On the origins & mechanisms of North Atlantic decadal variability between 1948-2007

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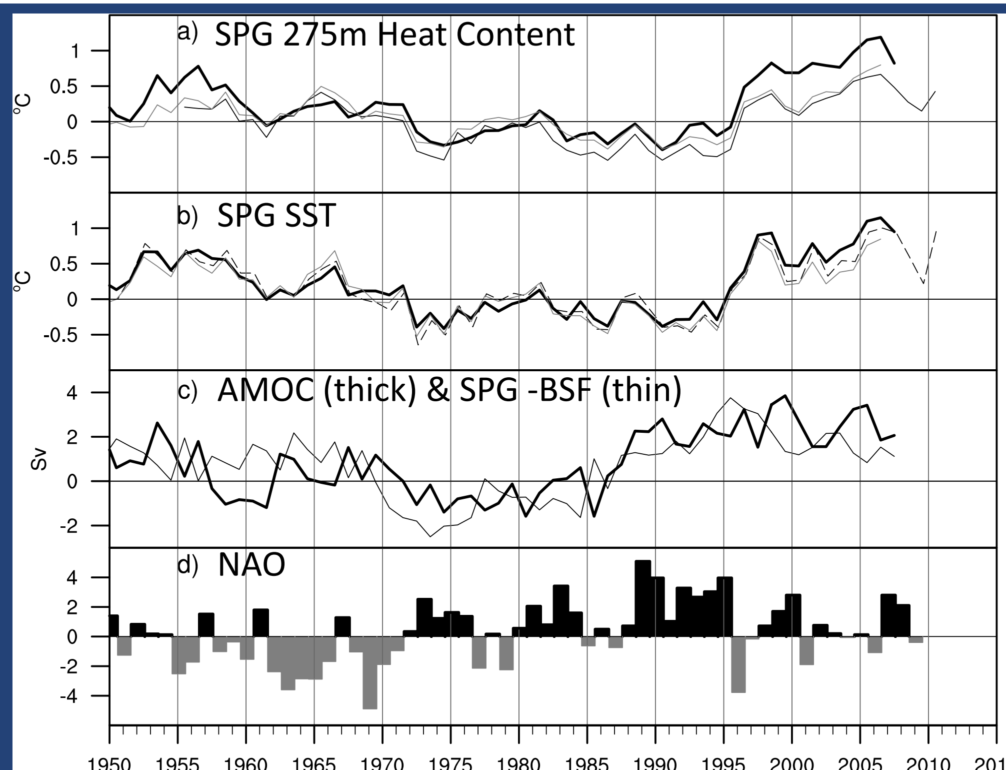
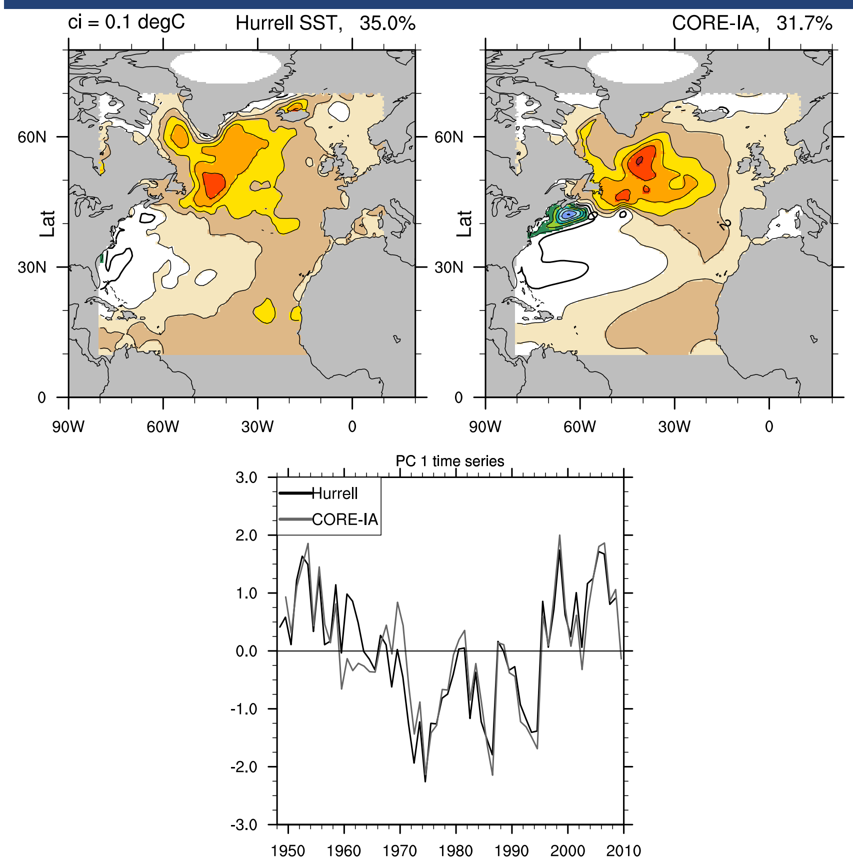
- AIM: Identify key forcings & mechanisms associated with historical (1948-2007) N. Atlantic decadal variability in CORE experiments (and nature). Use this to guide coupled model analysis & decadal prediction development.

- METHOD: CCSM4 coupled ocean-ice simulation driven by CORE historical forcing fields (“CORE-IA”) & perturbed forcing sensitivity experiments.

