# Estimating the Meridional Heat Transport and Overturning Circulation from XBTs

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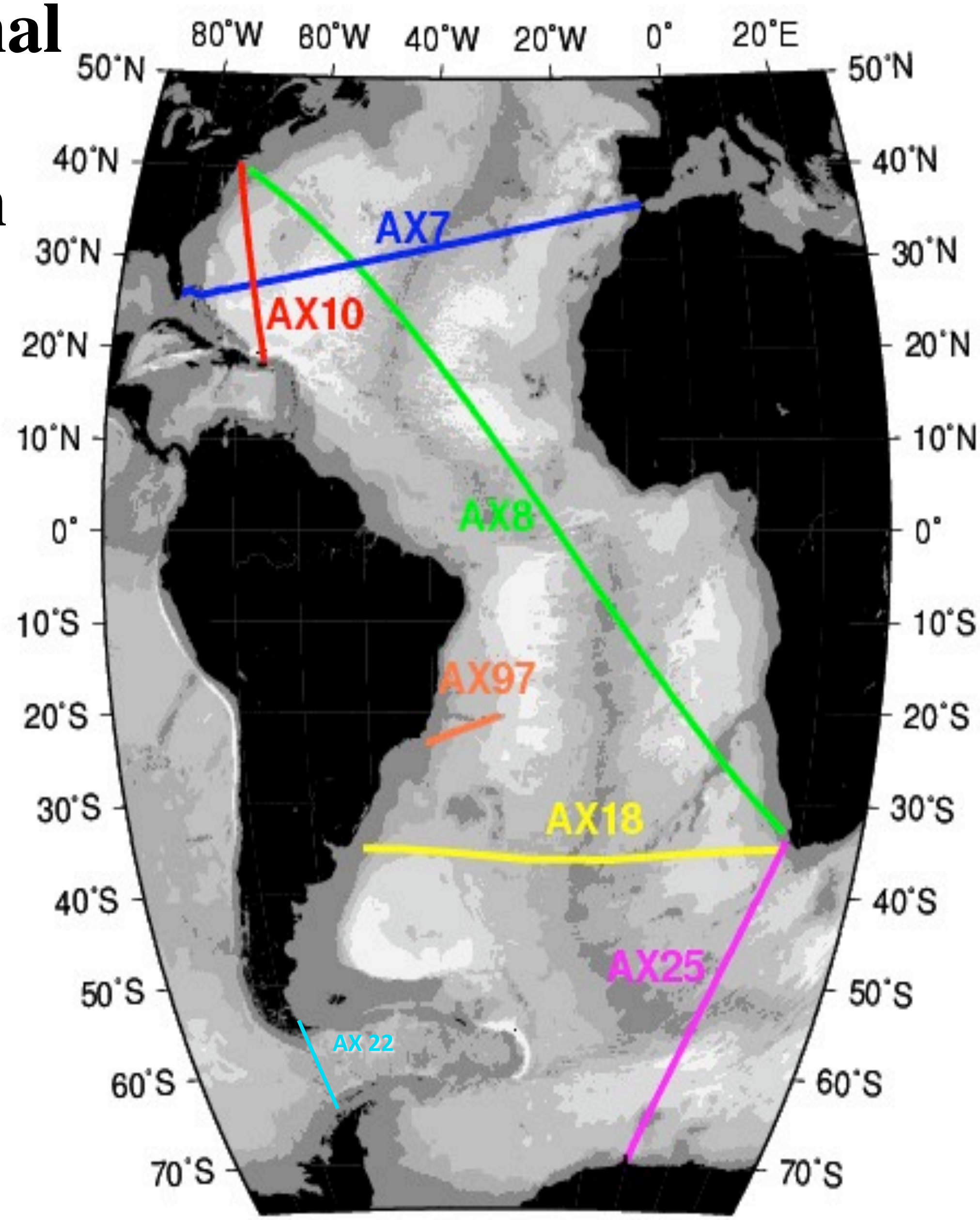
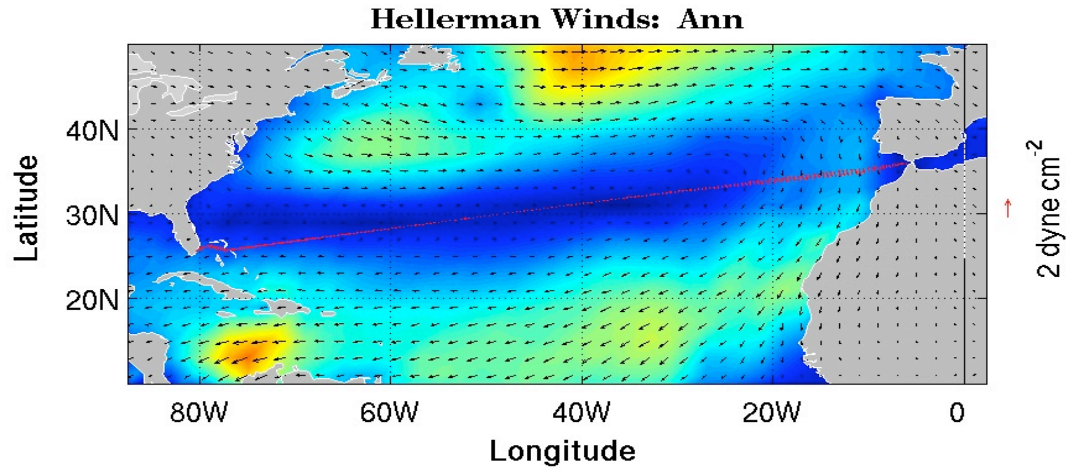
Objective: To analyze the AMOC variability in the Atlantic using both available observations and a non data-assimilative simulation of the AMOC with the aim of defining the importance of variations in inter-ocean and inter-basin exchange and the connectivity.



