Optimal Atmospheric Excitation of AMOC on Decadal Time Scales in CCSM4

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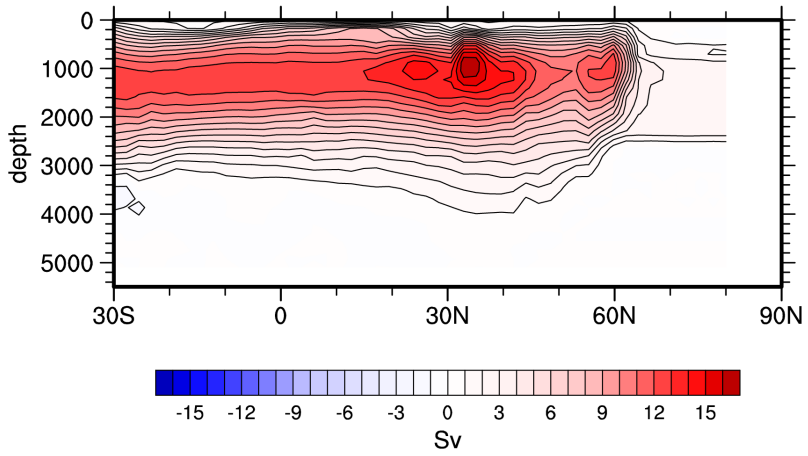
Andrey Gritsun, RAS



CCSM4 mean AMOC

T31, 3deg 8000 year control

(Simplified, Quasi-gaussian) Fluctuation Dissipation Theorem

(Leith, 1975; Deker&Haake, 1975; Risken, 1984)

Suppose have a discretized dynamical system with noise and a F-P eqn with unique solutions. Also assume gradients of the system PDF are well approximated by a Gaussian fit. Then the PDF-averaged response to weak forcing f is

$$r(t) = \int_{t_0}^{t} C(t-\tau)C^{-1}(0)f(\tau)\,d\tau$$

$$\text{for } C(\tau) = \text{lag}-\tau \text{ cov matrix}$$

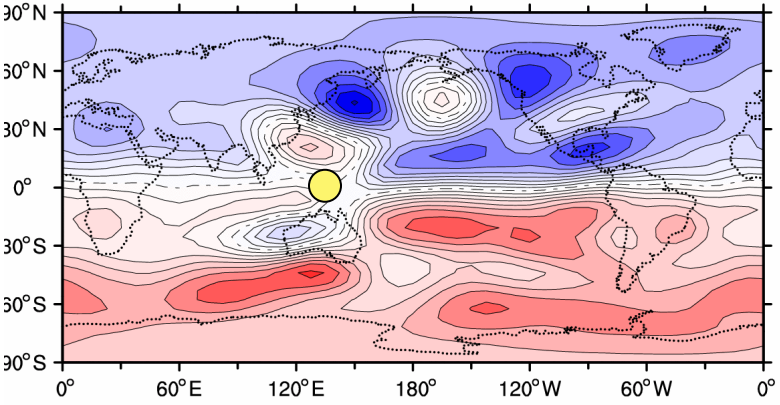
Sufficient data to find *C*

Atmospheric applications:

* *Gritsun, Branstator (2007)*
* *Gritsun, Branstator, Majda (2008)*
* *Liu et al. (2012)*

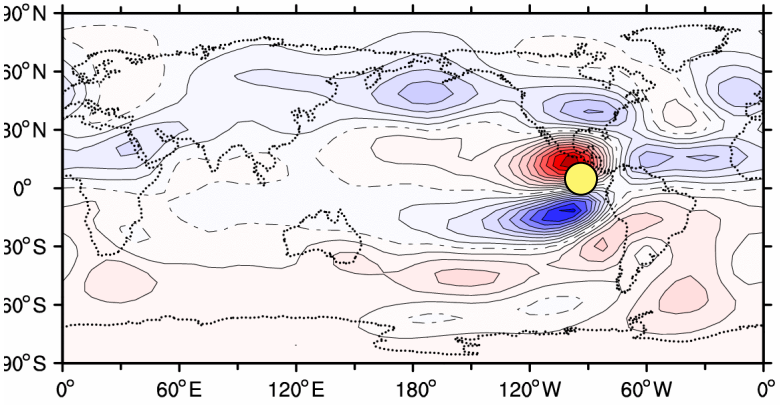
CCM0

CCM0 strong forcing
psi336
(135.00, 0.00) 2.5C/day



CONTOUR FROM -500 TO 400 BY 50 ($x10^4$)
FD vs CCM0 multifield cor= 0.81

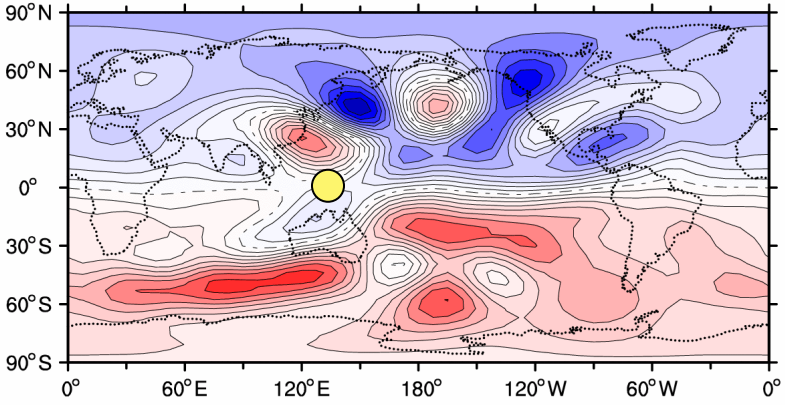
CCM0 strong forcing
psi336
(-90.00, 0.00) 2.5C/day



CONTOUR FROM -450 TO 500 BY 50 ($x10^4$)
FD vs CCM0 multifield cor= 0.77

FDT

FD
psi336
(135.00, 0.00) 2.5C/day



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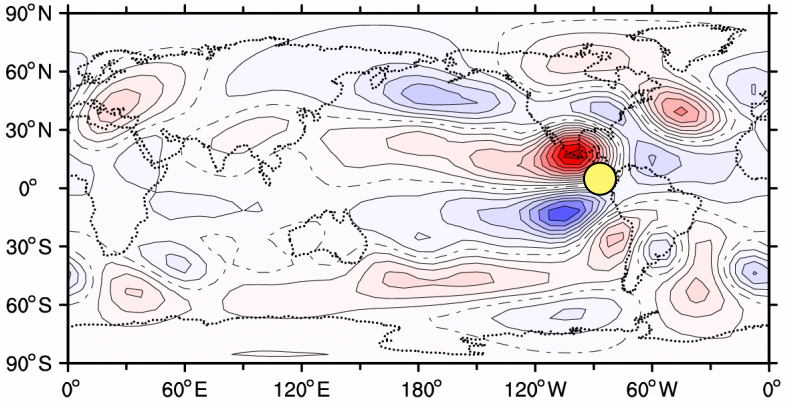


CONTOUR FROM -350 TO 500 BY 50 ($x10^4$)
FD vs CCM0 multifield cor= 0.77

Gritsun & Branstator (2007)