AMV in CORE-IA simulation

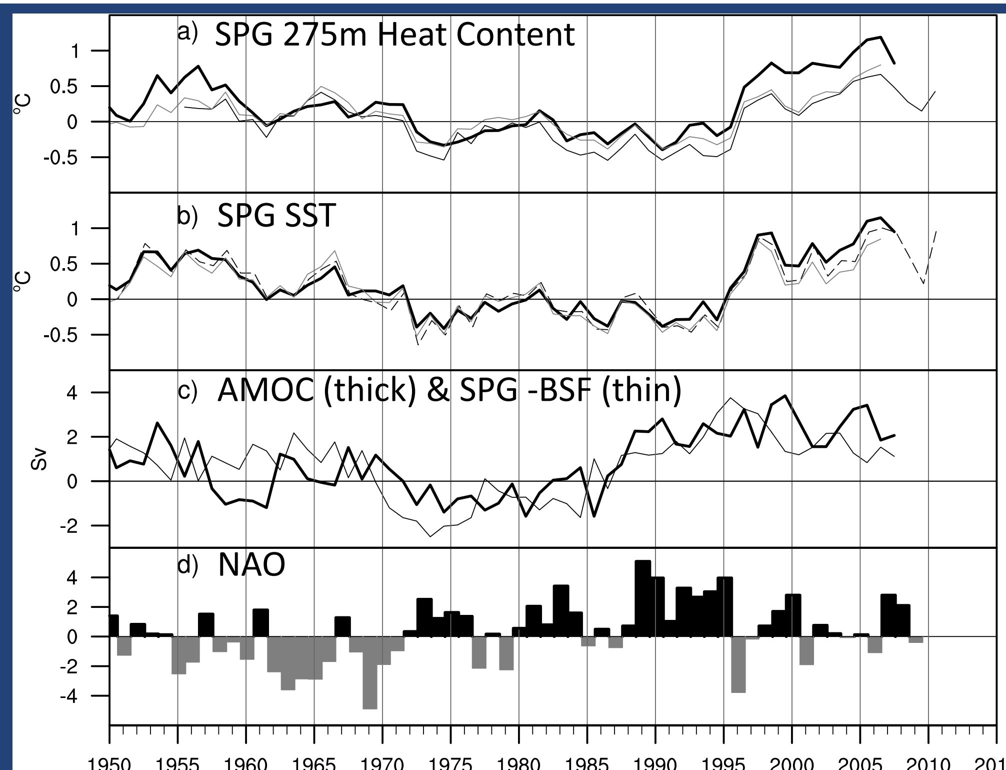


1st EOF of SST



- CORE-IA is skillful at reproducing observed AMV

AMV in CORE-IA simulation



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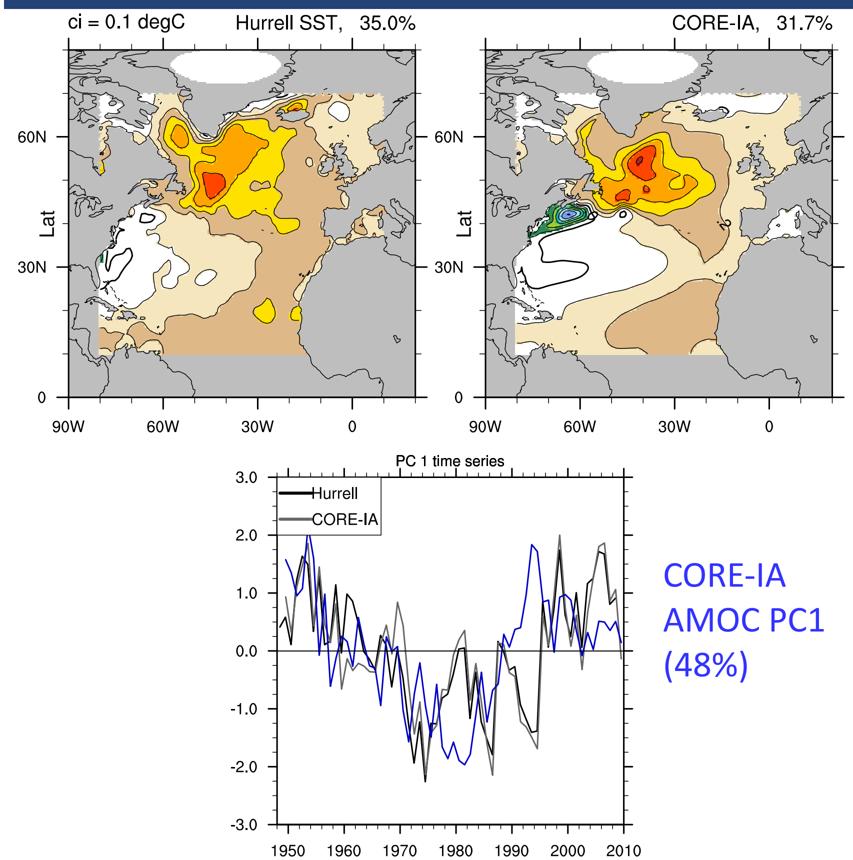
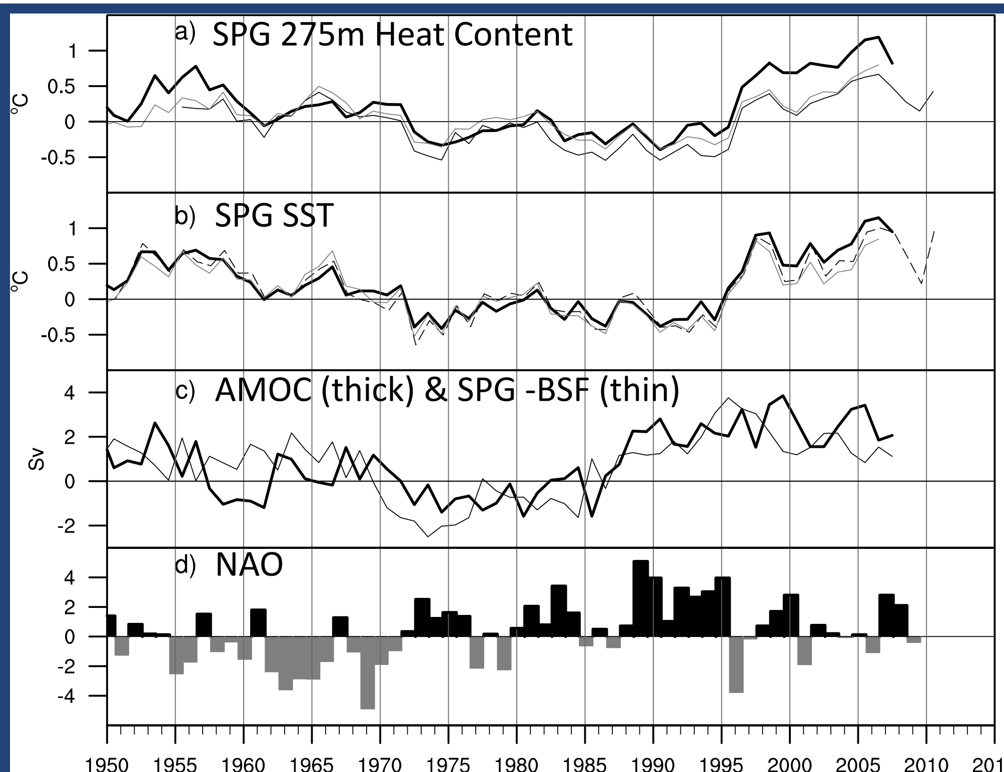


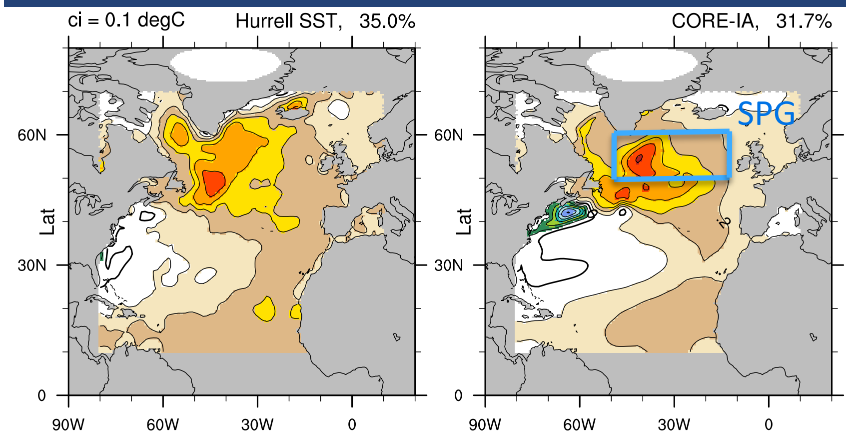
CORE-IA AMOC PC1 (48%)

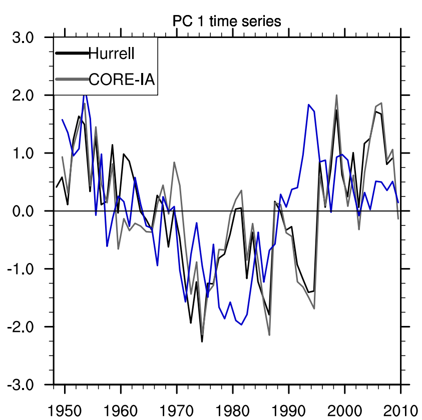
- CORE-IA is skillful at reproducing observed AMV
- AMOC 1st EOF time series leads AMV, suggesting prominent role of AMOC-related heat transport