*Direct estimates of meridional volume, mass and heat (H) transport across a vertical section require T, S and velocity observations:*



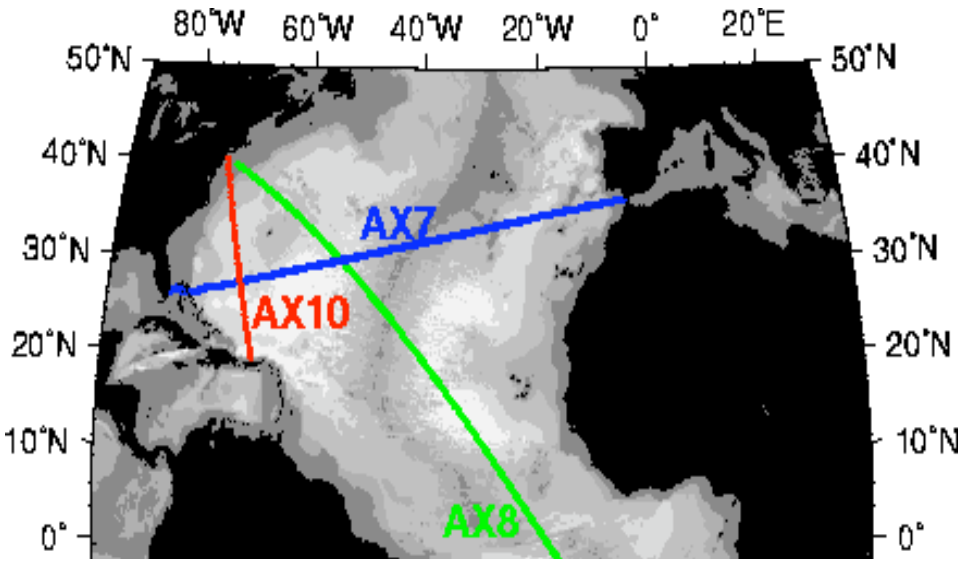

$$H = \int\int \rho c_p \theta v \, dx \, dz \qquad \left[PW = 10^{15} Watts\right]$$

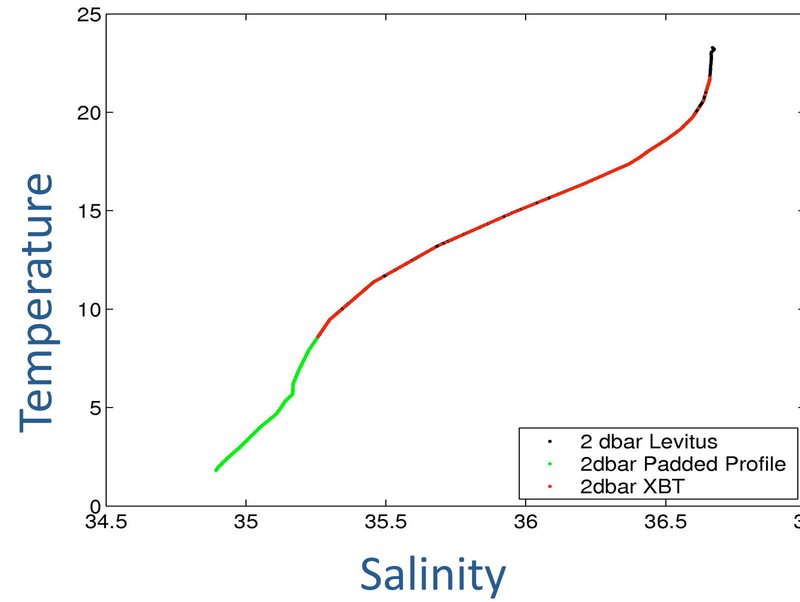
$$v = v_g + v_{ag} + v_b$$

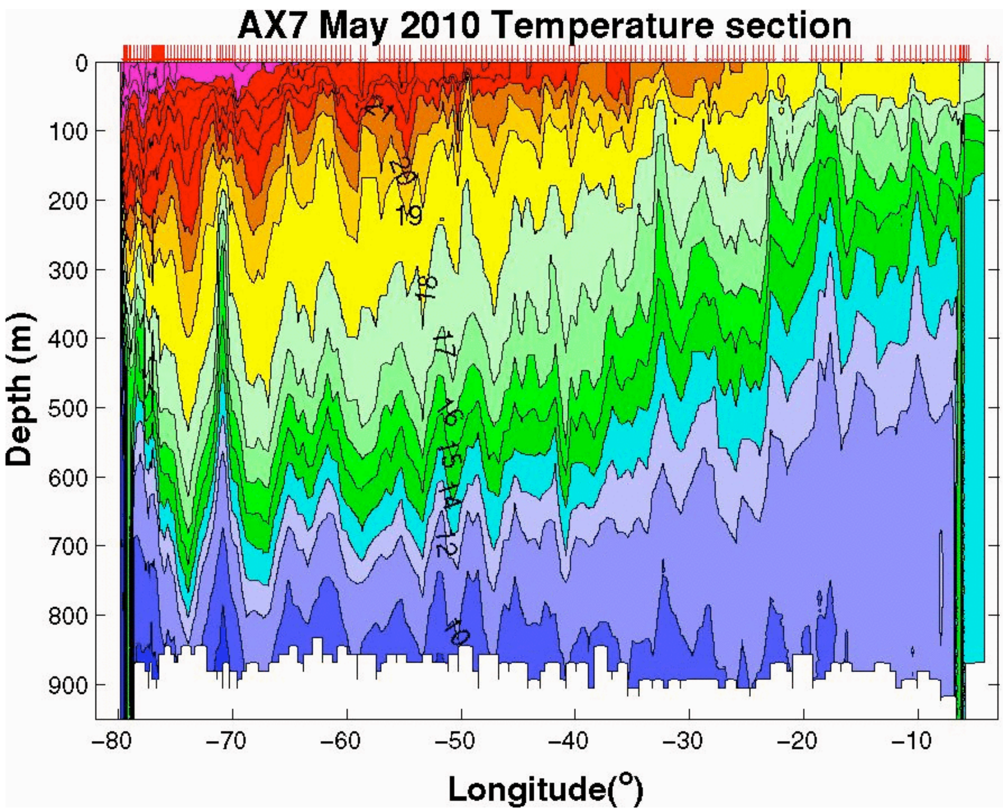
XBT observations ($v_g$)

