Surface Estimates of the Atlantic Overturning in Density Space in an Eddy-Permitting Ocean Model

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Context

Marsh (2000) described (but did not test) a method that might allow 'the meridional stream function to be largely inferred from surface fluxes alone".

We've examined this possibility using output from:

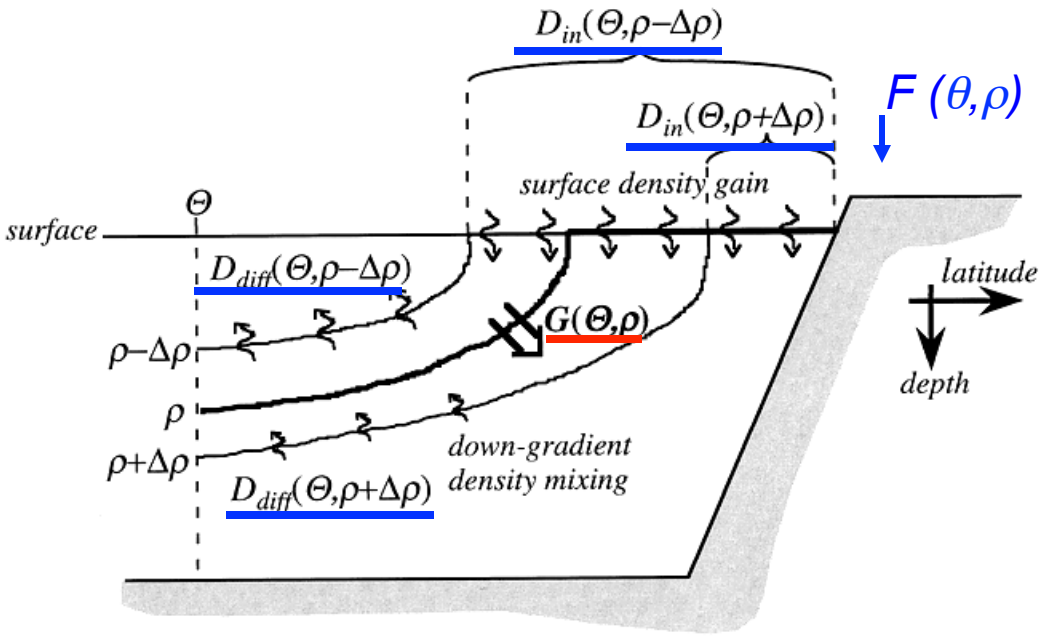
1) Three IPCC coupled climate models. (100-400 years of GFDL2.1, BCM, HadCM3) (Grist et al. 2009; Josey et al. 2009).

2) Eddy-permitting (1/4 º) ocean only model (78 years of ORCA-025, 'NEMO') (Grist et al., 2012).

Method

Marsh (2000), Walin (1982)

Net diapycnal volume flux, G (Θ,ρ) and Diapycnal density fluxes D (Θ,ρ) in an idealized North Atlantic.



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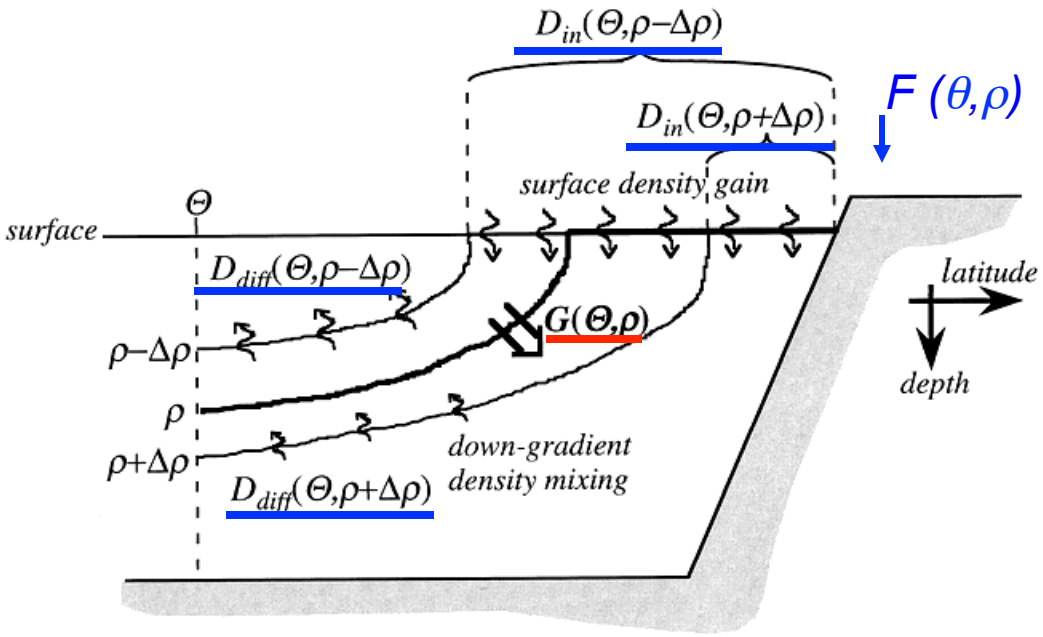

$$G(\Theta,\rho) = F(\Theta,\rho) - \frac{\partial D_{diff}(\Theta,\rho)}{\partial\rho} + C(\Theta,\rho)$$

$$F(\Theta,\rho) = \frac{\partial D_{in}(\Theta,\rho)}{\partial\rho}$$

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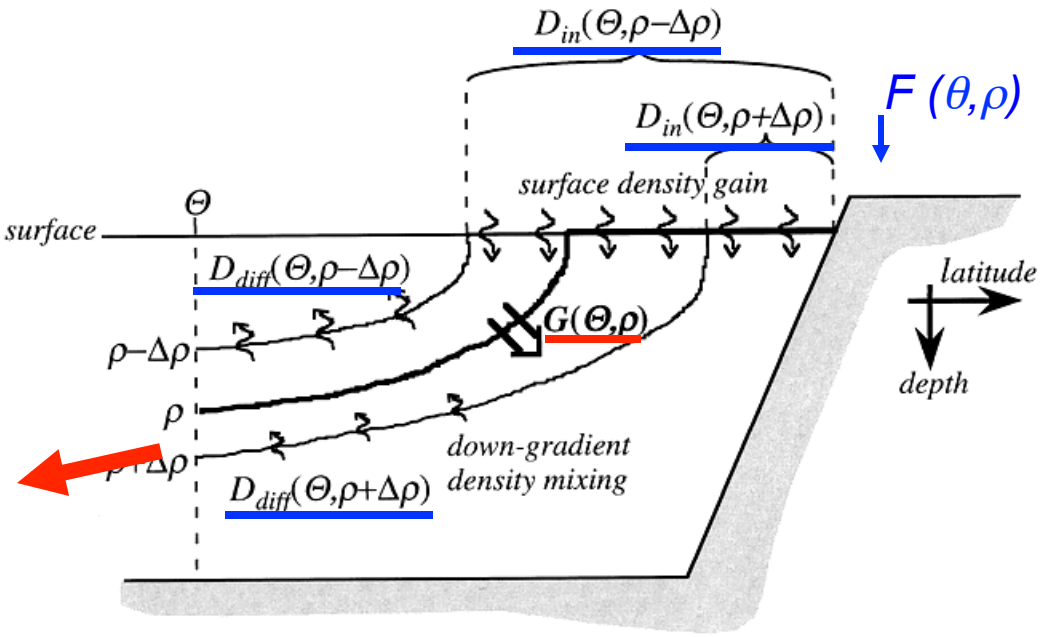

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Assuming incompressibility and steady state of water masses, the meridional streamfunction then:

$\psi\ (\Theta,\rho) = G\ (\Theta,\rho)$

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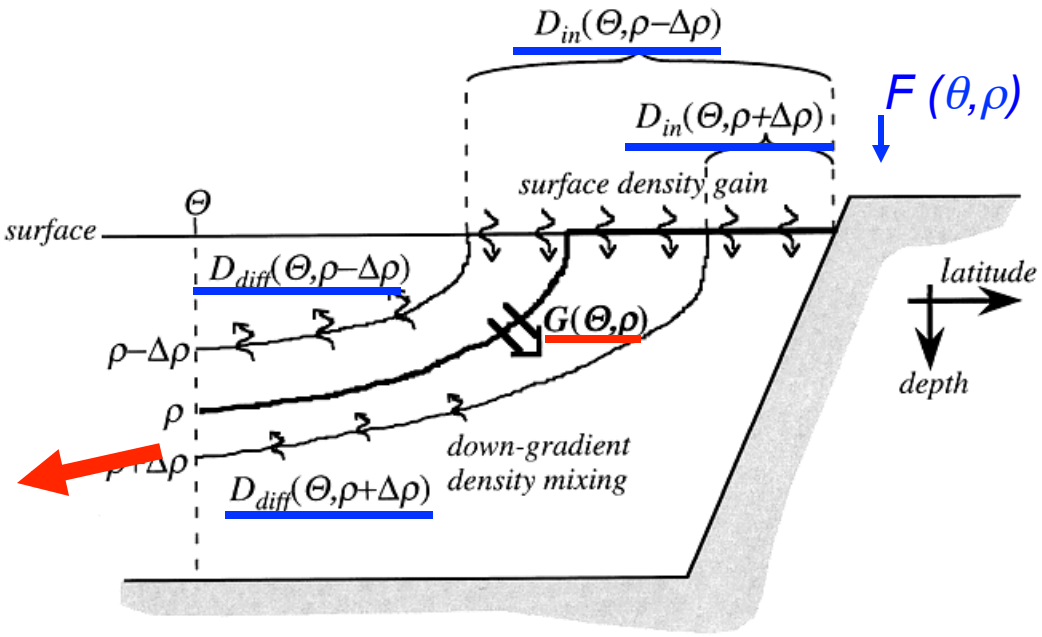