CCSM4

T31, 3deg, 26L 8000 year control

$$\begin{bmatrix} T(t) \\ S(t) \\ u(t) \\ v(t) \end{bmatrix} = r(t) = \mathbf{M}_t \bar{f} = \mathbf{M}_t \begin{bmatrix} \dot{T} \\ \dot{S} \\ \dot{u} \\ \dot{v} \end{bmatrix}$$

state of multivariate 3D fields
is represented by 675 EOFs

CCSM4

T31, 3deg, 26L 8000 year control

$$\begin{bmatrix} T(t) \\ S(t) \\ u(t) \\ v(t) \end{bmatrix} = r(t) = \mathbf{M}_t \bar{f} = \mathbf{M}_t \begin{bmatrix} \dot{T} \\ \dot{S} \\ \dot{u} \\ \dot{v} \end{bmatrix}$$

t = 5 yrs

singular value decomposition

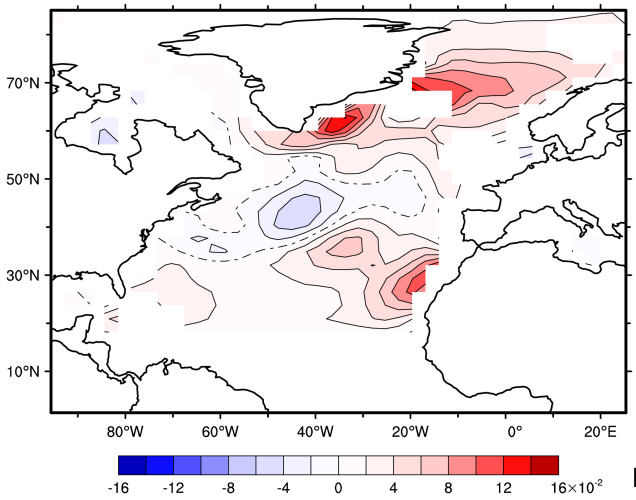
Optimal N Atlantic Salinity Forcing of AMOC

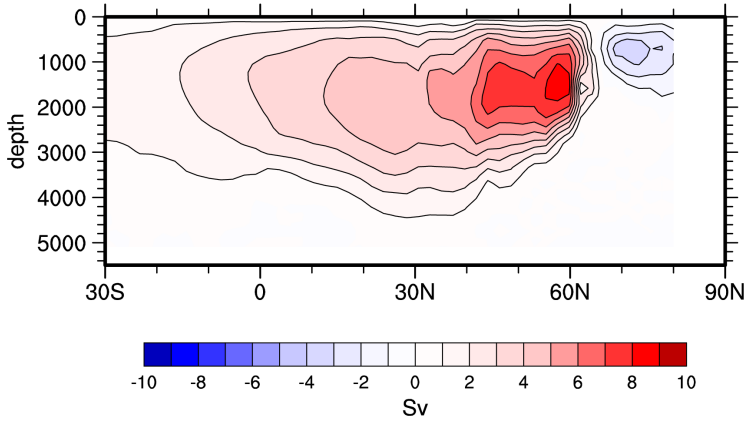
5 year forcing; year 5 response

force 0-100m

Singular Value Decomposition

SV1 35x

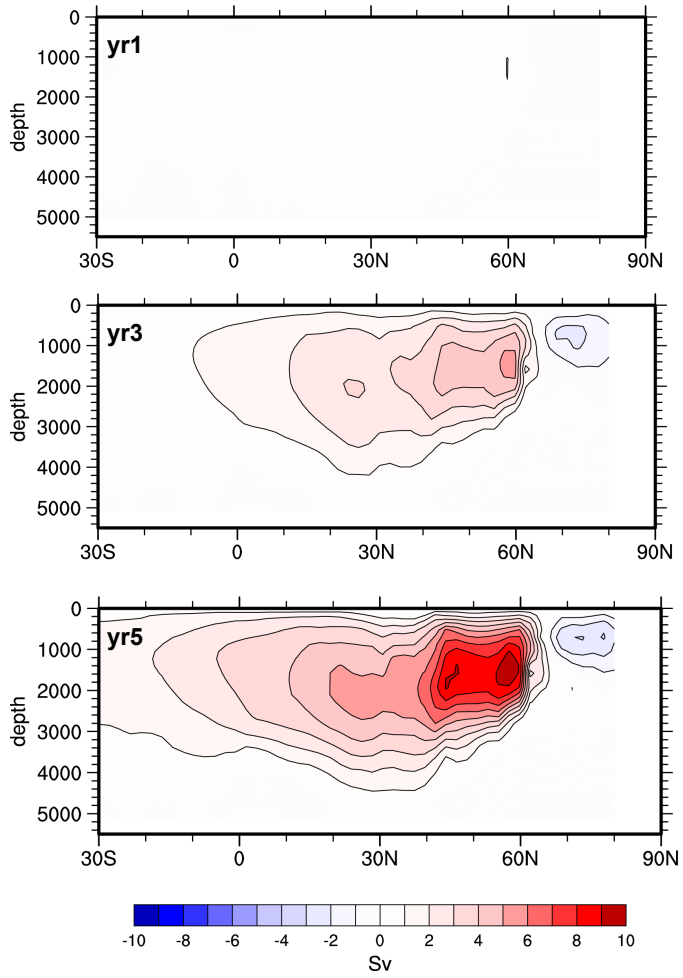




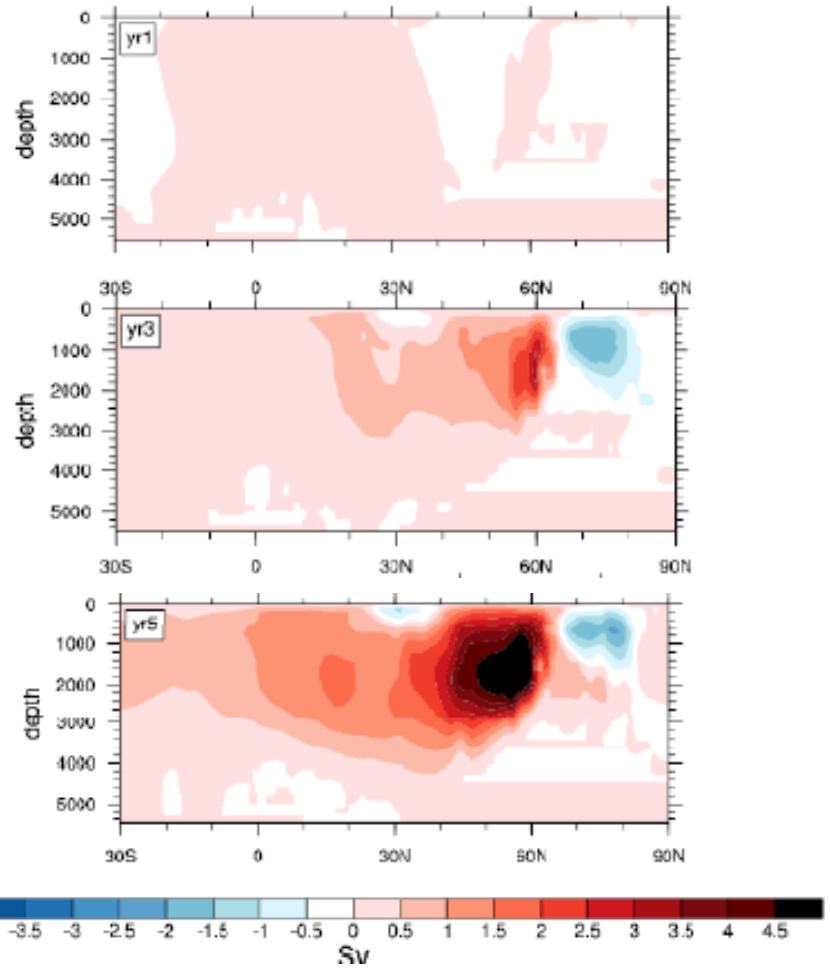
Optimal & CCSM4 Response of AMOC to Salinity Forcing