Wind products + ?? ($v_{ag}$)

?? Florida Current / Brazil Current / Mass Adjustments ($v_b$)



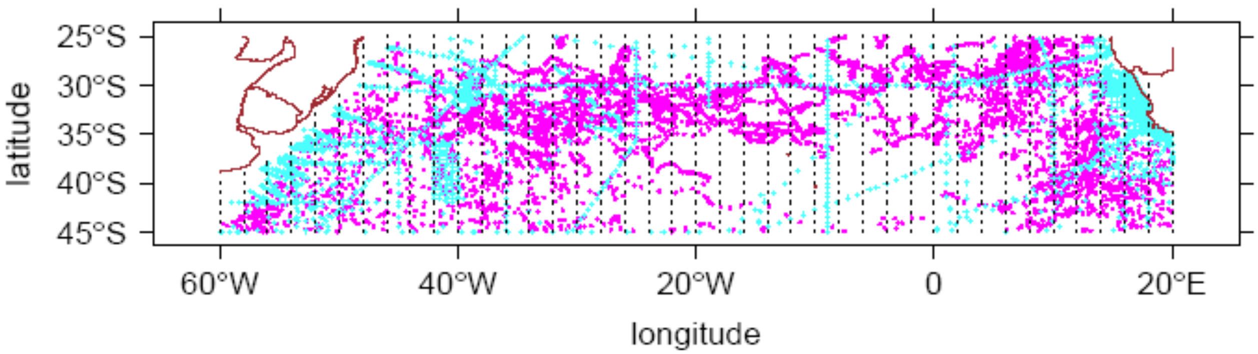



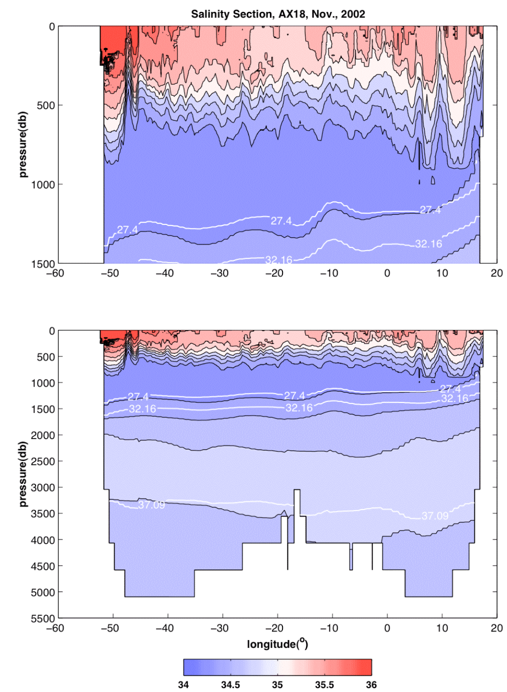



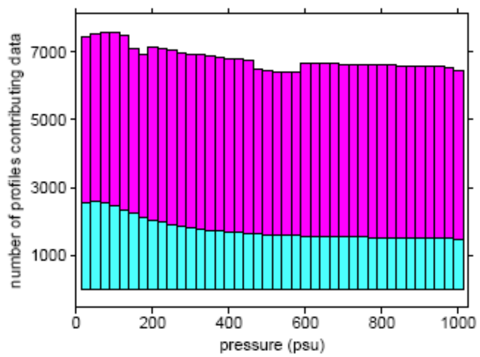

Annual mean Levitus
¼ degree climatology provides a T/S for missing data below the depth of the XBT.

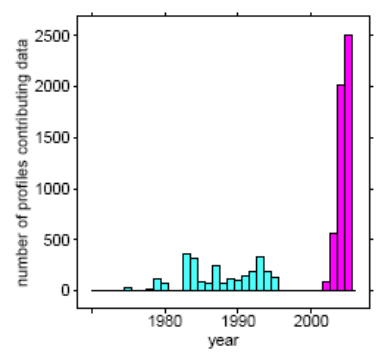
- North Atlantic: T/S lookup
- South Atlantic T/S lookup using Thacker2006 *f*(lat,lon,z,T)

