

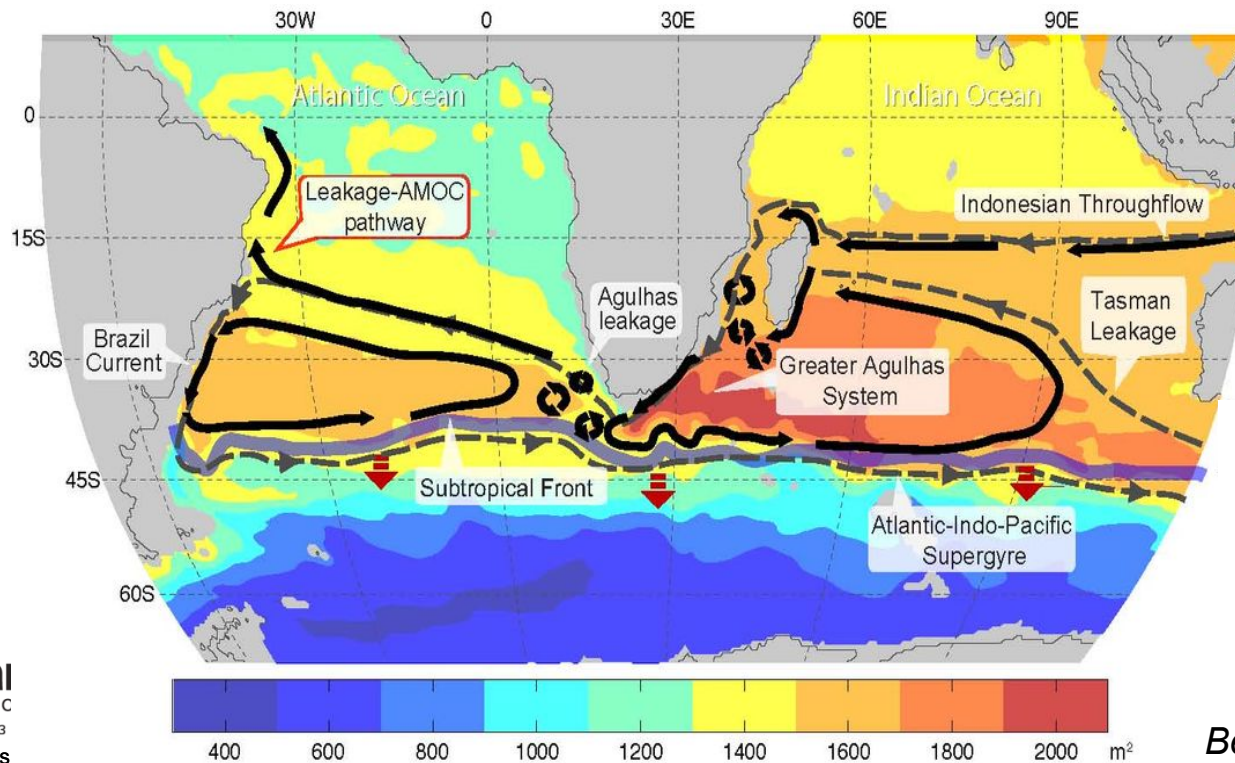
Agulhas Leakage in the CCSM4

Wilbert Weijer (LANL, Los Alamos)

Erik van Sebille (UNSW, Sydney)

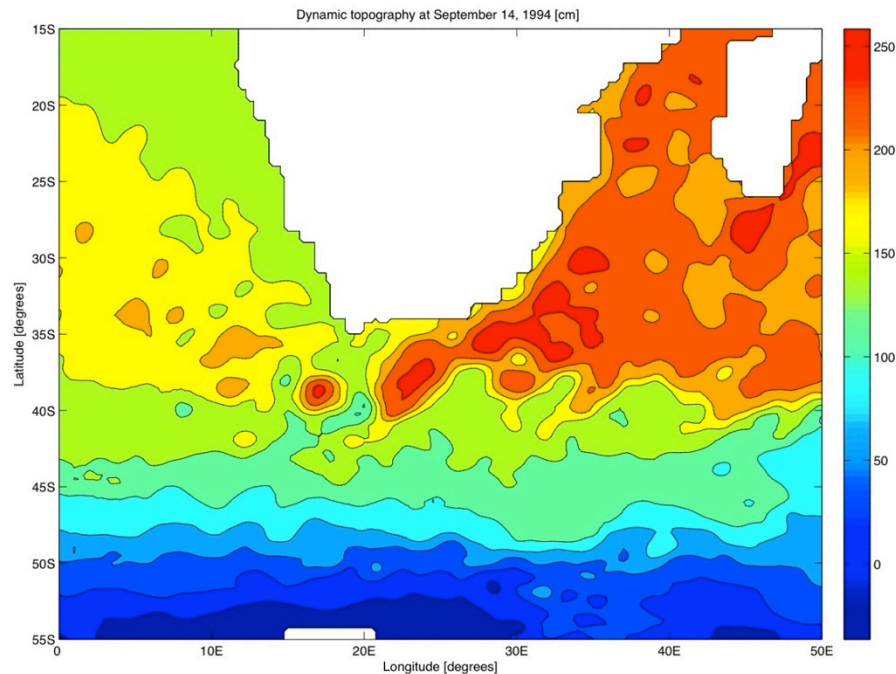
Agulhas Leakage

- Exchange of water between South Indian and Atlantic Oceans
- Takes part in
 - Supergyre
 - Meridional Overturning Circulation



Agulhas Leakage

- **Main mode of exchange**
 - Agulhas Rings
 - Instability of Agulhas Retroflection
 - ~ 6 per year
 - Filled with warm and salty water



Agulhas Leakage: Impact

- **Gordon (1985)**

- “Such a *warm water link* between the Atlantic and Indian oceans would *strongly influence global climate patterns*”

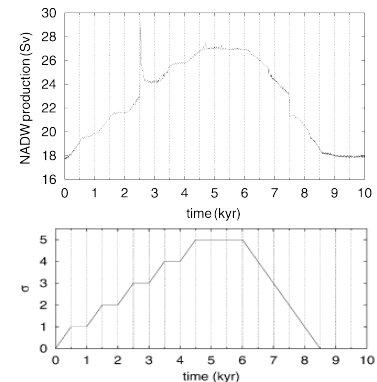
Agulhas Leakage: Impact

■ Gordon (1985)

- “Such a *warm water link* between the Atlantic and Indian oceans would *strongly influence global climate patterns*”

■ Weijer et al. (1999, 2001, 2002)

- Heat and salt injection through Agulhas Leakage
 - Strengthens MOC
 - Stabilizes MOC



Agulhas Leakage: Impact

■ Gordon (1985)

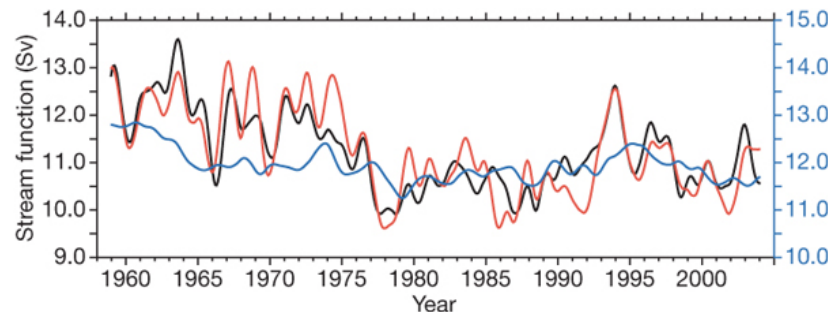
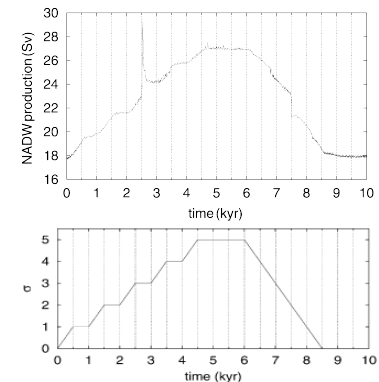
- “Such a *warm water link* between the Atlantic and Indian oceans would *strongly influence global climate patterns*”

■ Weijer et al. (1999, 2001, 2002)

- Heat and salt injection through Agulhas Leakage
 - Strengthens MOC
 - Stabilizes MOC

■ Biastoch et al. (2008)

- High-resolution model of Agulhas region, nested in global model
- “*Dynamical signals from Agulhas region contribute MOC signal of same order of magnitude as those arising in the north*”



Agulhas Leakage: Implications

- **No conclusive proof yet of AL \leftrightarrow MOC link**
 - Models too simplistic
 - More realistic models
 - Ocean-only, no atmospheric feedbacks
 - Too short integration

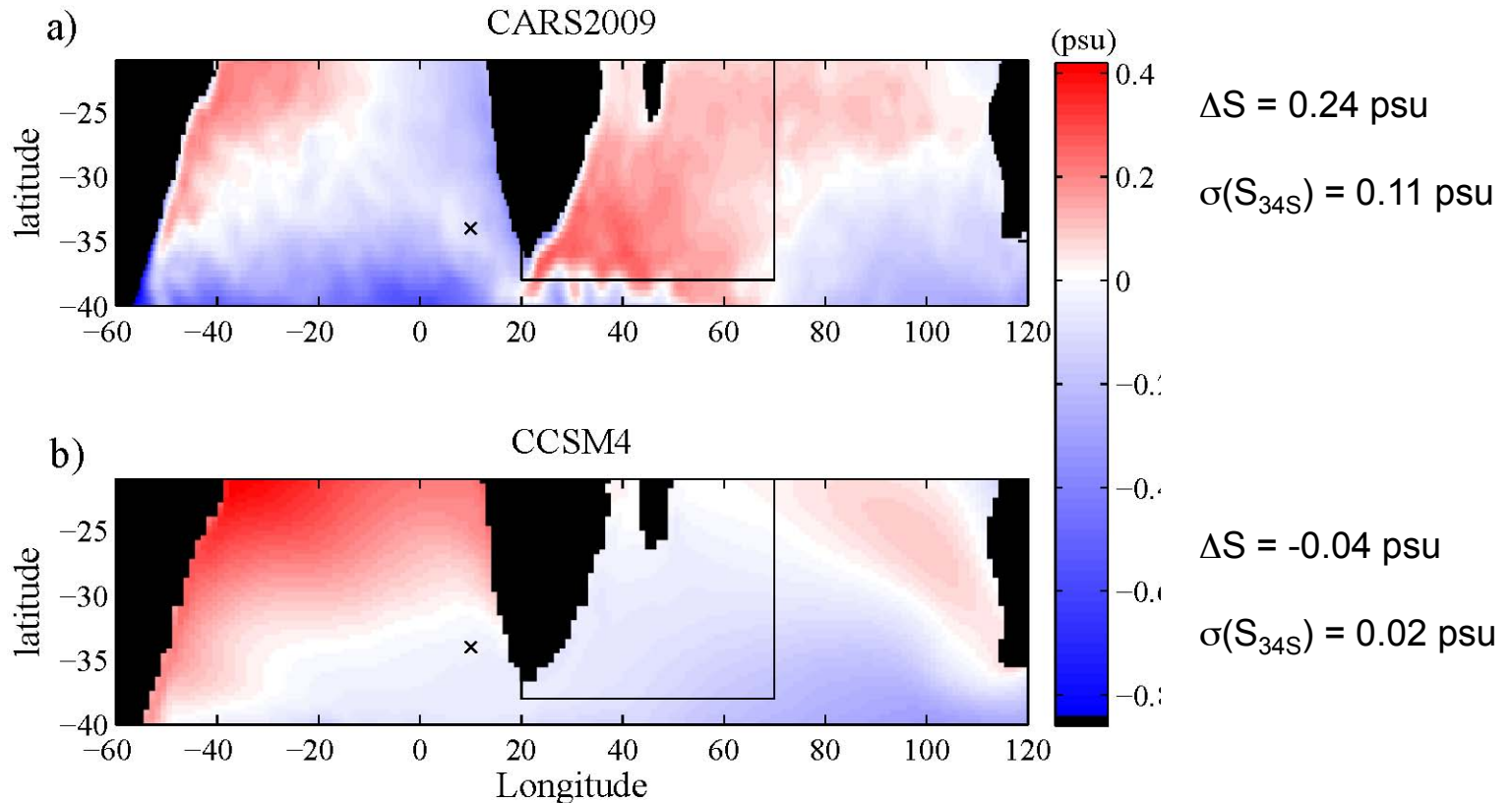
Agulhas Leakage: Implications

- **No conclusive proof yet of AL \leftrightarrow MOC link**
 - Models too simplistic
 - More realistic models
 - Ocean-only, no atmospheric feedbacks
 - Too short integration
- **Our best hope: Coupled climate models**
 - Coupled ocean-atmosphere
 - Long integrations

Agulhas Leakage: Implications

- **No conclusive proof yet of AL \leftrightarrow MOC link**
 - Models too simplistic
 - More realistic models
 - Ocean-only, no atmospheric feedbacks
 - Too short integration
- **Our best hope: Coupled climate models**
 - Coupled ocean-atmosphere
 - Long integrations
- **But: Low-res models do not represent Agulhas Leakage well**
 - CCSM4 overestimates Agulhas Leakage by factor 3 (Weijer et al. 2012)

Salinity Bias



Research Goal

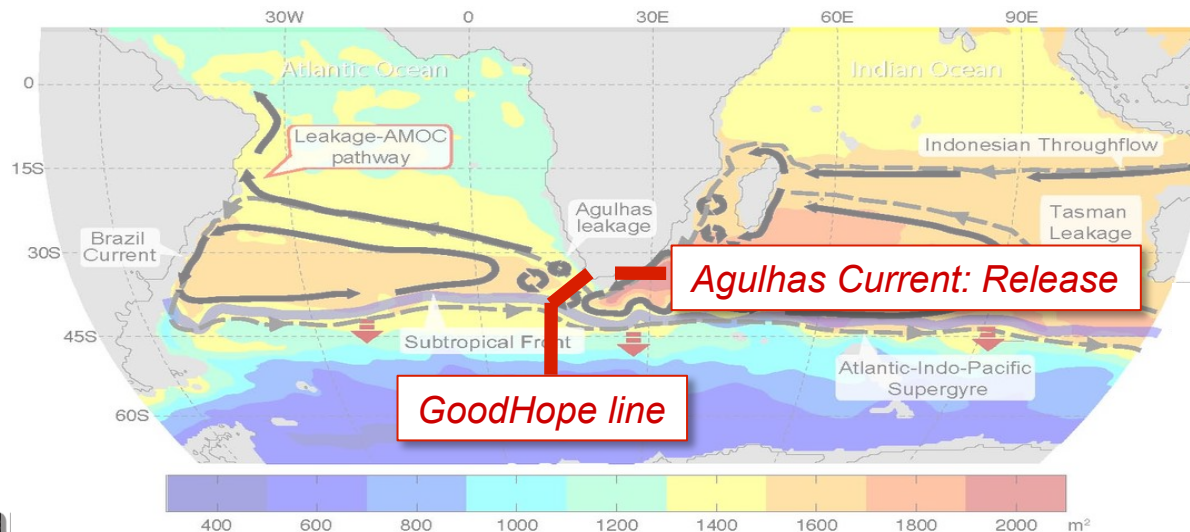
- Can we find evidence for Agulhas Leakage \leftrightarrow MOC link in CCSM4?

