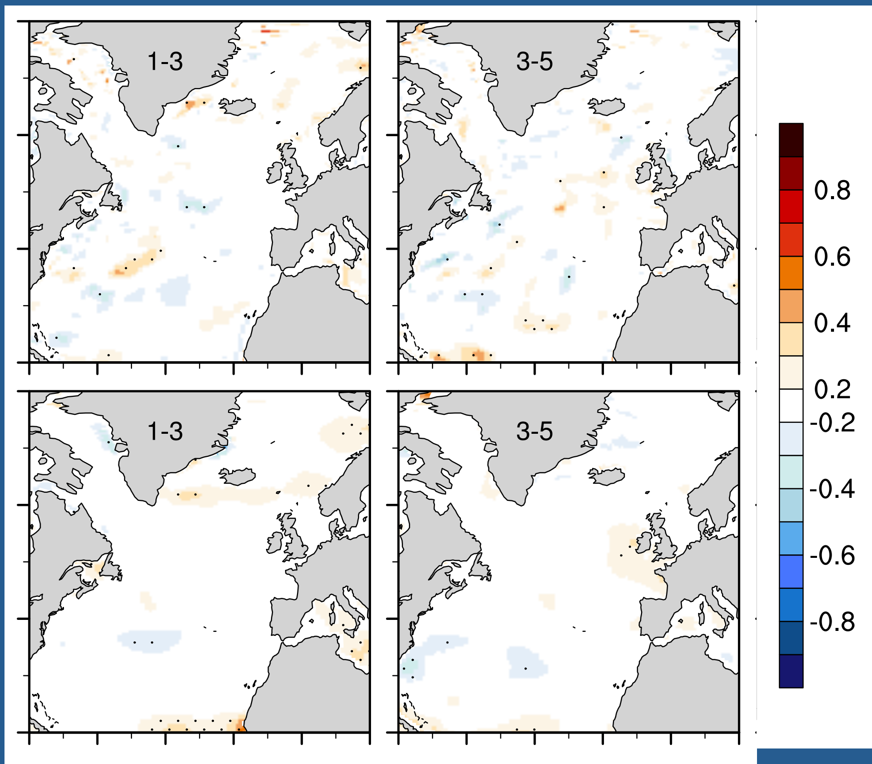
- Good skill at predicting gyre variations on the western flank of the MAR, where buoyancy forcing dominates in this model

Predicting Surface Fluxes

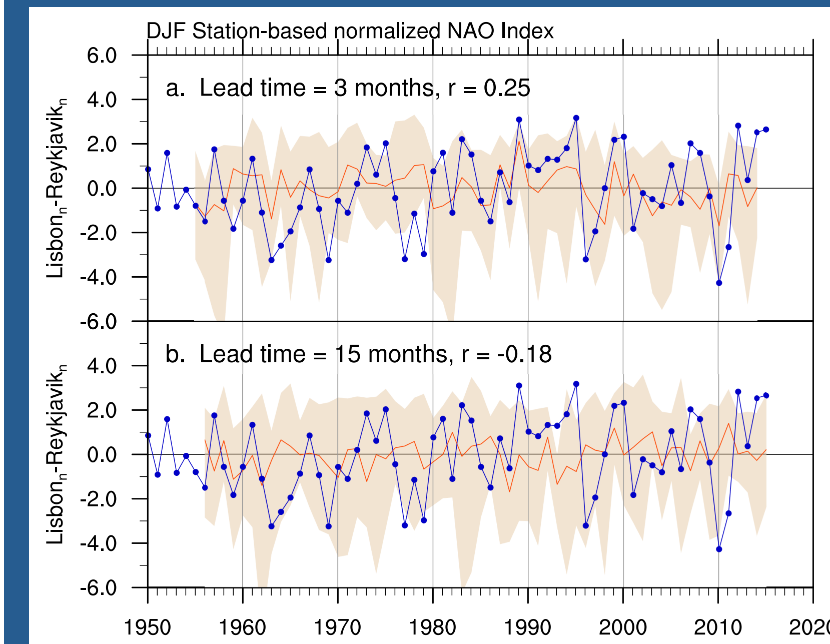
correlation(DP,HD/OBS)