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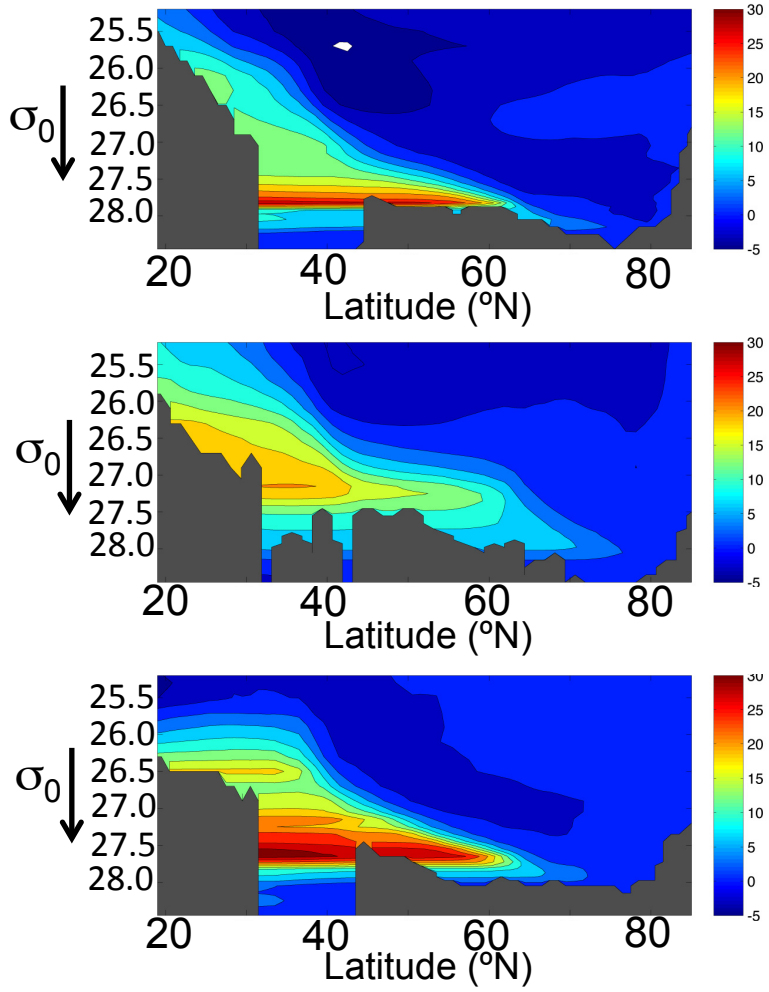
‘Surface-Forced’ Streamfunction (Sv)

GFDL2.1

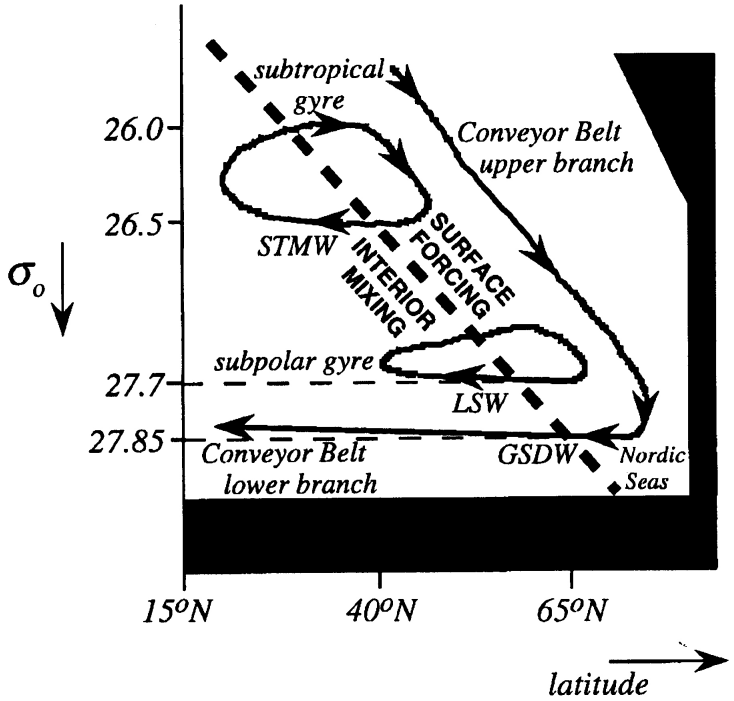
HadCM3

BCM2.0



Grist et al. (2009)

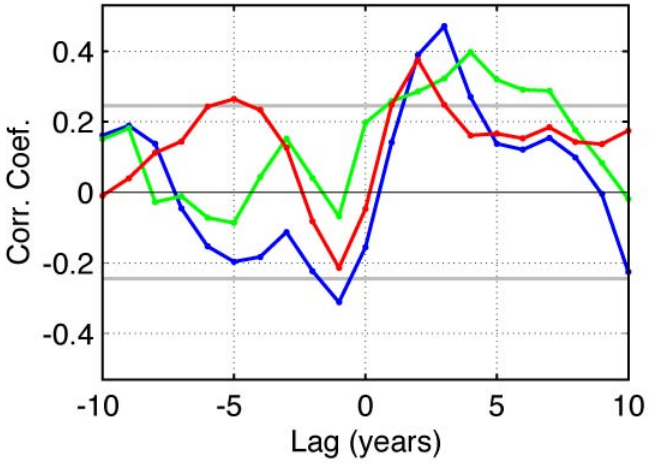
$$G(\Theta,\rho) \approx F(\Theta,\rho) = \frac{\partial D_{in}(\Theta,\rho)}{\partial \rho}$$



Marsh (2000)

Correlations Maximum 'Surface-Forced' (SFI) & Overturning Stream functions

Correlation of AMOC (48N) vs Surface Forced Index (SFI)



GFDL2.1

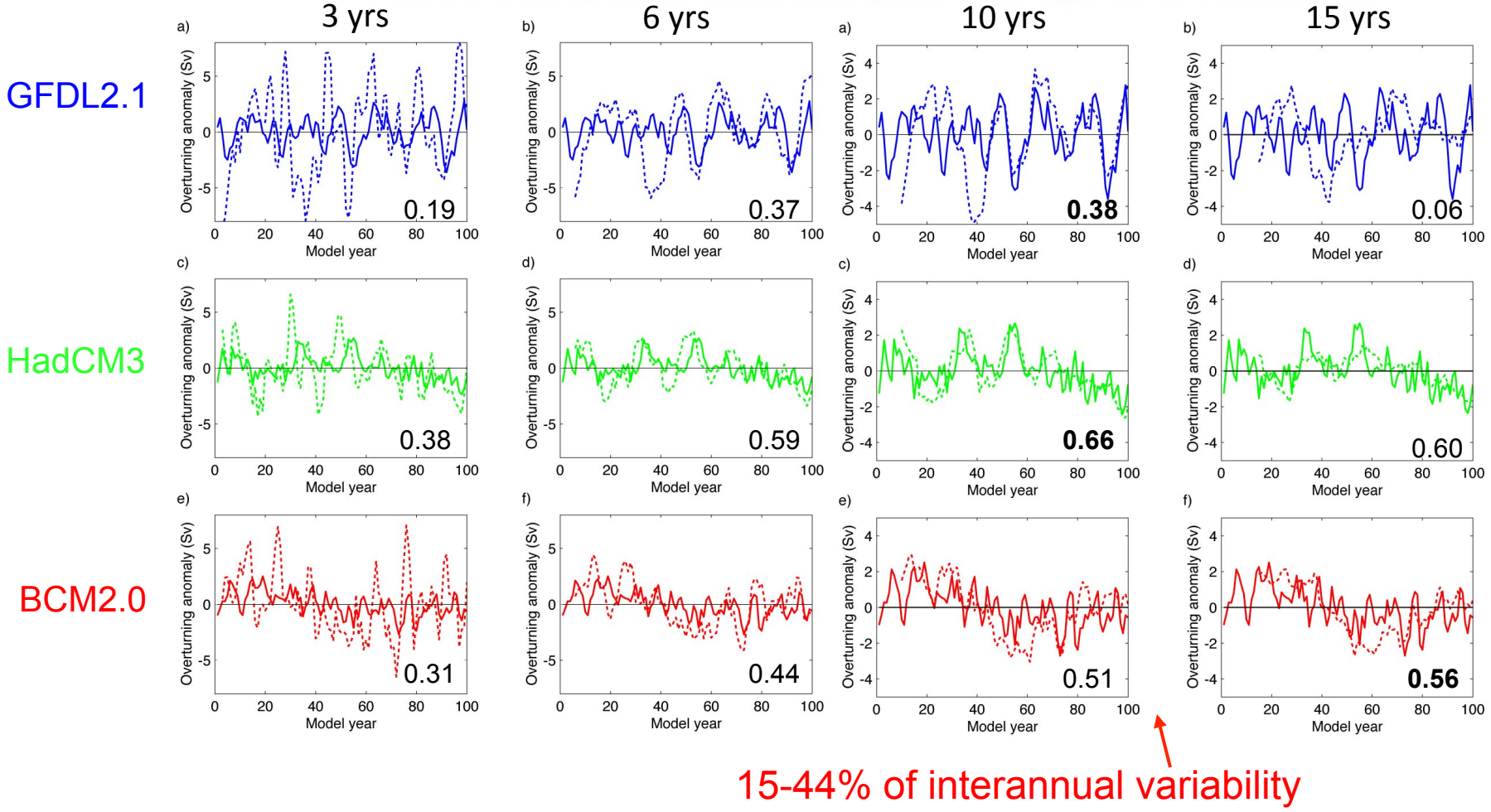
HadCM3

BCM2.0

- Year on year SFI ≠ AMOC
- But significant correlation when SFI leads by a few years in all models.
- Averaging the SFI over preceding years may give a useful estimate of AMOC variability.

