Decadal Variability and Potential Predictability in the Atlantic

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GFDL/NOAA

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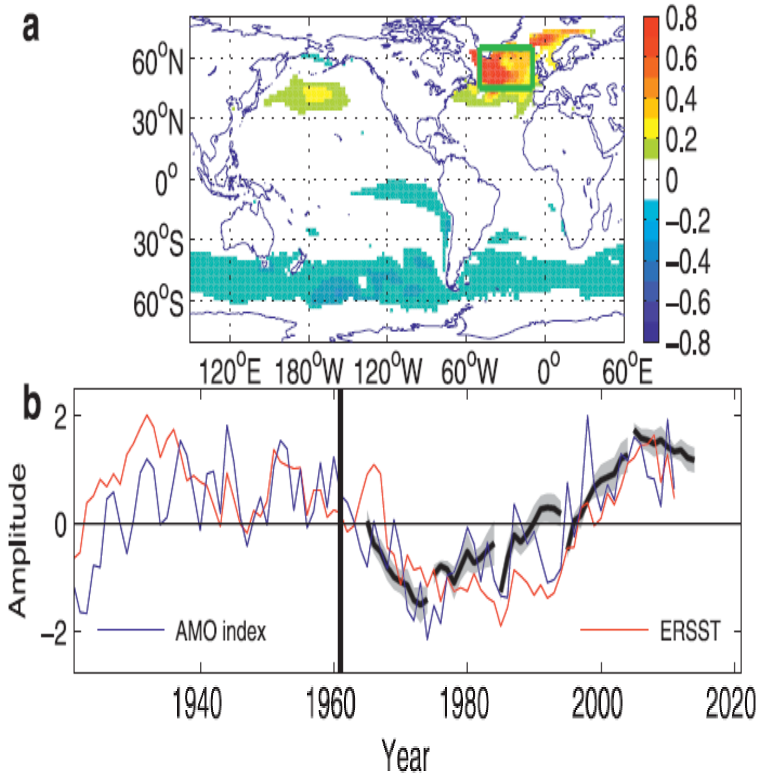
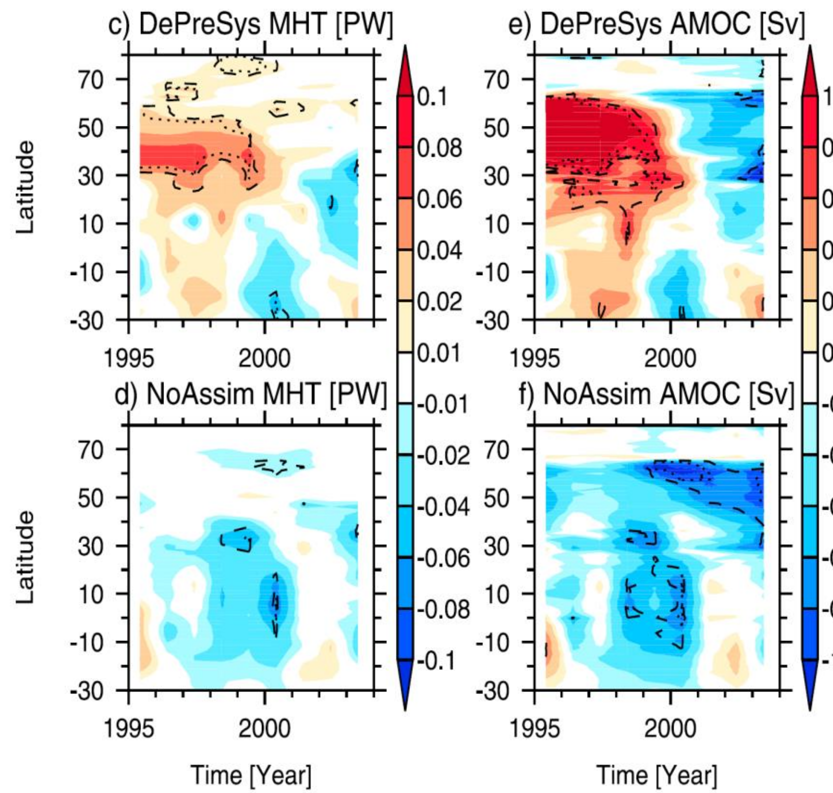
Decadal Prediction of the Observed Atlantic Multidecadal Variability (AMV)



Yang et al, 2013, JOC



Robson et al. 2012, GRL

- Recent decadal prediction studies (Yeager et al. 2012; Robson et al. 2012; Yang et al., 2013; Msadek et al. 2014) successfully predicted the decadal warming shift in the mid 90's in the NA SPG with initialized ocean state
- Initializing a strong AMOC at northern high latitudes is the key for the successful predictions
- Hindcasts with no initialization in the ocean state are not able to predict the decadal warming shift