force 0-100m

FDT response
SV1



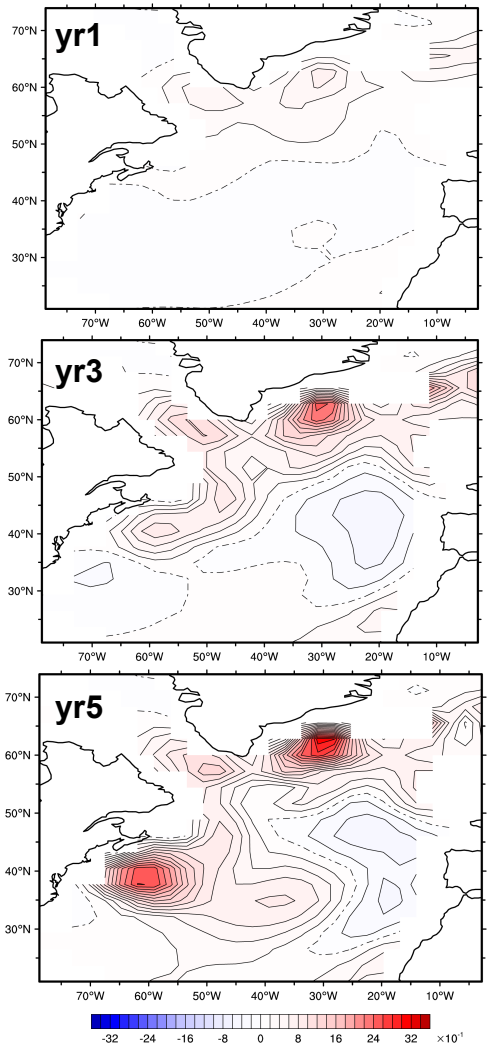
difference of two
20 member CCSM4 ensembles



FDT & CCSM4 SST Response to Optimal Salinity Forcing of AMOC

force 0-100m

FDT response



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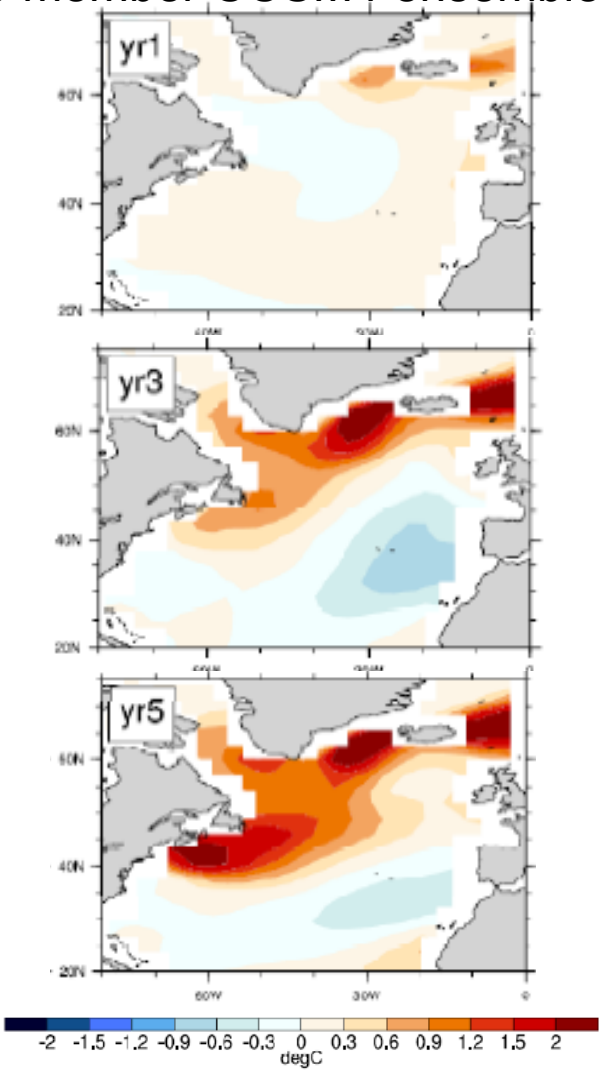


Remember

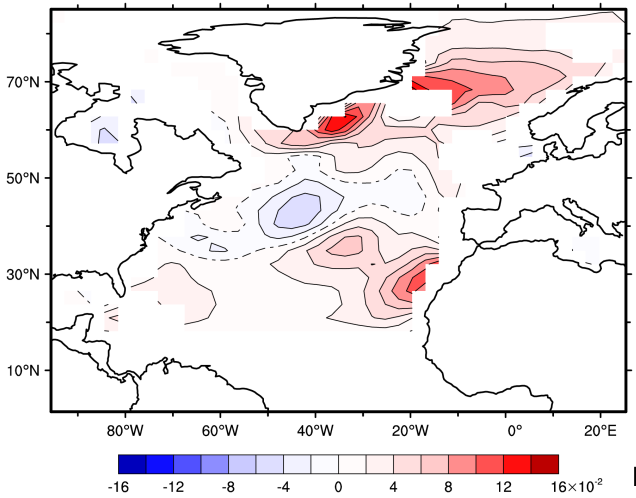
- FDT can be used to systematically study ocean response
- The leading patterns of AMOC variability do not depend on the existence of special atmospheric structures
- The effect of a given atmospheric pattern on AMOC depends strongly on details of its structure and of ocean dynamics
- The surface fields associated with AMOC anomalies depend on the atmospheric forcing