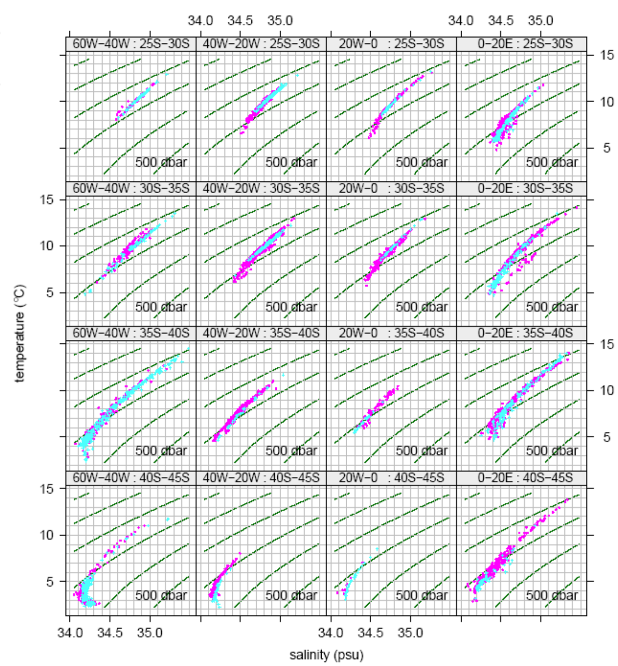
# Salinity Estimation

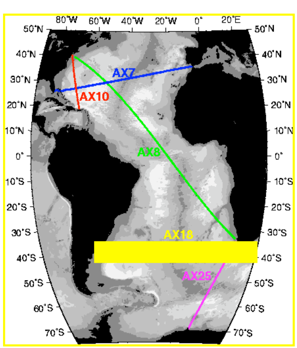


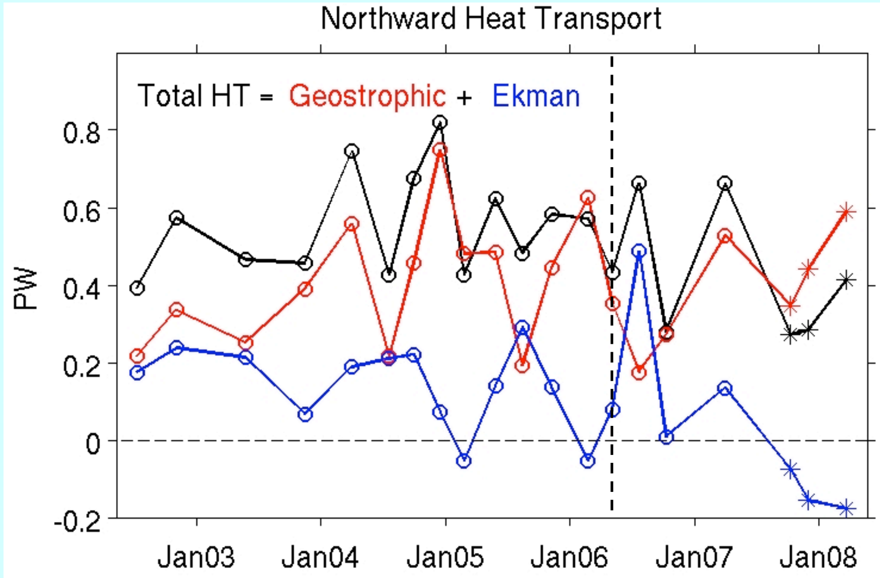



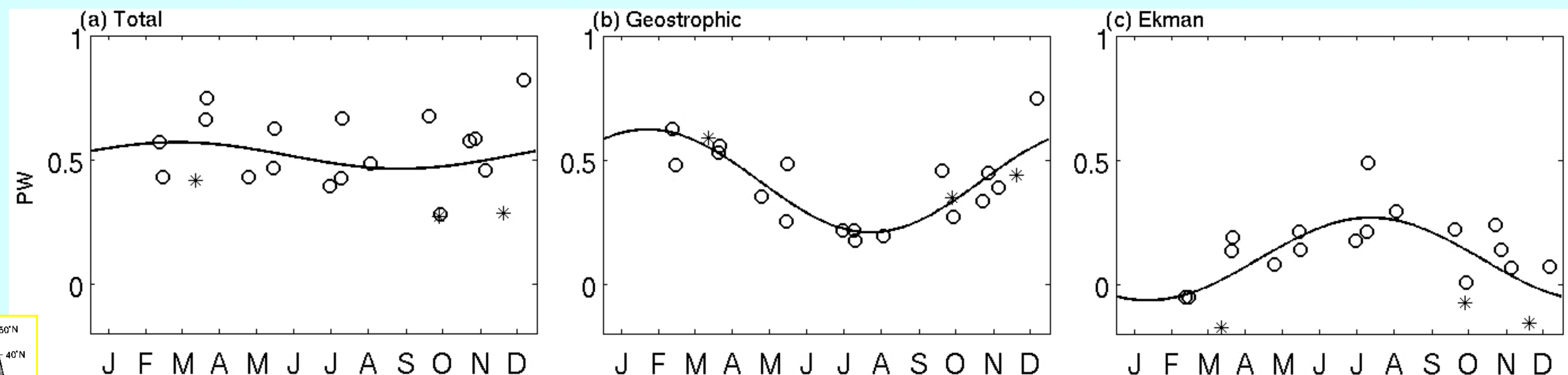

**Salinity** is estimated for each XBT profile by using S(T, P, Lat, Long) derived from Argo and CTD data Thacker (2006). Above Argo data (magenta) and CTD data (pink)

# Northward Heat Transport

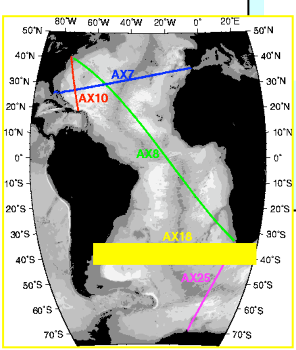



Total = 0.51 ± 0.15 PW
Geos. = 0.40 ± 0.16 PW
Ekman = 0.11 ± 0.16 PW

- Geostrophic transport controls the total northward heat transport.
- Geostrophic and Ekman transports experience comparable variability