Extra-tropical AMOC Fingerprint – Leading Mode of Upper Ocean Heat Content

Southward propagation of AMOC anomaly

↓

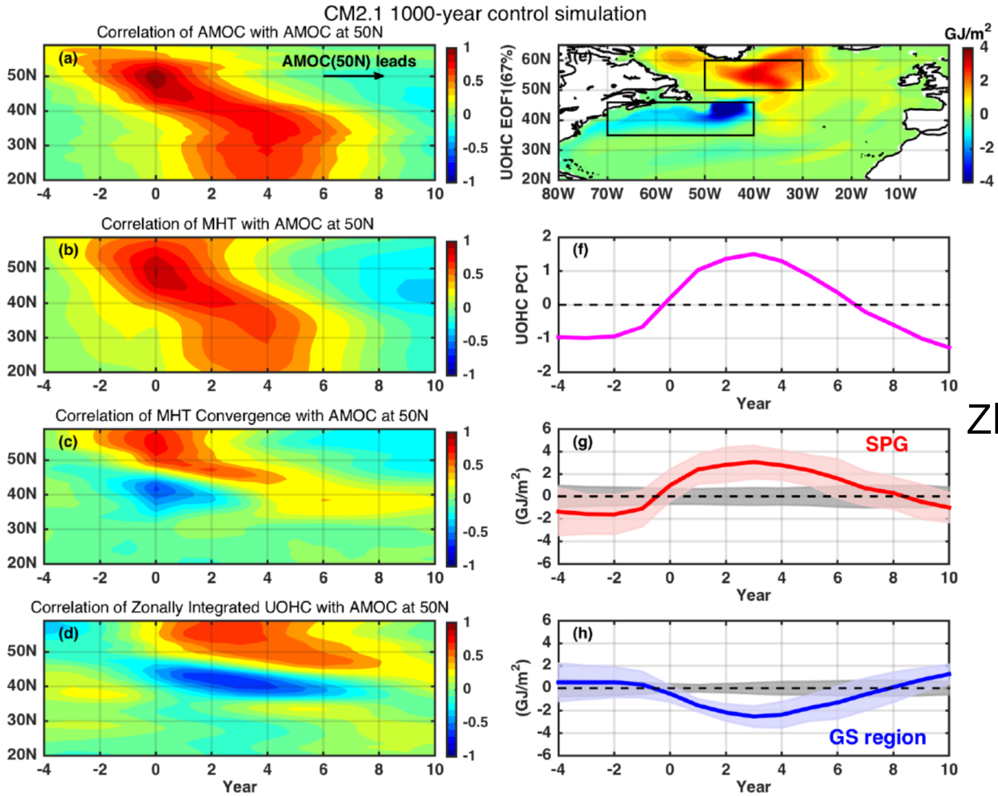
Southward propagation of MHT anomaly

↓

MHT convergence in SPG and divergence in GS

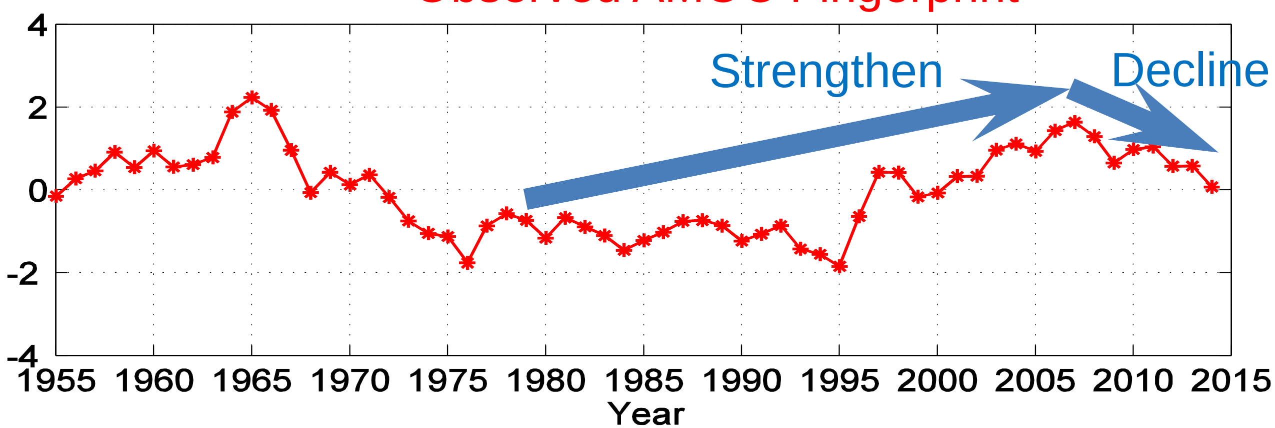
↓

Warming in SPG and cooling in GS

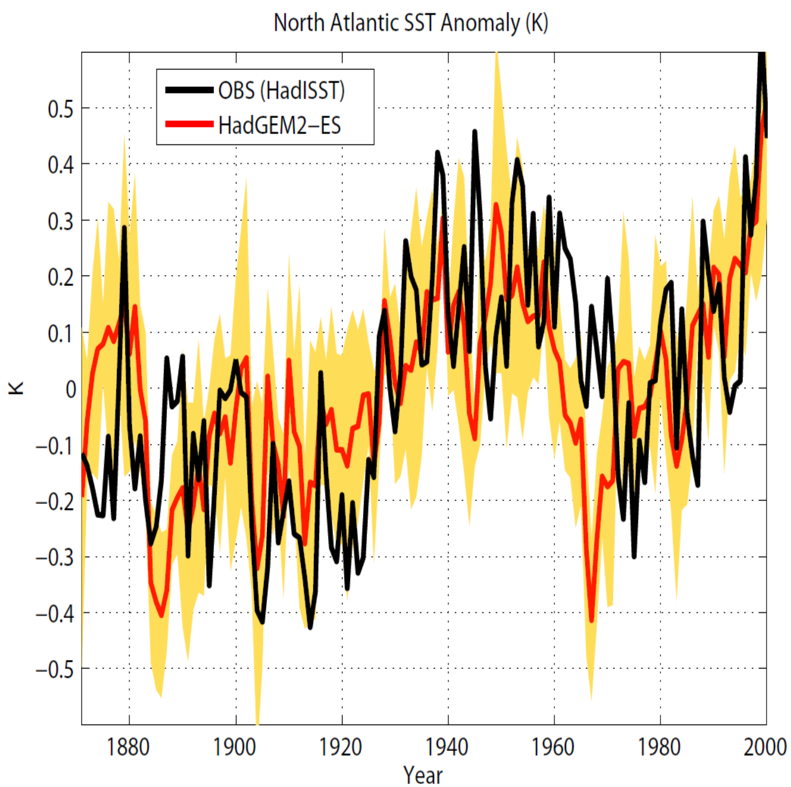


Zhang and Zhang, 2015, GRL

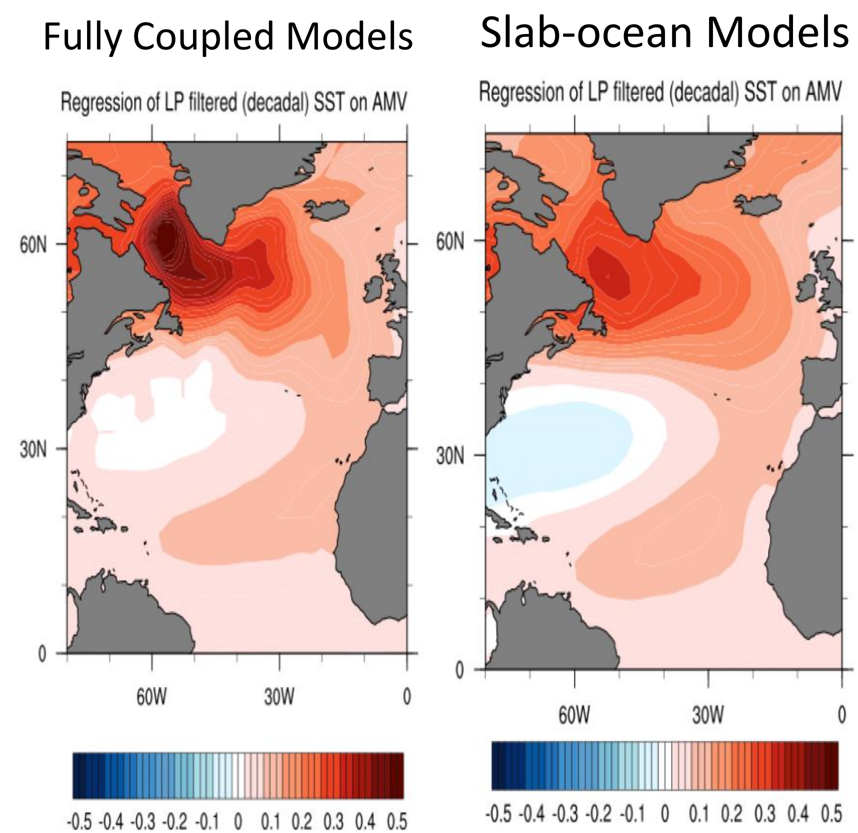
Observed AMOC Fingerprint



Recent Debate on Mechanisms of the AMV



Booth et al., 2012, Nature

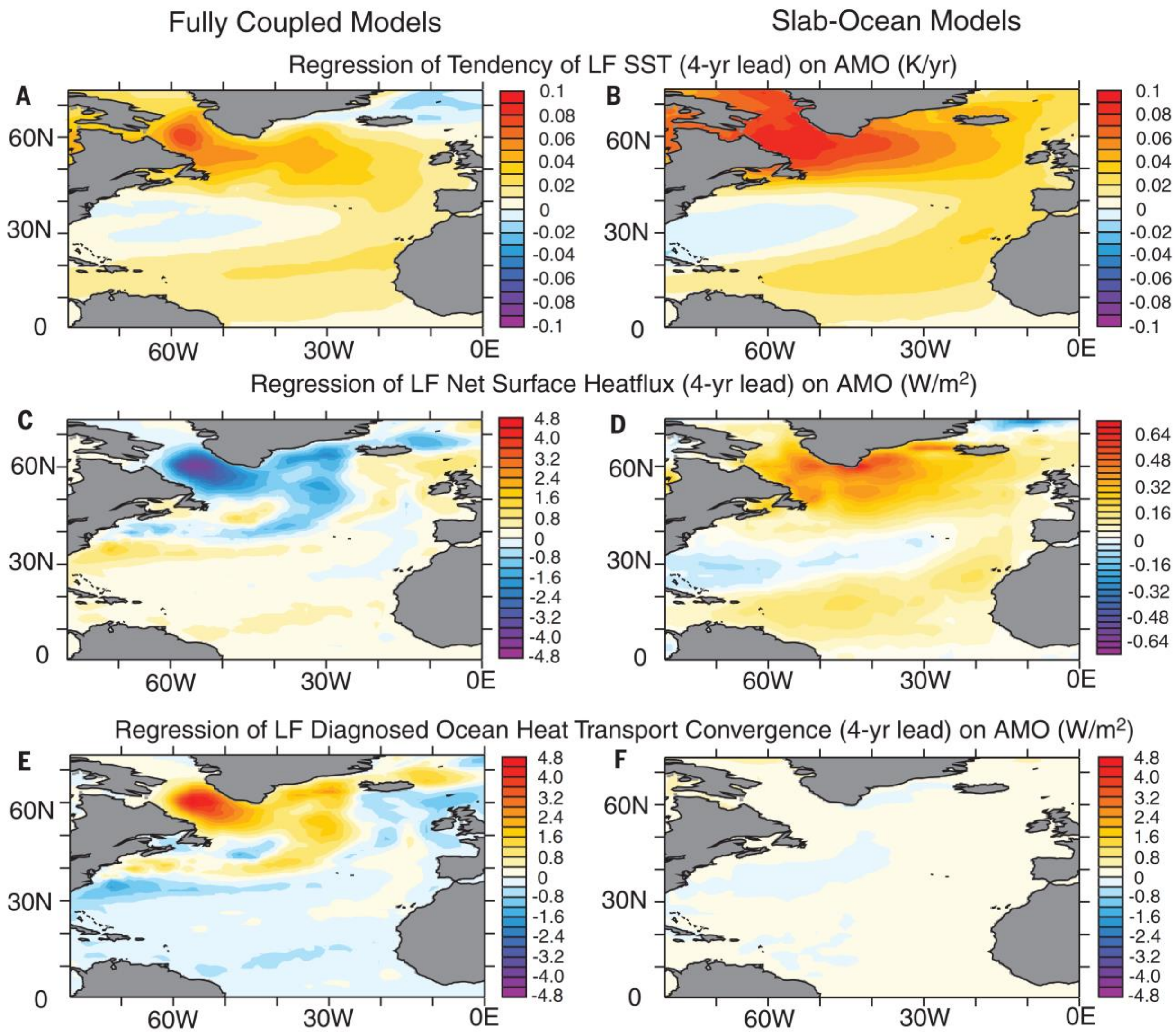


Clement et al., 2015, Science

Recent studies suggest that the AMV is mainly a direct response of the North Atlantic SST to external radiative forcing (Booth et al. 2012) or stochastic atmospheric forcing as found in models coupled with slab oceans (Clement et al. 2015)

Comment on "The Atlantic Multidecadal Oscillation without a role for ocean circulation"

Rong Zhang[1*], Rowan Sutton[2], Gokhan Danabasoglu[3], Thomas L. Delworth[1], Who M. Kim[3], Jon Robson[2], Stephen G. Yeager[3]



Zhang et al. 2016, Science

Zhang et al., 2016 shows that fundamental equation and mechanisms for the AMV are quite different between fully coupled models and slab-ocean models

The negative regression between net downward surface heat flux and SST in subpolar NA in fully coupled models indicate the important role of ocean dynamics in the AMV, consistent with many recent studies (Gulev et al. 2013; O'Reilly et al. 2016; Drews and Greatbatch, 2016; 2017)

A Simple Conceptual Model for SST Anomalies

$$\rho c_p h \frac{\partial T'}{\partial t} \approx F'_{Net} + F'_O \approx -\lambda_A T' + f'_A - \lambda_O T' + f'_O$$