AMV in CORE-IA simulation



1st EOF of SST

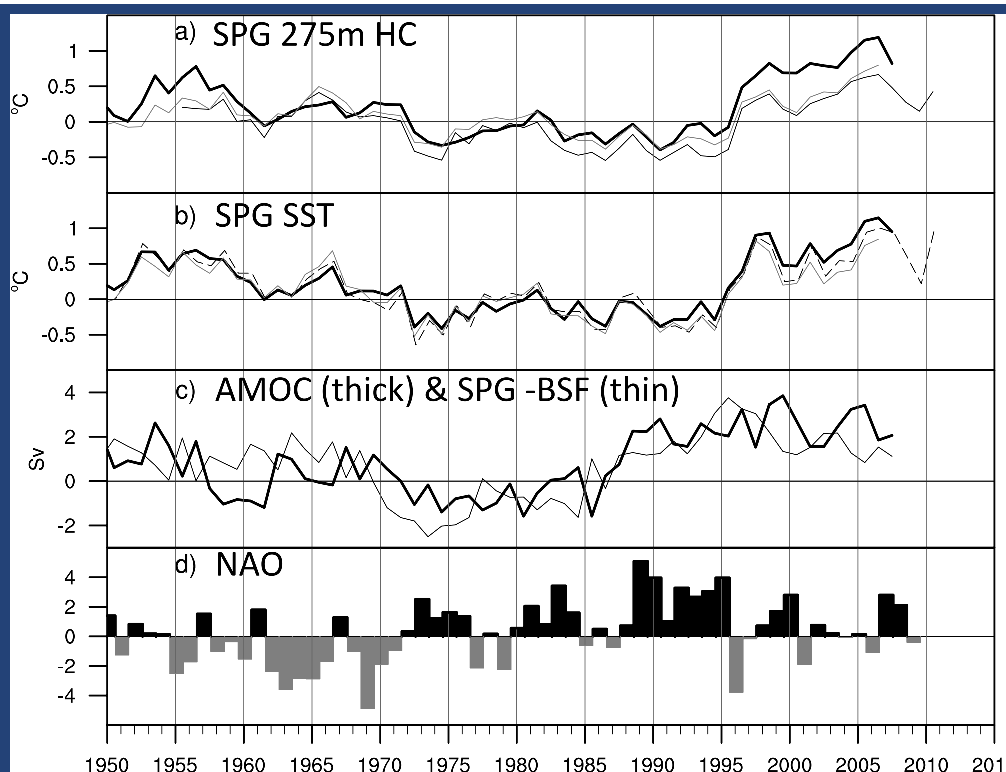




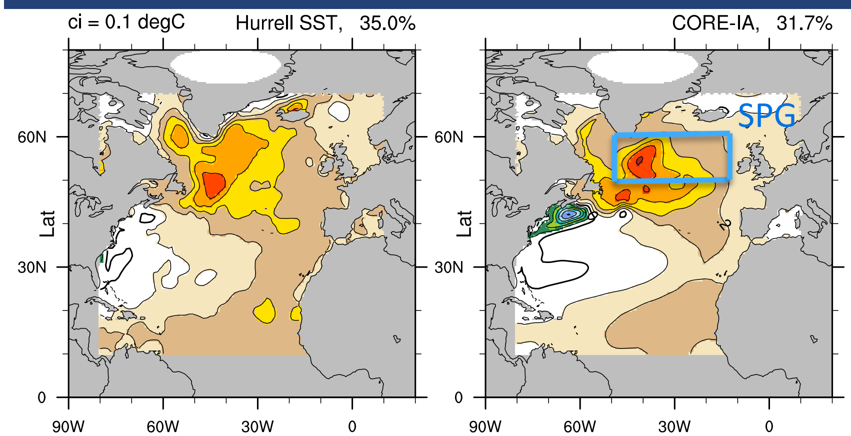
CORE-IA AMOC PC1 (48%)

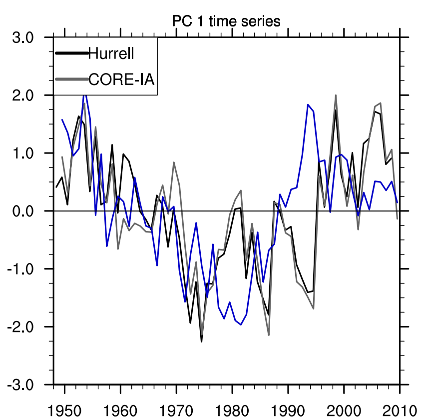
- CORE-IA is skillful at reproducing observed AMV
- AMOC 1st EOF time series leads AMV, suggesting prominent role of AMOC-related heat transport
- Yeager et al. (*J. Climate* 2012) show that gyre heat transport convergence was a dominant driver of observed SPG HC'/SST'. AMOC and SPG barotropic Ψ covary on decadal timescales.
- Skillful decadal predictions of SPG SST attributable to accurate initialization of low-frequency variations in large-scale circulation.

AMV in CORE-IA simulation



1st EOF of SST





CORE-IA AMOC PC1 (48%)

- NAO-related forcing would appear to be key, consistent with Marshall et al (2001), Eden & Willebrand (2001), Böning et al (2006), Lozier et al. (2008), Lohmann et al (2008, 2009), Robson et al (2008), ...

but what NAO-related forcing components in particular give rise to slow variations in large-scale circulation? Is the trend in SAM playing a role?

1. CORE-IA hindcast ("CONTROL")

$Q_{as} = Q_s + Q_L + Q_E(|\Delta\mathbf{u}|, \Delta q) + Q_H(|\Delta\mathbf{u}|, \Delta\theta)$

$F_{as} = P + E(|\Delta\mathbf{u}|, \Delta q) + R$

$\tau_{as} = \tau(\Delta\mathbf{u})$

- interannually-varying 1948-2009 (red)
- "normal" year repeated (cyan)

2. Buoyancy-forced variability ("BUOY")

$Q_{as} = Q_s + Q_L + Q_E(|\Delta\mathbf{u}|, \Delta q) + Q_H(|\Delta\mathbf{u}|, \Delta\theta)$

$F_{as} = P + E(|\Delta\mathbf{u}|, \Delta q) + R$

$\tau_{as} = \tau(\Delta\mathbf{u})$

3. Momentum-forced variability ("MOM")

$Q_{as} = Q_s + Q_L + Q_E(|\Delta\mathbf{u}|, \Delta q) + Q_H(|\Delta\mathbf{u}|, \Delta\theta)$

$F_{as} = P + E(\Delta\mathbf{u}, \Delta q) + R$

$\tau_{as} = \tau(\Delta\mathbf{u})$

*Caveats:

$|\Delta\mathbf{u}| = |\mathbf{u}_a - \mathbf{u}_o|$

$\Delta\theta = \theta_a - SST$

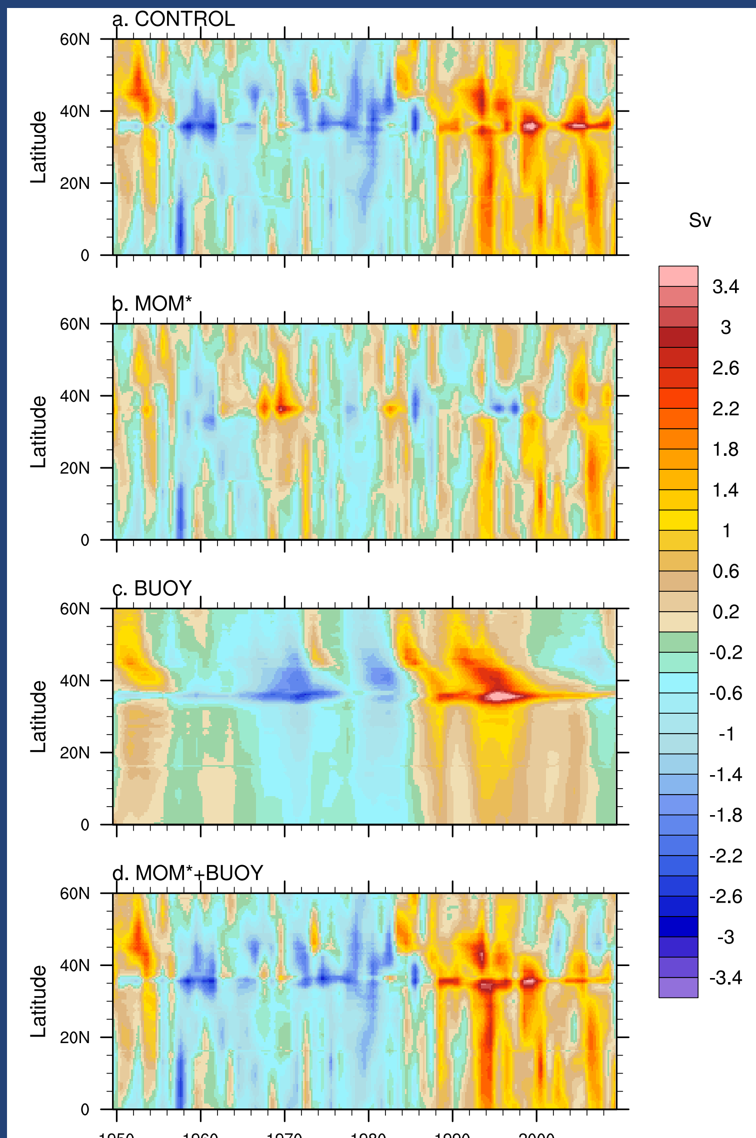
$\Delta q = q_a - q_{SAT}(SST)$

$Q_L = Q_{Ldn} + Q_{Lup}(SST)$

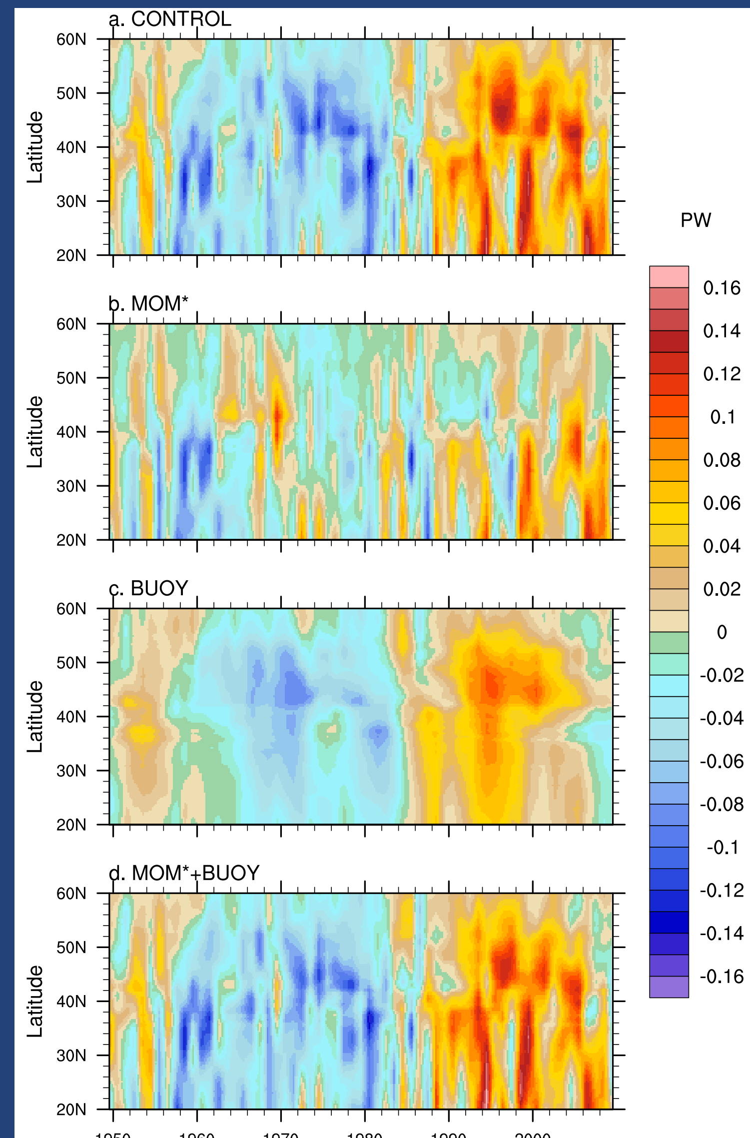
F_{io}, Q_{io}

- Builds on the work of Eden & Willebrand (2001), Böning et al (2006), Robson et al (2011)
- Designed specifically to shed light on variability in CORE experiments (active ice, weak salinity restoring, bulk flux forcing) & makes use of normal year forcing.

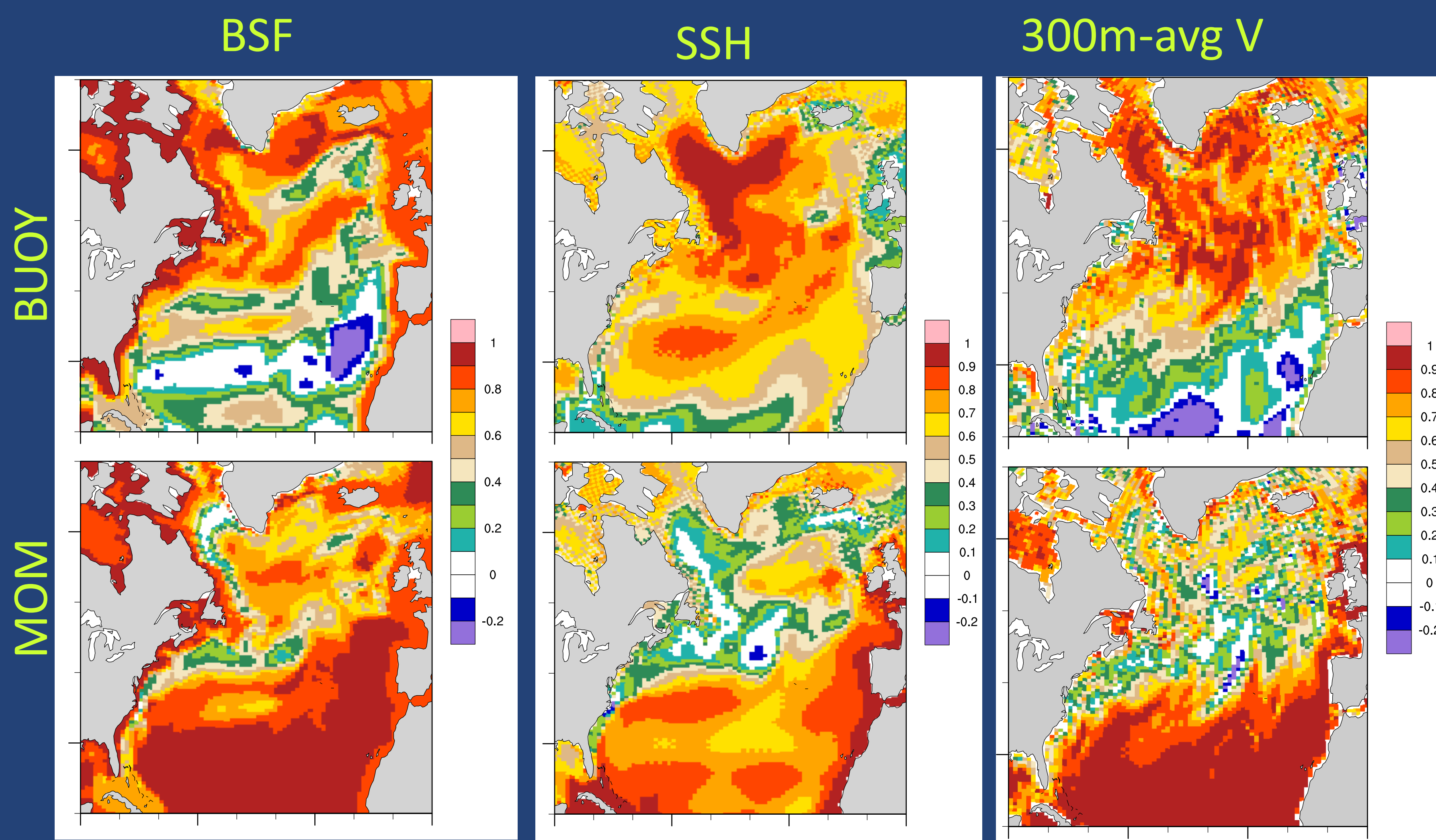
AMOC’(y,t)



MHT’(y,t)



Correlations of 1949-2009 annual anomalies with CONTROL:

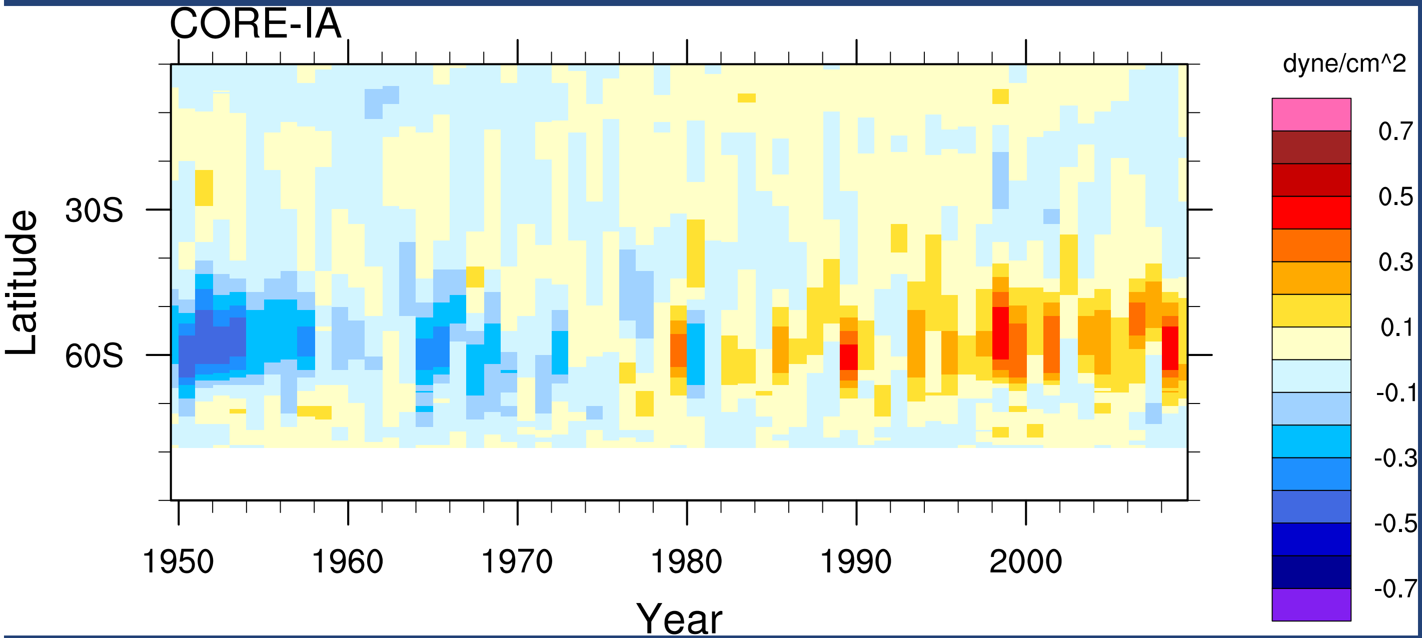


• Buoyancy forcing accounts for most of the interannual variability throughout SPG – explains the correlation of AMOC & subpolar gyre strength on long timescales.