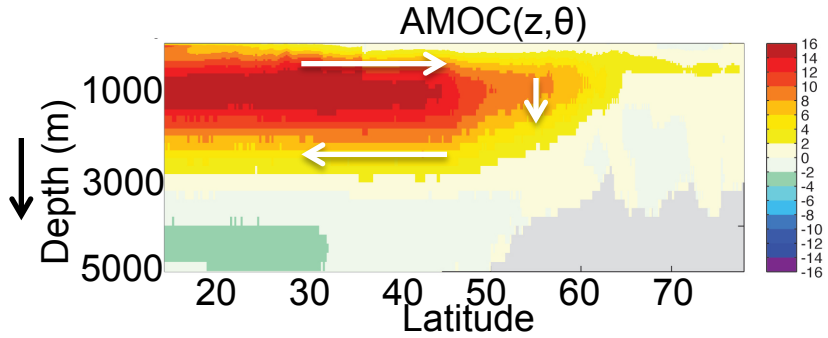
SFI & AMOC in the Coupled Models

AMOC (48N) solid lines and past average of SFI (dashed)



AMOC in ¼° NEMO Model

We compared our estimate to AMOC (z,θ)



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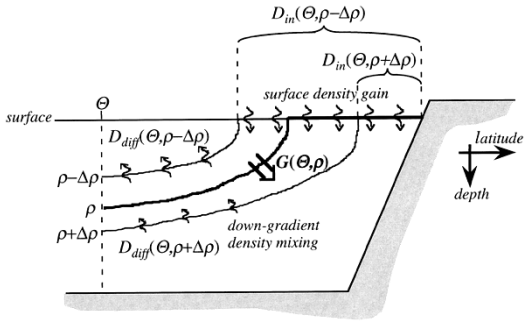
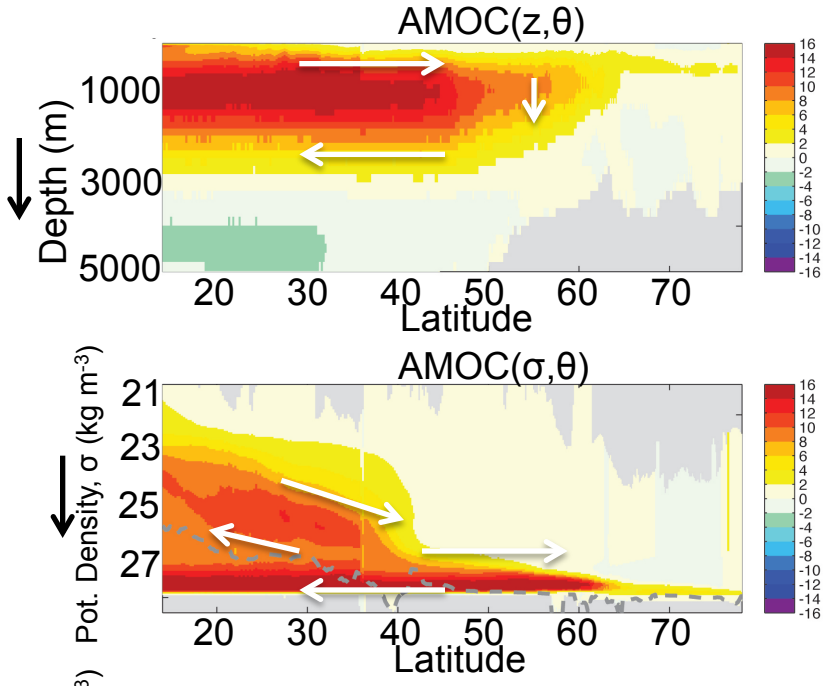


The theory suggests compare
With AMOC (σ or ρ,θ).
(Density as a vertical coordinate)



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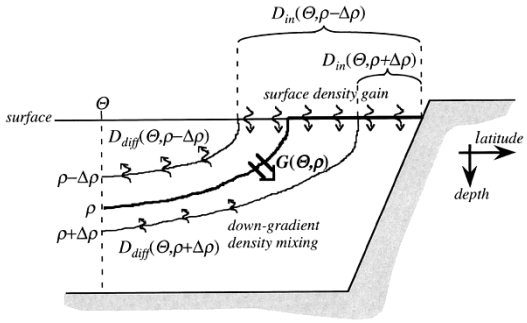

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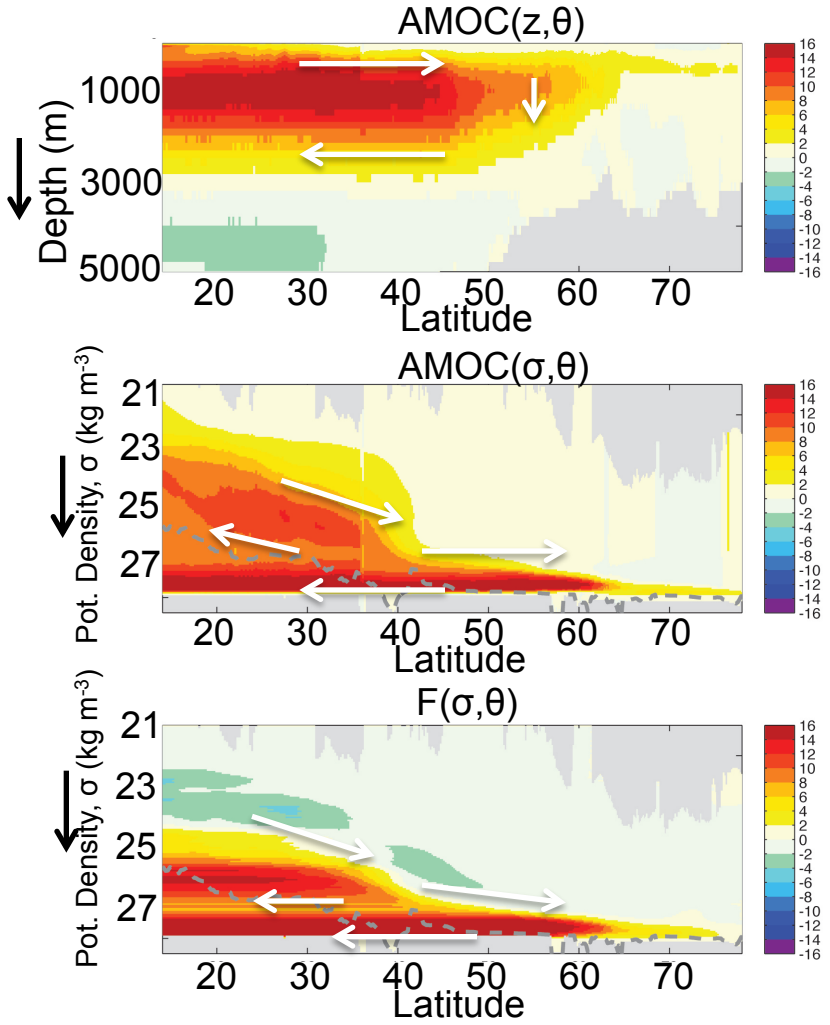
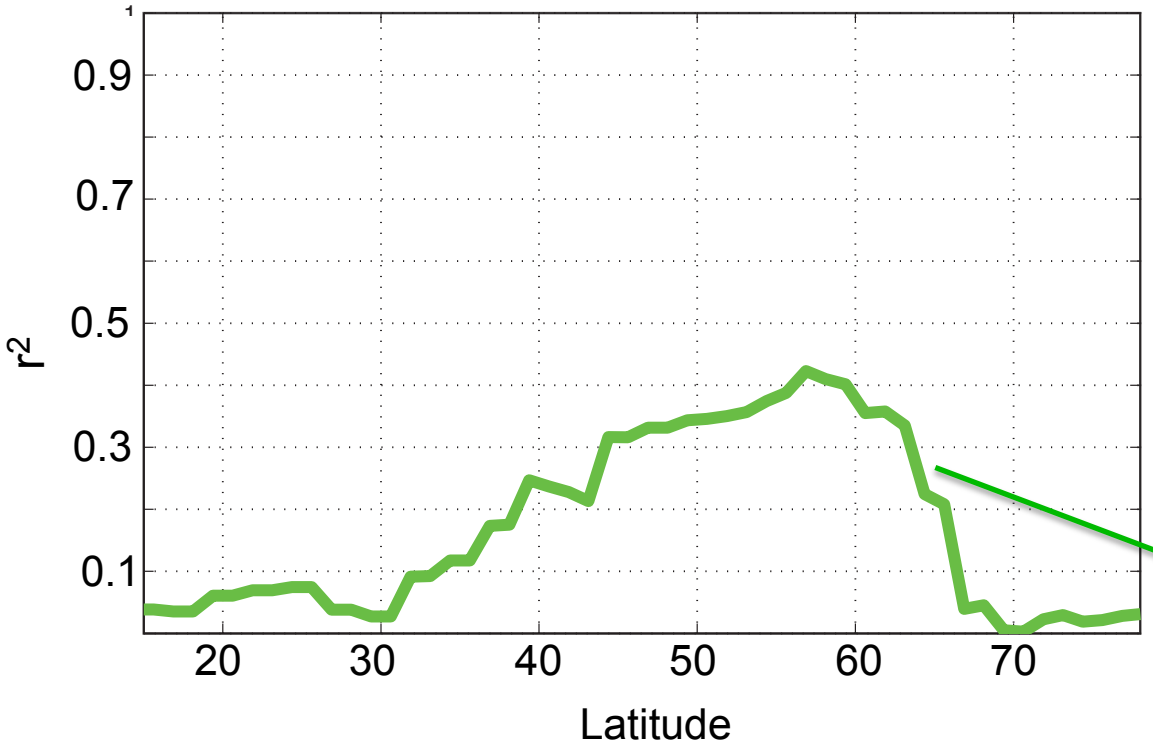
Our surface forced streamfunction shows similarities to AMOC (σ,θ).