Does Agulhas Leakage influence MOC in CCSM4?

- **1850 pre-industrial control**
 - Final 500 yr of 1300 yr integration

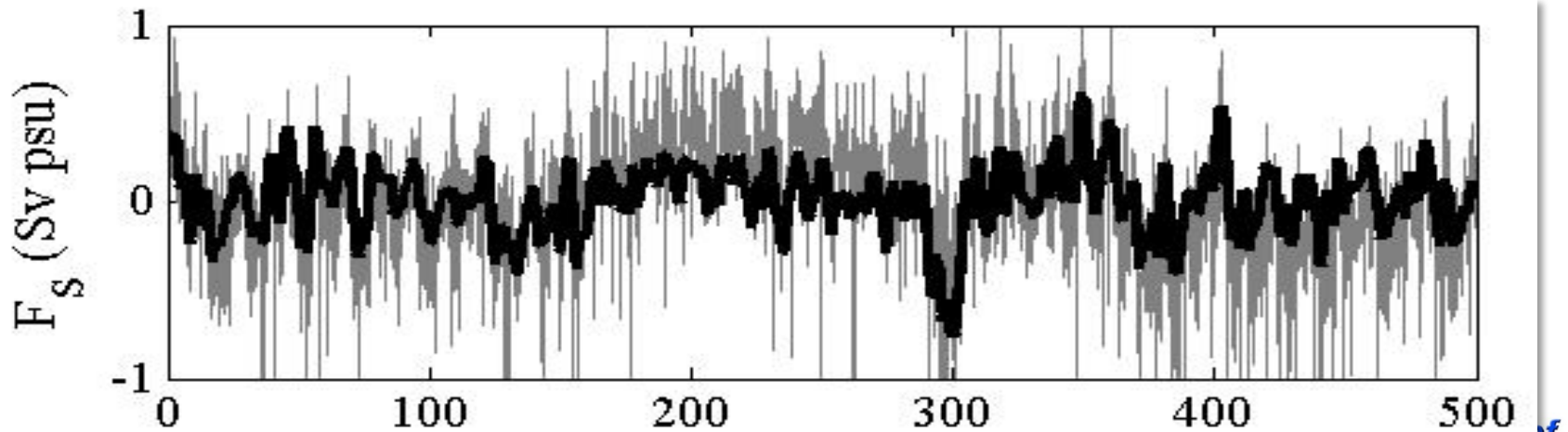
Does Agulhas Leakage influence MOC in CCSM4?

- **1850 pre-industrial control**
 - Final 500 yr of 1300 yr integration
- **Agulhas Leakage: Lagrangian analysis**
 - Monthly 3D velocity fields
 - Release 2M+ numerical floats in Agulhas Current
 - Diagnose floats crossing GoodHope line



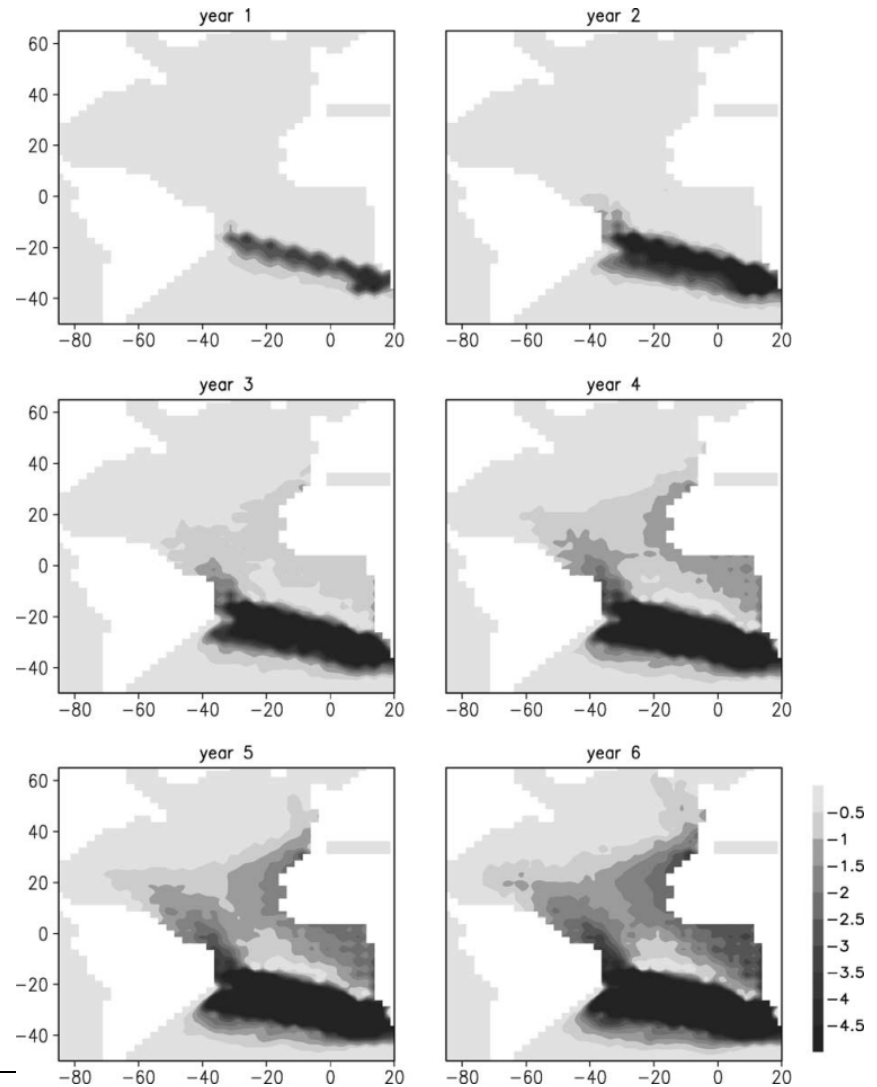
Does Agulhas Leakage influence MOC in CCSM4?

- **1850 pre-industrial control**
 - Final 500 yr of 1300 yr integration
- **Agulhas Leakage: Lagrangian analysis**
 - Monthly 3D velocity fields
 - Release 2M+ numerical floats in Agulhas Current
 - Diagnose floats crossing GoodHope line
 - Diagnose associated salt flux F_S



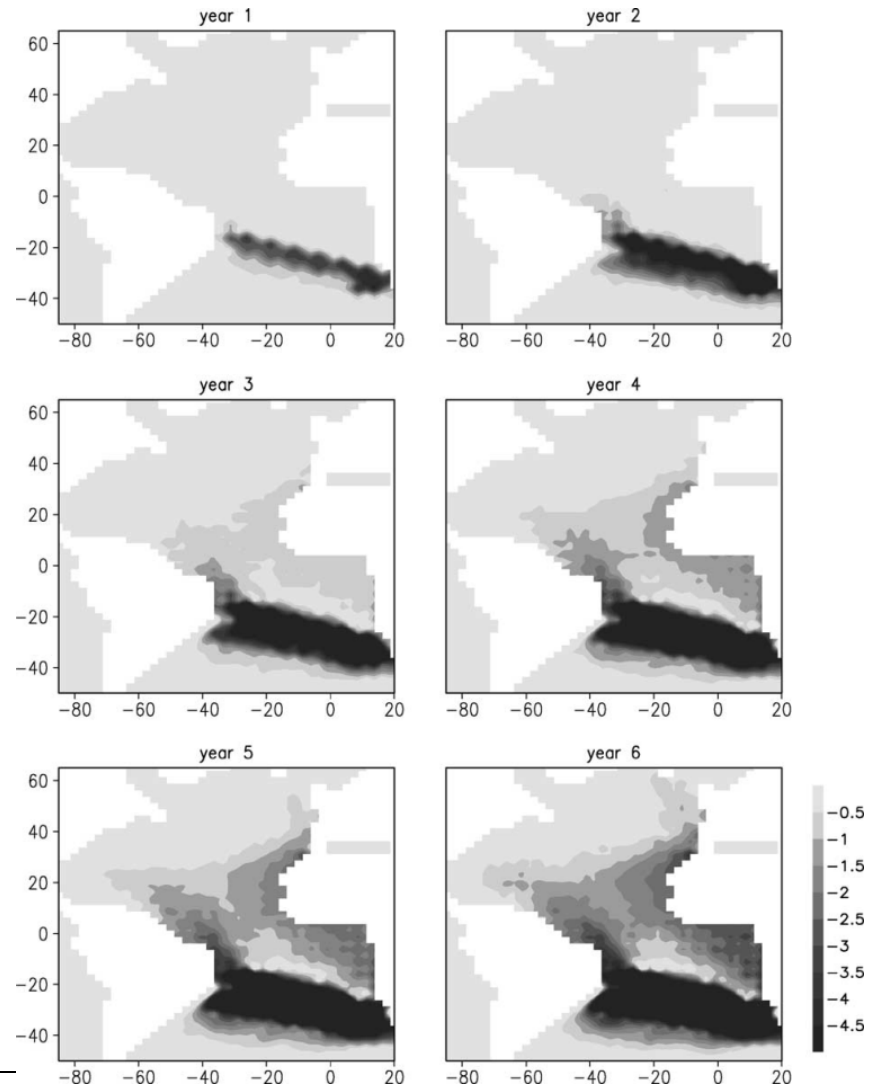
Wave Adjustment

- Kelvin/Rossby waves

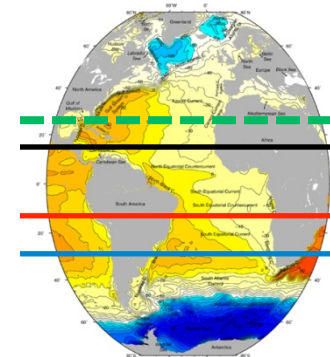
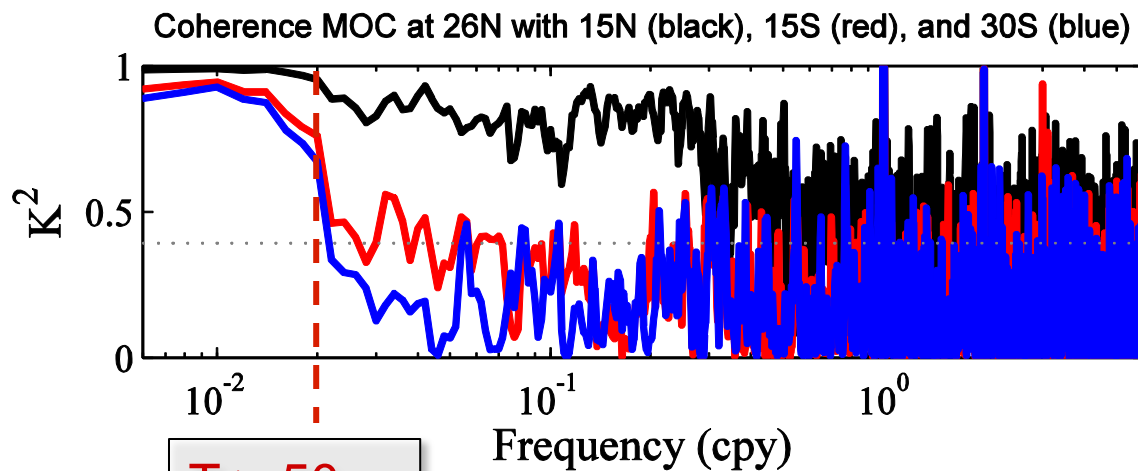
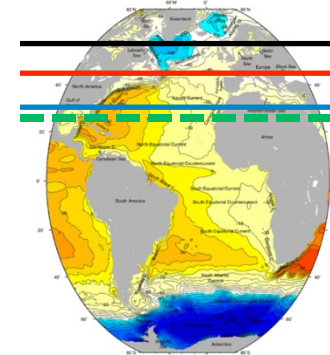
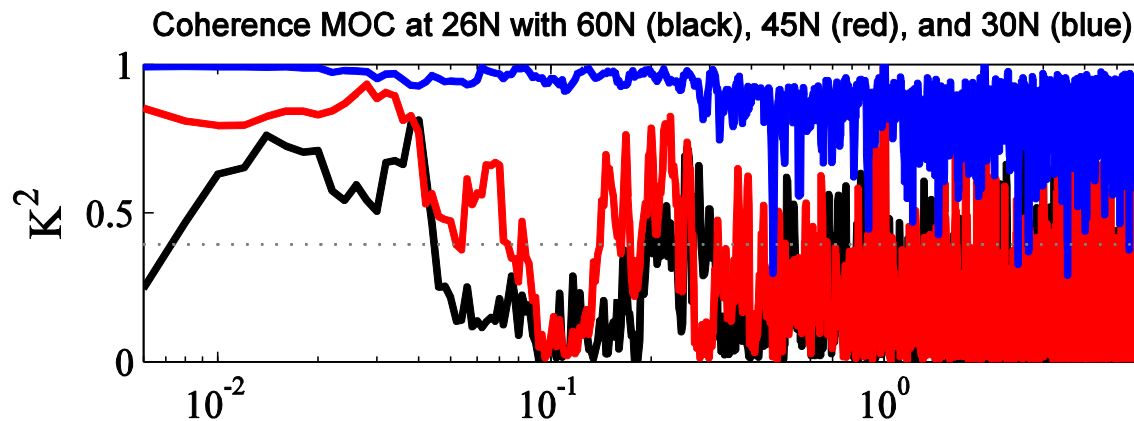


Wave Adjustment

- Kelvin/Rossby waves
- Johnson & Marshall (2002)
 - No cross-equatorial transport of MOC anomalies
 - Time scales shorter than decadal
 - *Equatorial Buffer*