Optimal Salinity Forcing of AMOC

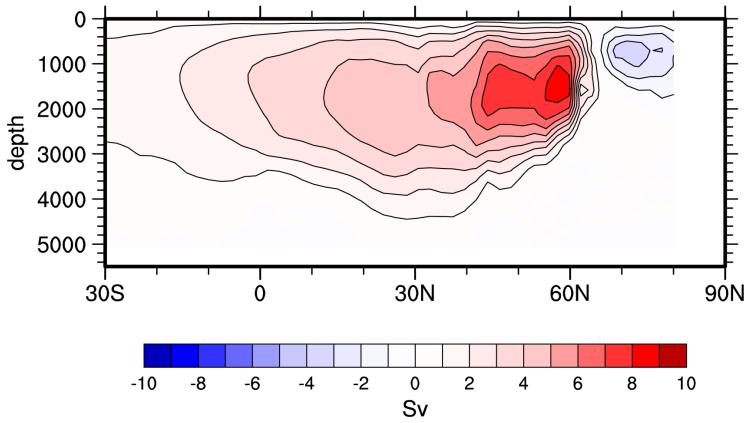
5 year forcing; year 5 response

force 0-100m

SV1 35x 55%



PSU/mon



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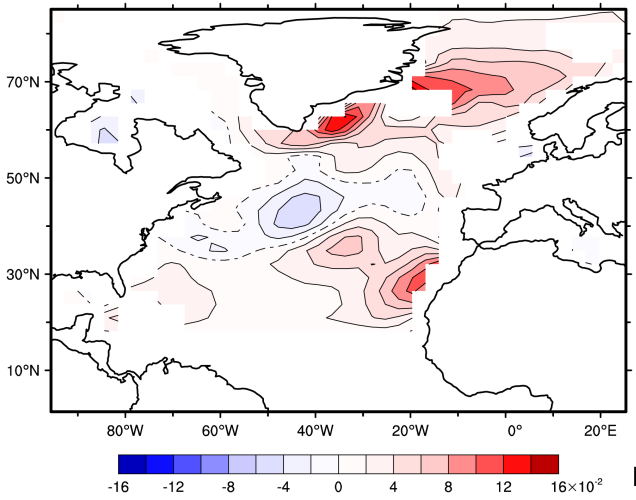
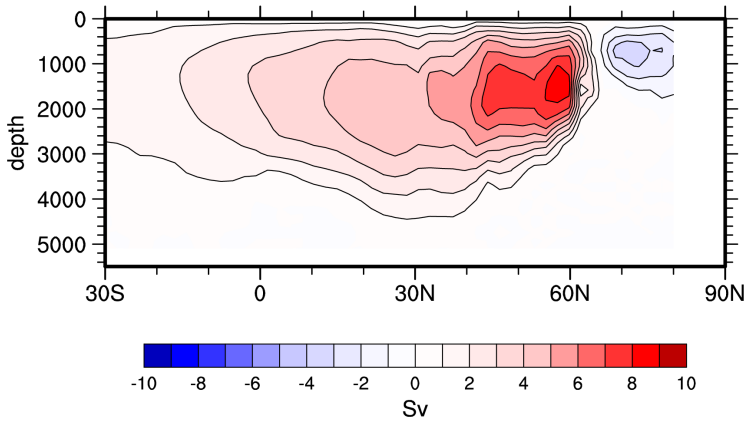
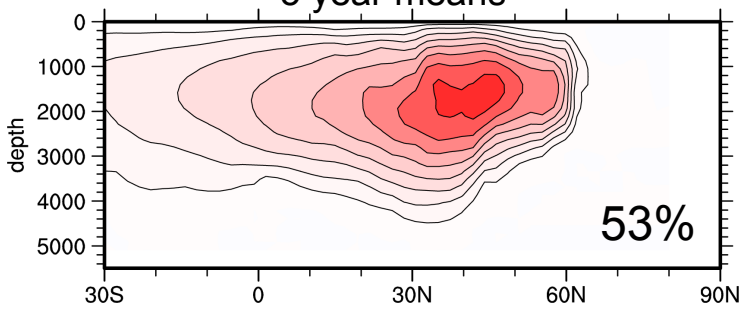


PSU/mon



CCSM4 EOF1

5 year means

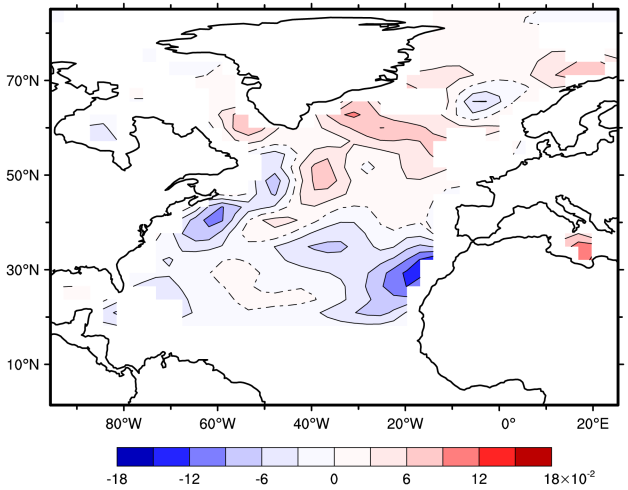


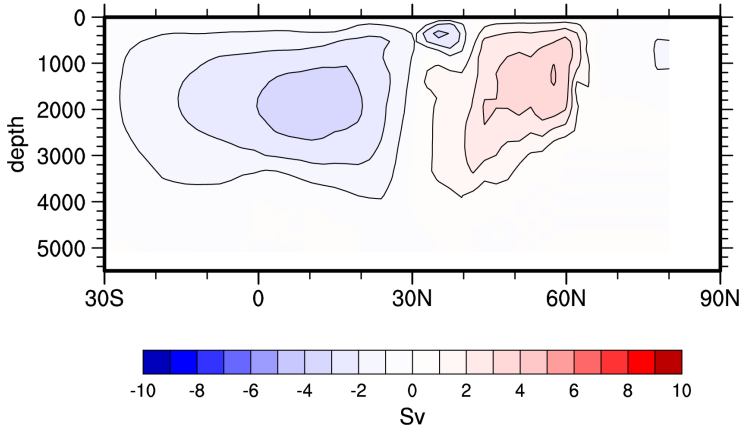
Optimal Salinity Forcing of AMOC

5 year forcing; year 5 response

force 0-100m

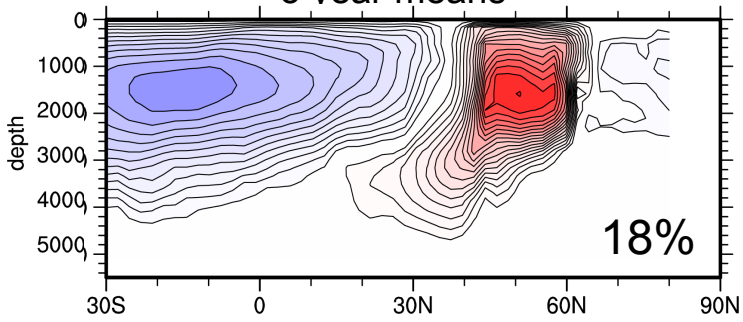
SV2 17x 14%





CCSM4 EOF2

5 year means

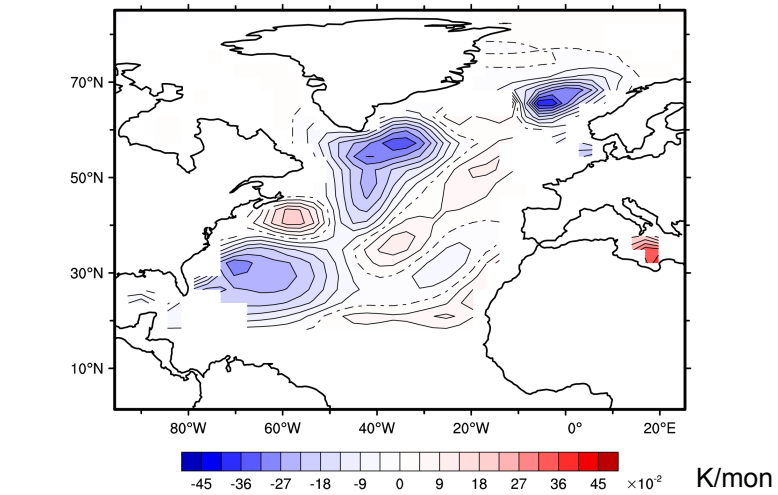


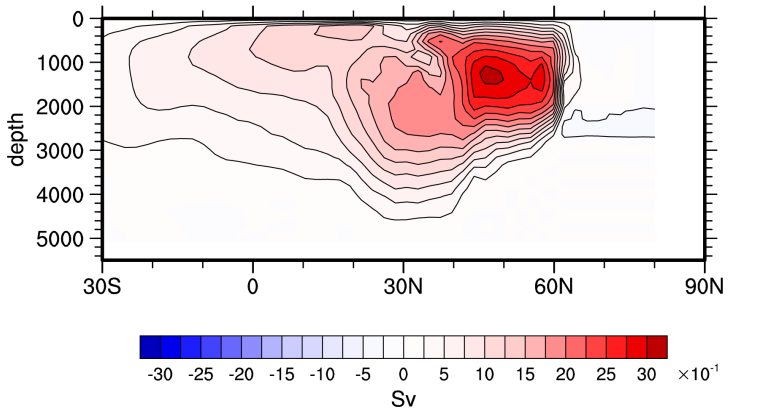
Optimal North Atlantic Temperature Forcing of AMOC