$$F'_{Net} \approx -\lambda_A T' + f'_A$$

$$F'_O \approx -\lambda_O T' + f'_O$$

λ_A: net surface heat flux damping rate, λ_O: oceanic damping rate

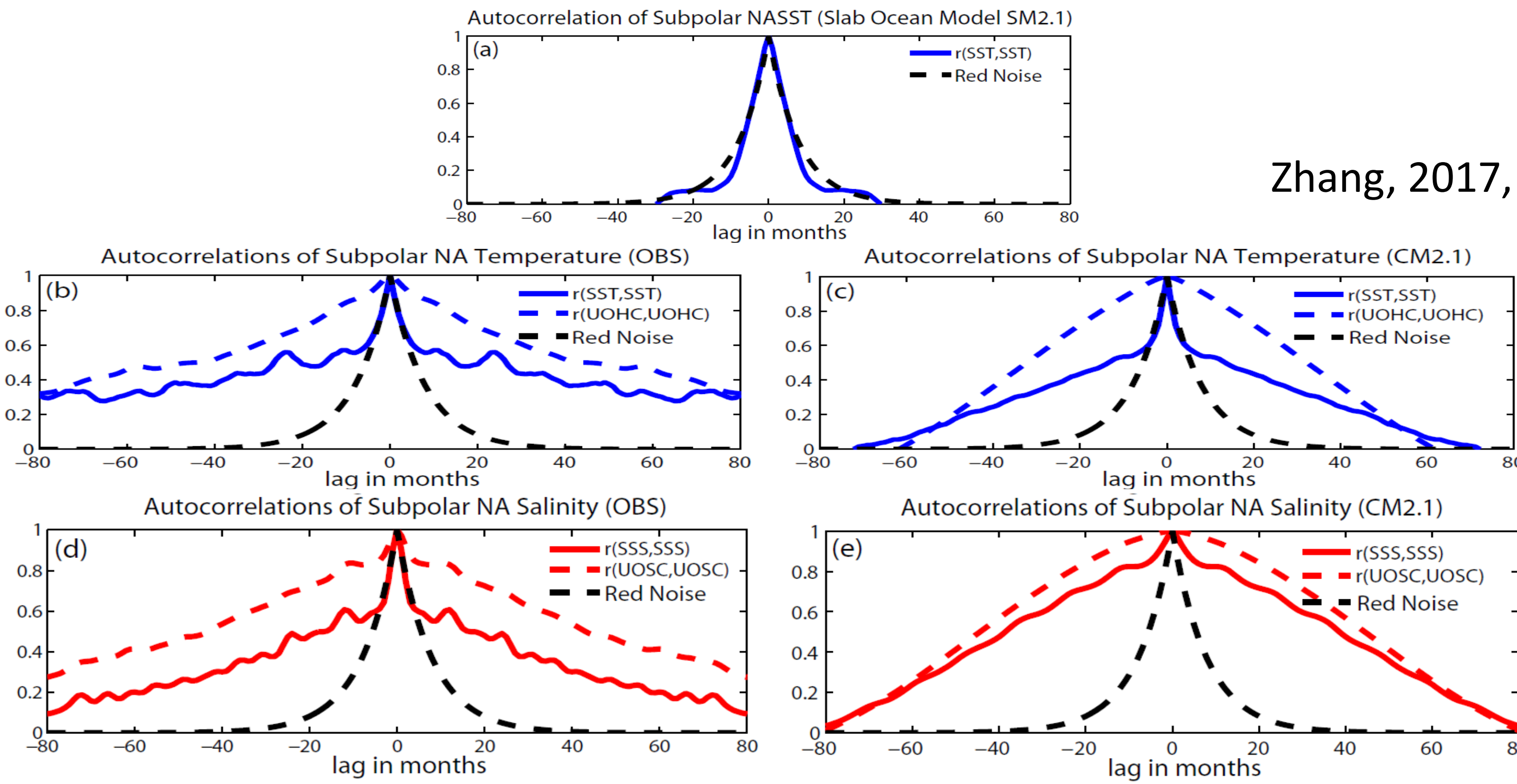
$$\frac{cov(f'_O, T')}{cov(f'_A, T')} \approx \frac{\lambda_O - \frac{r(F'_{Net}, T')\sigma_{F'_{Net}}}{\sigma_{T'}}}{\lambda_A + \frac{r(F'_{Net}, T')\sigma_{F'_{Net}}}{\sigma_{T'}}}$$

- For both observations and CM2.1, $\frac{cov(f'_O,T')}{cov(f'_A,T')} \gg 1$, f'_O has a dominant role for low frequency Subpolar NASST anomalies associated with the AMV
- The red noise model (Clement et al. 2016; Cane et al. 2017) without oceanic damping ($\lambda_O = 0$), leads to the unrealistic conclusion:

$$\frac{cov(f'_O, T')}{cov(f'_A, T')} \ll 1$$

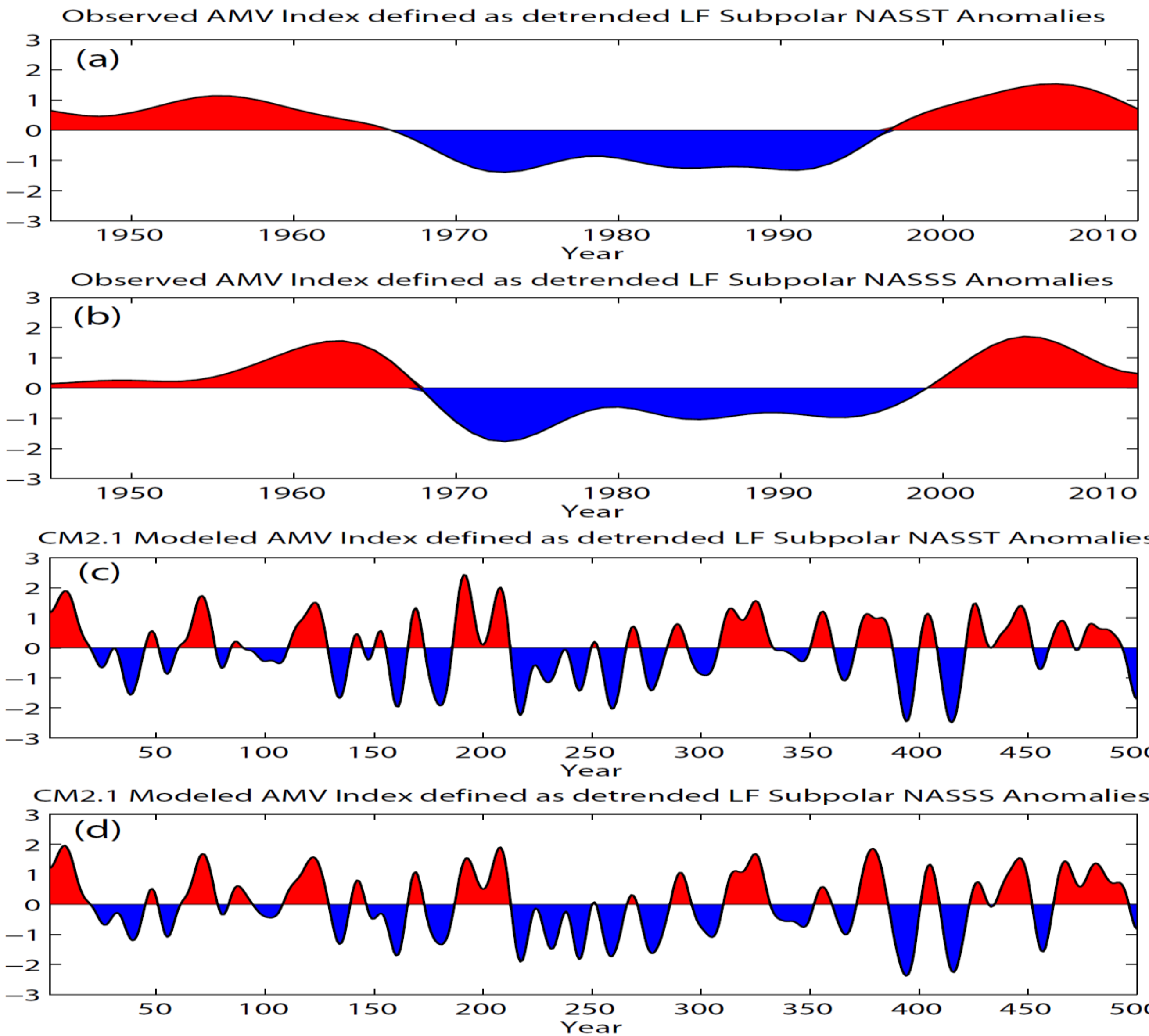
i.e. f'_O has a negligible role and f'_A is the main driver of the AMV to interpret the result $r(F'_{Net}, T') < 0$ at low frequency (Gulev et al. 2013; O'Reilly et al. 2016; Zhang et al. 2016; Drews and Greatbatch, 2016)