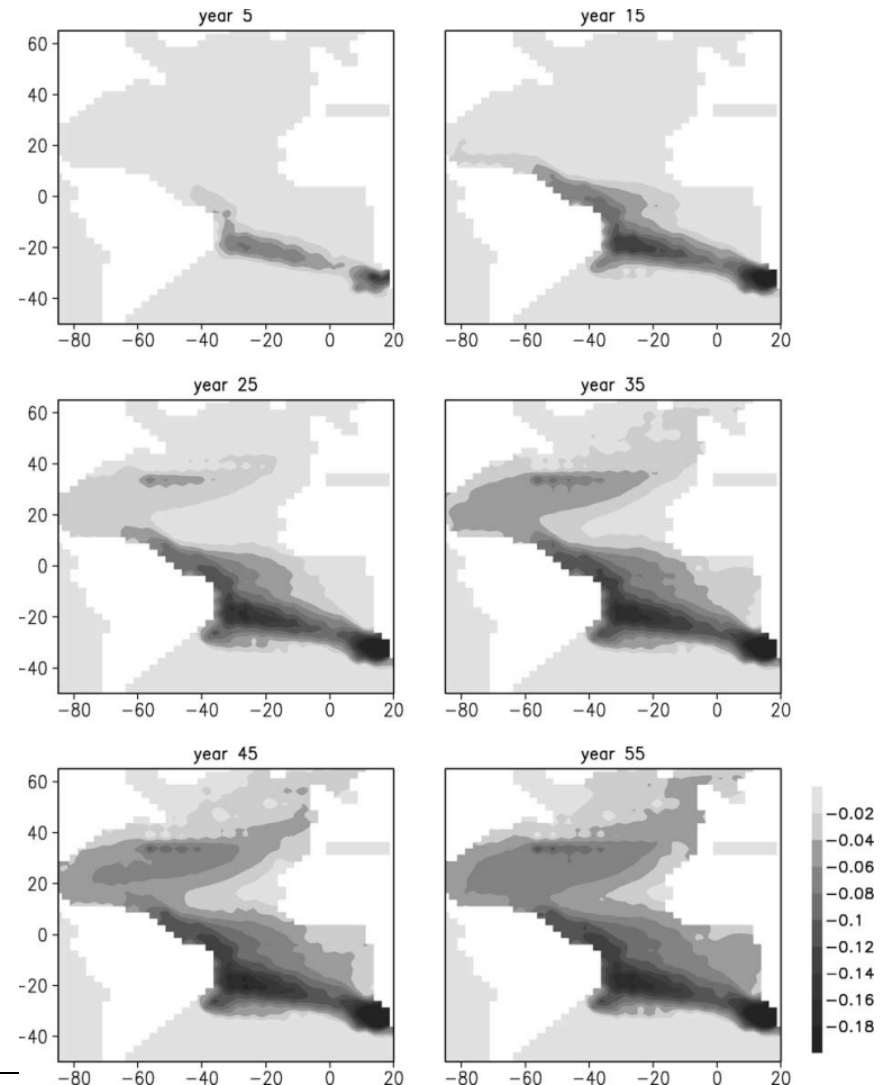
Meridional Coherence of the AMOC



$T > 50 \text{ yr}$

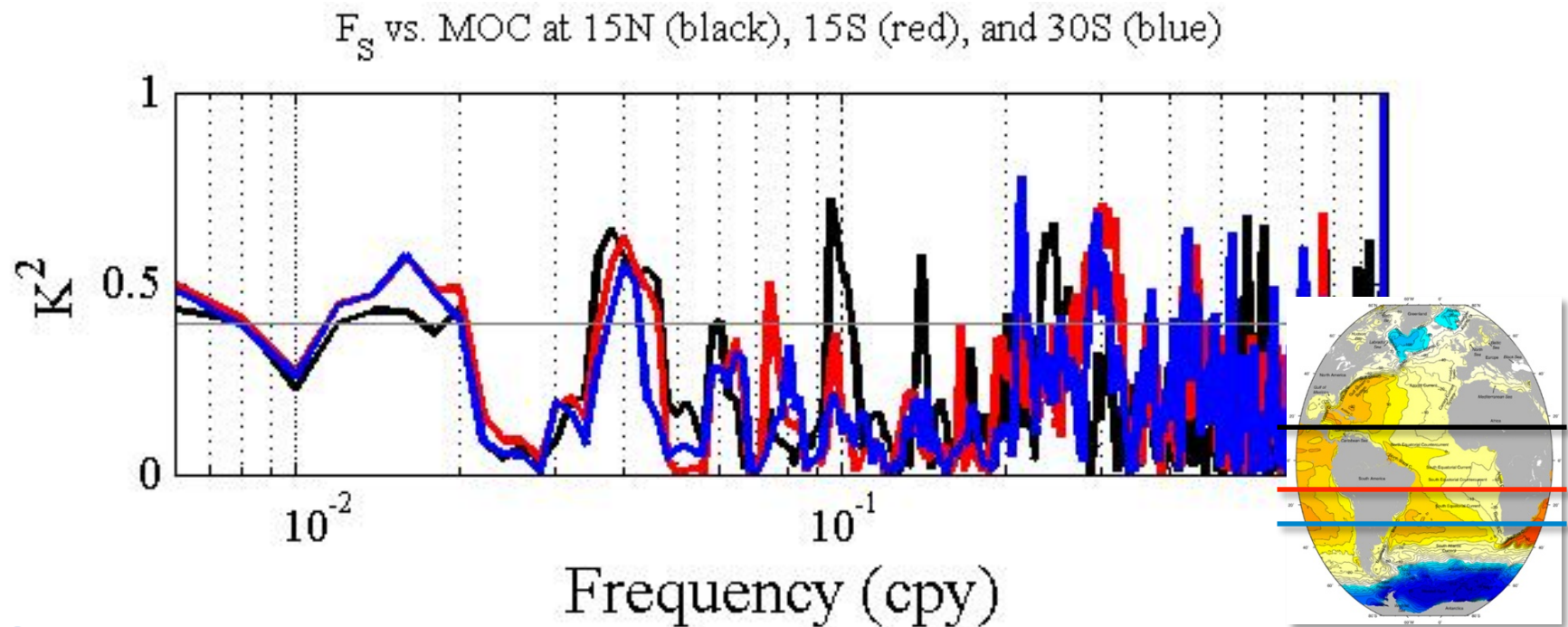
Advective Adjustment

- Advection of density anomalies



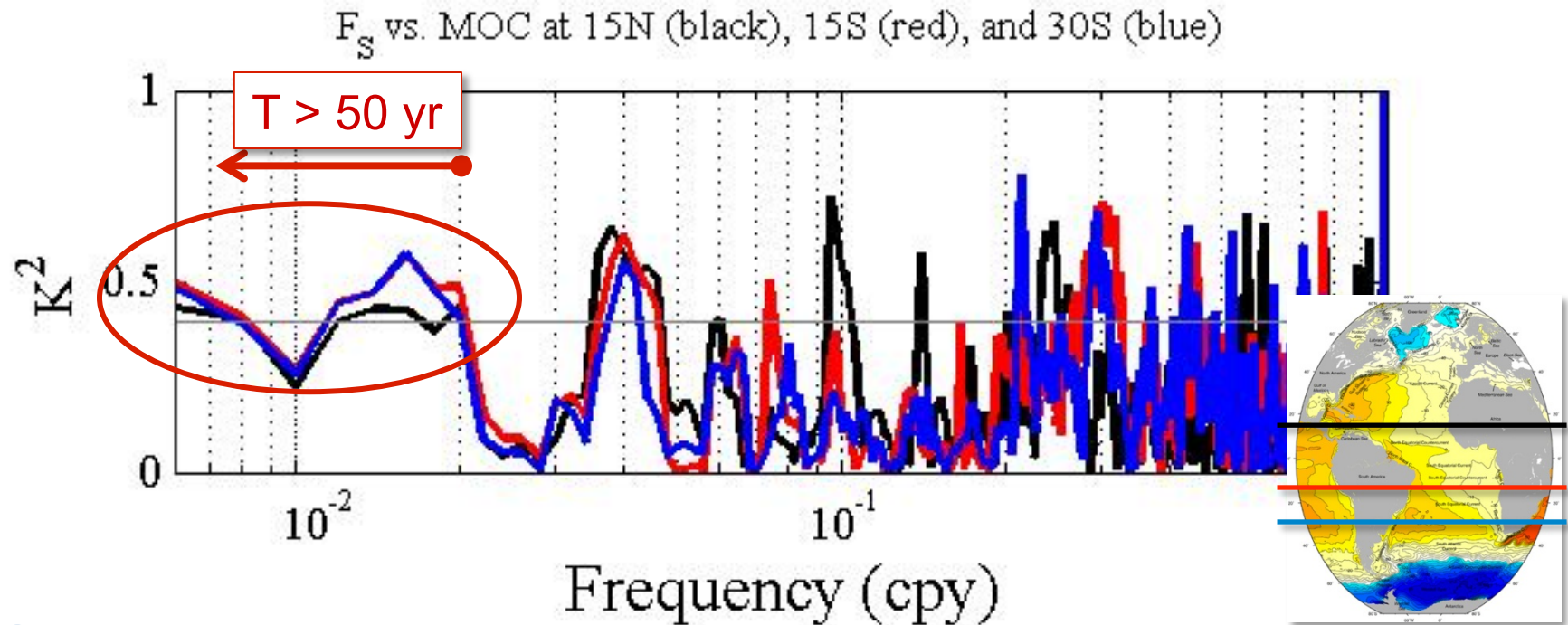
Agulhas Leakage vs. MOC

- Coherence



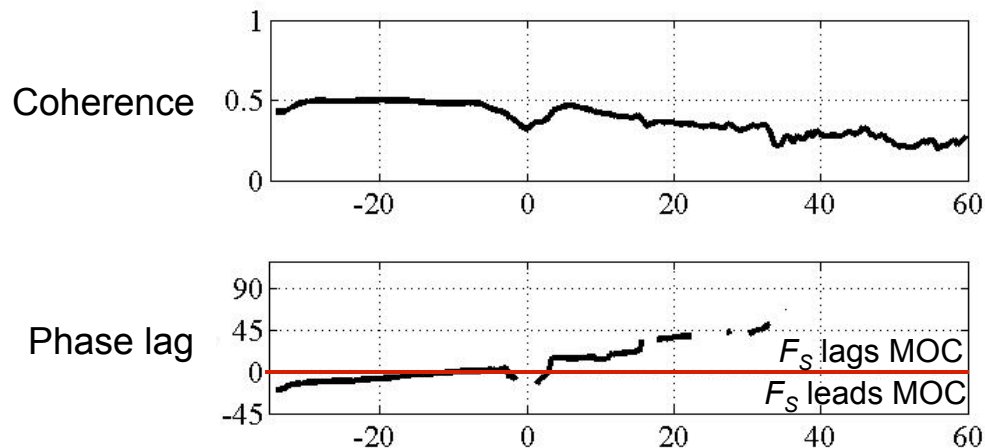
Agulhas Leakage vs. MOC

- Coherence: **Multidecadal (50-100 yr)**
 - F_S is *marginally coherent* with MOC



Agulhas Leakage vs. MOC

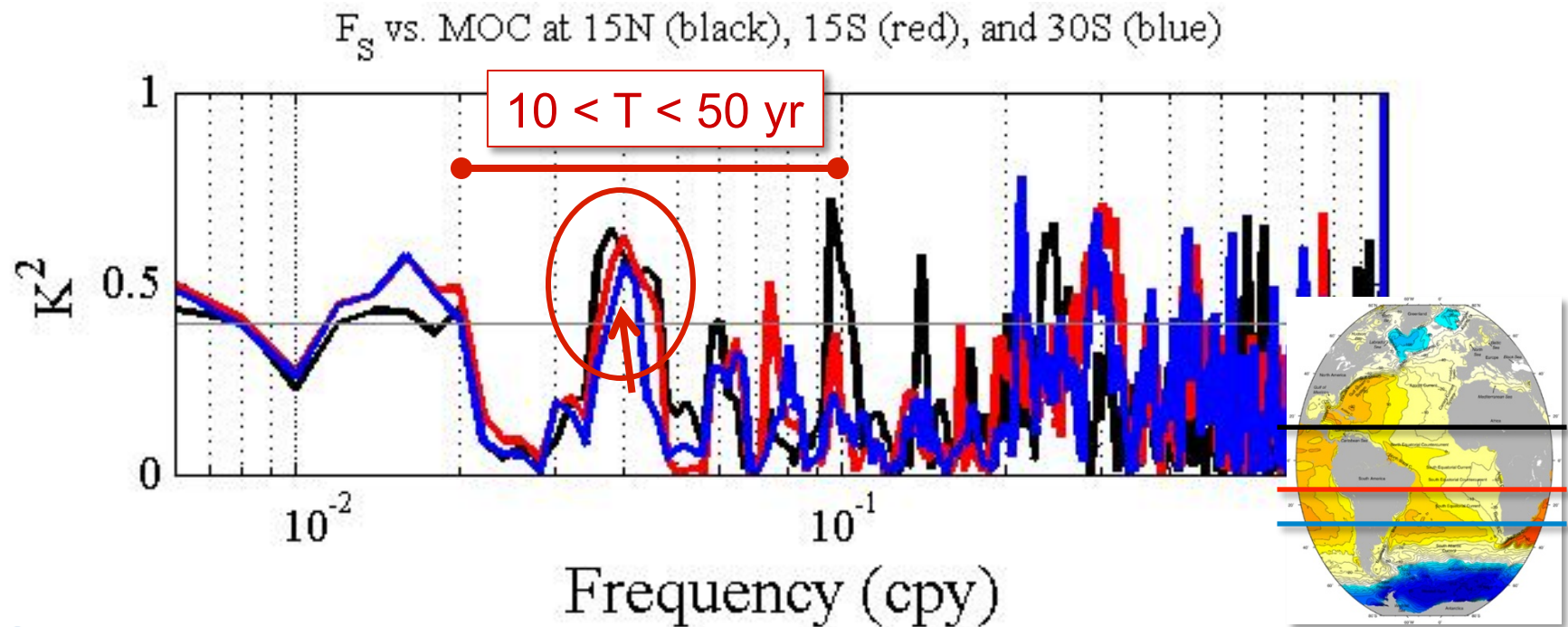
- Coherence: **Multidecadal (50-100 yr)**
 - F_S *is marginally coherent* with MOC
 - Very small lag/lead, southward propagation, so causality...?