WSC:

TAU$_x$:



DJF NAO index:



→ Skill at predicting buoyancy-forced gyre flow appears to be entirely associated with (buoyancy-forced) initial conditions → anomalous water masses

Labrador Sea Water

Labrador Sea water mass thickness

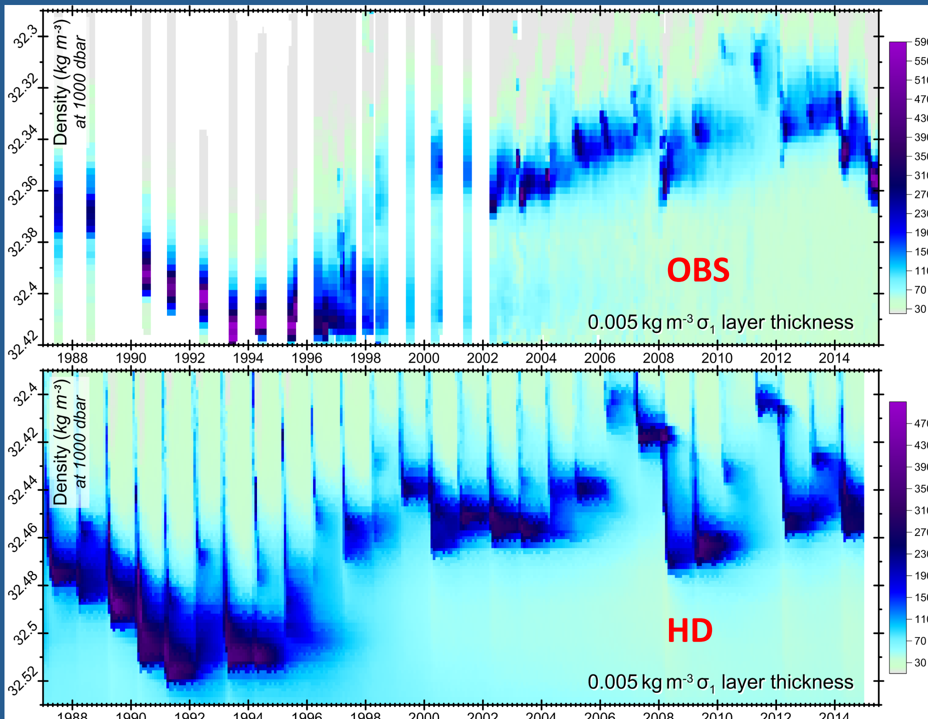
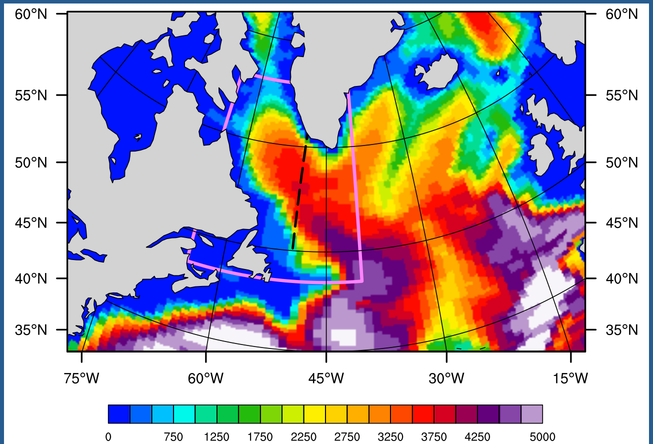
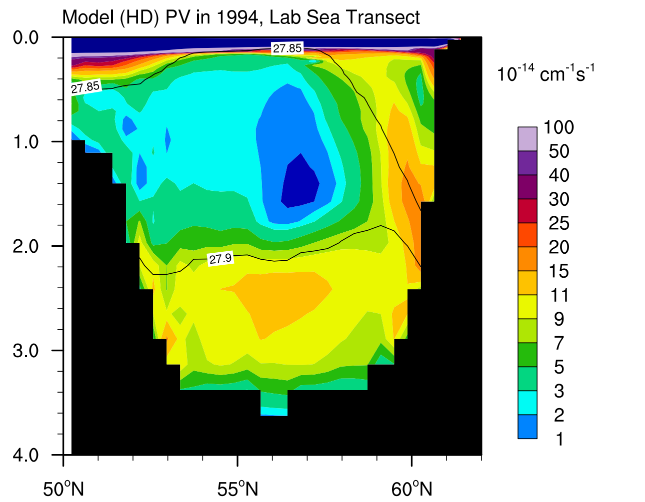