Zhang, 2017, GRL

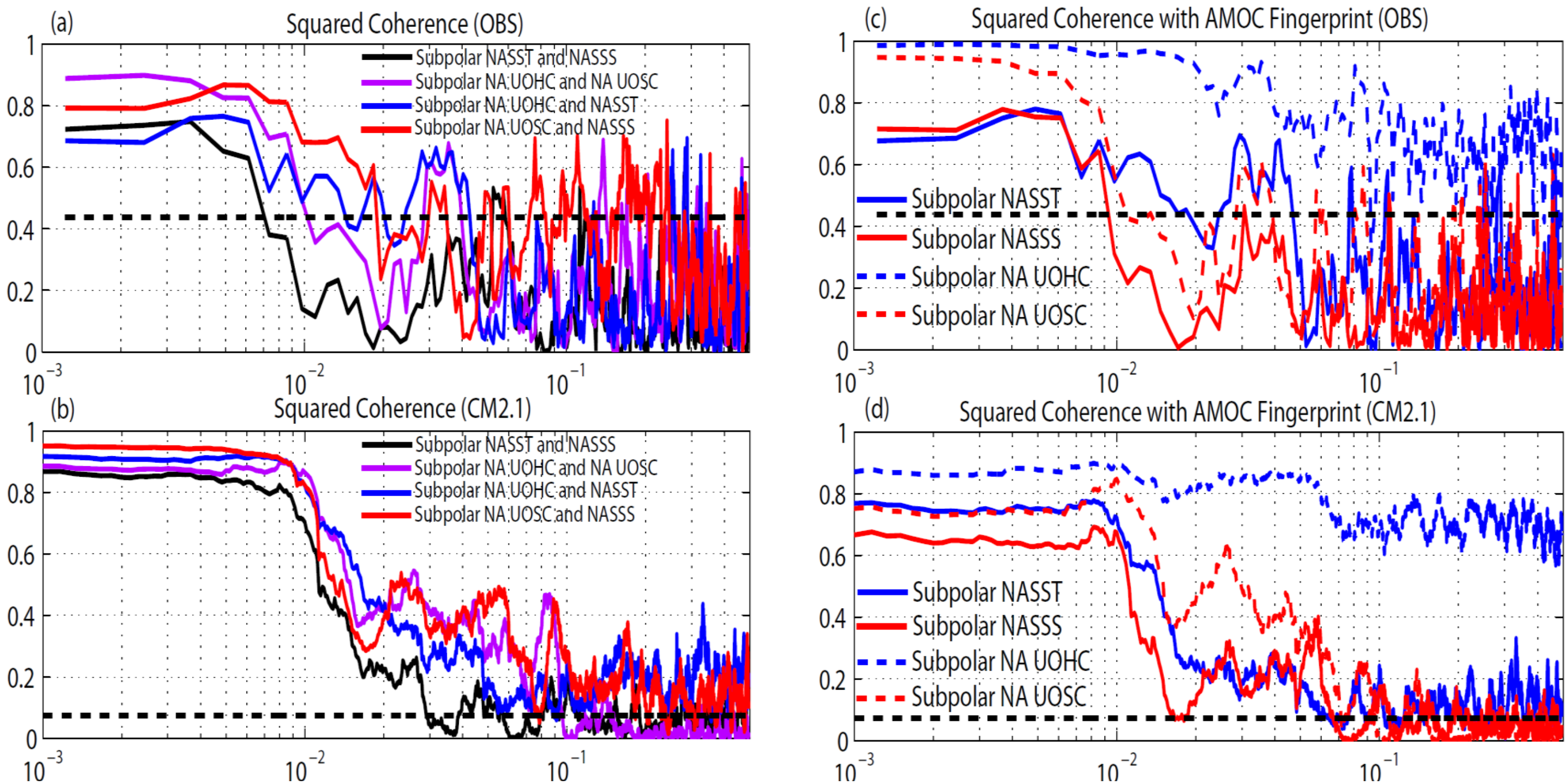


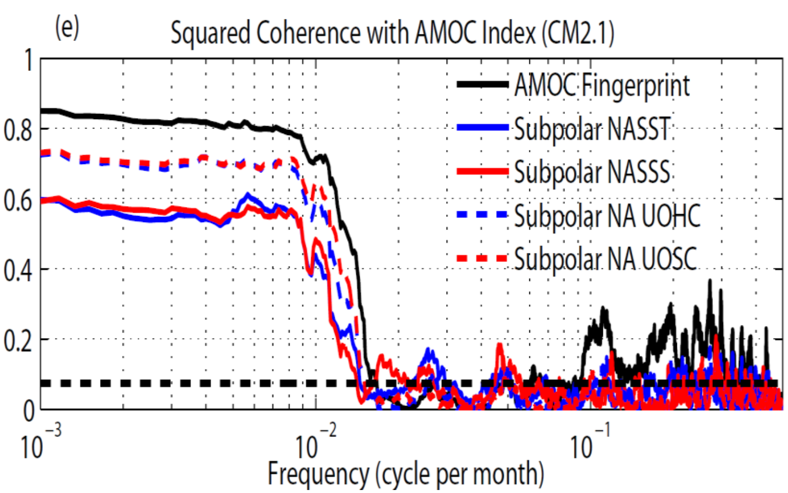
Zhang, 2017, GRL

- Decadal persistence of Subpolar NASST anomalies associated with the AMV in observations and GFDL CM2.1 control simulation will lead to much higher decadal prediction skill than that obtained from the slab ocean models or the fitted red noise model
- Consistent with successful decadal predictions in subpolar North Atlantic by initializing observed ocean states in fully coupled models (Robson et al., 2012b; Yeager et al., 2012;Yang et al., 2013; Msadek et al., 2014)
- Subpolar NASSS and Subpolar NA UOHC/UOSC exhibit similar decadal persistence