5 year forcing; year 5 response

force 0-100m

SV1 34x



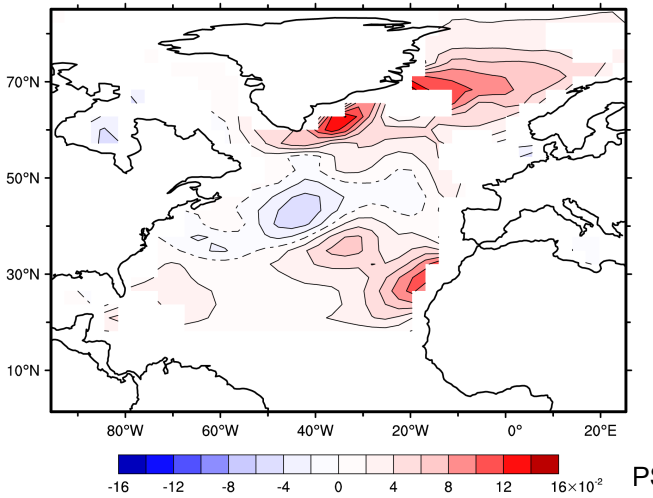


Optimal Salinity & Temperature Forcing of AMOC

5 year forcing; year 5 response

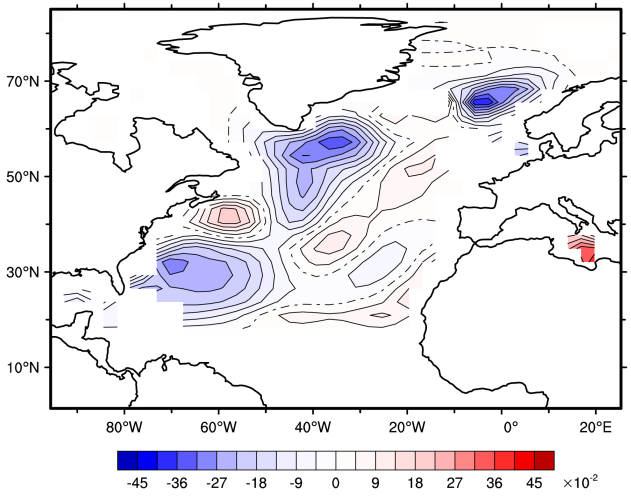
force 0-100m

SV1 35x



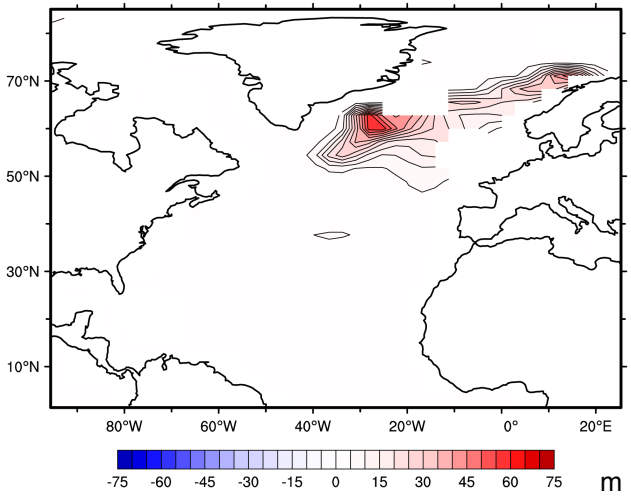
PSU/mon

SV1 34x



K/mon

Std Dev Boundary Layer Depth

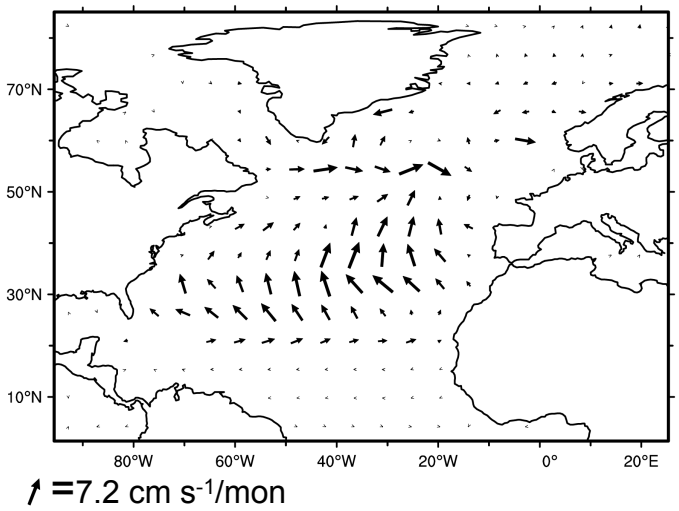


m

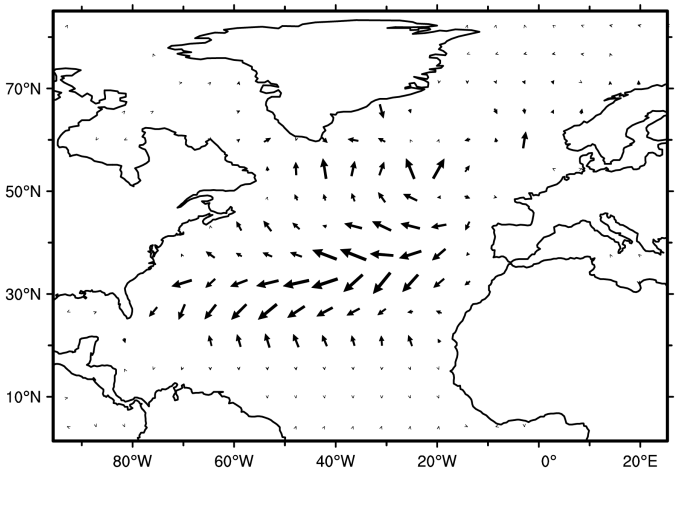
Optimal Excitation of AMOC by Currents in the North Atlantic

SV1 35x

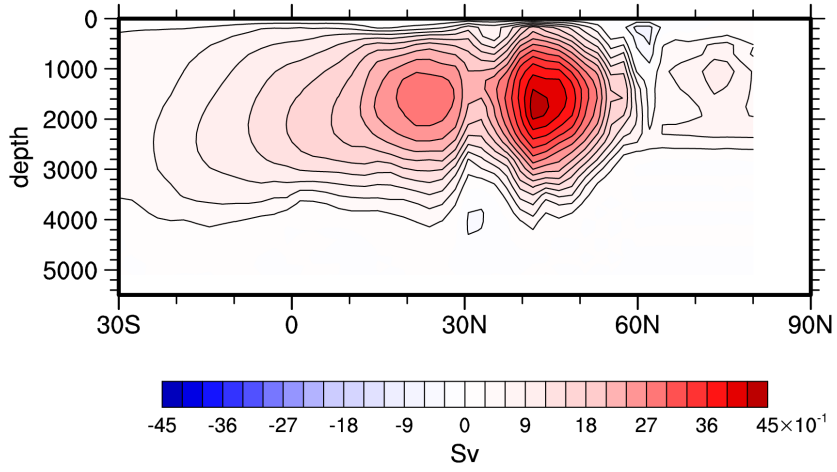
forcing of 0-100m currents



wind stress



↗ =7.2 cm s^{-1}/mon



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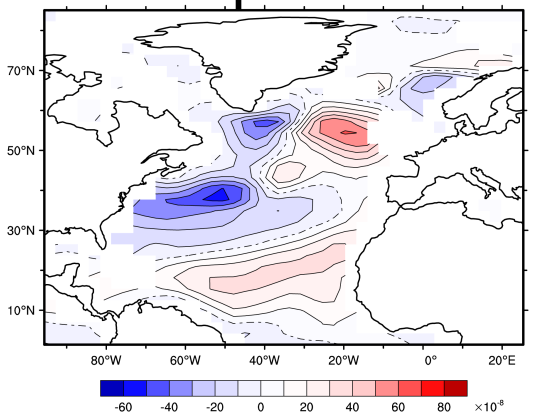
Comparing NAO Fluxes & Optimal Forcing