Coherence between F_S and MOC
averaged for $50 < T < 100$ yr

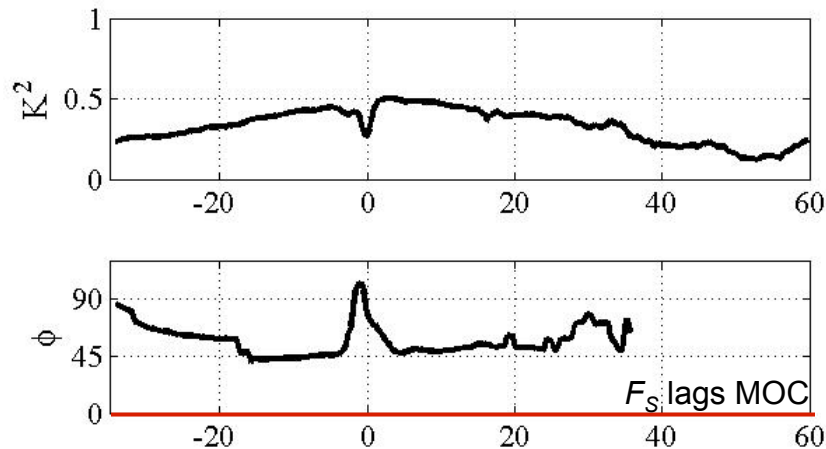
Agulhas Leakage vs. MOC

- Coherence: *Decadal (10-50 yr)*
 - F_S *not* coherent with MOC, except at 25 yr



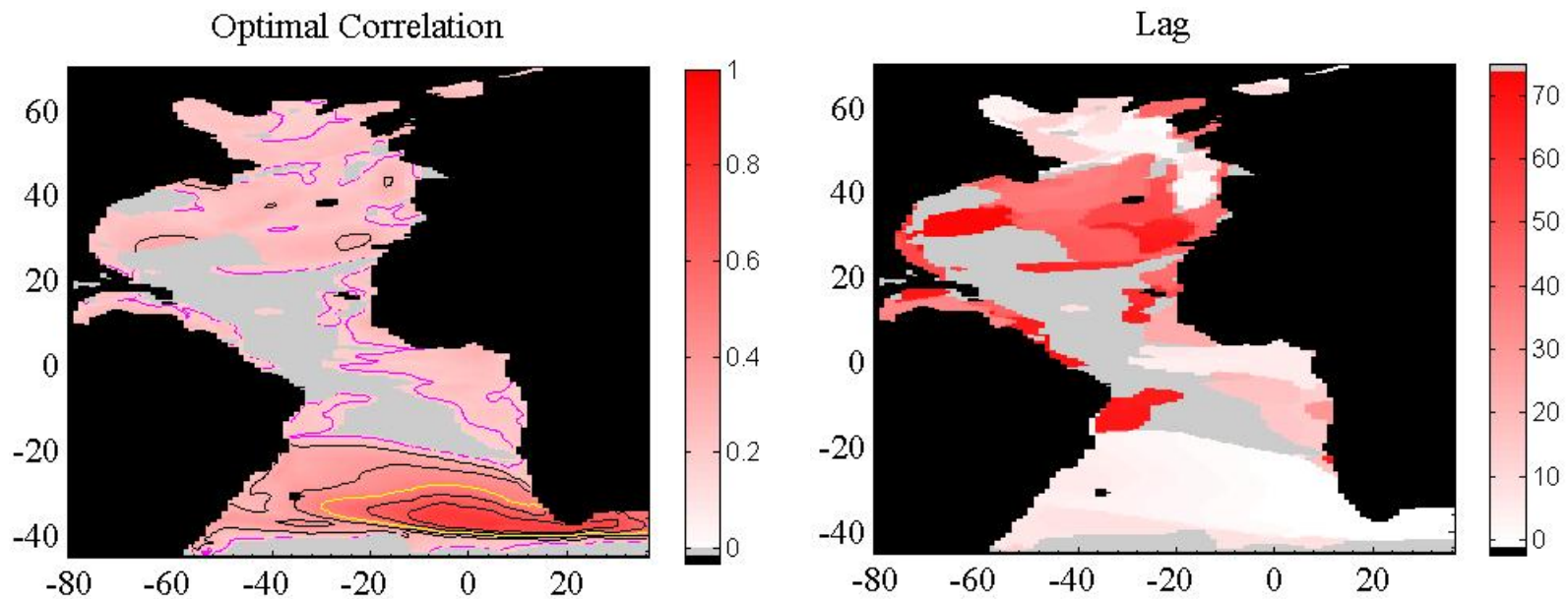
Agulhas Leakage vs. MOC

- Coherence: *Decadal (10-50 yr)*
 - F_S *not* coherent with MOC, except at 25 yr
 - At 25 yr, F_S *leads* MOC