Figure courtesy Igor Yashayaev



HD (1994)

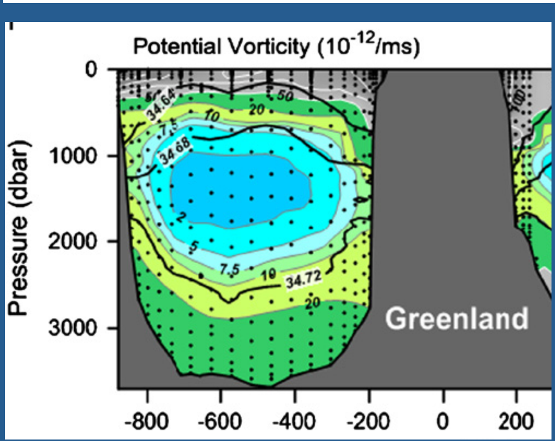


Model LSW is denser than observed but shows similar variability.

Consider variations in thickness of dense LSW (27.85 - 27.9 kg/m^3) as simulated in HD…

OBS (1994)

Yashayaev (2007)
Van Aken et al (2011)



Labrador Sea Water Thickness (HD)

<u>Color</u>:
LSW thickness anomaly

<u>Contours</u>:
Upper 315m northward heat transport anomaly

(anomalies relative to 1958-2014 monthly climatology)