Zhang, 2017, GRL

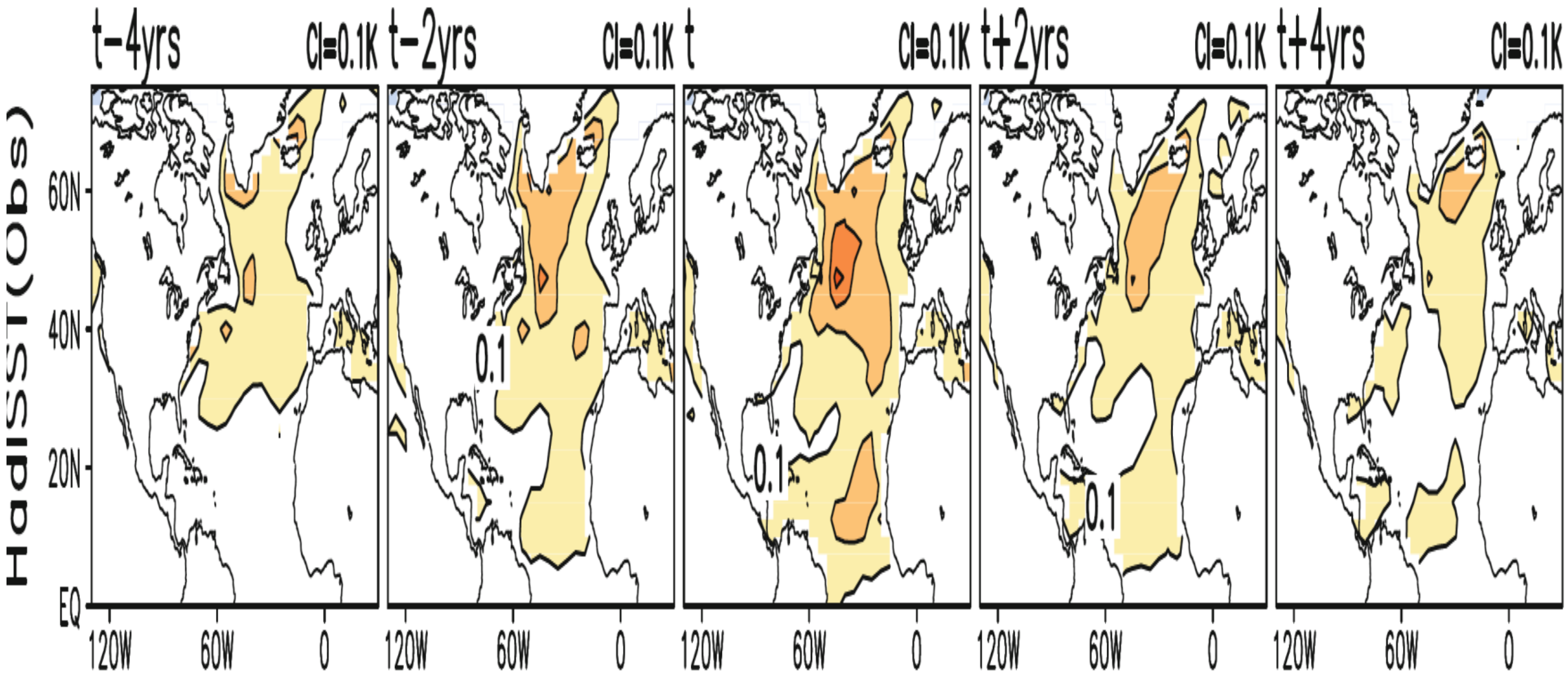




Zhang, 2017, GRL

High coherence among Subpolar NA SST/SSS, UOHC/UOSC, and AMOC fingerprint at low frequency cannot be explained by slab ocean model results or the red noise process, but is consistent with the ocean dynamics mechanism (e.g. low frequency AMOC variability)