What is the impact of Southern Ocean wind variability?

- Toggweiler and Samuels, 1995, *Deep Sea Res I.*
- de Boer et al, 2010, *JPO*.
- Shakespeare and Hogg, 2012, *JPO*, in press.
- Nikurashin and Vallis, 2012, *JPO*, in press.

Zon avg τ_x'



What is the impact of Southern Ocean wind variability?

- Momentum-forced variability over Southern Ocean, "MOM(SO)":

$Q_{as} = Q_s + Q_L + Q_E(|\Delta \mathbf{u}|, \Delta q) + Q_H(|\Delta \mathbf{u}|, \Delta\theta)$

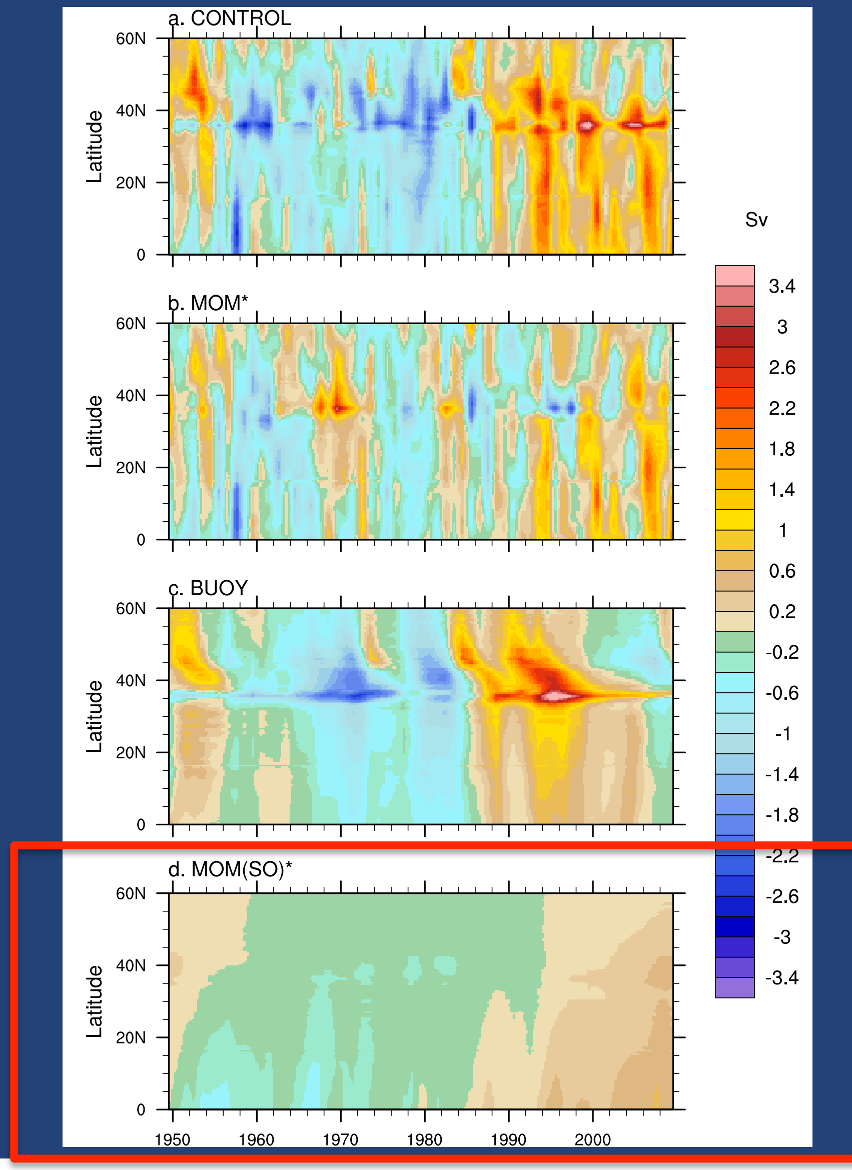
$F_{as} = P + E(|\Delta \mathbf{u}|, \Delta q) + R$

$\tau_{as} = \tau(\Delta \mathbf{u})$, north of 35°S

$\tau(\Delta \mathbf{u})$, south of 35°S

★ Trend in 20th century wind stress over Southern Ocean contributes negligibly to AMOC variability compared to other (N. Atlantic) forcings

AMOC'



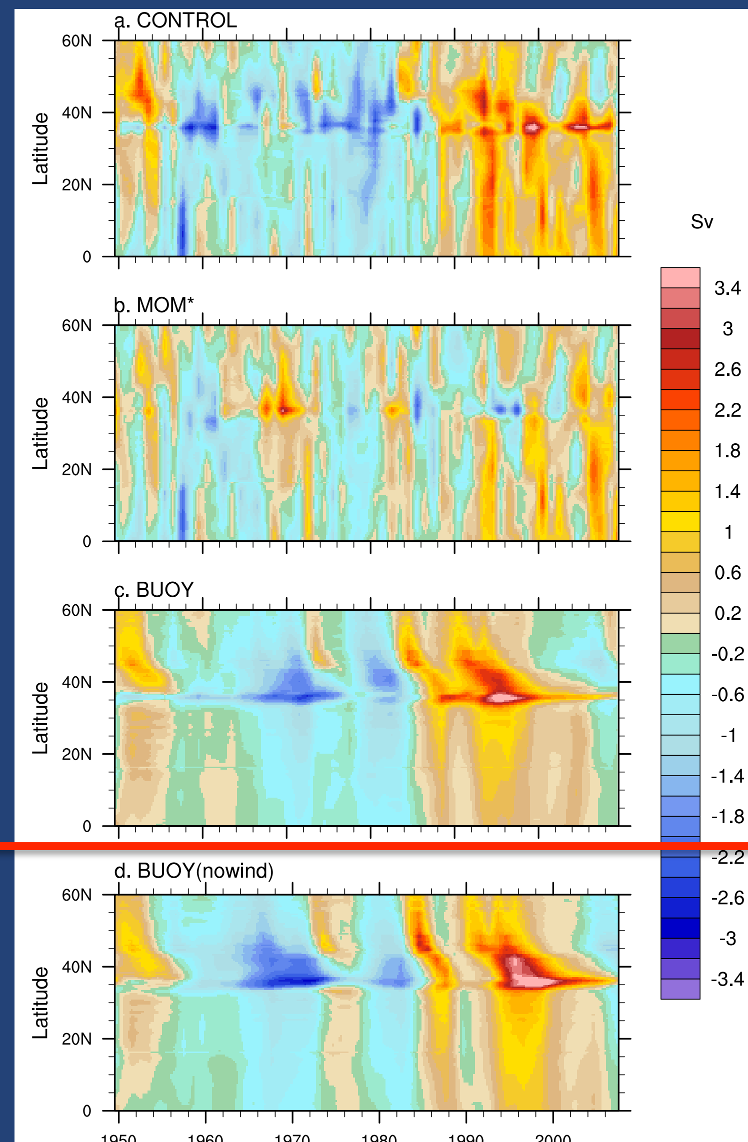
What is the impact of NAO winds on turbulent buoyancy forcing?