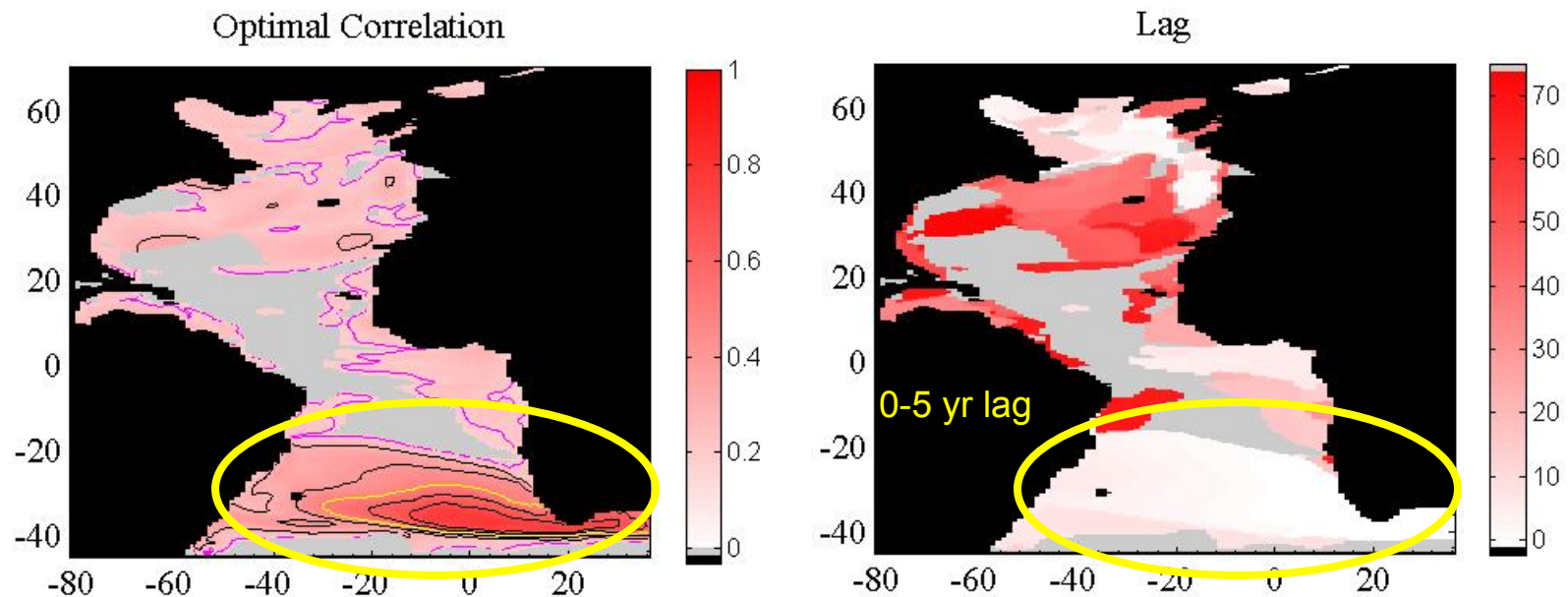


Coherence between F_S and MOC
averaged for $20 < T < 33$ yr

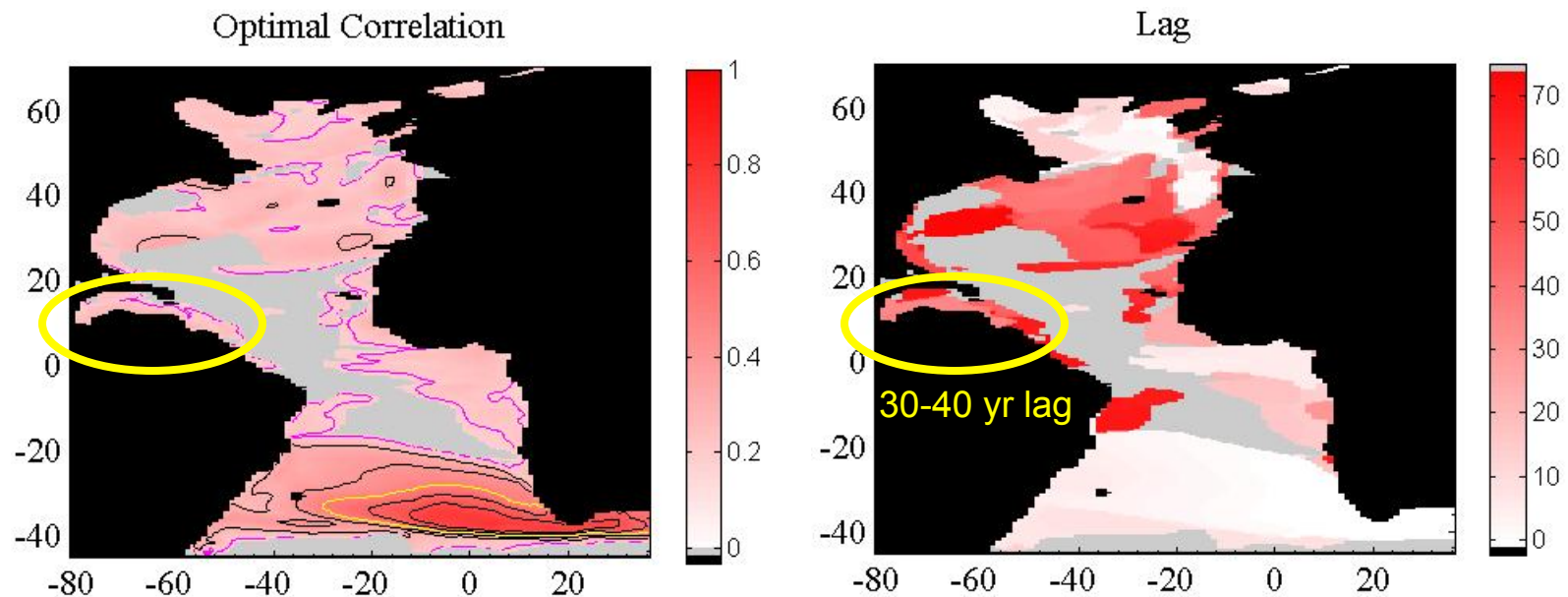
Signal Propagation: Lagged Correlation



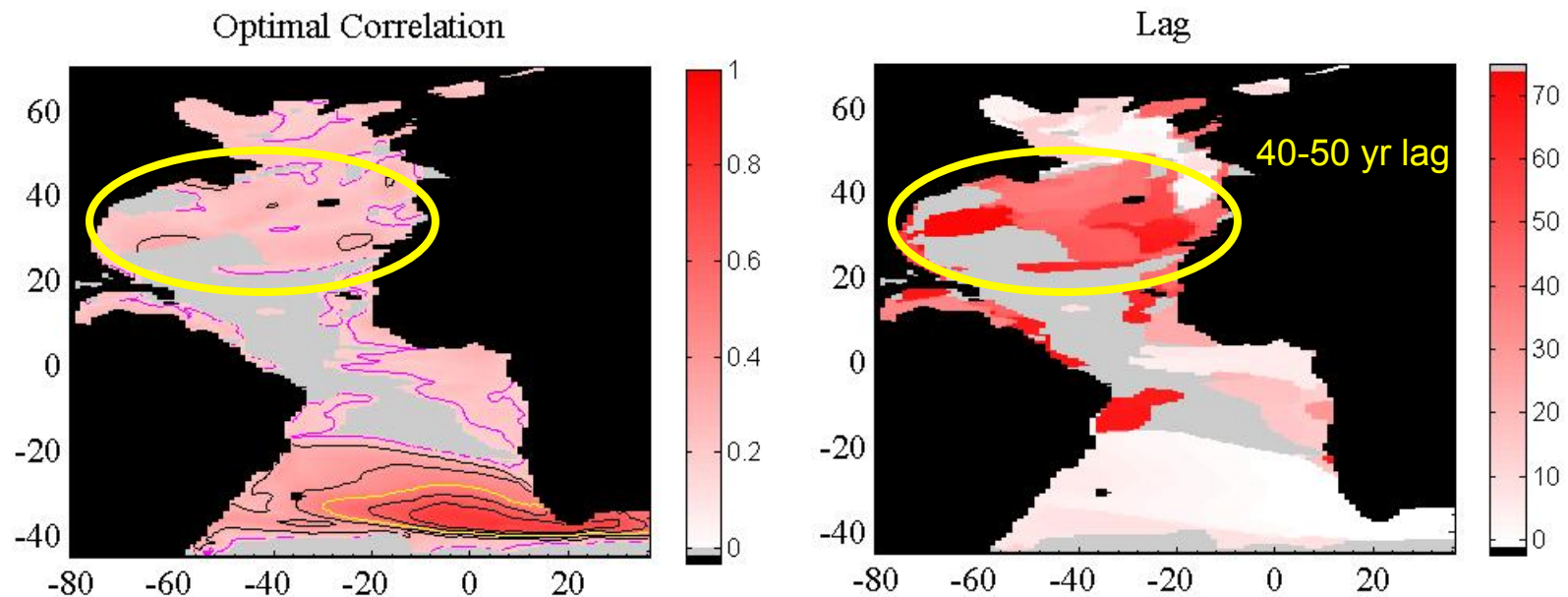
Signal Propagation: Lagged Correlation



Signal Propagation: Lagged Correlation

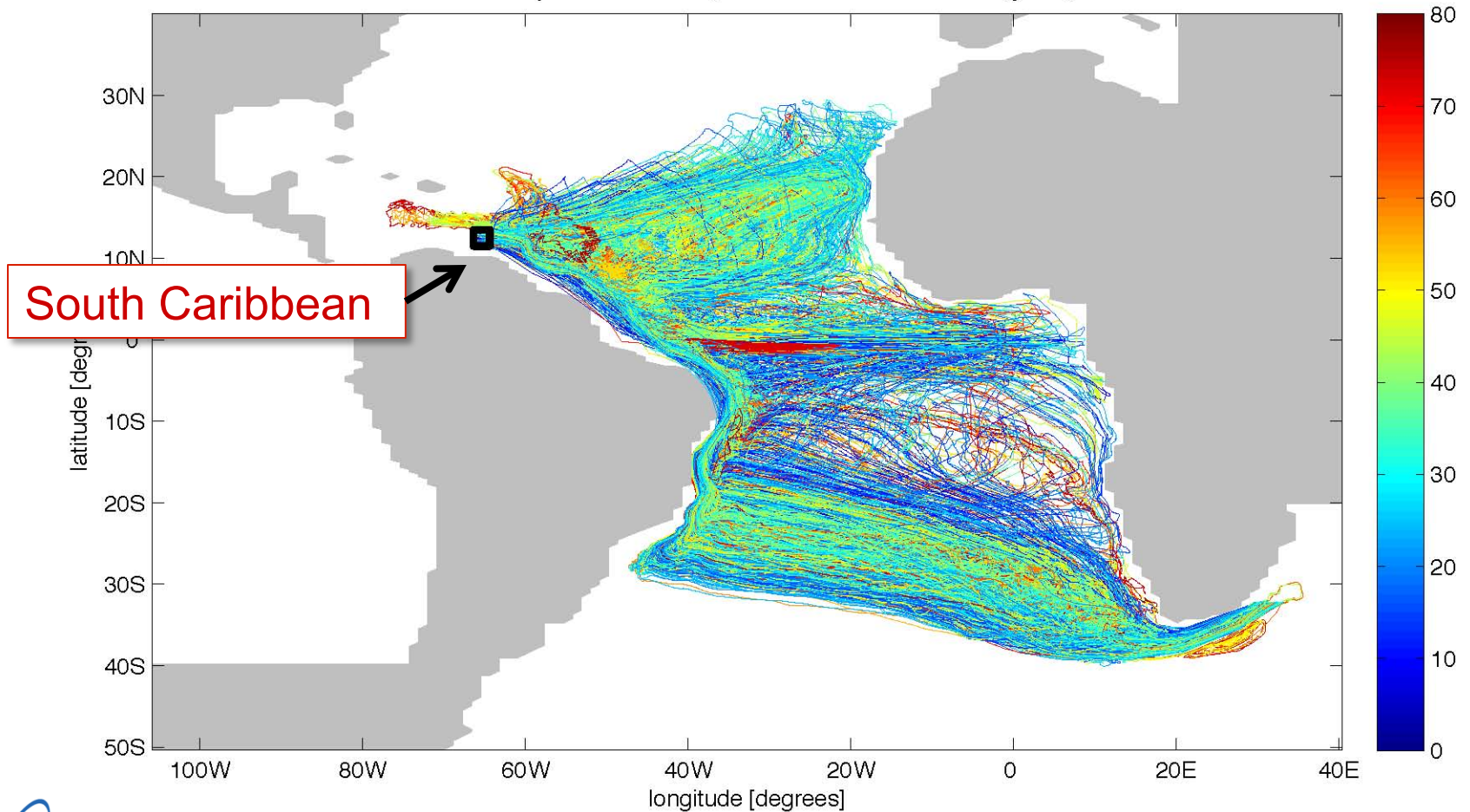


Signal Propagation: Lagged Correlation



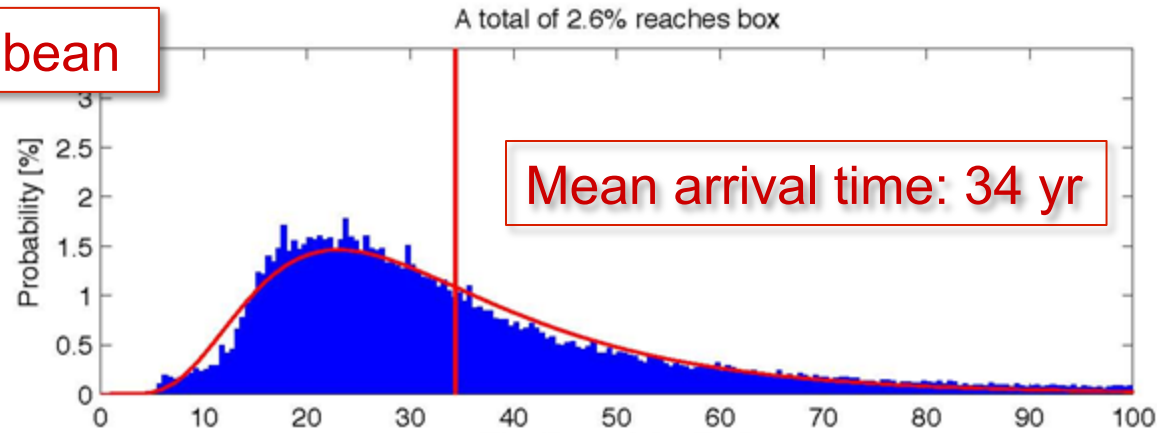
Signal Propagation: Lagrangian Floats

All 1258 trajectories into box, color coded for transit time [years]



Signal Propagation: Lagrangian Floats

South Caribbean



Conclusions

- **No discernible impact of Agulhas Leakage variability on MOC**
 - Study is inconclusive: salinity variability too weak
- **Advective pathway is present**

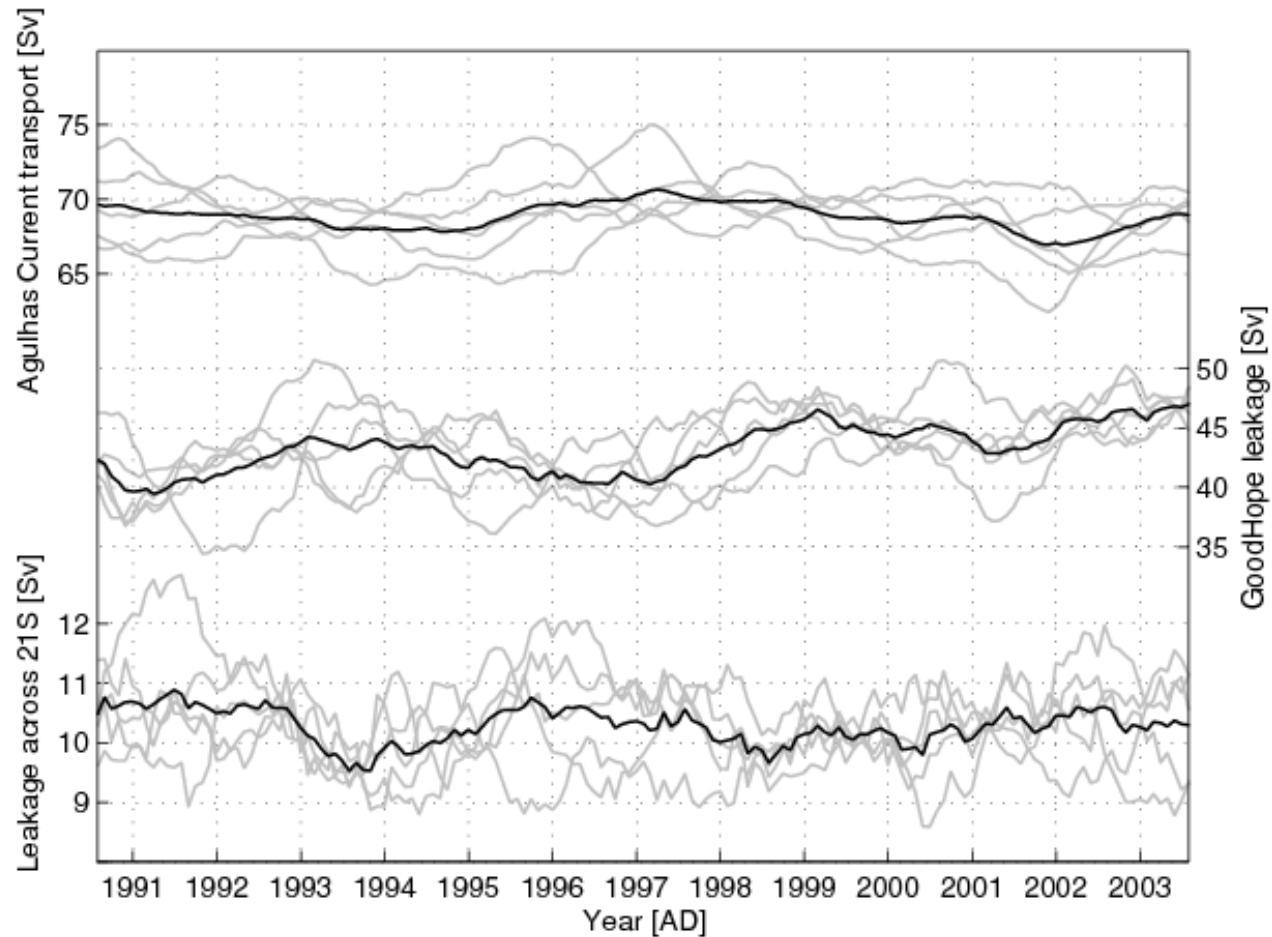
CCSM4: Analyses

- **1850 Pre-industrial control**
 - Spun up from rest
 - Fixed 1850 conditions
 - Last *500 yr* of 1300 yr simulation
- **20th century runs**
 - Initialized at 1850
 - Time-varying forcing
 - Greenhouse gases
 - Solar output
 - ...
 - Last *26 yr* of 156 yr simulations
 - 5 ensemble members

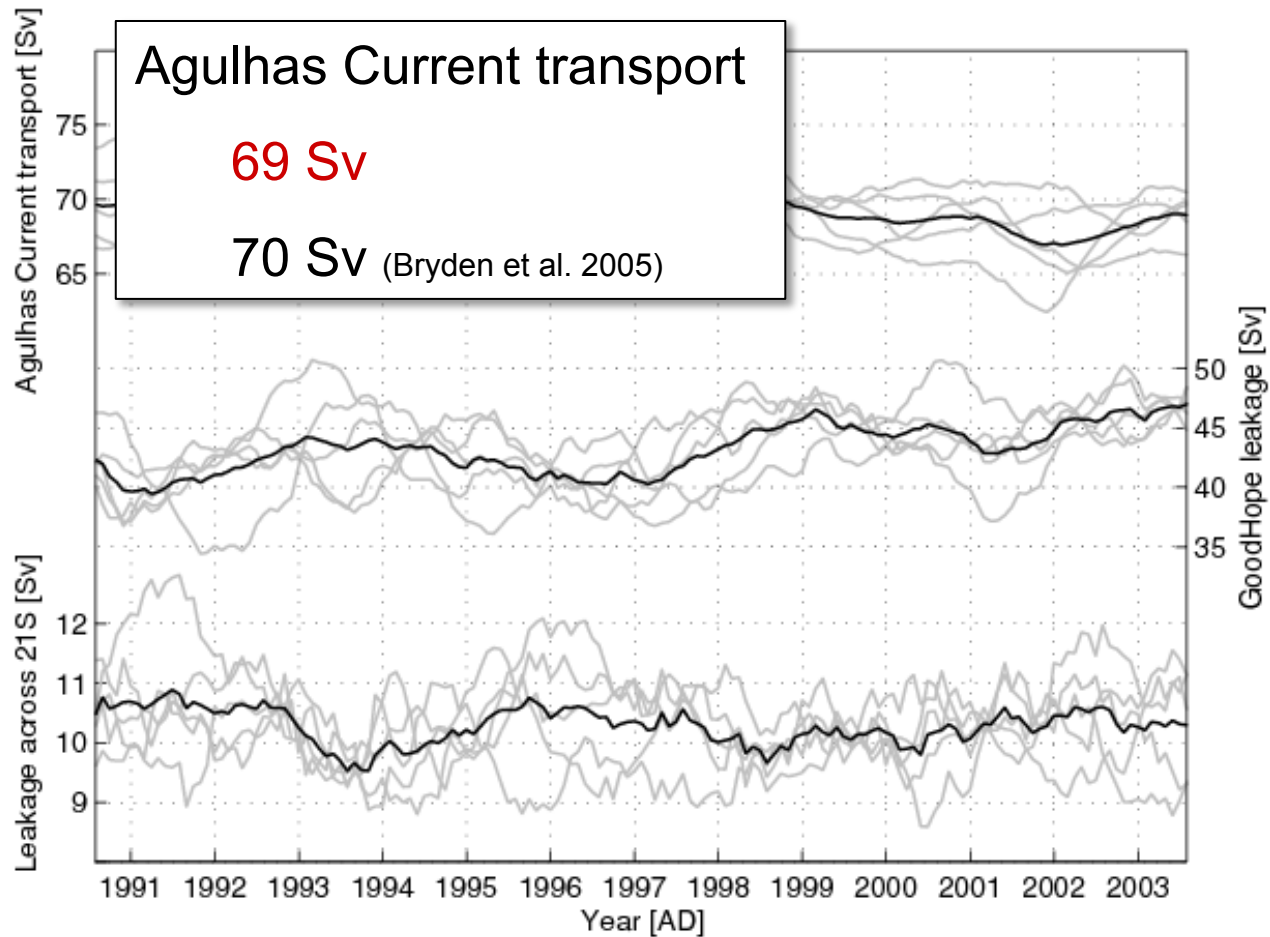
Agulhas Leakage in CCSM4

- **20th century runs**
- **Lagrangian analysis**
 - Monthly 3D velocity fields, 1980-2005
 - Release 110,000 numerical floats in Agulhas Current
 - How many make it into South Atlantic?
 - How many make it across 21°S?