Fraction AMOC explained By Surface Fluxes



AMOC (Z)
HadCM3
Climate Model
Josey et al. 2009

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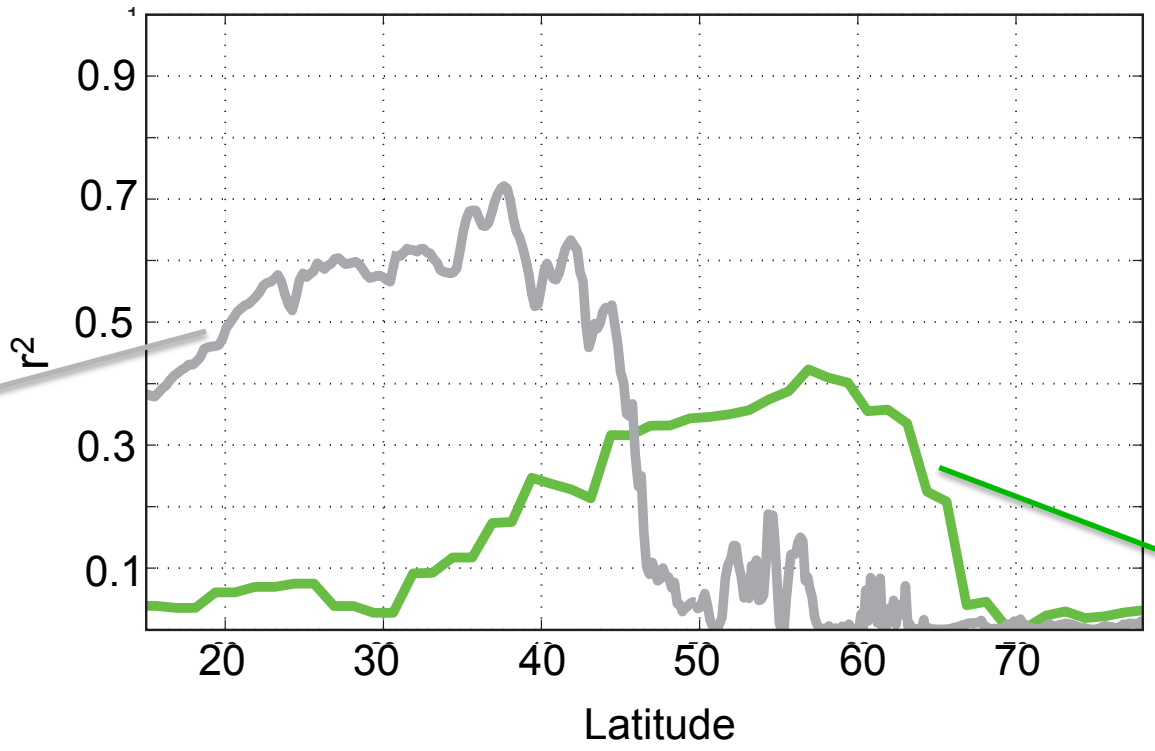

AMOC (z)
NEMO
Ocean Model

AMOC (Z)
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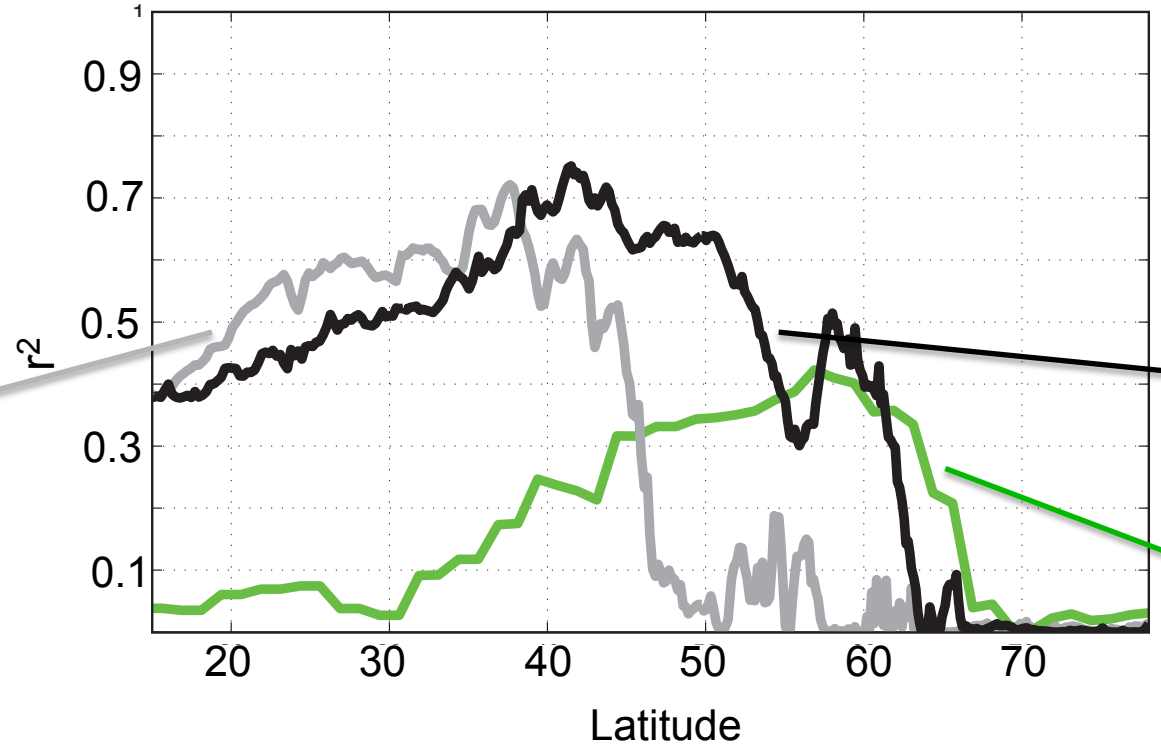