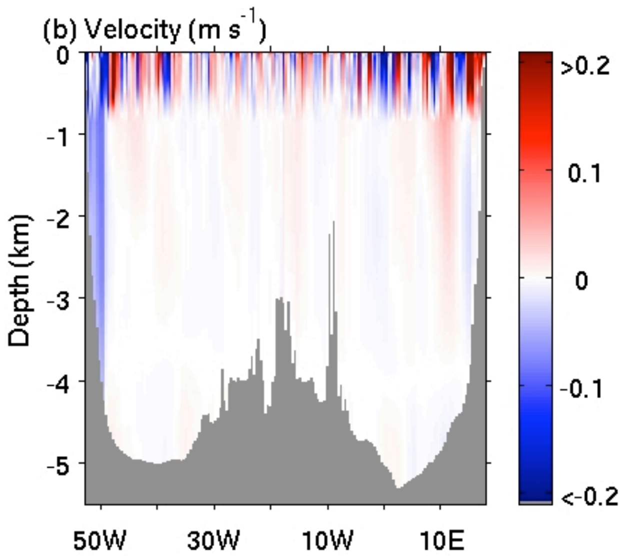



Both geostrophic and Ekman transports experience annual cycles, but they are out of phase.



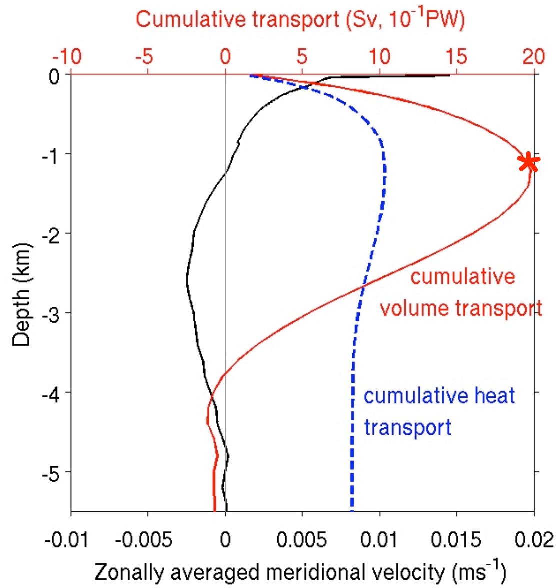

*Garzoli and Baringer (2007)*
*Baringer and Garzoli (2007)*

# Meridional Velocity and Transport Across AX18

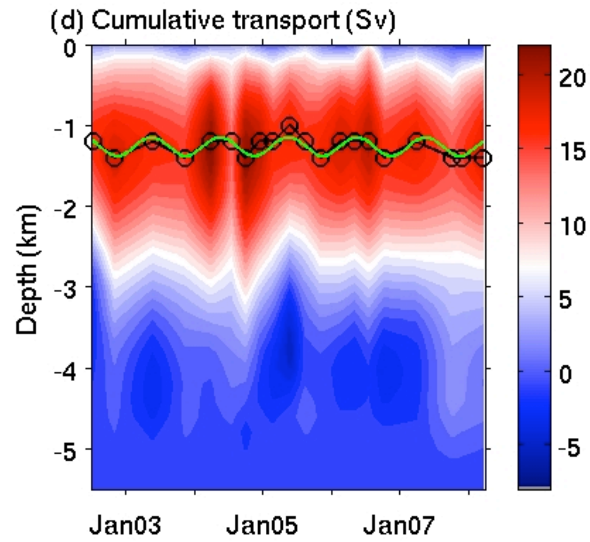



Meridional velocity distribution for December 2004 transect.

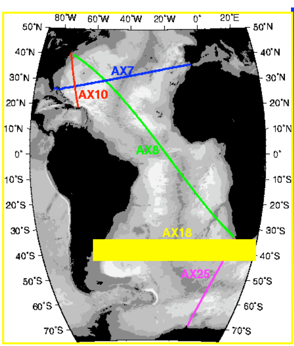
$$AMOC = \max\left(\int_0^Z \left[\int_{X_w}^{X_e} v(x,z)\,dx\right] dz\right)$$




Zonally averaged meridional velocity, and cumulative volume transport from sea surface to ocean floor.



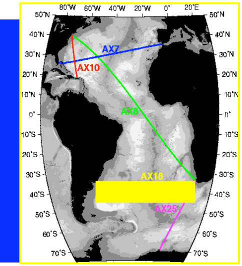

Cumulative volume transport (color), which reaches its maximum at 1300 m depth (black).

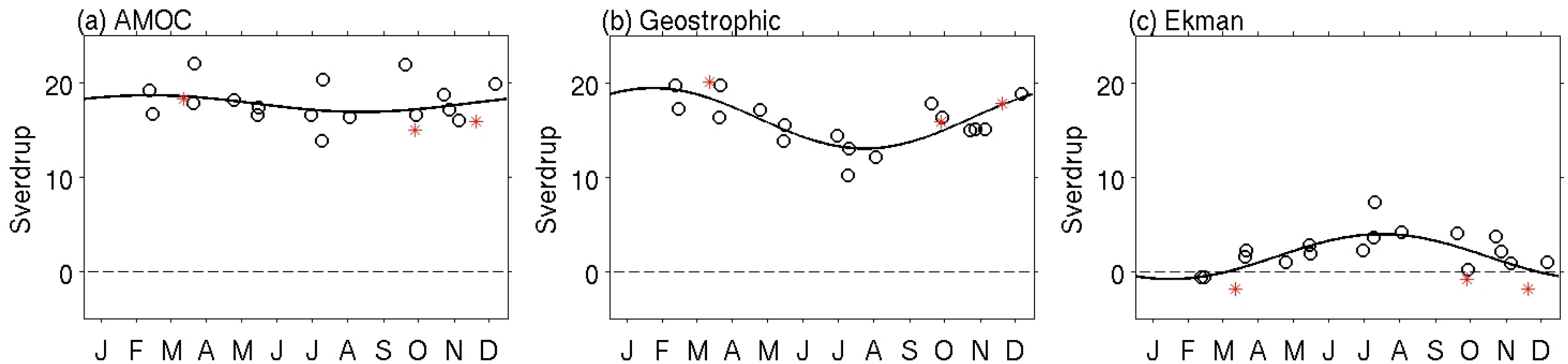



**Strength of AMOC**: the maximum cumulative transport (trans-basin integrated) from the sea surface to the ocean bottom, represents the total northward transport in upper water column.