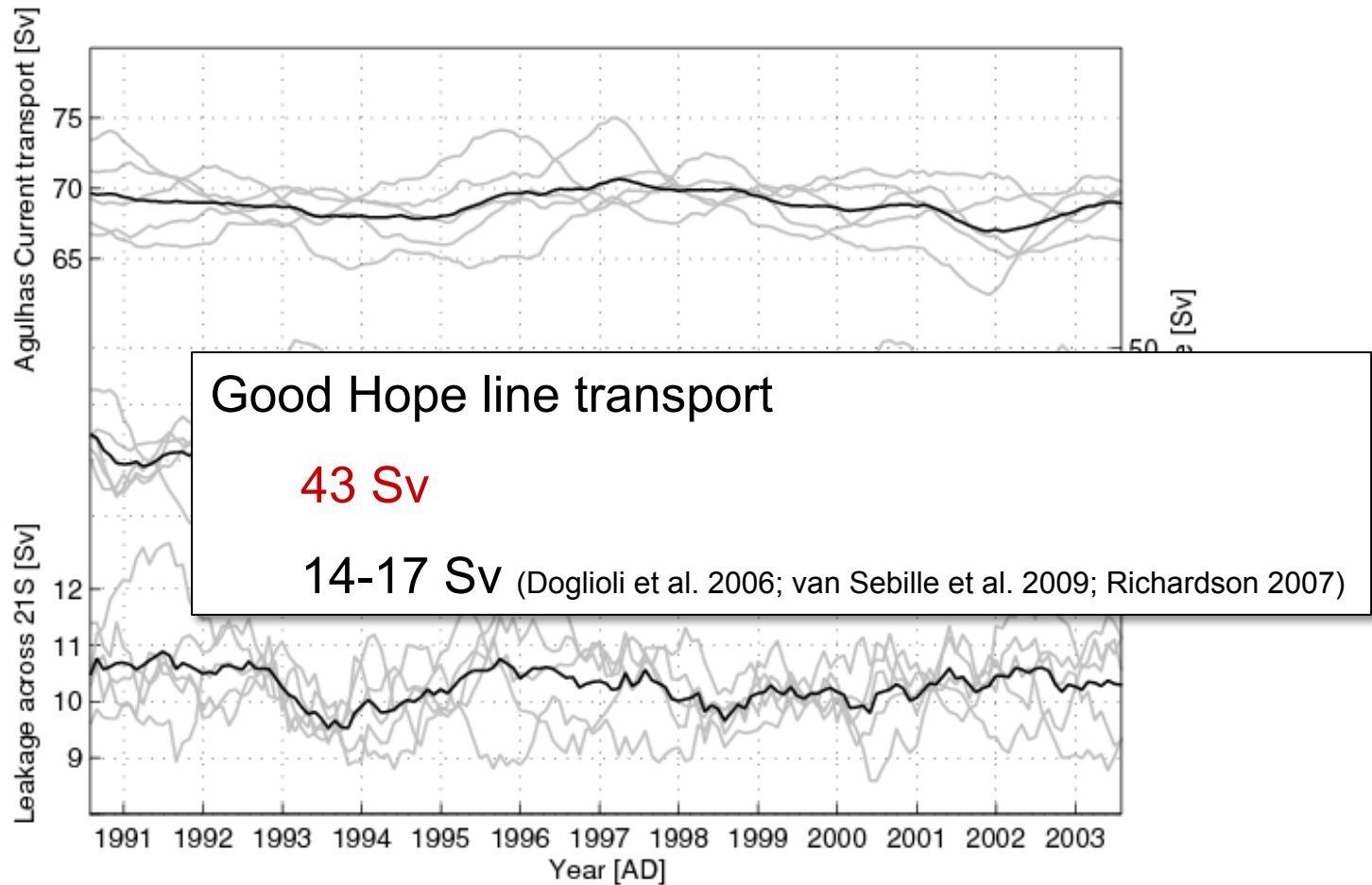
Agulhas Leakage in CCSM4: Mean Transports



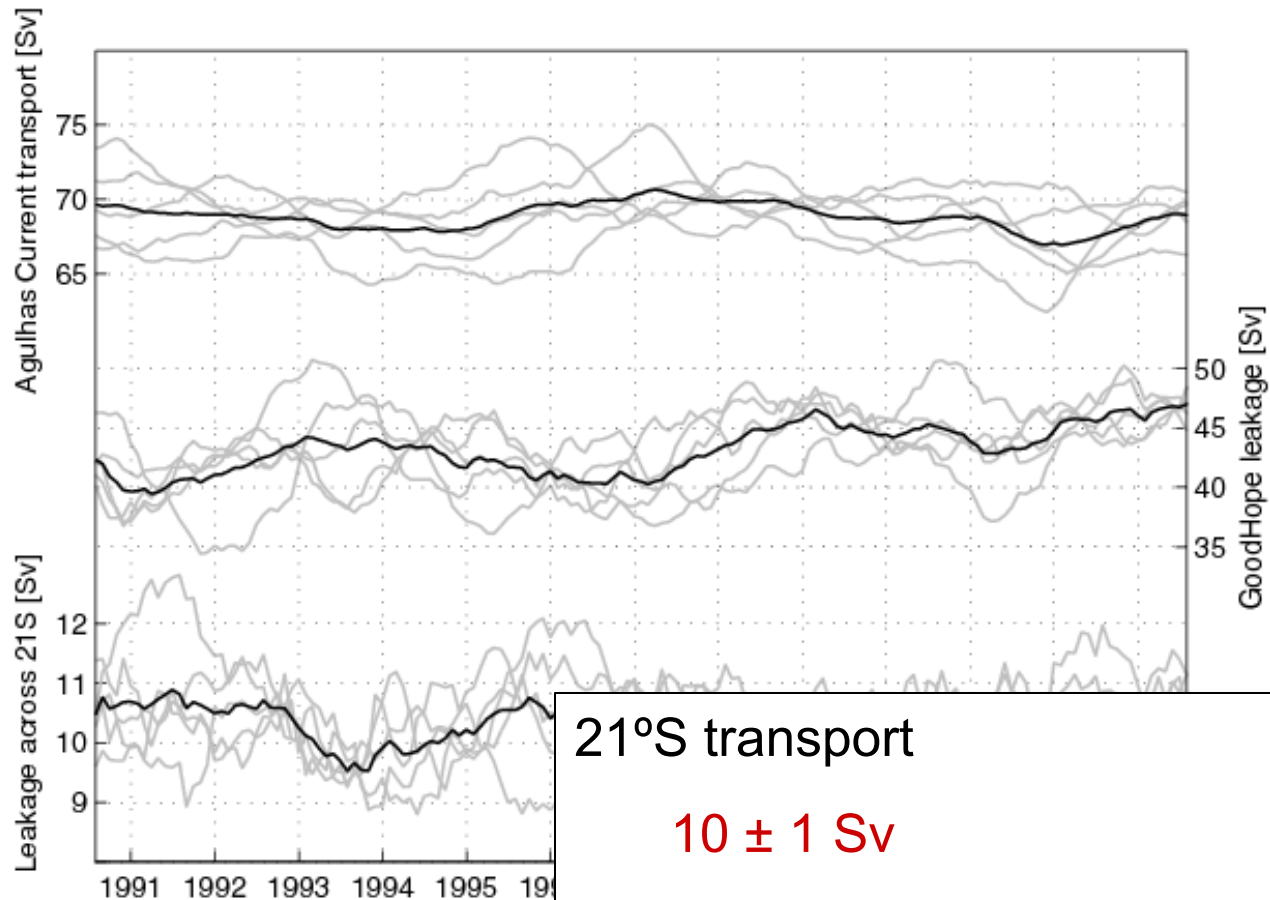
Agulhas Leakage in CCSM4: Mean Transports



Agulhas Leakage in CCSM4: Mean Transports



Agulhas Leakage in CCSM4: Mean Transports



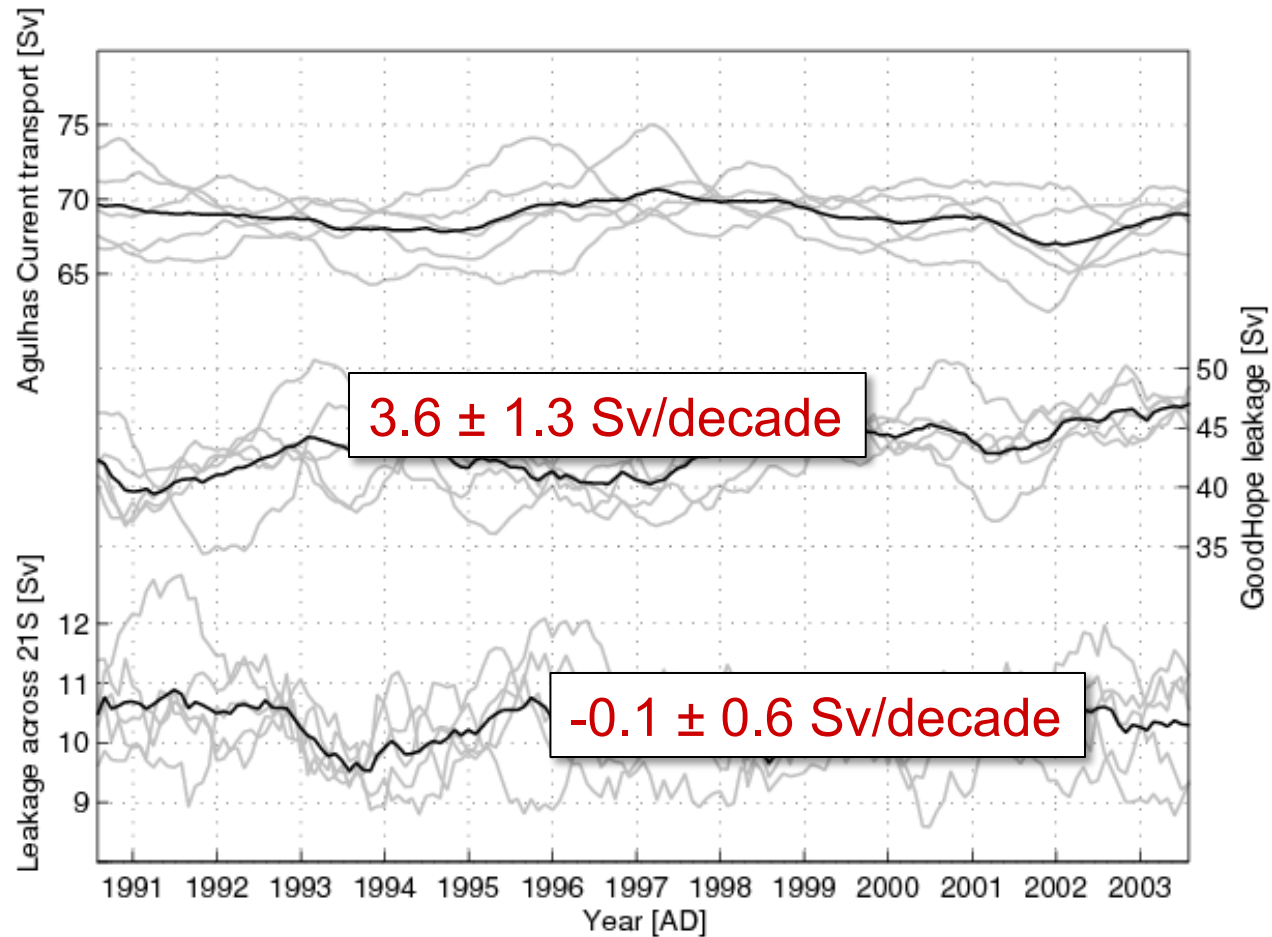
21°S transport

10 ± 1 Sv

10 Sv (Donners and Drijfhout 2004)

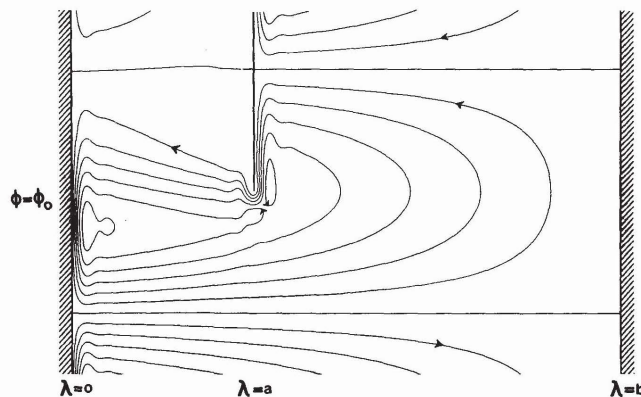
4 Sv (Biaostoch et al. 2009)

Agulhas Leakage in CCSM4: Trends



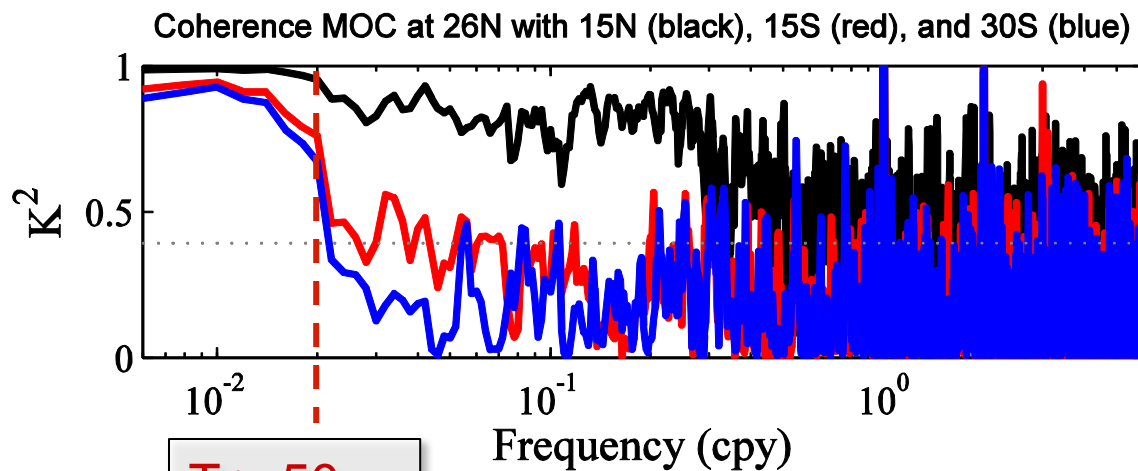
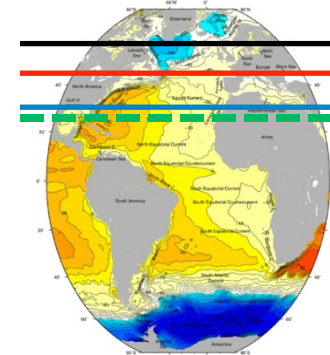
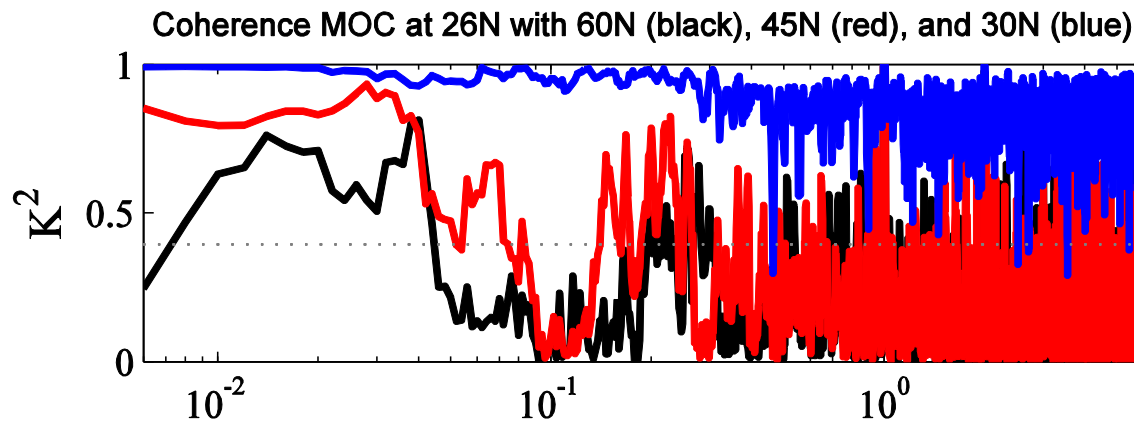
Agulhas Leakage in CCSM4: Conclusions

- Agulhas Current okay
- Agulhas Leakage overestimated by factor ~ 3
- 75 % recirculates in super-gyre
- Why?
 - Agulhas Retroflection *inertial* process
 - Not captured by low-resolution 1° models
 - Instead, leakage takes place in *viscous* boundary layer