AMOC (z)
NEMO
Ocean Model

AMOC (σ)
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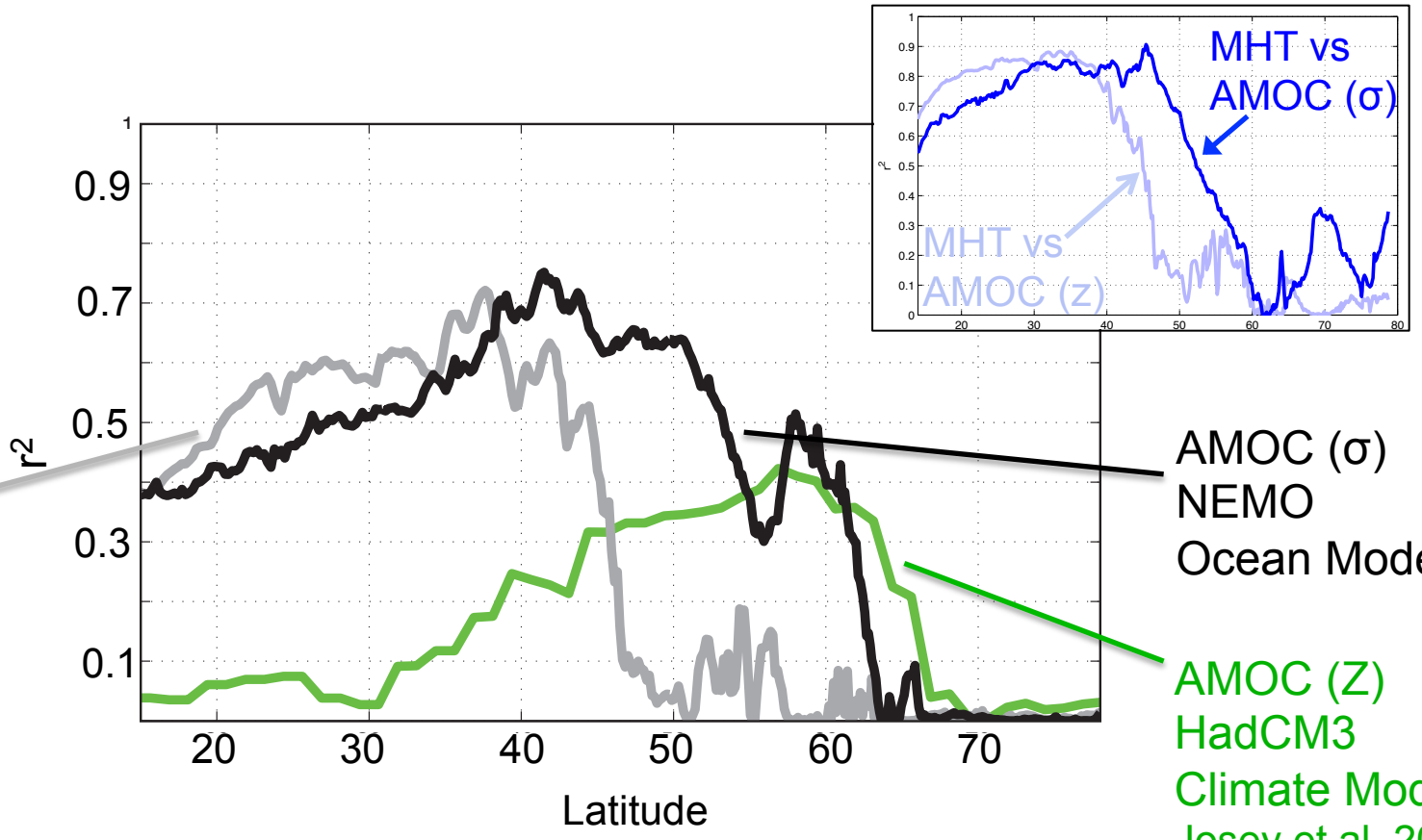

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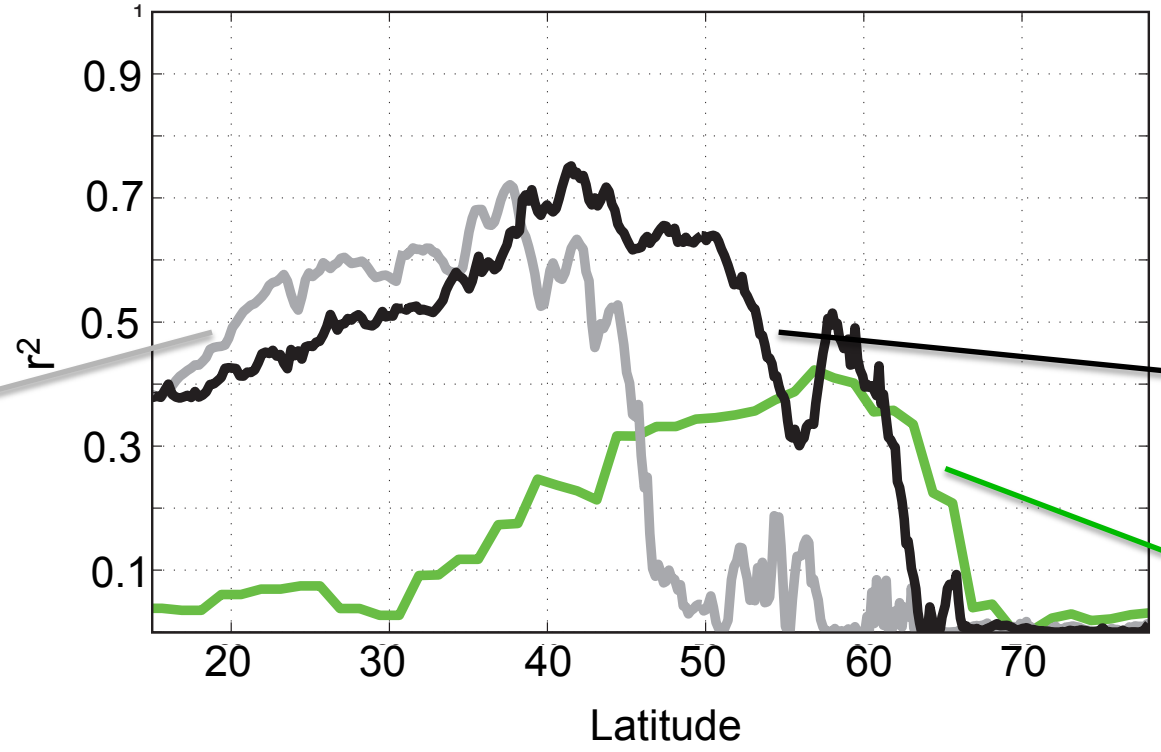

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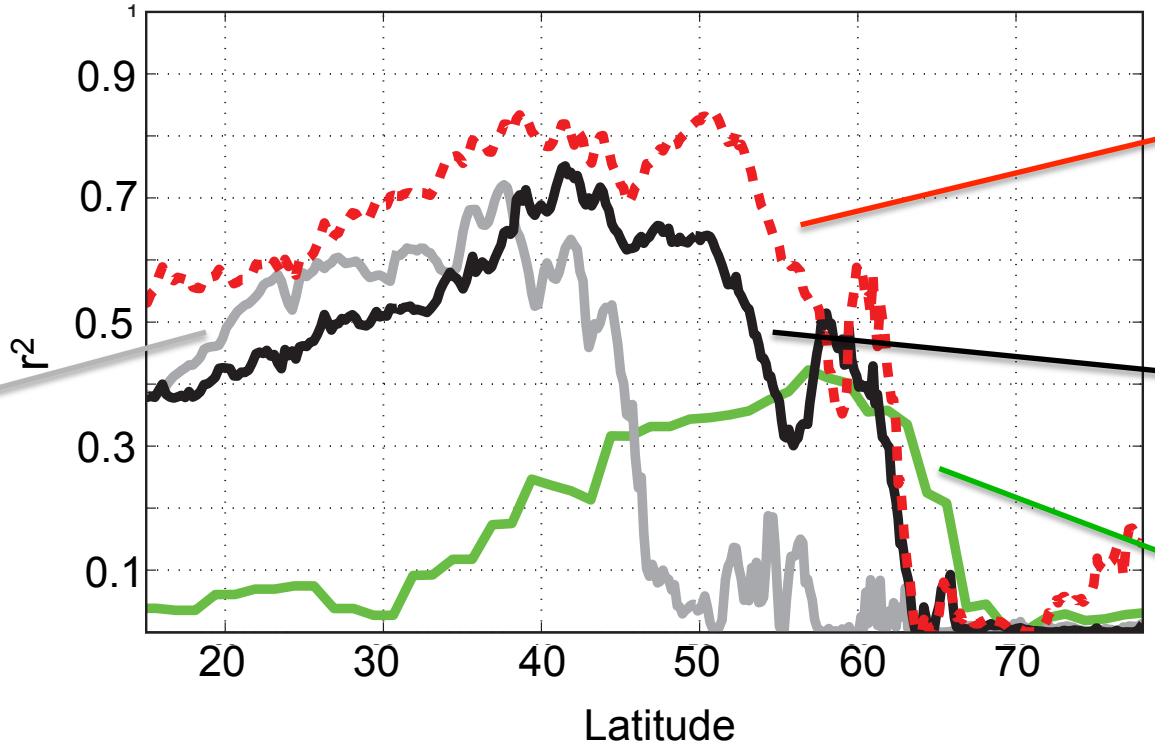

AMOC (σ)
Ocean Model
+ Ekman wind
variability

AMOC (σ)
NEMO
Ocean Model

AMOC (z)
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Ocean Model

AMOC (Z)
HadCM3
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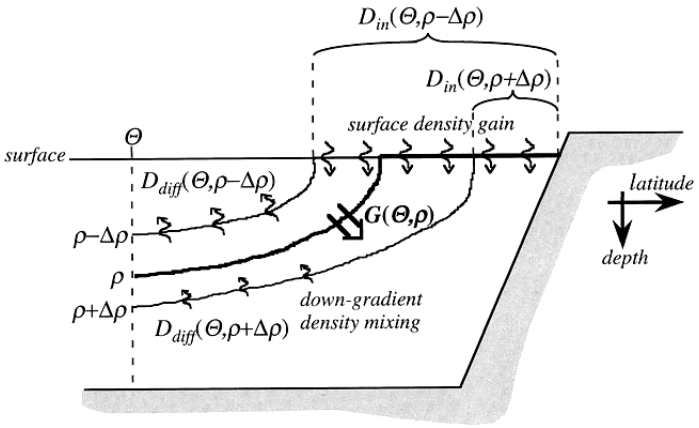
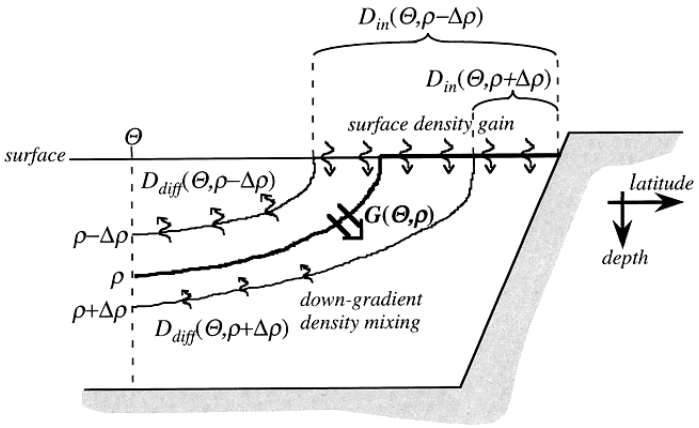
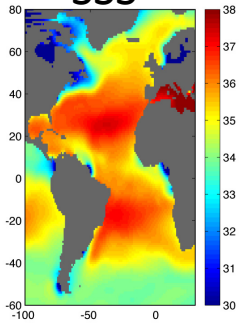
Theory