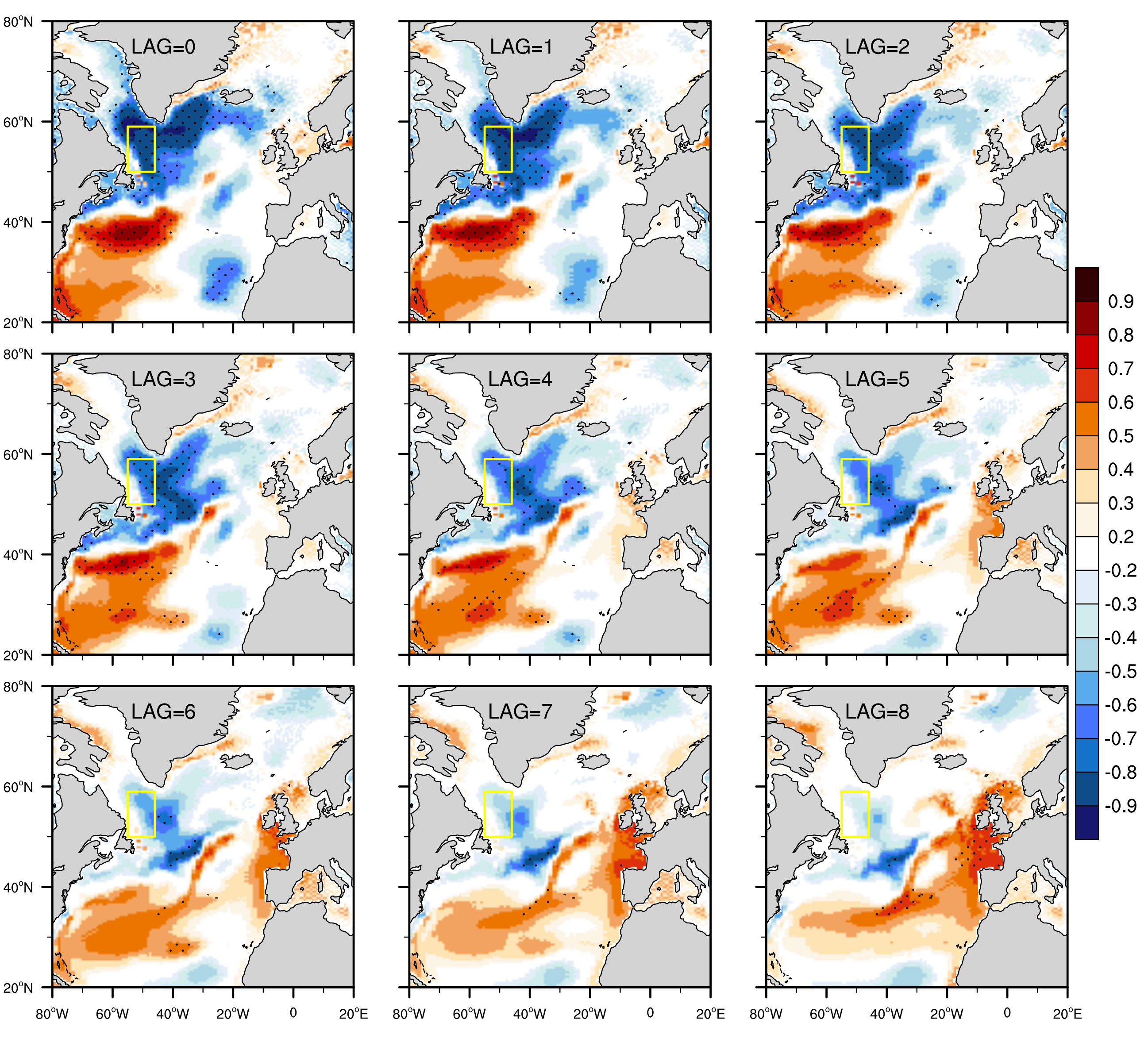
LSW formation/SSH relationship in HD

Hypothesis:

LSW formation in the Labrador Sea drives SSH variations over the MAR at decadal lead times

(3-year mean detrended time series)

Lag correlations of (LSW thickness in central Lab Sea, SSH) in HD:



Predicting the Thermohaline Gyre

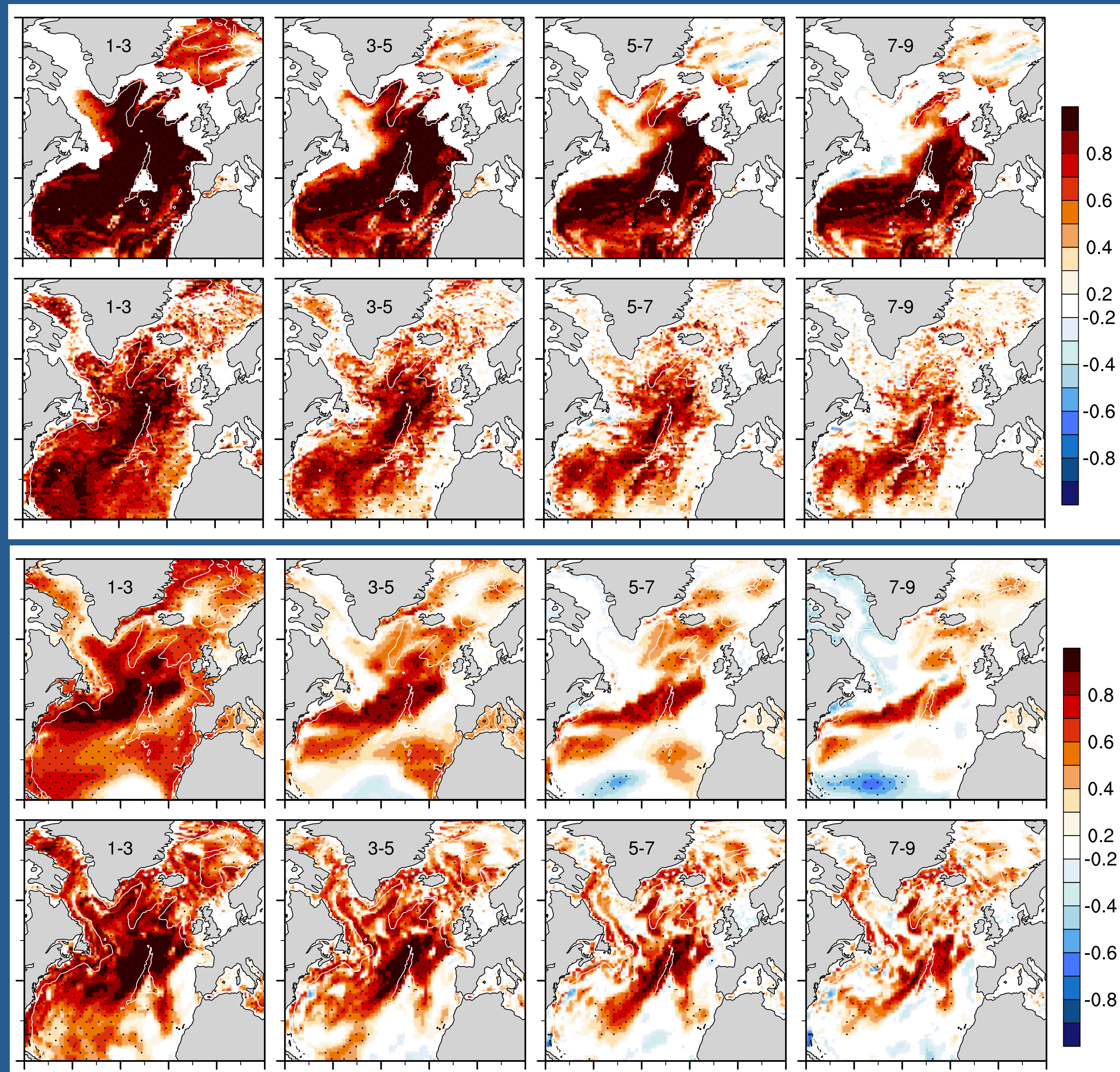
correlation(DP,HD)

LSW Δz

W_{bottom}

SSH

$<V^*T>_{315m}$



Summary

- Initialized CESM simulations show good skill at predicting recent observed upper ocean heat content, SST, and sea ice extent changes in the North Atlantic, up to a decade in advance.

- Recent predictions suggest that we should expect continued ocean-driven cooling of the SPG & Nordic Seas, and a slowdown in the rate of winter sea ice loss, due to a weakening thermohaline circulation--the integral effect of recent weak NAO forcing. (Hermanson et al. 2014; McCarthy et al. 2015; Yeager et al. 2015; Robson et al. 2016)

- The primary mechanism underpinning predictable N. Atlantic decadal variability appears to be persistent NAO, which imprints strongly on ocean initial conditions (V' and T'), allowing for long lead time prediction of anomalous ocean heat transport (north of ~40N) despite a rapid loss of AMOC skill.

- Predictable decadal ocean heat transport variations associated with THC change (V'<T>) appear to be dominated by highly predictable fluctuations in the strength of the intergyre gyre, not AMOC. Decadal prediction simulations underscore the distinction between THC and AMOC, with the former playing a key role in prediction.

- In CESM, NAO-driven LSW anomalies follow highly predictable interior pathways. These generate large, buoyancy-driven surface flow (& SSH) anomalies upon reaching the Mid-Atlantic Ridge, through flow-bathymetry interaction, that can be well-predicted up to 10 years in advance.