Evolution of the Observed AMV

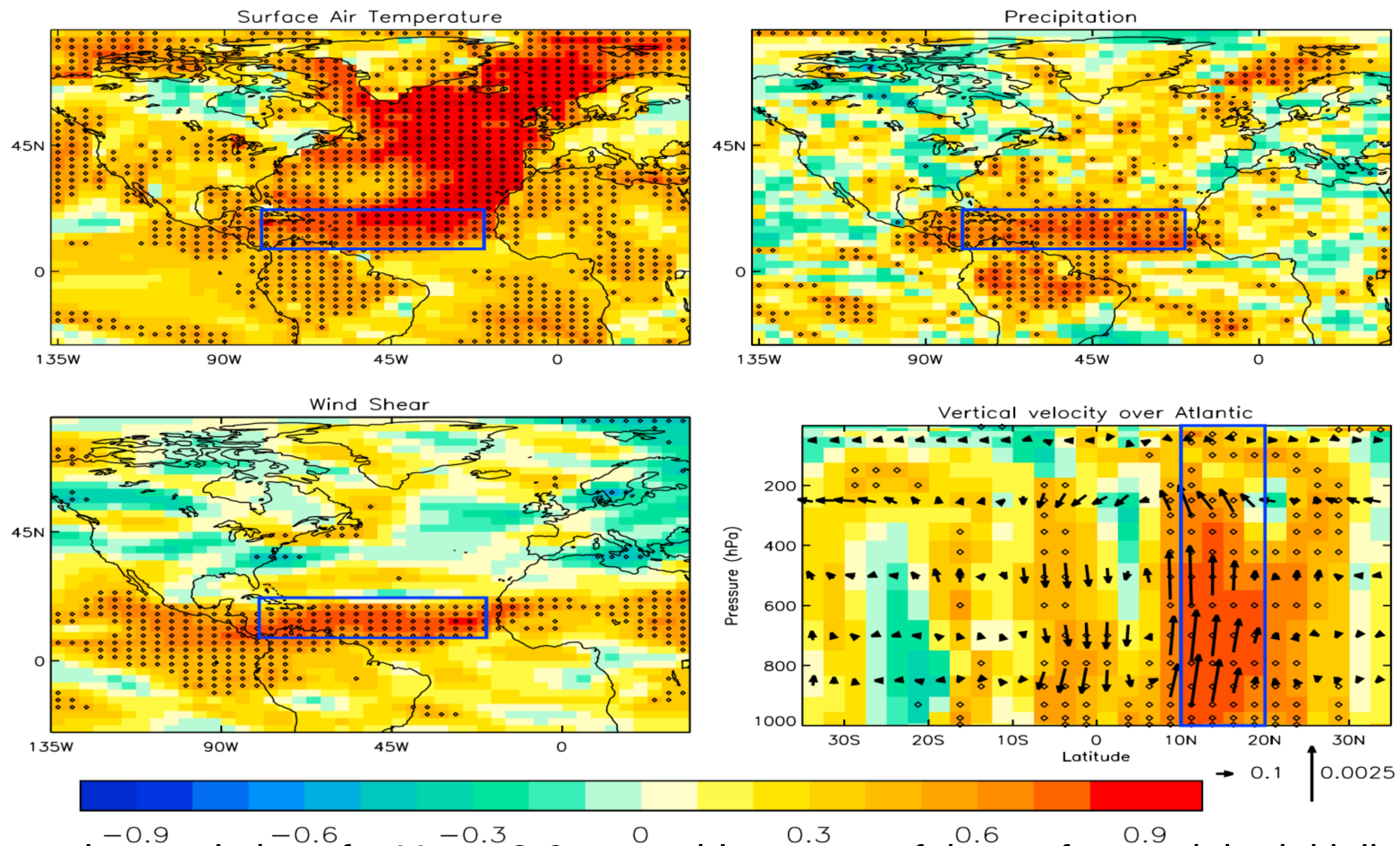


Ruiz-Barradas et al. 2013, Climate Dynamics

The weaker tropical AMV signal responds to the stronger subpolar AMV signal through combined oceanic and atmospheric teleconnections, including changes in the Hadley circulation, WES feedback, and cloud and dust feedback (Zhang, 2007; Dunstone et al. 2011; Wang et al. 2012; Hodson et al. 2014, Yuan, et al. 2016; Brown et al. 2016)

Multi-year Predictability of Tropical Atlantic Atmosphere driven by the Subpolar North Atlantic Ocean

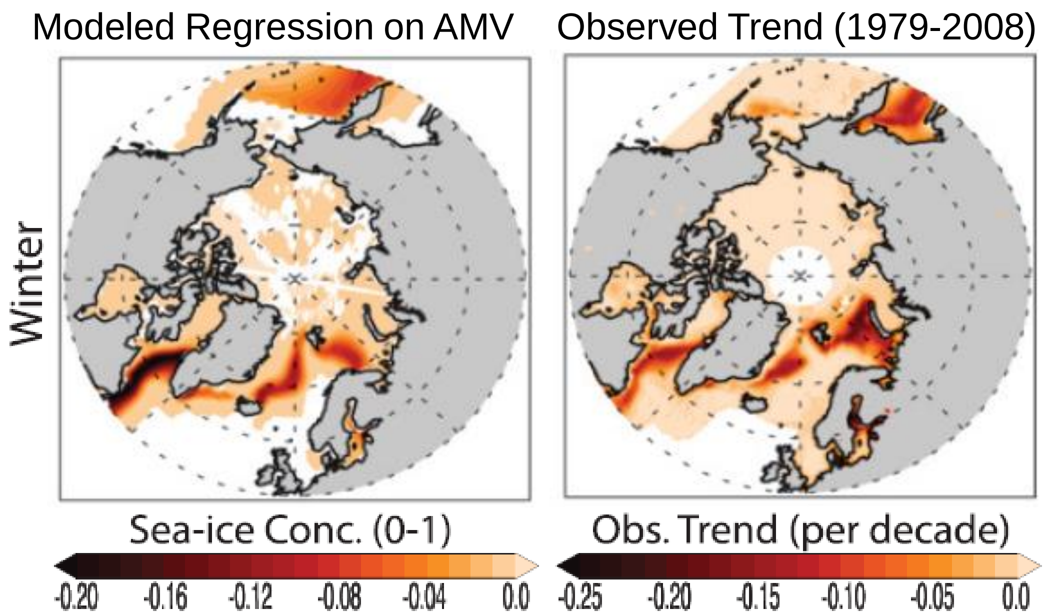
The North Atlantic Subpolar Gyre (SPG) is identified as a key driver of skills in predicting the tropical Atlantic atmosphere, including tropical precipitation, wind shear, vertical velocity, and storm numbers



Anomaly correlations for Years 2-6 ensemble means of the perfect and the initialized forecast experiments using HadCM3

Dunstone et al. 2011, GRL

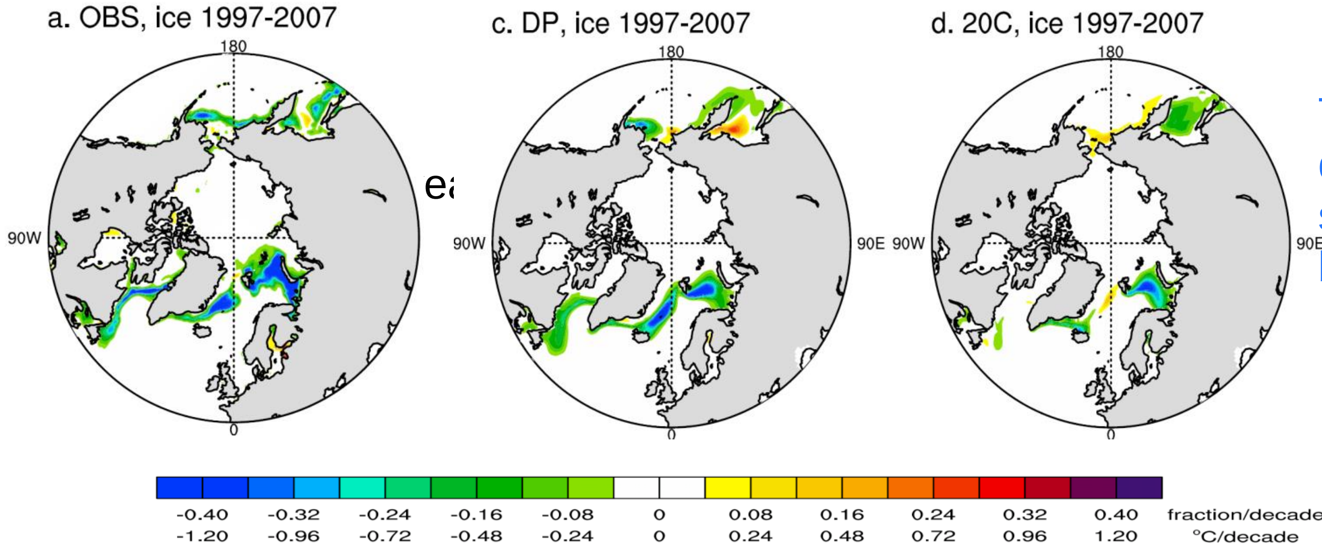
AMV and Arctic Sea Ice Variability



Winter Arctic sea ice in the Atlantic side declines with an intensified AMOC/positive AMV