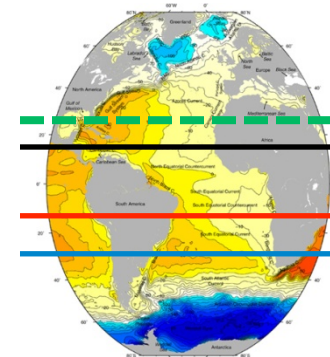


De Ruijter (1982)

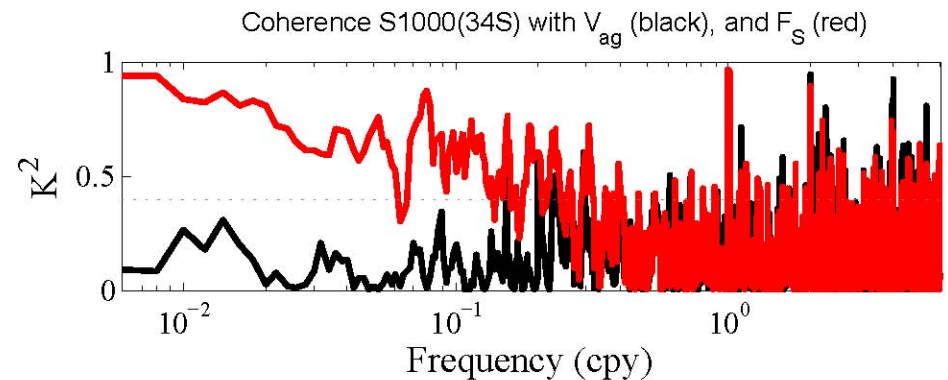
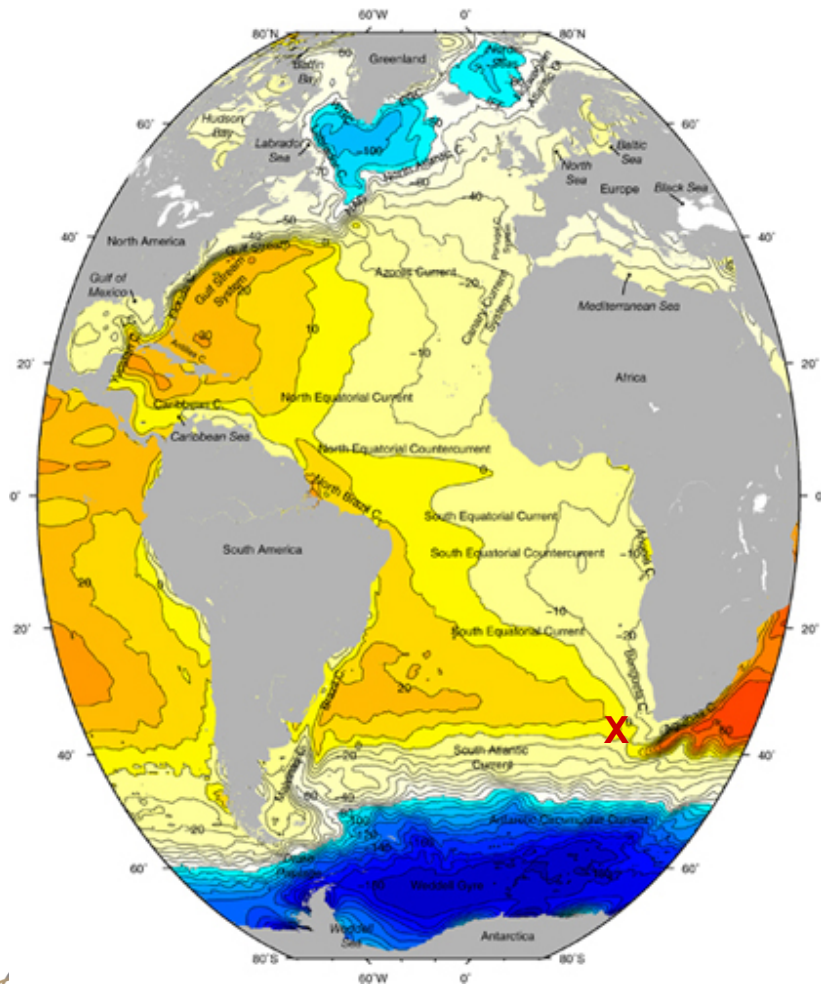
Meridional Coherence of the AMOC



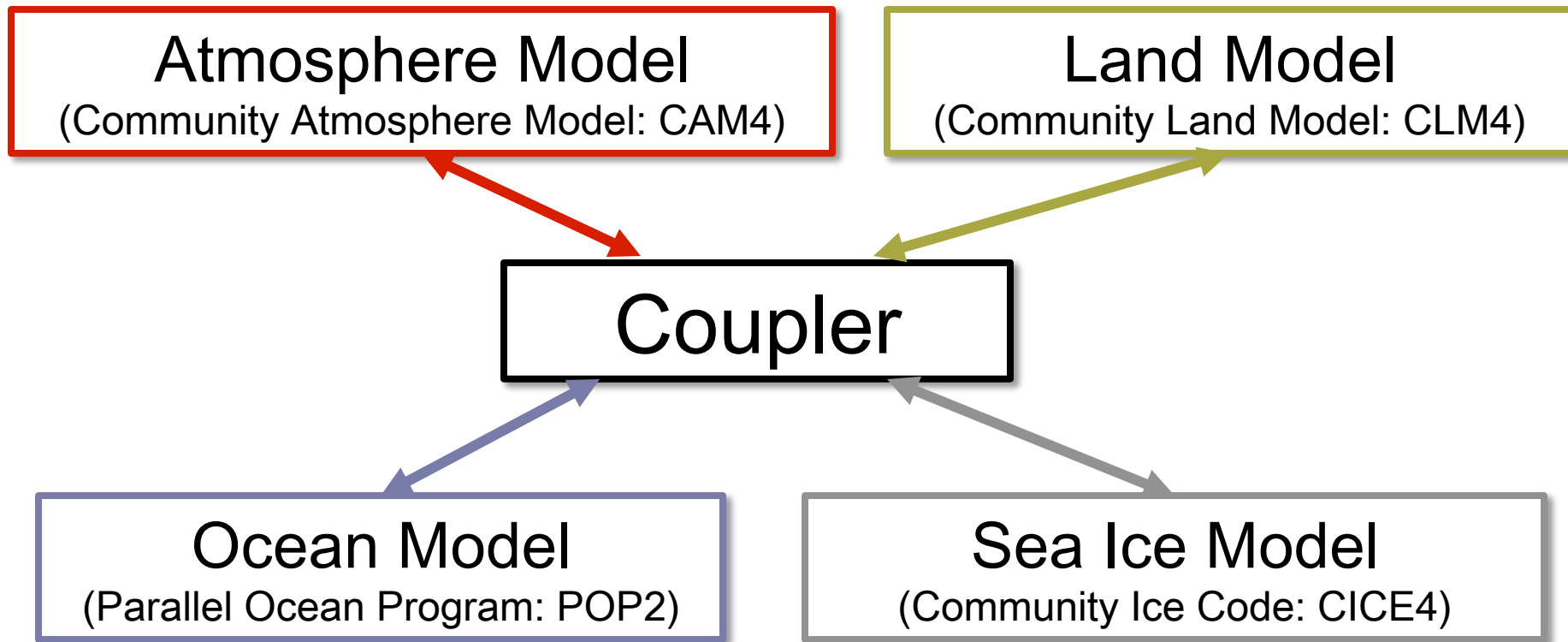
$T > 50 \text{ yr}$



Good Metric of Agulhas Leakage Impact?



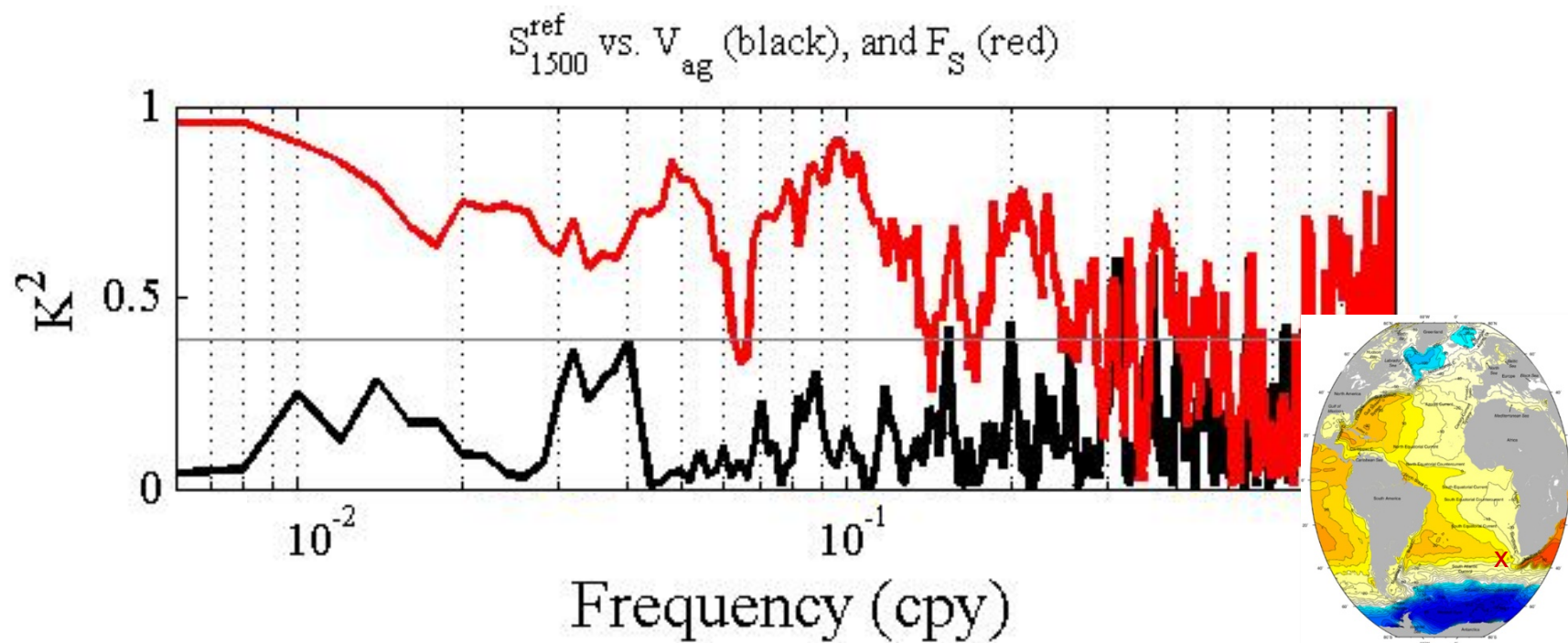
CCSM4



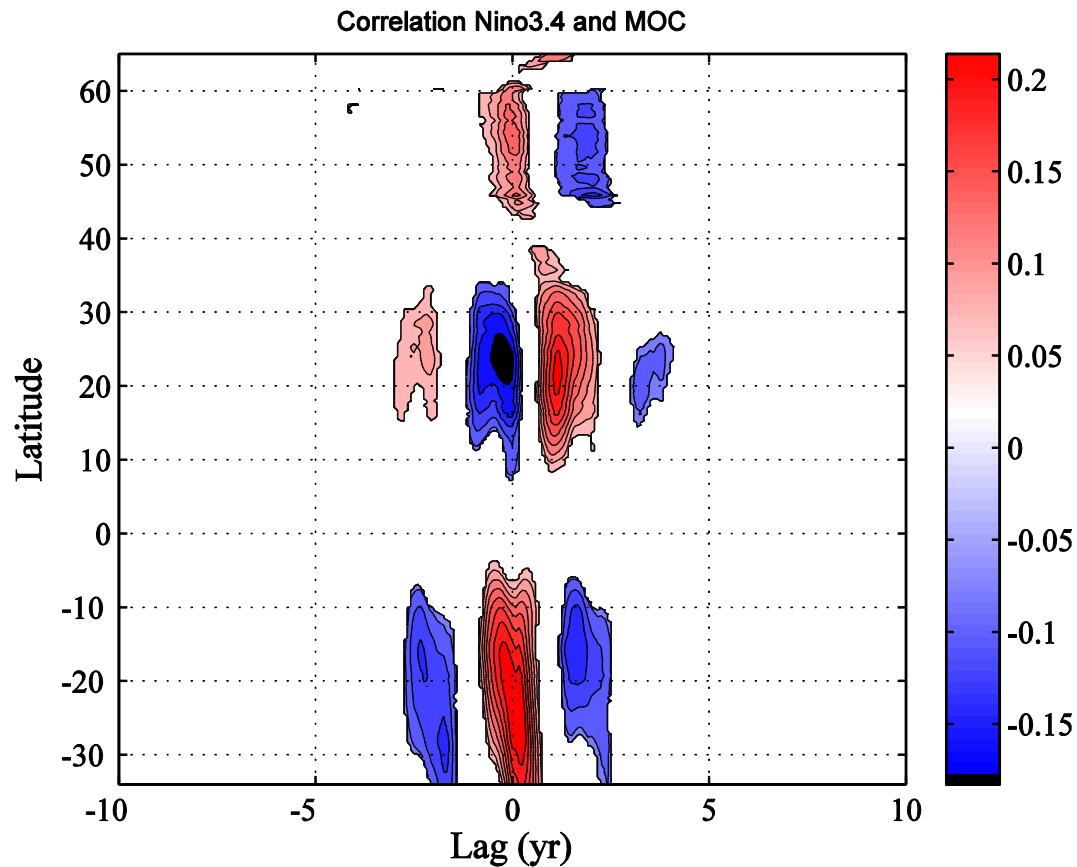
Does Agulhas Leakage influence MOC in CCSM4?