**Dong et al 2009**

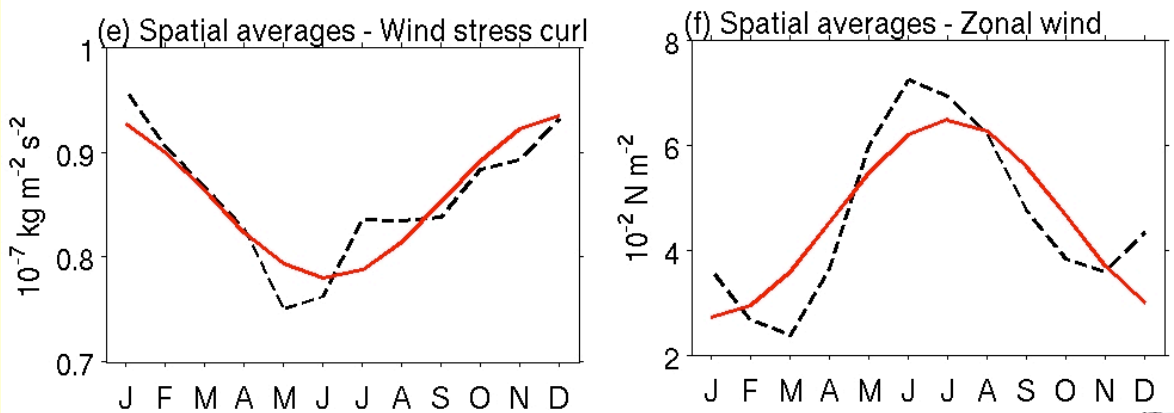
# Seasonal Variability of the Strength of the Meridional Overturning





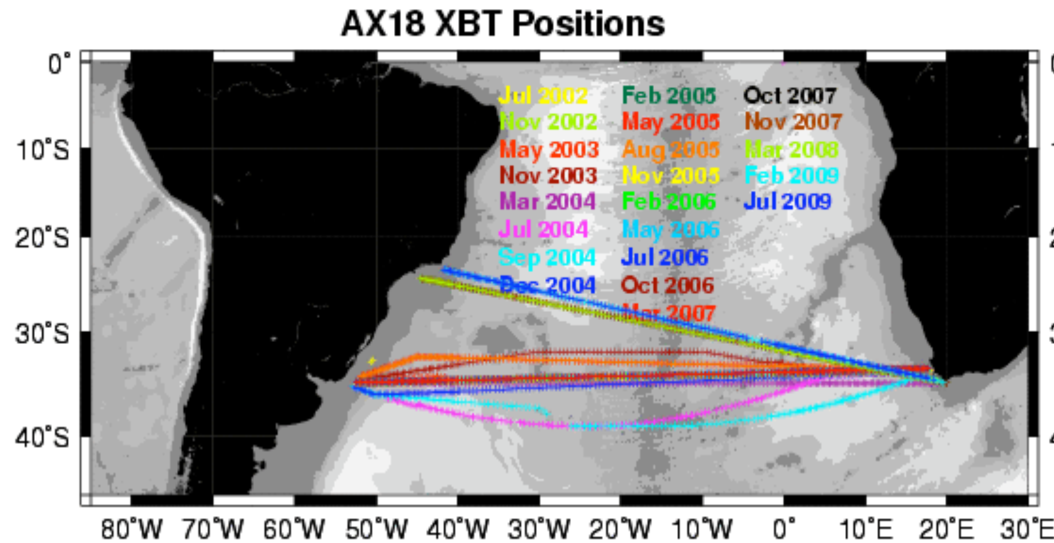

Both geostrophic and Ekman contributions to the AMOC experience annual cycles, but they are out of phase.