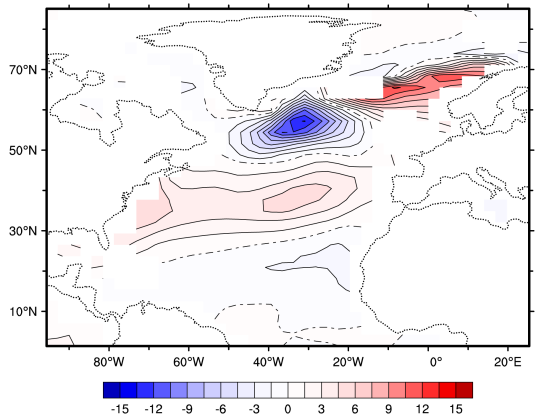
5 year forcing; year 5 response

NAO

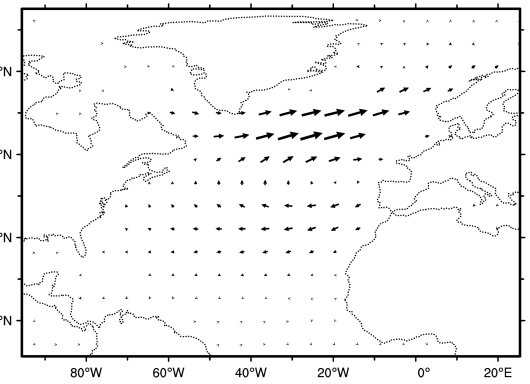
Evaporation



Surface heat flux

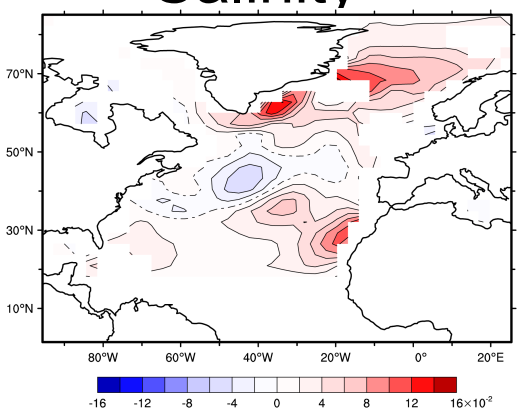


Wind stress

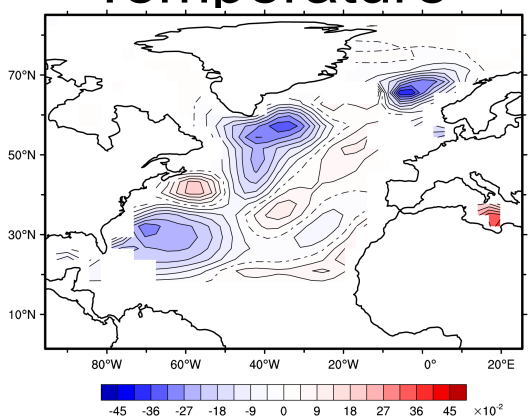


Optimal forcing
force 0-100m

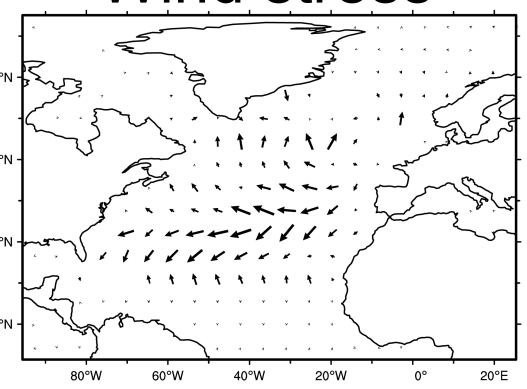
Salinity



Temperature



Wind stress



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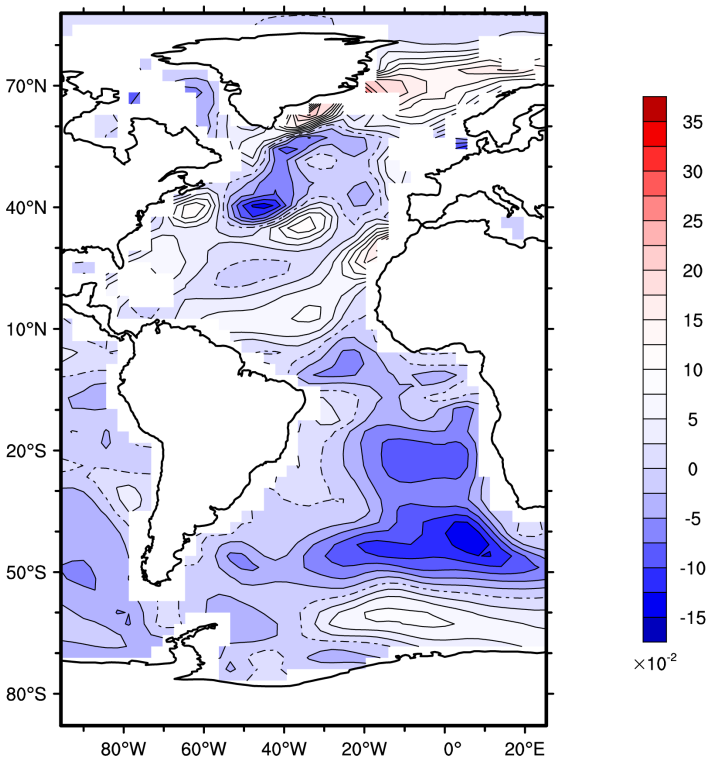
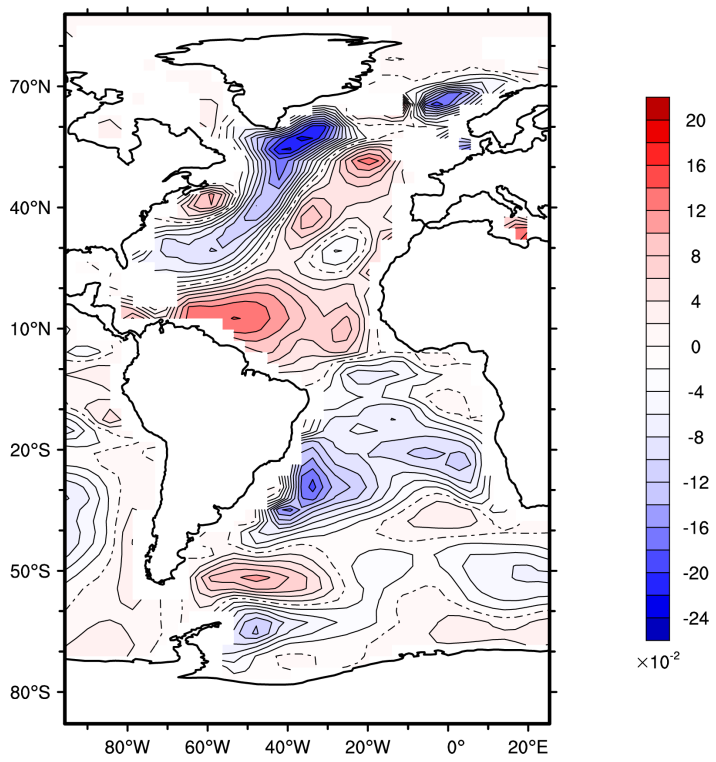
Year 5 Response of AMOC PC1 to Point Sources