■ Coherence

- Salinity in southeastern Atlantic coherent with F_S but not with V_{ag}



Joint Response to ENSO: AMOC



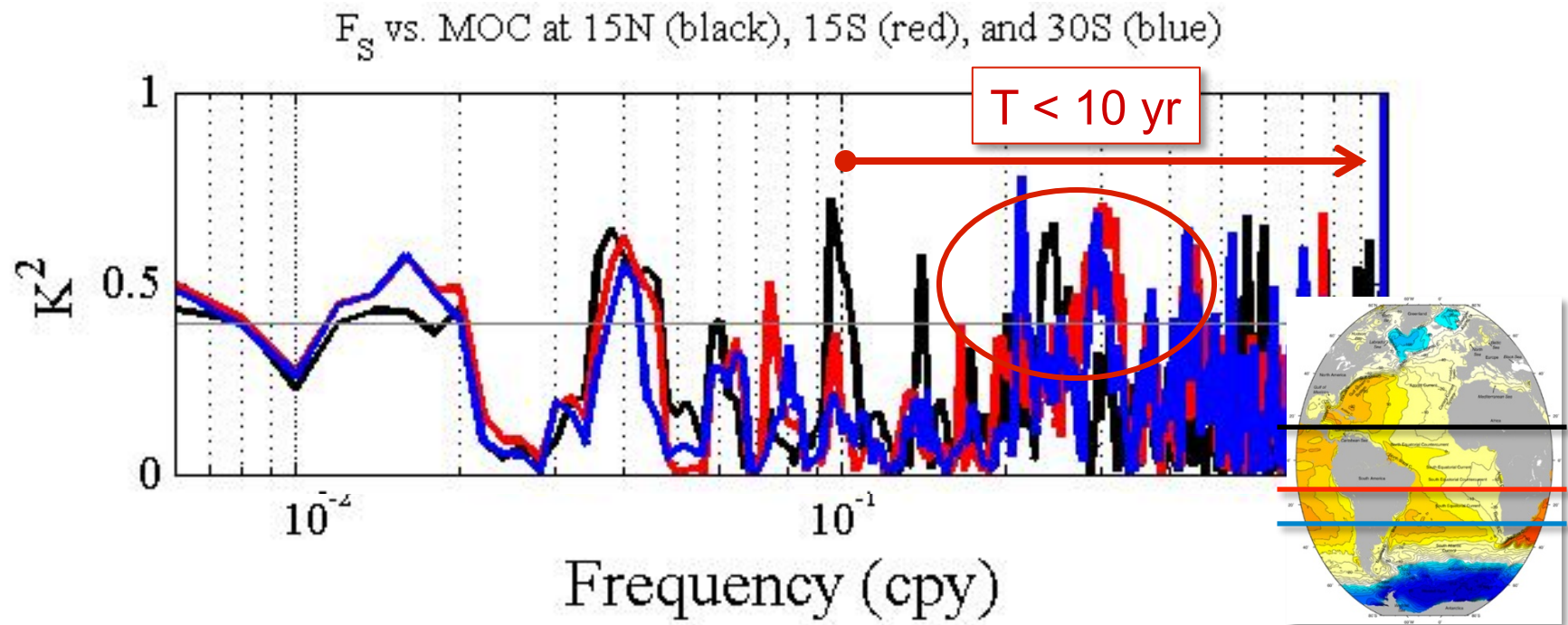
CCSM4

- **Community Climate System Model, version 4**
 - Joint NSF/DOE funded project
 - National Center for Atmospheric Research (NCAR)
 - Los Alamos National Laboratory (LANL)
- **CMIP5: Coupled Model Intercomparison Project**
 - World Climate Research Program (WCRP)
 - Standard experimental protocol for climate model comparison
 - Science input into IPCC's 5th assessment report (AR5; 2013)

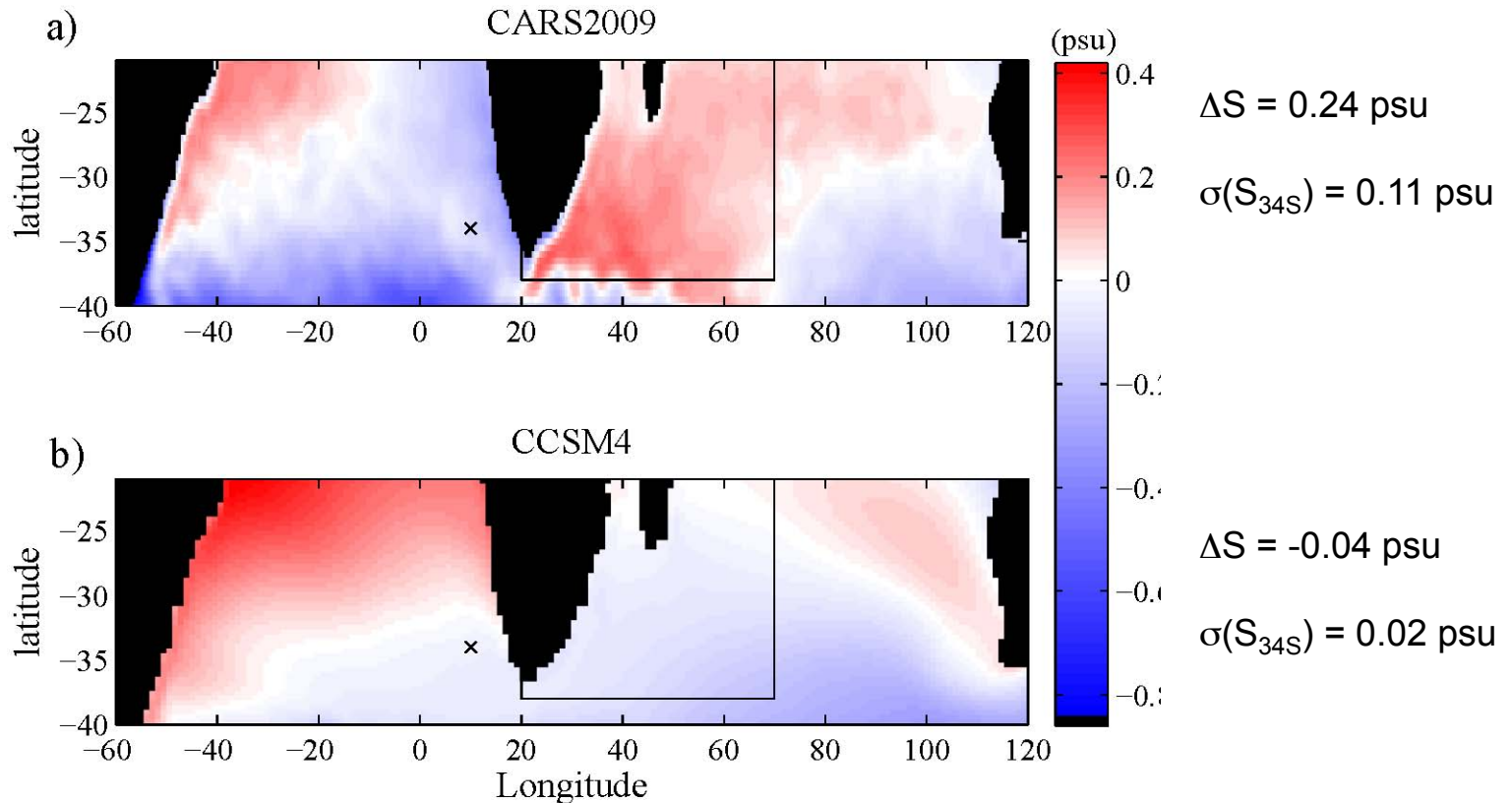
Agulhas Leakage vs. MOC

■ Coherence: *Interannual (1-10 yr)*

- F_S *not* coherent with MOC
- At 4-5 yr, joint response to ENSO

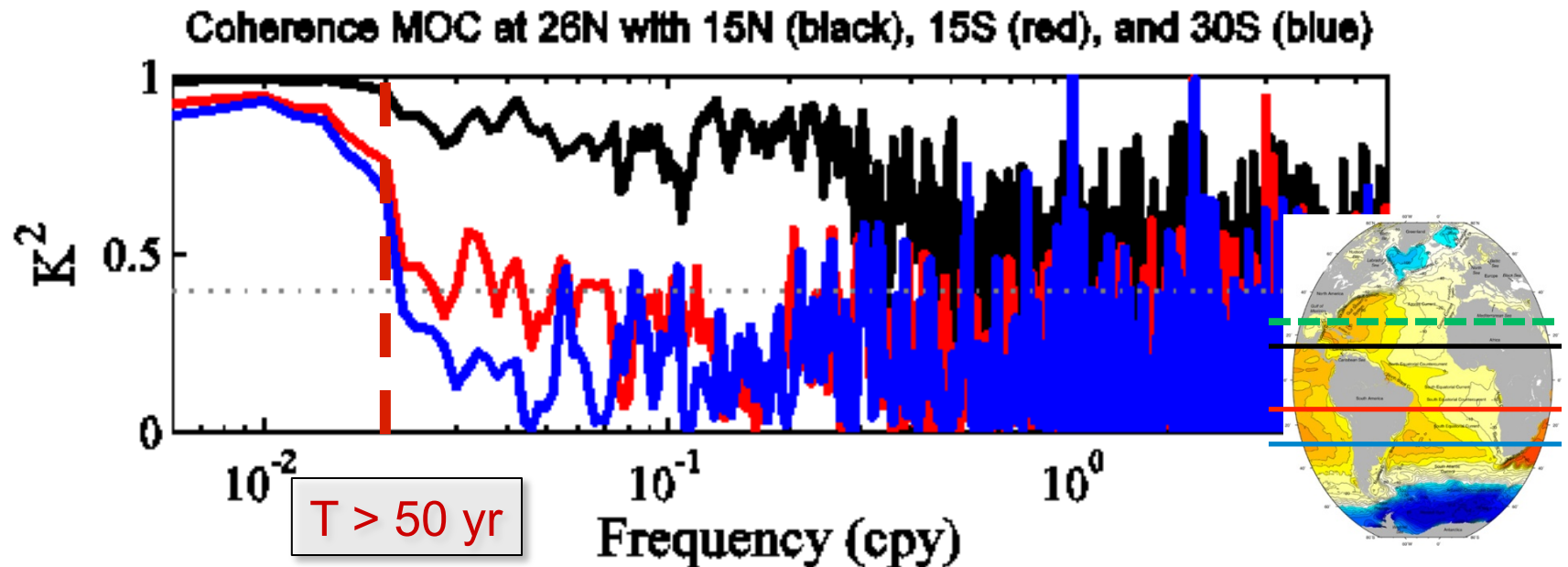


Salinity Bias



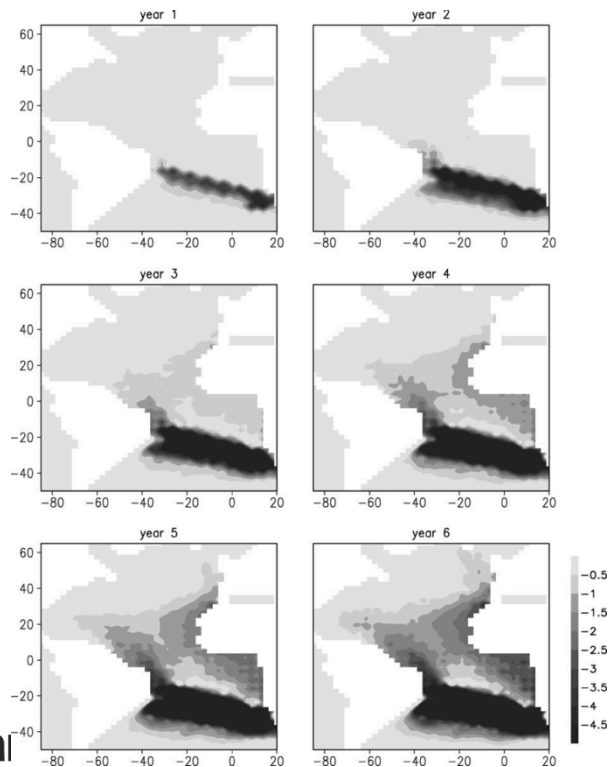
Wave Adjustment

- Meridional coherence of the AMOC
 - MOC at 26°N with MOC at 15°N, 15°S, 30°S



Mechanisms

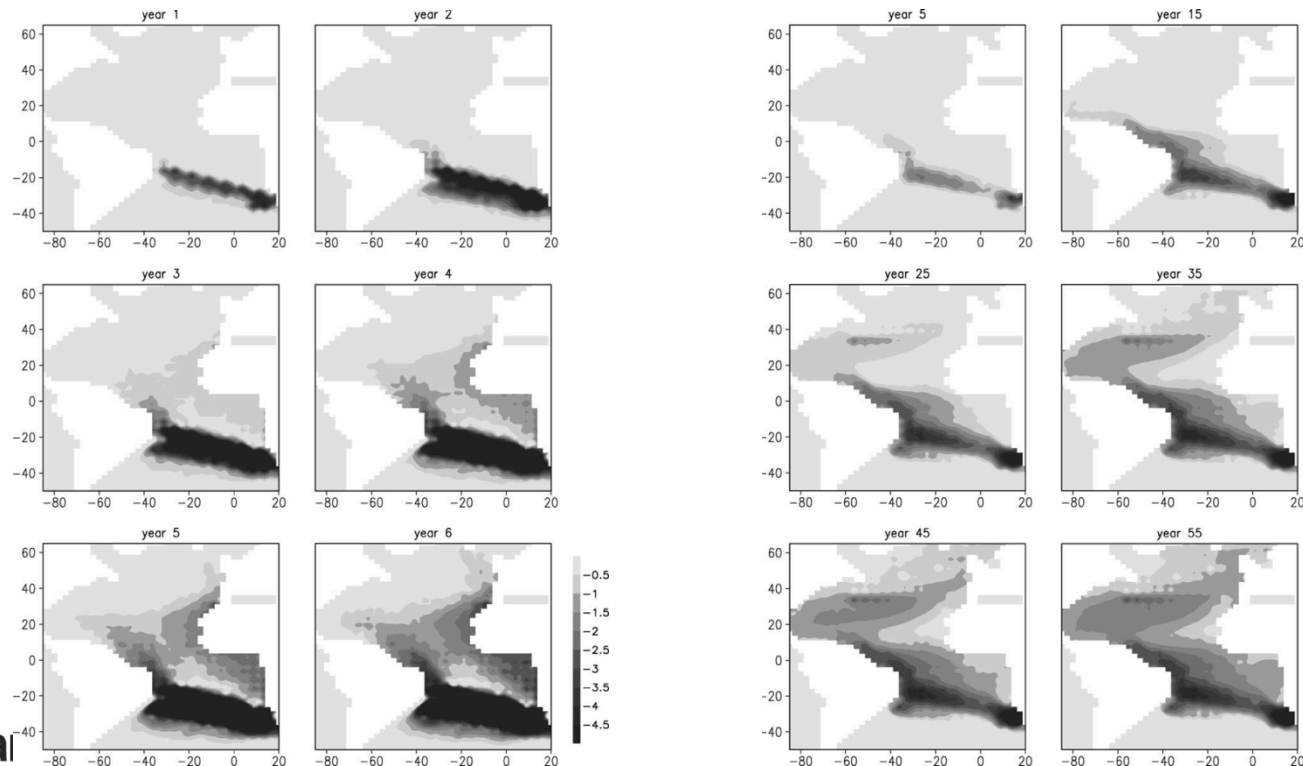
- **Wave adjustment**
 - Kelvin/Rossby waves



Weijer et al. (2002)

Mechanisms

- **Wave adjustment**
 - Kelvin/Rossby waves
- **Advective adjustment**



Weijer et al. (2002)