$D_{in}(\Theta,\rho-\Delta\rho)$
$D_{in}(\Theta,\rho+\Delta\rho)$
surface density gain
surface
Θ
$D_{diff}(\Theta,\rho-\Delta\rho)$
$G(\Theta,\rho)$
latitude
depth
$\rho-\Delta\rho$
ρ
$\rho+\Delta\rho$
down-gradient
density mixing
$D_{diff}(\Theta,\rho+\Delta\rho)$

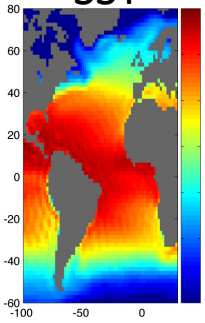
Theory + Surface Observations



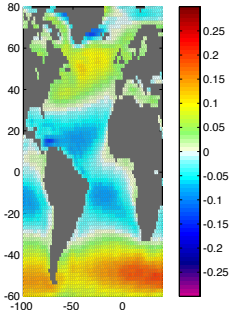
SSS



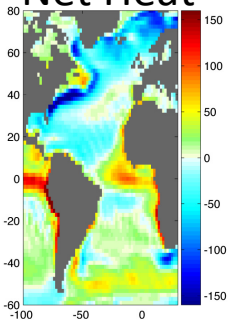
SST



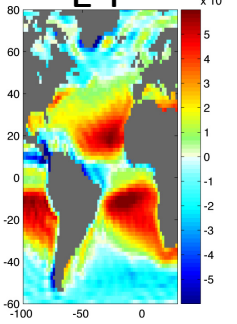
Wind Stress



Net Heat



E-P



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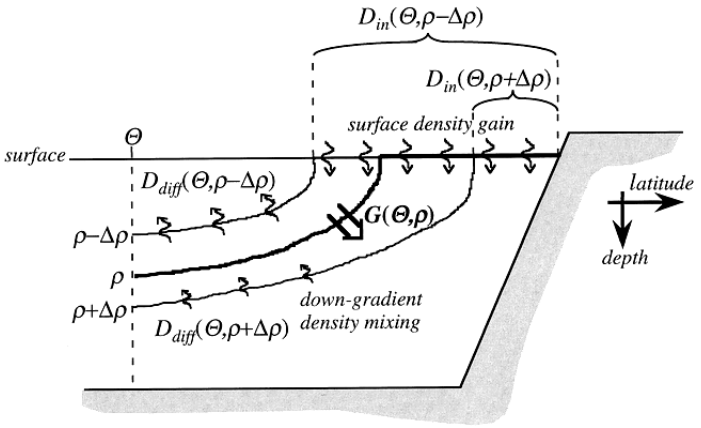
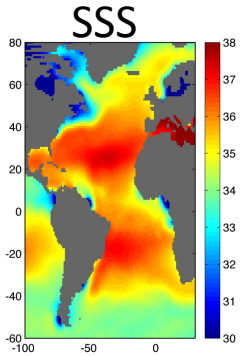
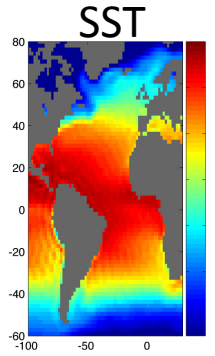
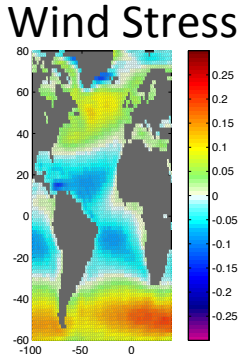
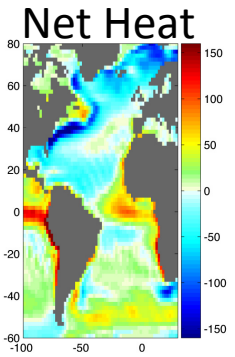
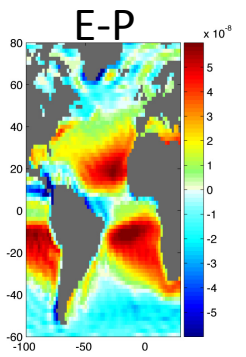




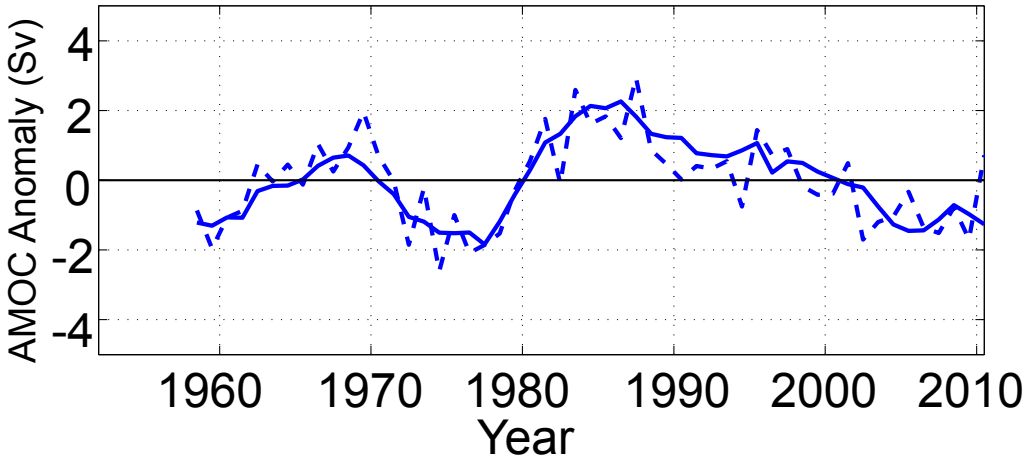






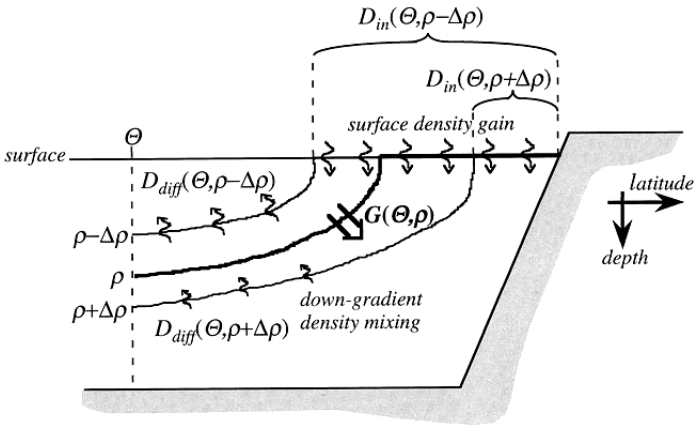


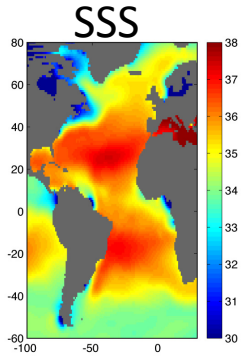
Surface-Forced Overturning Anomaly (Sv) at 48ºN (solid) with Ekman Contribution (dashed)

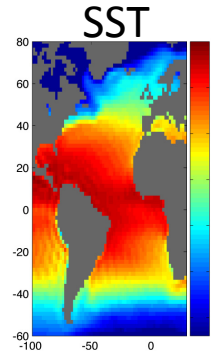


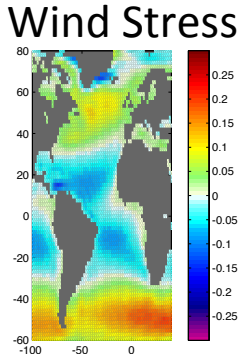
Updated from Grist et al. (2009)