- Buoyancy-forced variability, without wind effects, "BUOY(nowind)":

$$Q_{as} = Q_s + Q_L + Q_E(|\Delta \mathbf{u}|,\Delta q) + Q_H(|\Delta \mathbf{u}|,\Delta \theta)$$
$$F_{as} = P + E(|\Delta \mathbf{u}|,\Delta q) + R$$
$$\tau_{as} = \tau(\Delta \mathbf{u})$$

★ minimal effect ➔ low-frequency AMOC variability is not directly related to wind forcing

AMOC'



What are the relative roles of thermal vs haline buoyancy forcing?

- Temperature-forced variability ("BUOY_T")

$Q_{as} = Q_s + Q_L + Q_E(|\Delta \mathbf{u}|,\Delta q) + Q_H(|\Delta \mathbf{u}|,\Delta \theta)$

$F_{as} = P + E(|\Delta \mathbf{u}|,\Delta q) + R$

$\tau_{as} = \tau(\Delta \mathbf{u})$

- Salinity-forced variability ("BUOY_S")

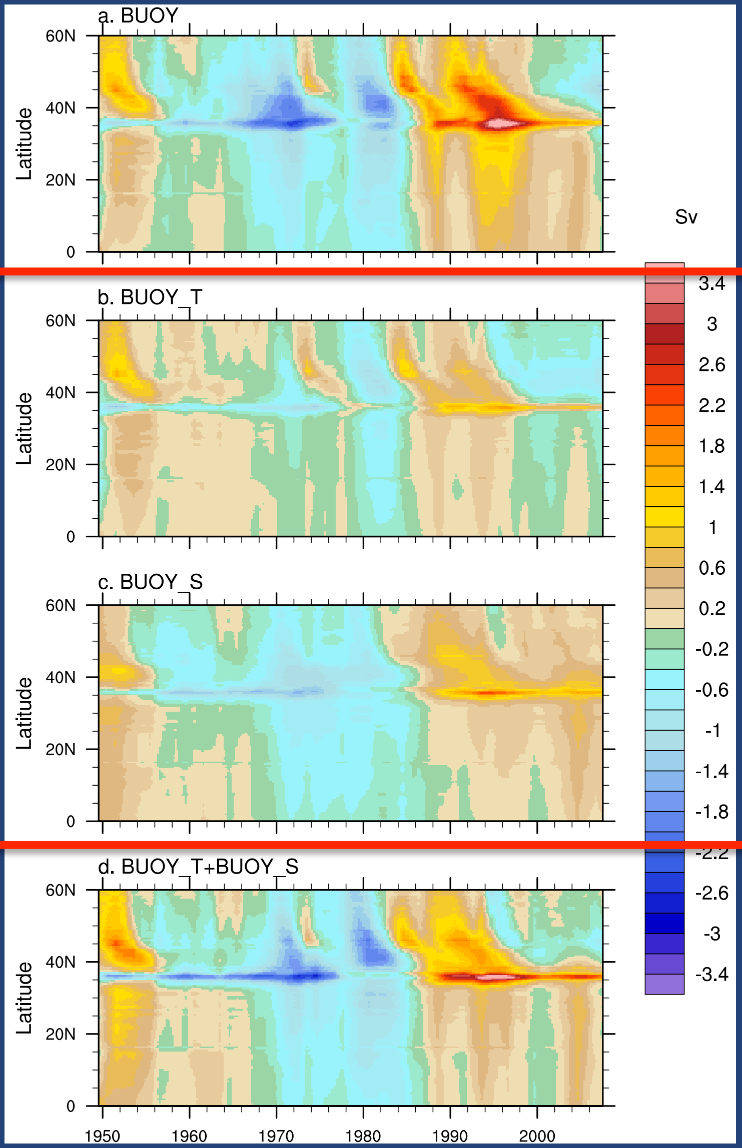
$Q_{as} = Q_s + Q_L + Q_E(|\Delta \mathbf{u}|,\Delta q) + Q_H(|\Delta \mathbf{u}|,\Delta \theta)$

$F_{as} = P + E(\Delta \mathbf{u},\Delta q) + R$

$\tau_{as} = \tau(\Delta \mathbf{u})$

★ Both heat and freshwater forcing are important. Freshwater forcing contributes particularly to low frequency AMOC variability.

AMOC'

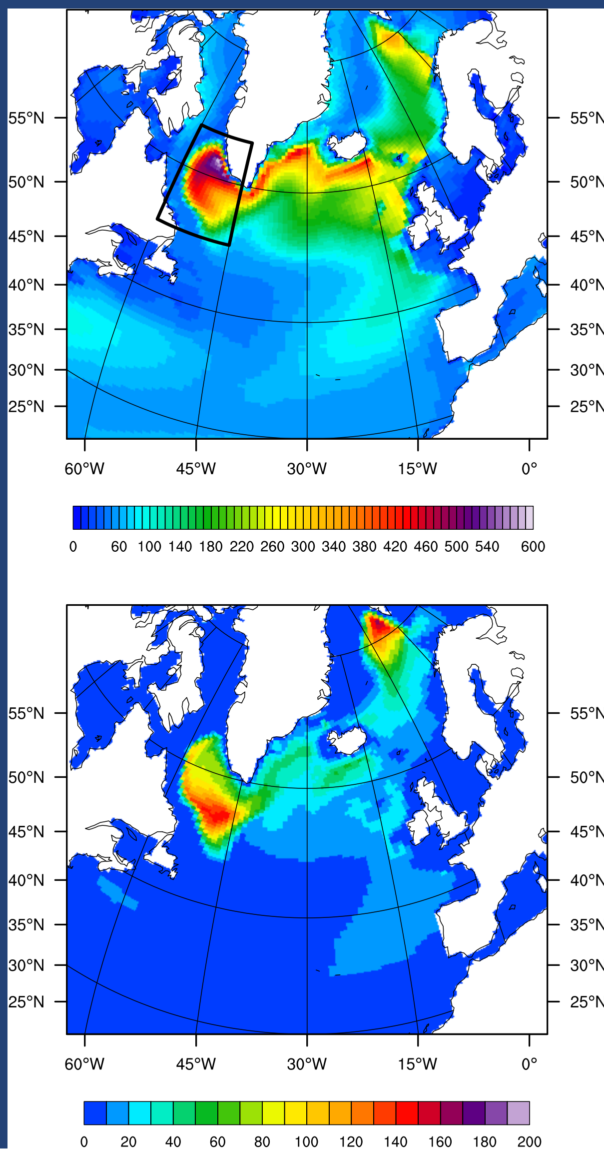


What is the relative role of Lab Sea buoyancy forcing?

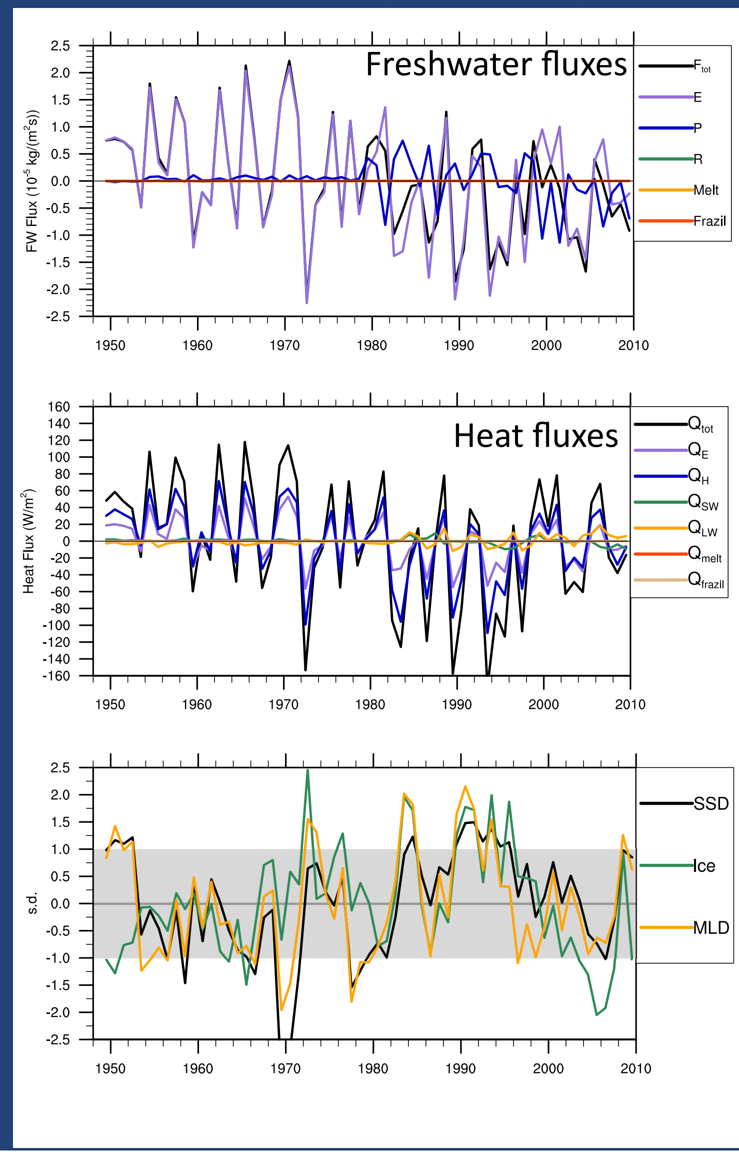
MLD (CONTROL)