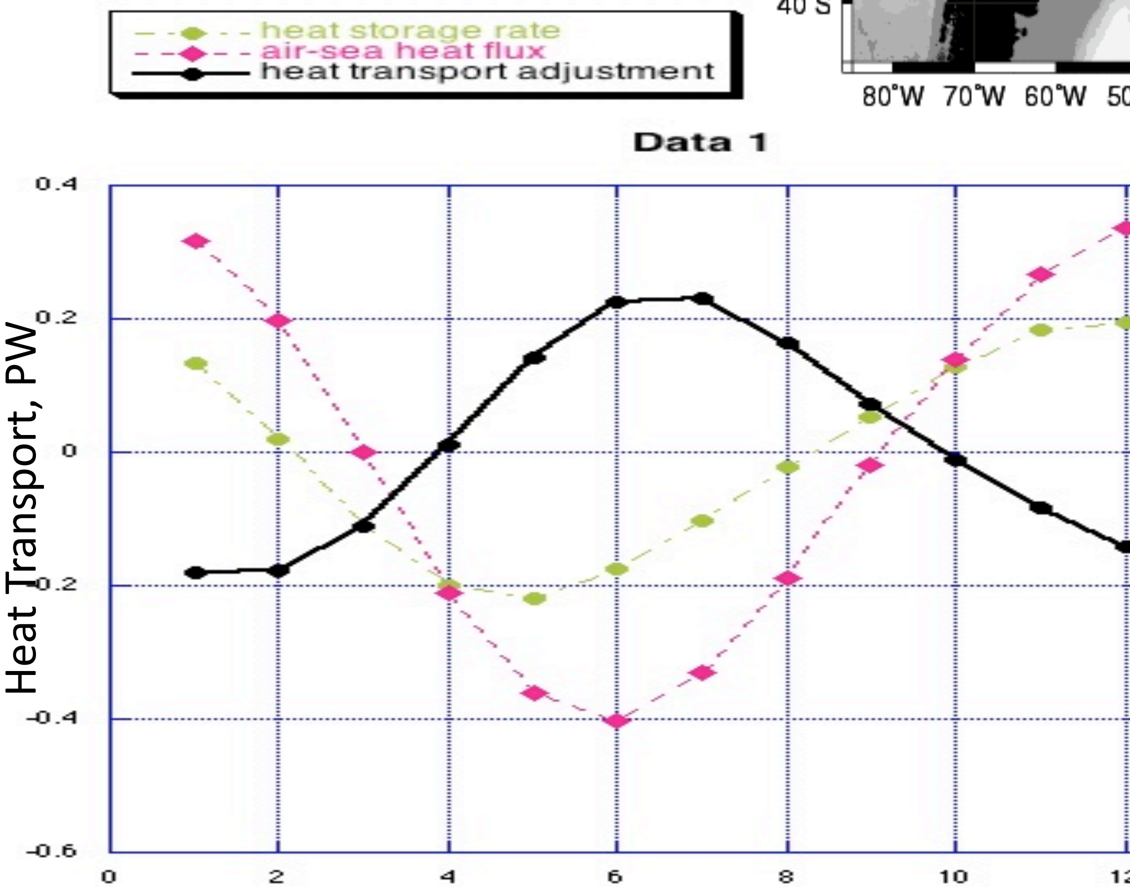
Seasonal cycles in geostrophic and Ekman components are consistent with the seasonal variations in wind stress curl and zonal wind stress, respectively.