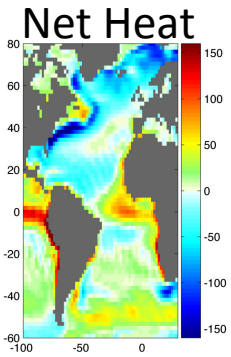
Theory + Surface Observations

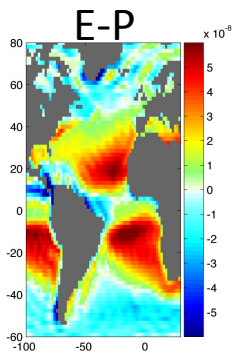












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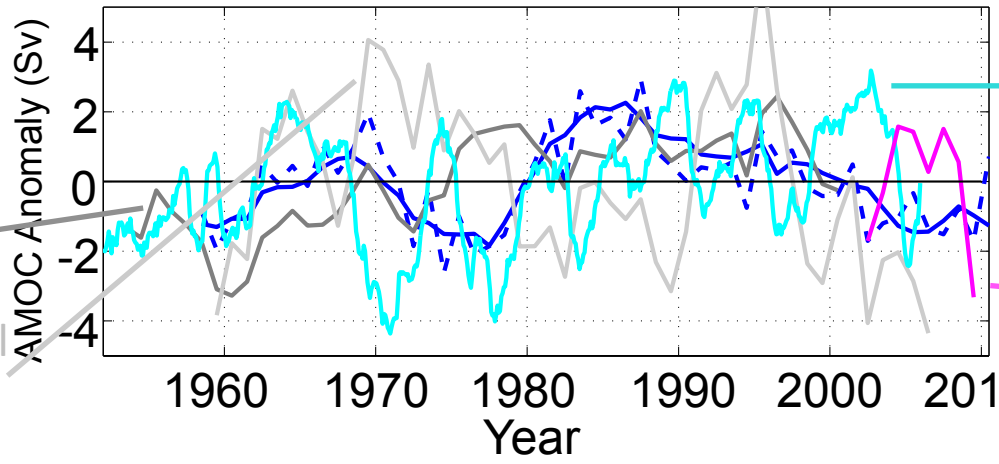


GECCO

Balmaseda et al (2007)

Bingham & Hughes (2009)

Hobbs & Willis (2012)

Updated from Grist et al. (2009)

Summary

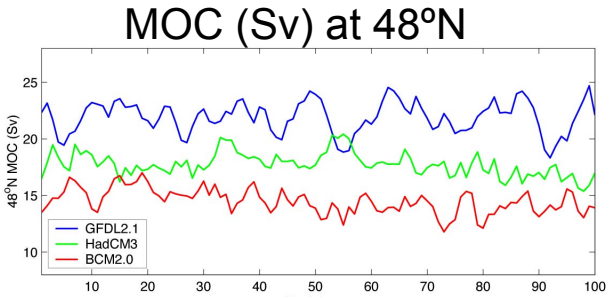
- In ¼º NEMO ocean model, the water mass transformation method can be used to estimate AMOC variability.
- In sub-polar regions the method explains much more variability in AMOC (σ_0) than AMOC (z).
- The surface density fluxes capture much of the decadal signal while the additional calculation of Ekman transport allows the higher frequency variability to be captured
- The method shows greatest potential between 33ºN and 54ºN where 70-84% of the AMOC (σ_0) variance is explained.
- As the method relies only on surface observations, estimate of AMOC variability can be made for the reanalysis era.
- We seek to determine the spread in time series resulting from the different reanalysis / salinity products & reconcile the surface forced signal with other mid-latitude AMOC estimates.