force 0-100m

forcing = 0.1PSU/mon



forcing = 1K/mon

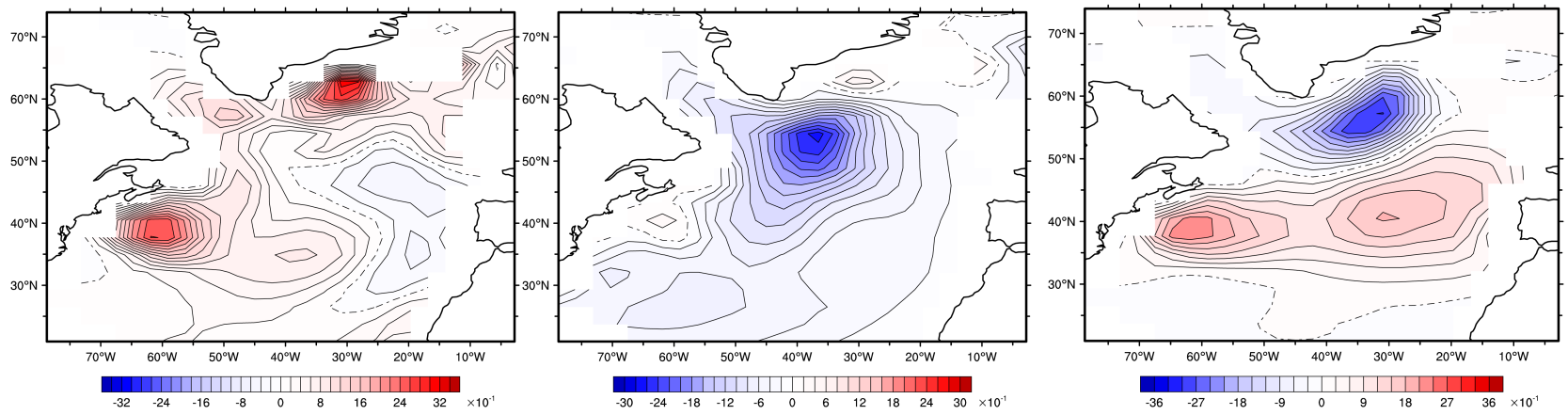


Year 5 SST Response to Optimal AMOC Excitation by SHF, Salt & Wind stress

force 0-100m

force the salinity | force by heat | force the currents

SST response



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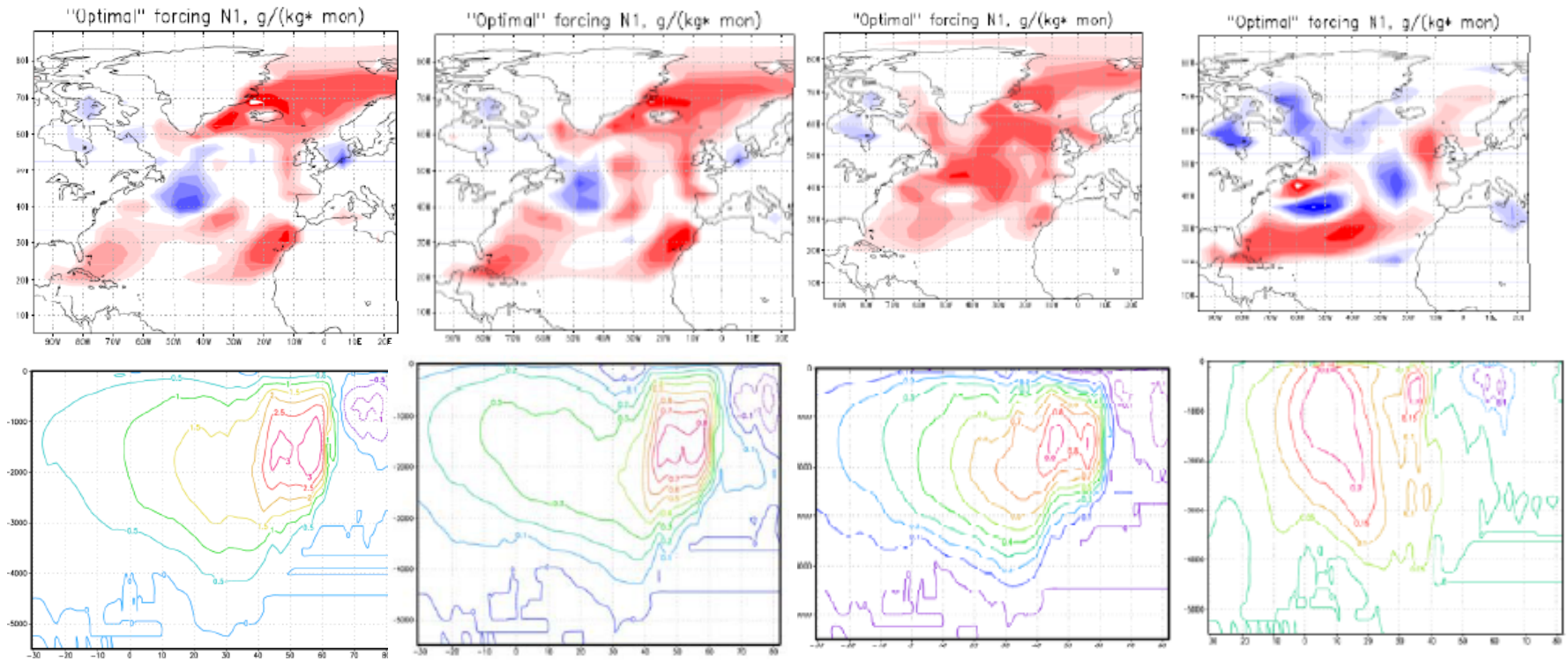
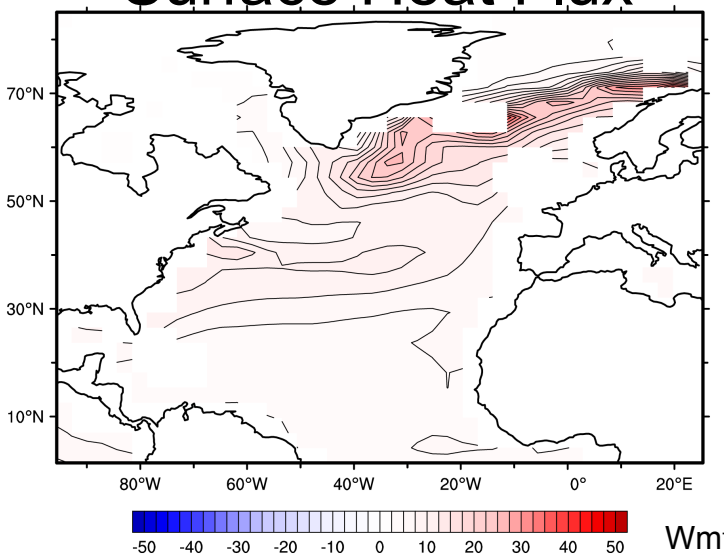


5y response to 5y forcing 5y response to 1y forcing 10y response to 1y forcing 1y response to 1y forcing

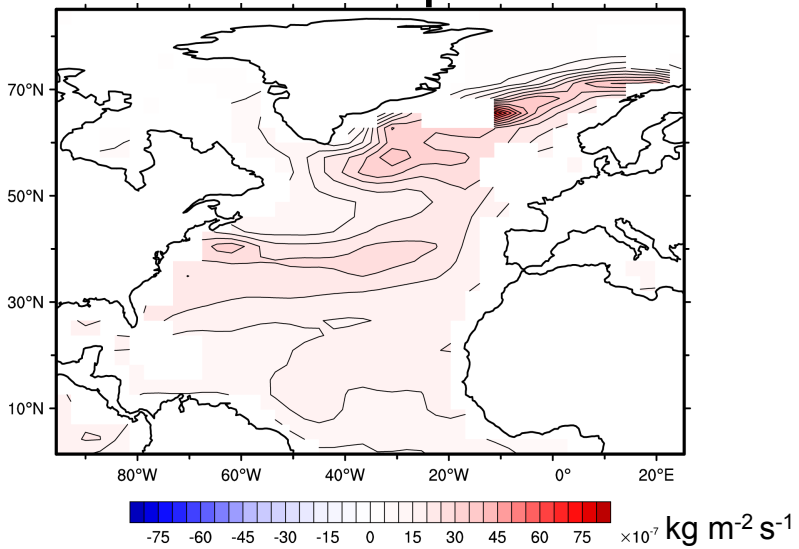
note SV2 for this case is like SV1 in other cases