Similar spatial patterns suggest a possible role of the AMOC/AMV in the observed winter sea ice decline

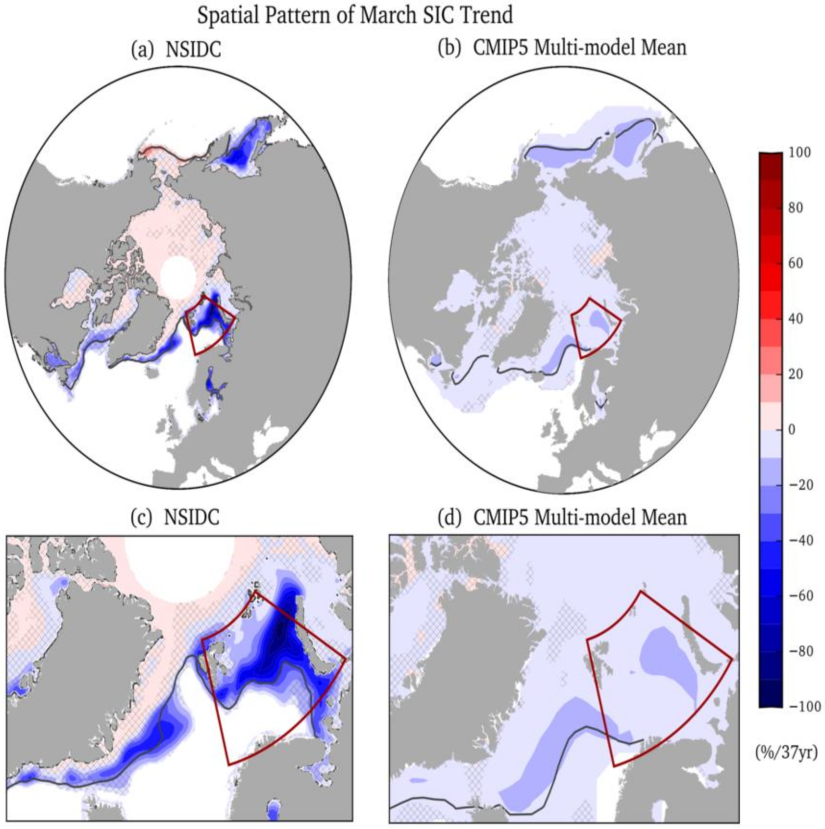
Mahajan et al. 2011, JOC

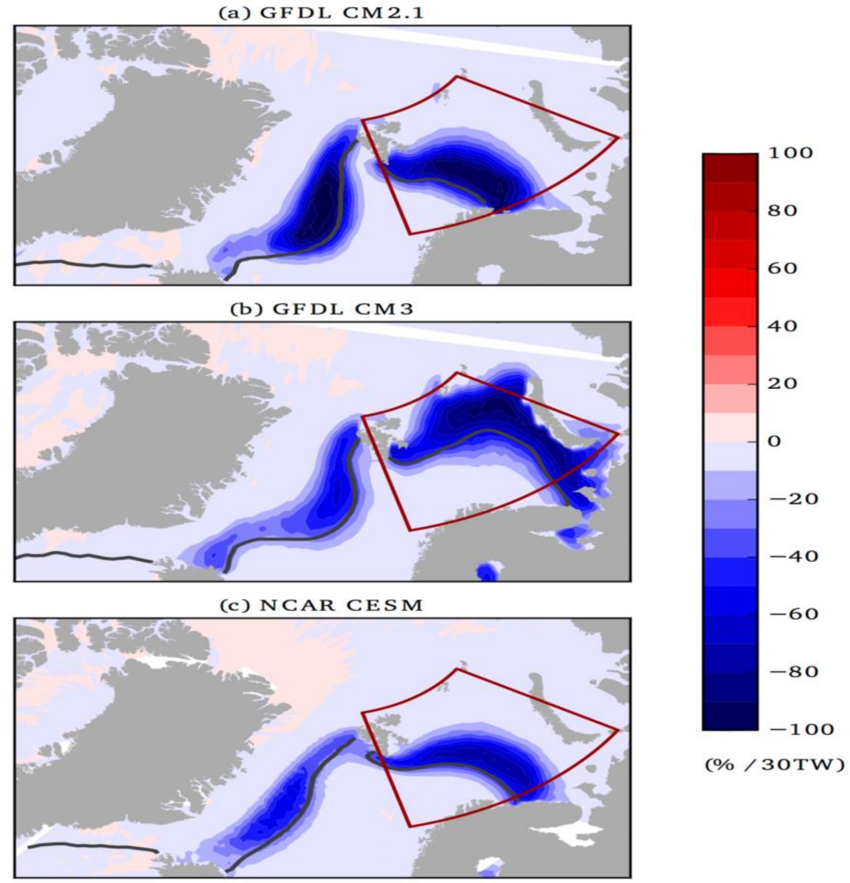


The observed decadal decline of winter Arctic sea ice can be predicted by initializing ocean states

Yeager et al. 2015, GRL

Discrepancy between Observed and CMIP5 Multi-Model Simulated Barents Sea Winter Sea Ice Decline





Li et al. 2017, Nature Communications

CMIP5 externally forced March NH SIC trend in individual regions (especially in Barents Sea) differs substantially from that observed

Internal Atlantic variability may have played a leading role in the observed winter sea ice decline in Barents Sea

Summary

- The AMV is associated with coherent multivariate low frequency variability observed in the Atlantic, including coherent multidecadal variations in Atlantic SST, SSS, upper ocean heat/salt content, ocean-driven surface turbulent heat fluxes

- The observed decadal persistence of Subpolar NASST anomalies will lead to much higher decadal prediction skill than that obtained from the slab ocean models or the red noise process

- These key observed AMV features cannot be explained by a direct response to stochastic atmospheric forcing or external radiative forcing, but are consistent with the ocean dynamics mechanism (e.g. low frequency AMOC variability)

- The SST-based AMV Index often leads to incomplete understanding of the AMV mechanism only in terms of SST anomalies

- The correlation and regression between net surface heat flux and SST at low frequency are key indicators for the relative roles of oceanic vs. atmospheric forcing in SST anomalies. The red noise model with no oceanic damping gives unrealistic interpretation of the negative correlation

- The oceanic forcing has a dominant role in the low frequency Subpolar NASST anomalies, and is closely linked to AMOC variability, which is a major source for the decadal persistence in subpolar temperature and salinity

- The subpolar North Atlantic is a key region for generating the AMV and predicting the tropical Atlantic atmosphere

- The ocean dynamics associated with the AMV has a predictable impact on winter Arctic sea ice