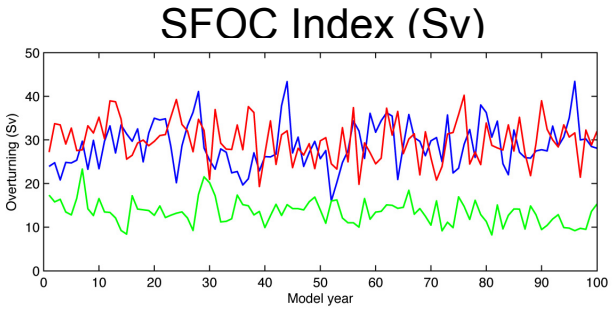
MOC vs SFOC in Coupled Climate Models

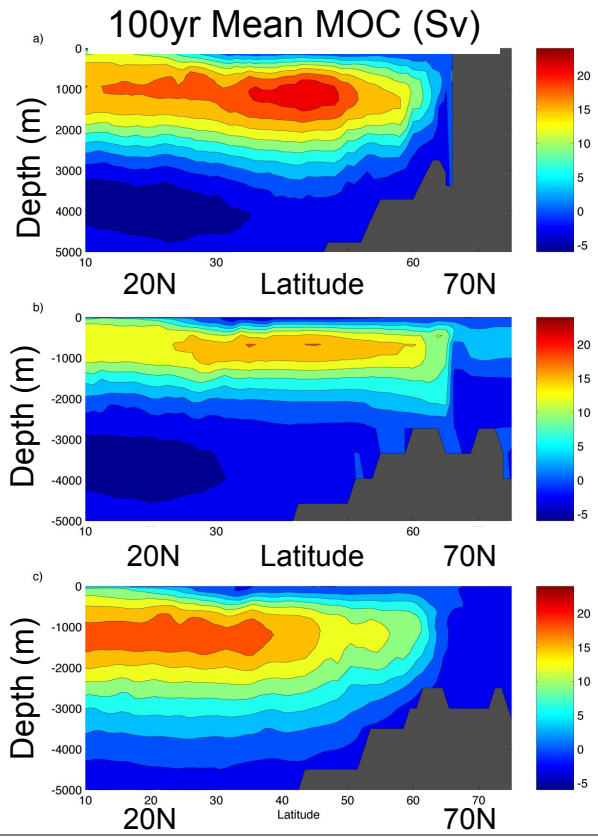
GFDL2.1

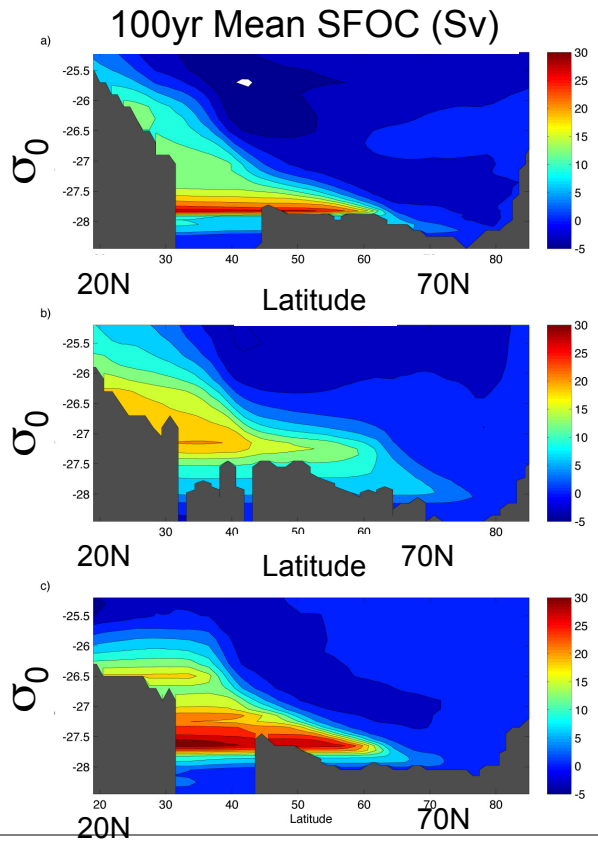
HadCM3

- BCM 2.0

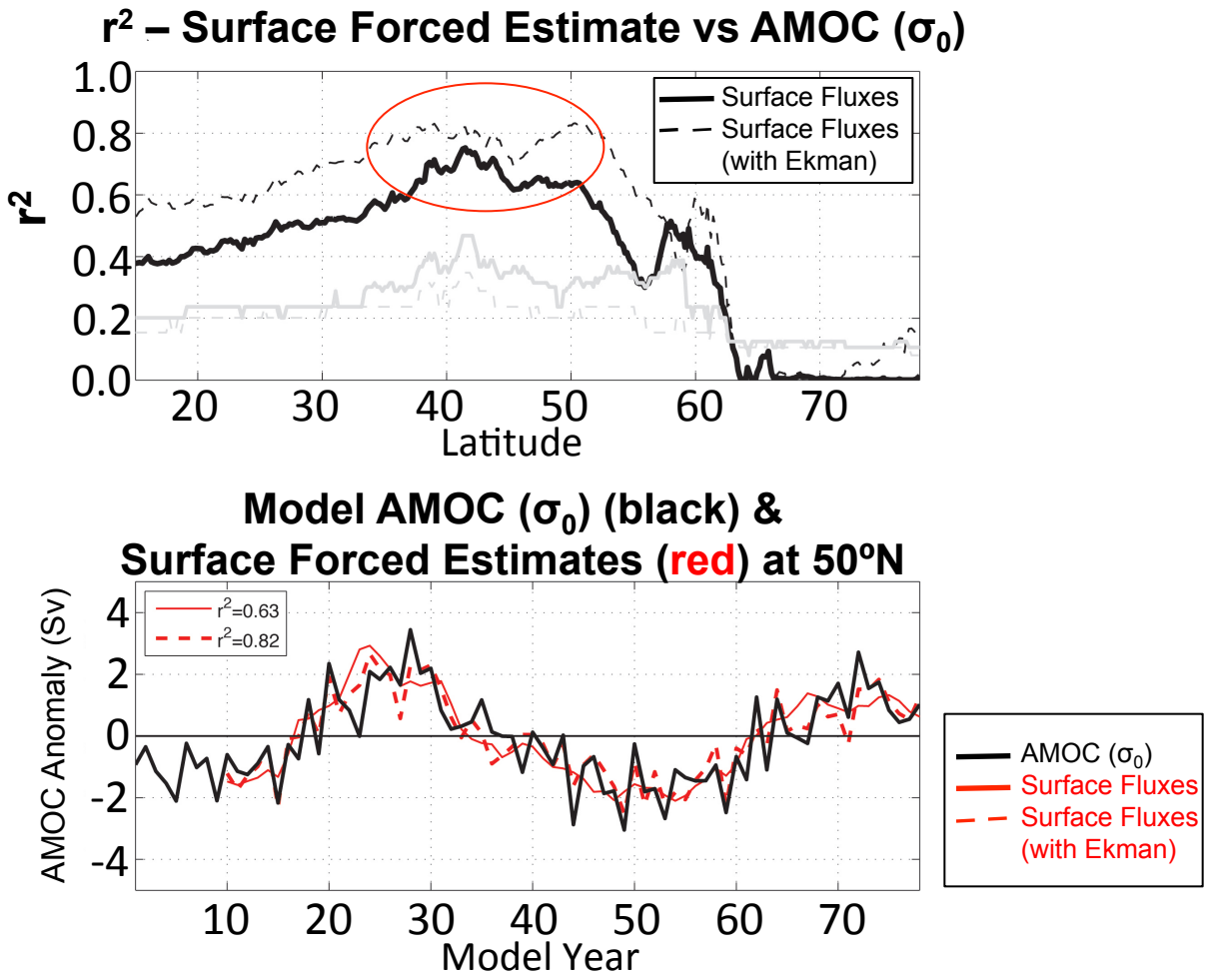






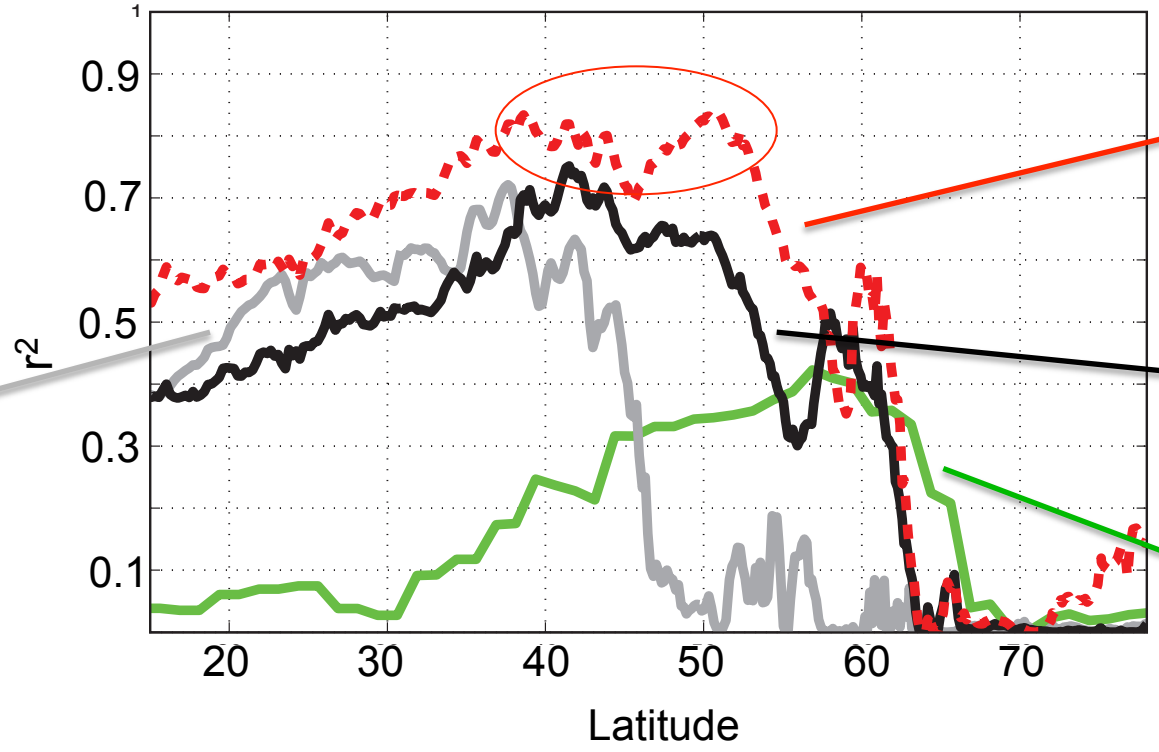


4. Influence of Surface Fluxes on AMOC Variability



Grist, Josey, Marsh (*JGR-Oceans, under review,* 2012)

Fraction AMOC explained By Surface Fluxes



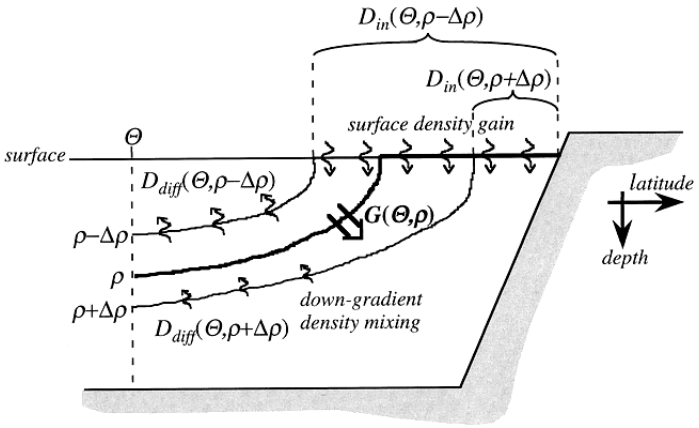
AMOC (σ)
Ocean Model
+ Ekman wind
variability

AMOC (σ)
Ocean Model

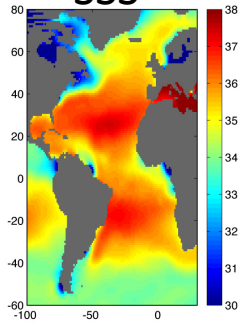
AMOC (z)
NEMO
Ocean Model

AMOC (Z)
HadCM3
Climate Model

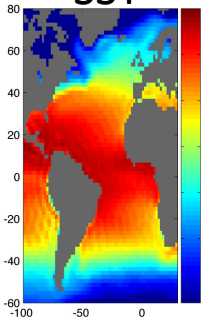
Theory + Surface Observations



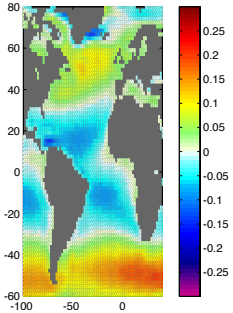
SSS



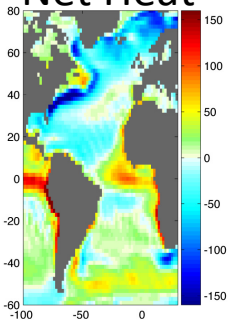
SST



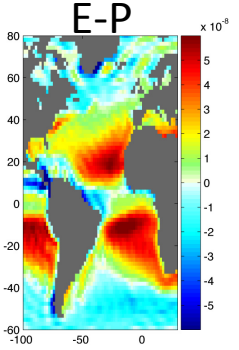
Wind Stress



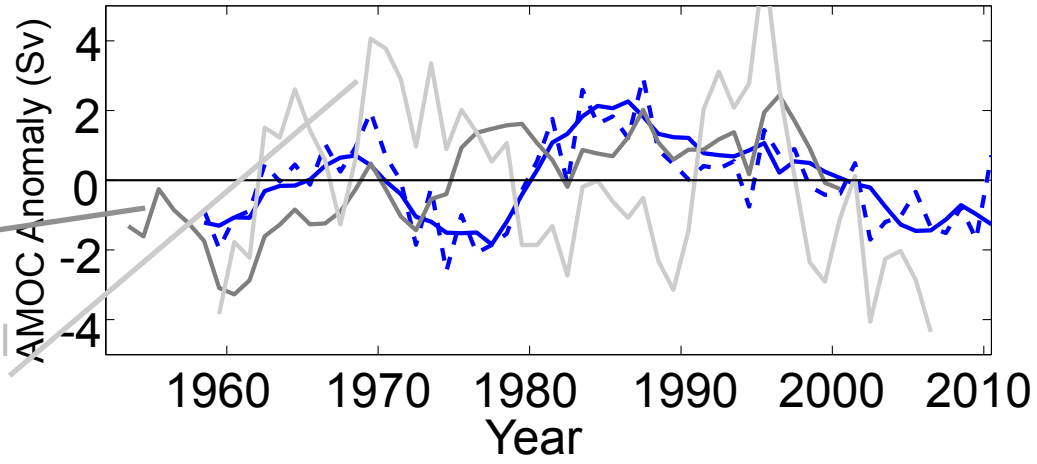
Net Heat



E-P



Surface-Forced Overturning Anomaly (Sv) at 48ºN (solid) with Ekman Contribution (dashed)



GECCO

Balmaseda et al (2007)

Updated from Grist et al. (2009)