Std dev of Annual Mean Surface Forcing Fields

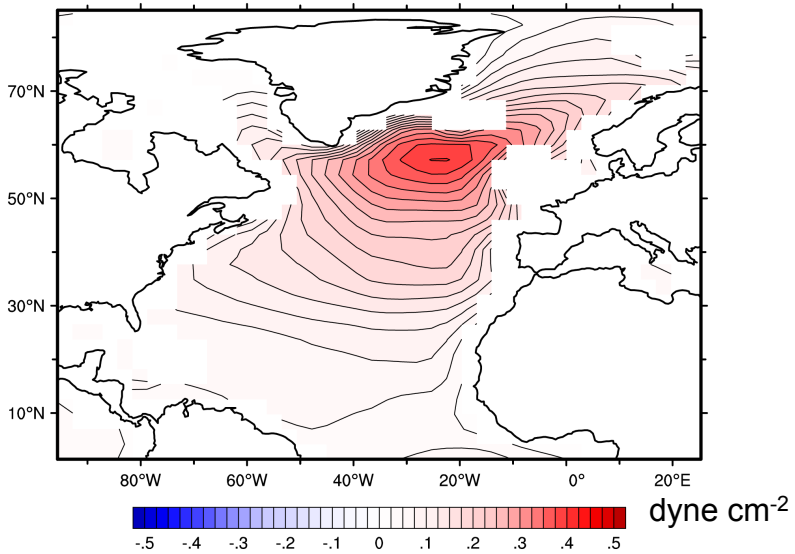
Surface Heat Flux



Surface Evaporation

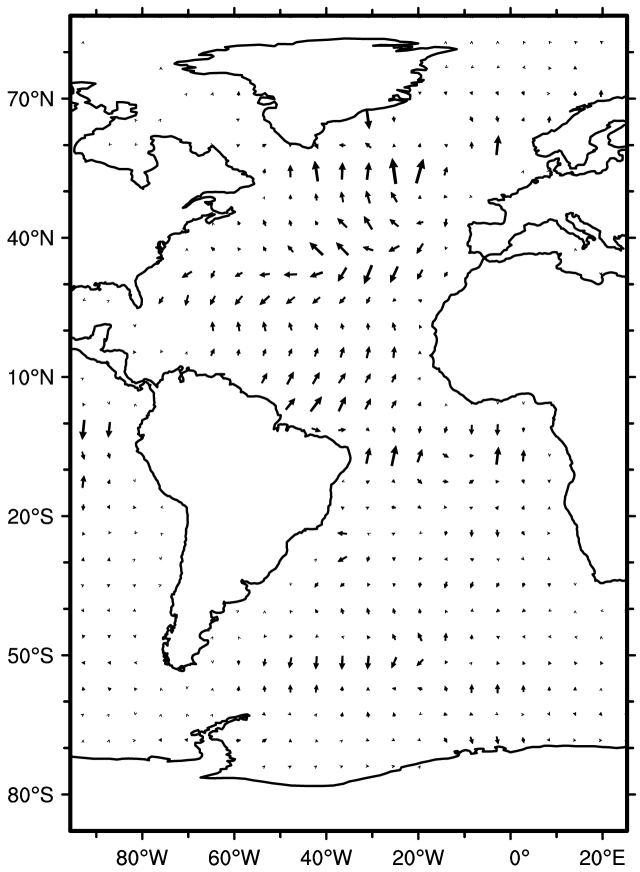


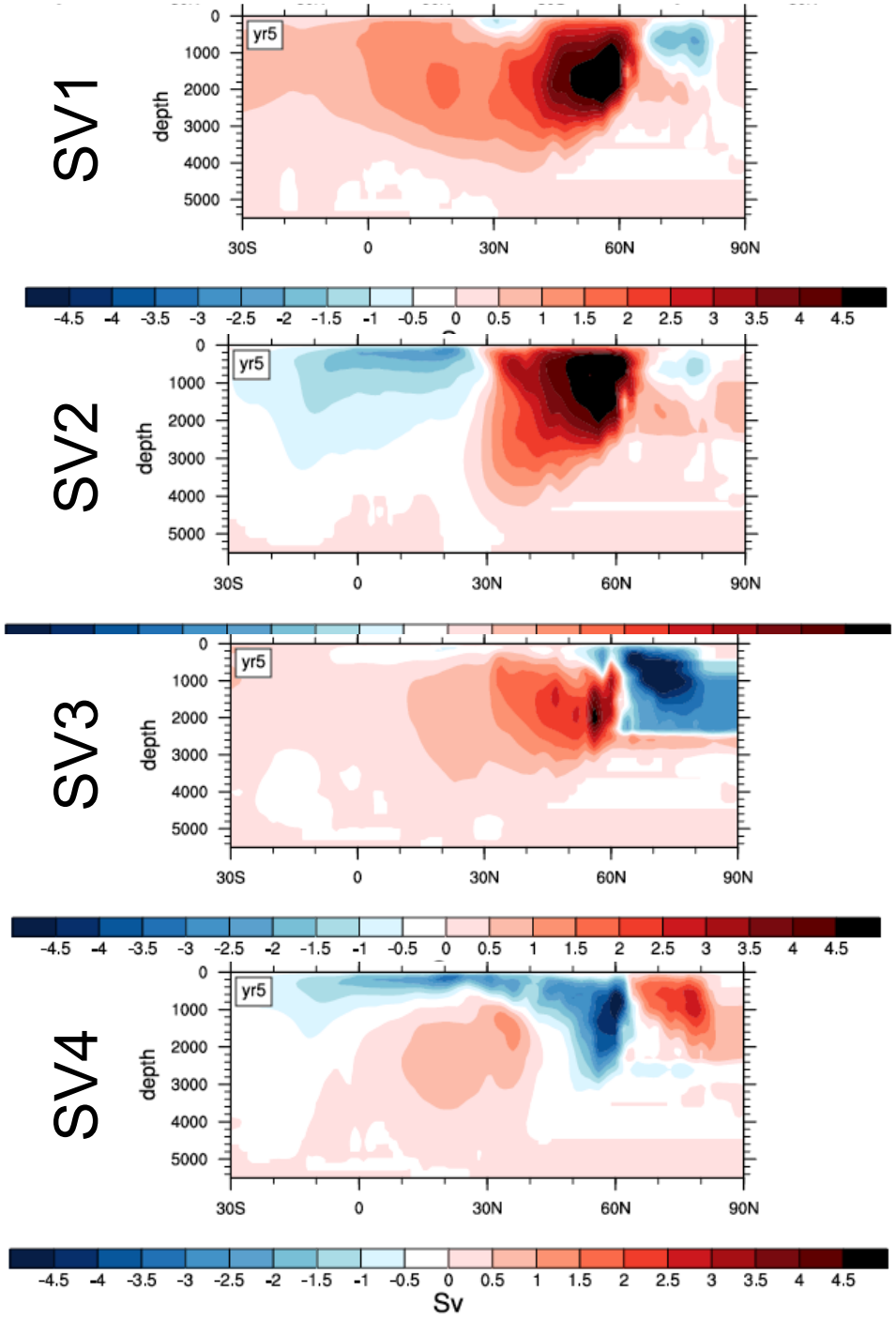
Wind Stress



Green's function of AMOC EOF1 for wind stress

force 0-100m





CCSM4 response to SV forcing