mean

rms

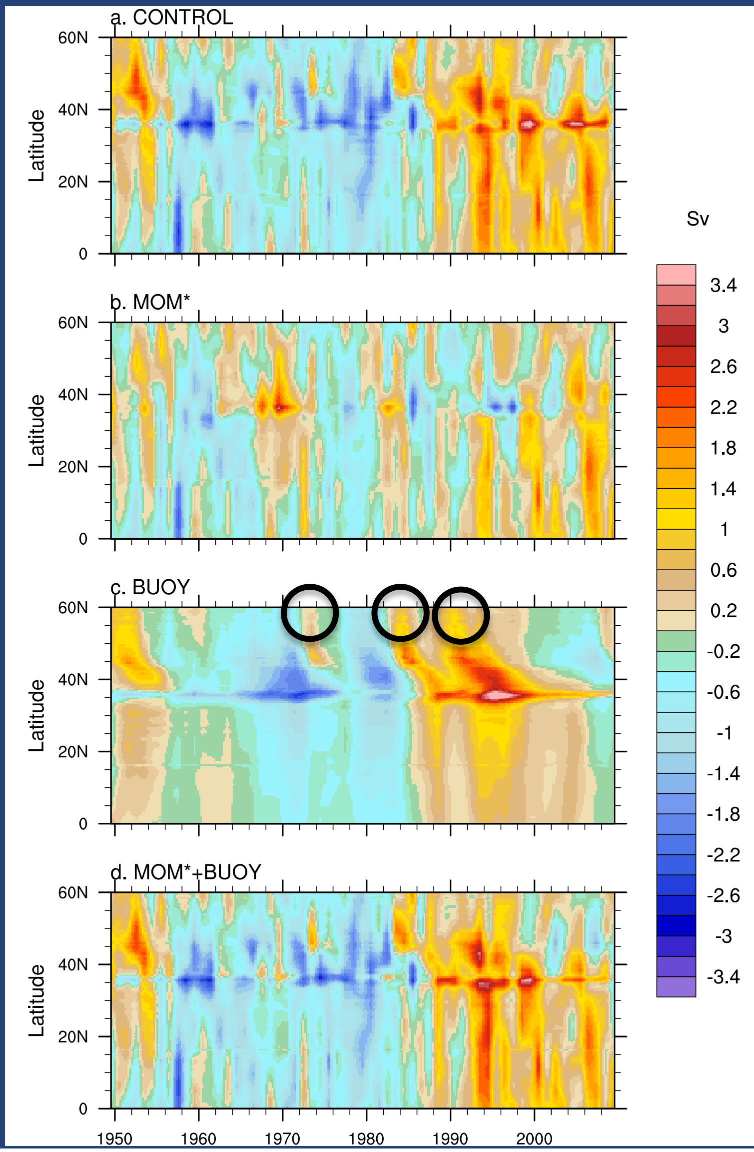


Lab Sea Box, open-ocean
March anomalies (CONTROL)



What is the relative role of Lab Sea buoyancy forcing?

AMOC’



Lab Sea Box, open-ocean

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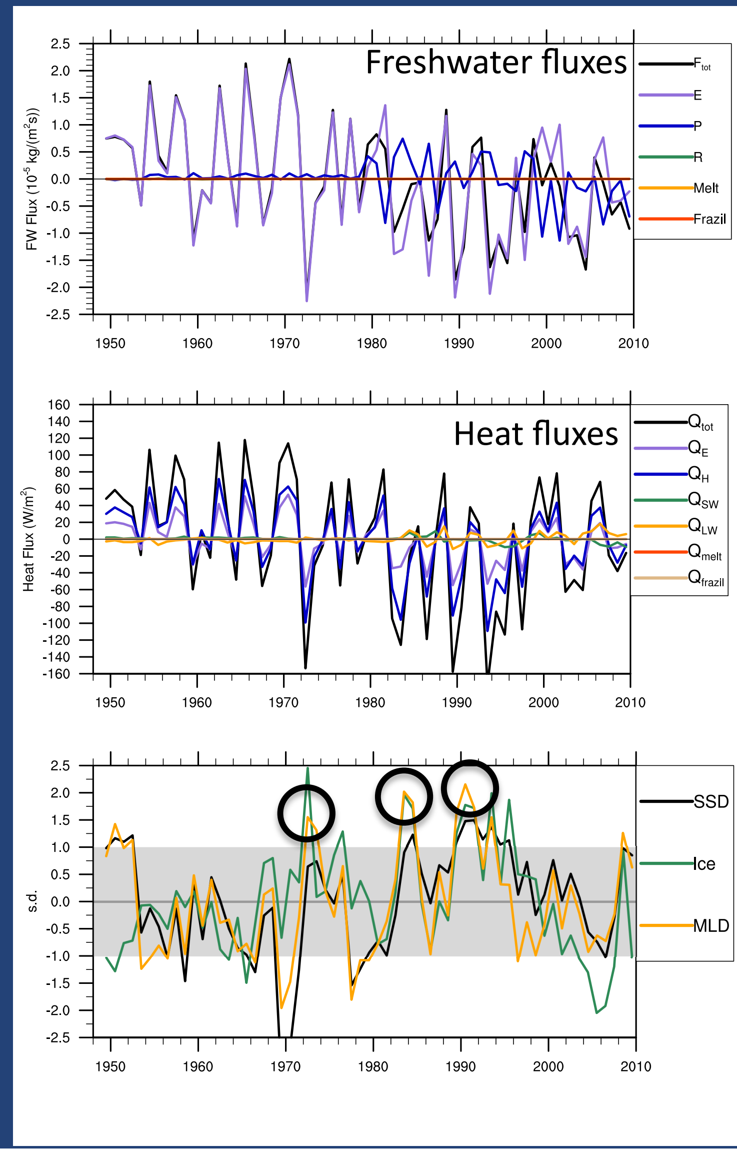

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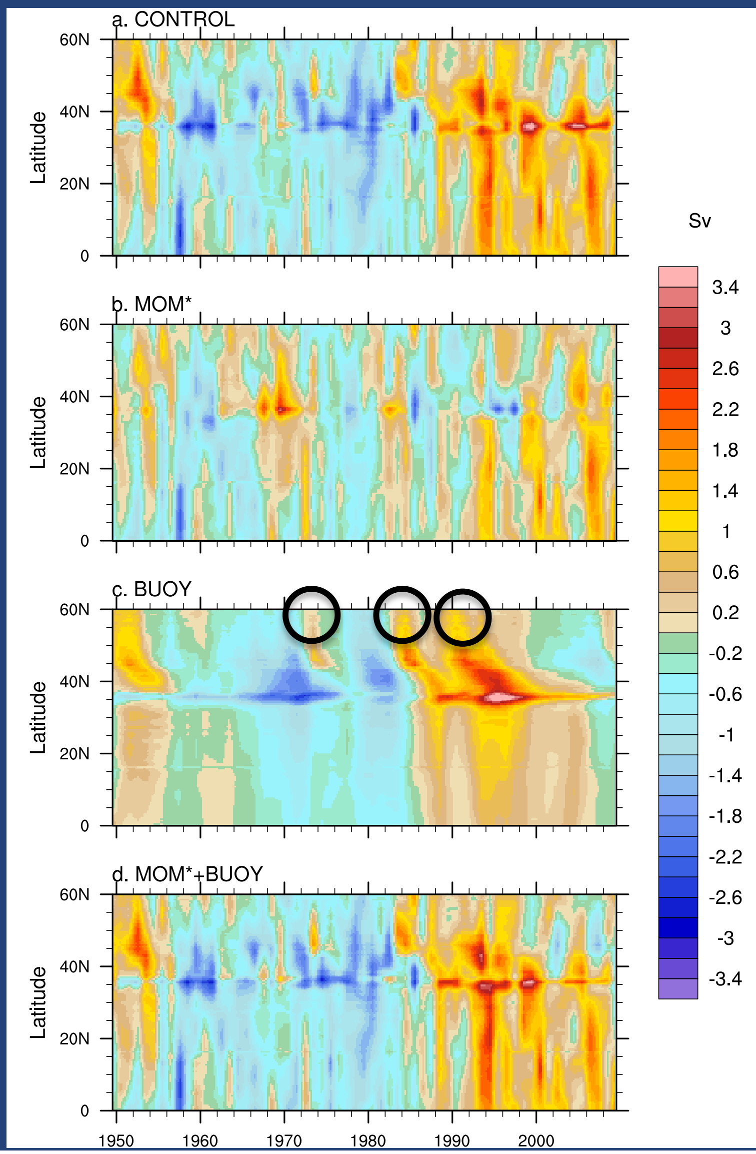
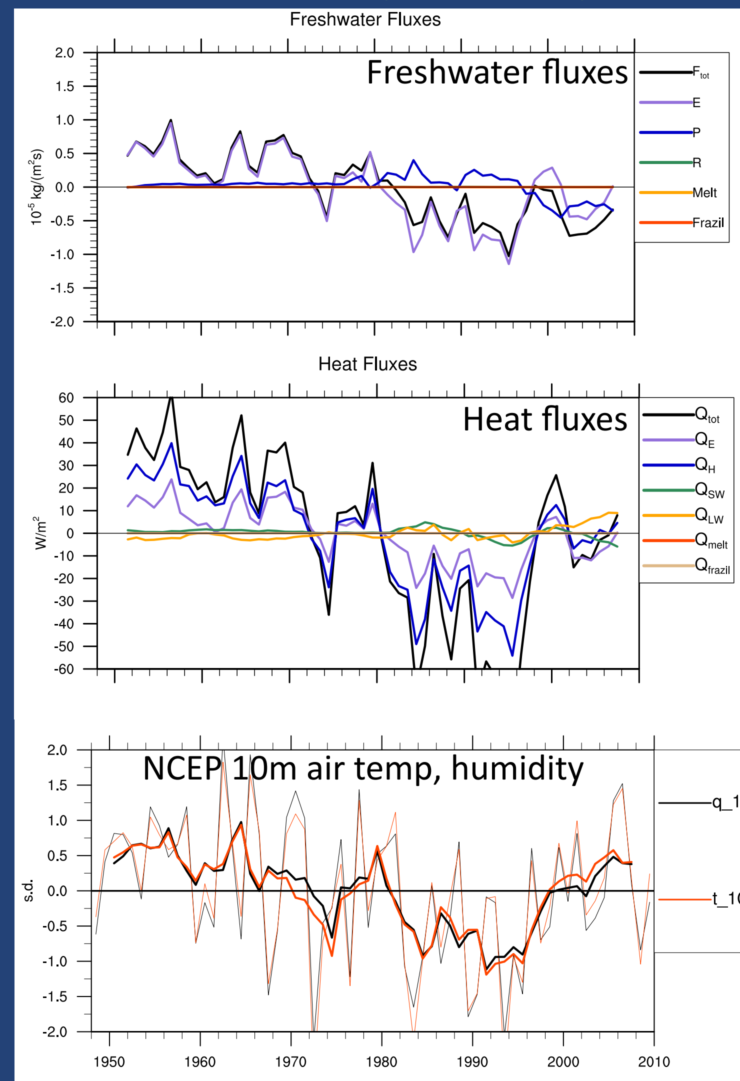
AMOC’



Lab Sea Box, open-ocean
March anomalies (CONTROL)



What is the relative role of Lab Sea buoyancy forcing?

- Latent+Sensible-forced variability, "BUOY(Q_E+Q_H)":

  $Q_{as} = Q_S + Q_L + Q_E(|\Delta\mathbf{u}|,\Delta q) + Q_H(|\Delta\mathbf{u}|,\Delta\theta)$

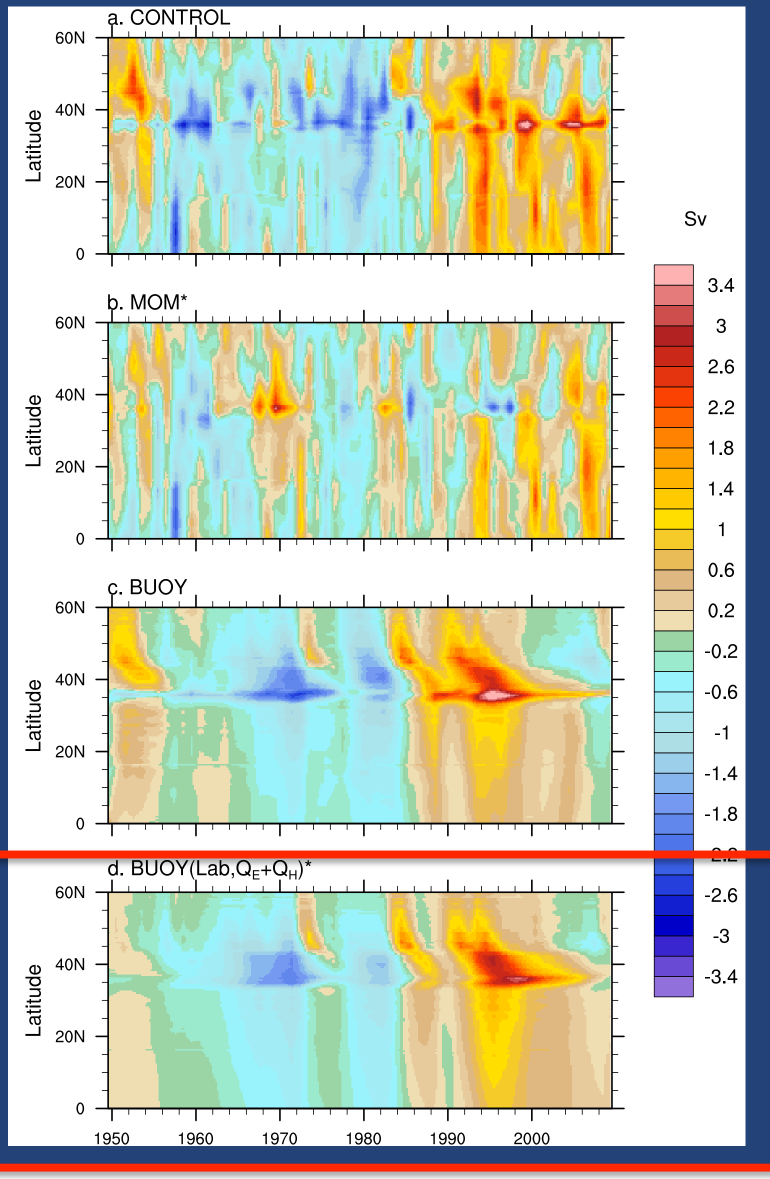
  $F_{as} = P + E(\Delta\mathbf{u},\Delta q) + R$

  $\tau_{as} = \tau(\Delta u)$

  (interannually-varying forcing in Lab Sea box only)

★ latent+sensible flux variability in Lab Sea explains almost all low-frequency AMOC variability.

AMOC'



Conclusions

- COREII-forced POP hindcast suggests that SPG heat content change of late 20th C was driven in large part by correlated decadal variations in strength of AMOC and subpolar gyre.

- These large-scale, slow circulation changes were buoyancy-driven, as was most of the near-surface flow variability throughout SPG (including NAC). Southern Ocean winds played a minimal role.

- Heat and freshwater fluxes contributed about equally to AMOC decadal variability between 1948-2007.

- Decadal AMOC variations are explained almost entirely by anomalous (latent+sensible) buoyancy loss in the Labrador Sea. Anomalous convection generates AMOC anomalies which propagate southward at latitudinally-dependent speeds.

- The low-frequency AMOC variability between 1948-2007 can ultimately be traced to slow variations in atmospheric surface temperature/humidity in Lab Sea. Improved AMOC prediction may result from improved representation of the processes which set surface temperature/humidity in this key region.