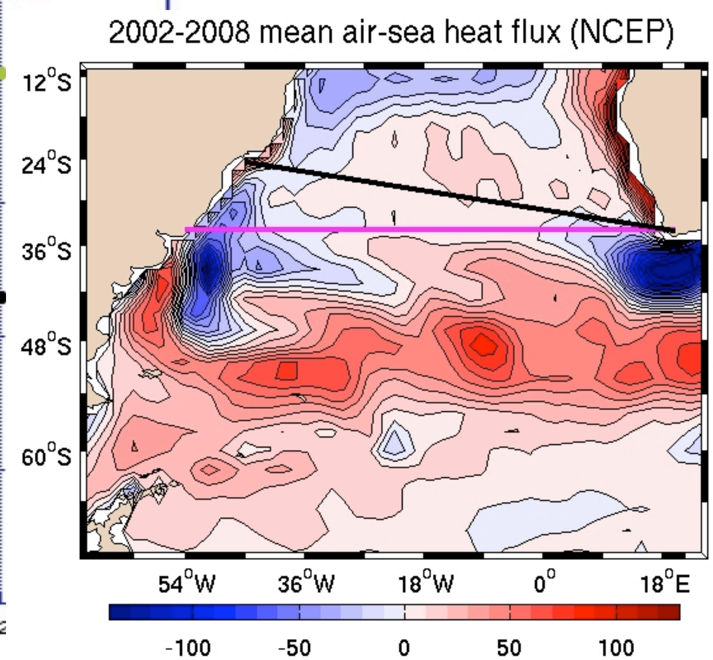



**Dong et al 2009**

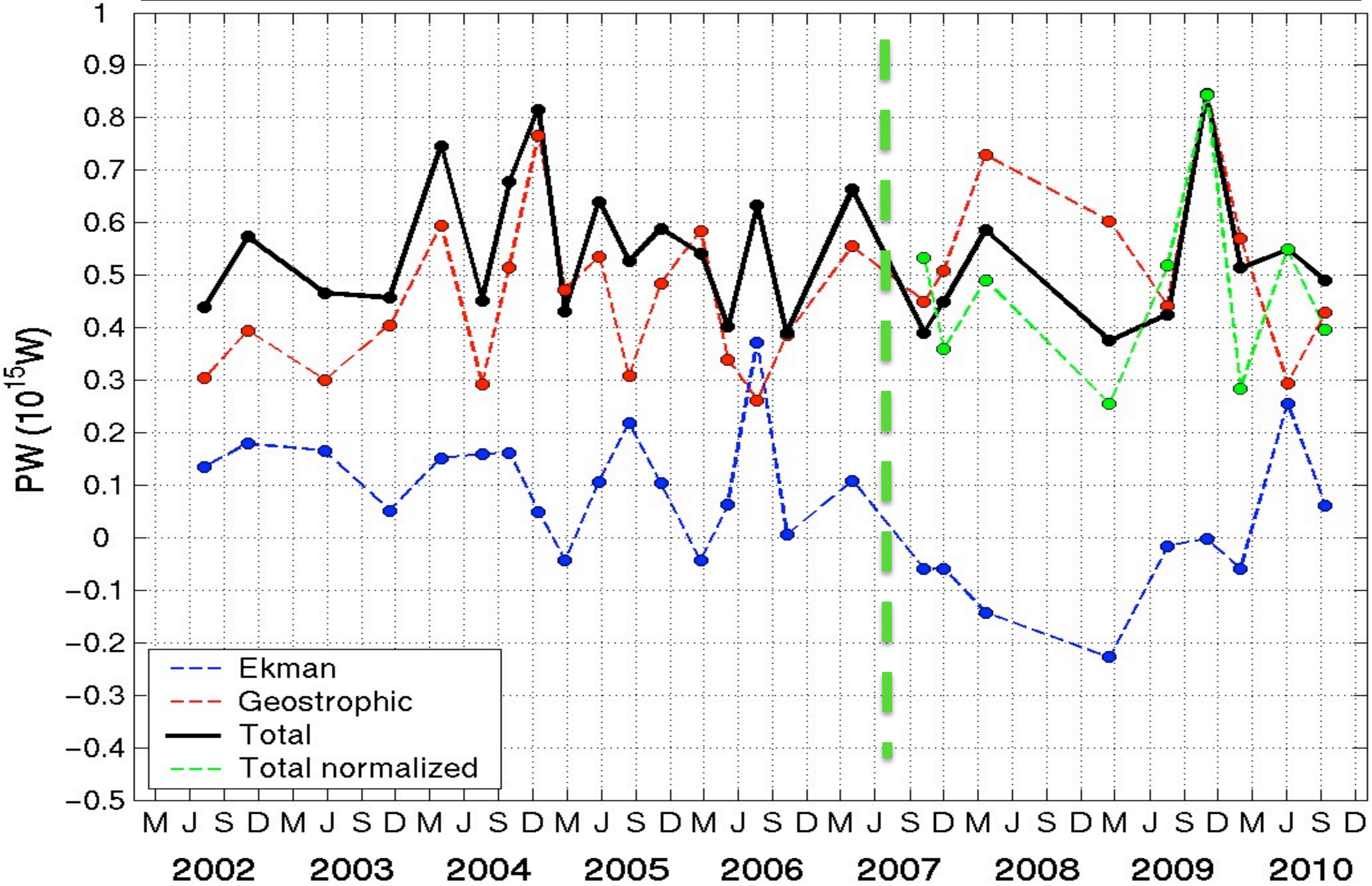
# Heat Transport across 35°S

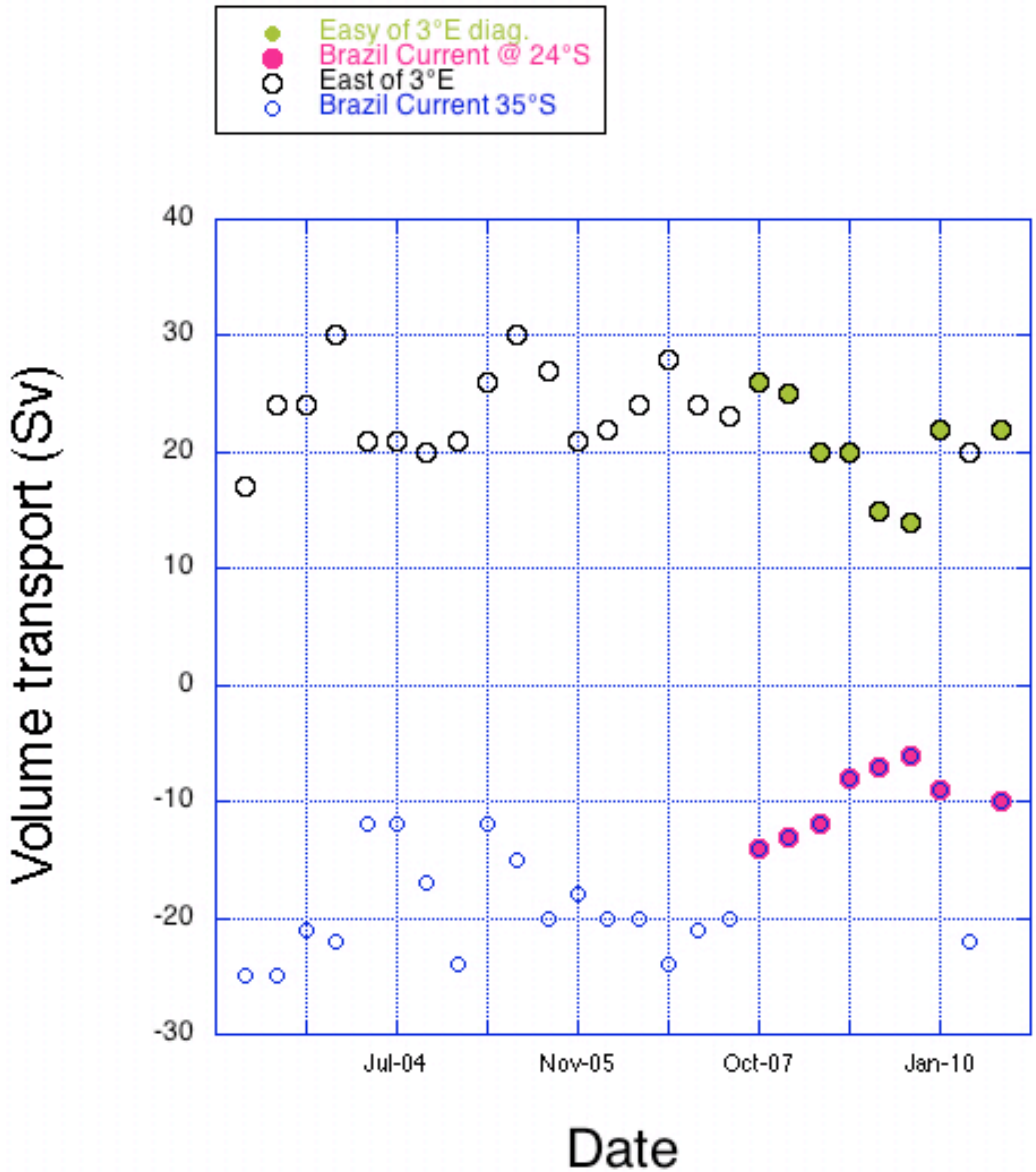


# Heat Transport across 35S: Adjusted Update Time Series

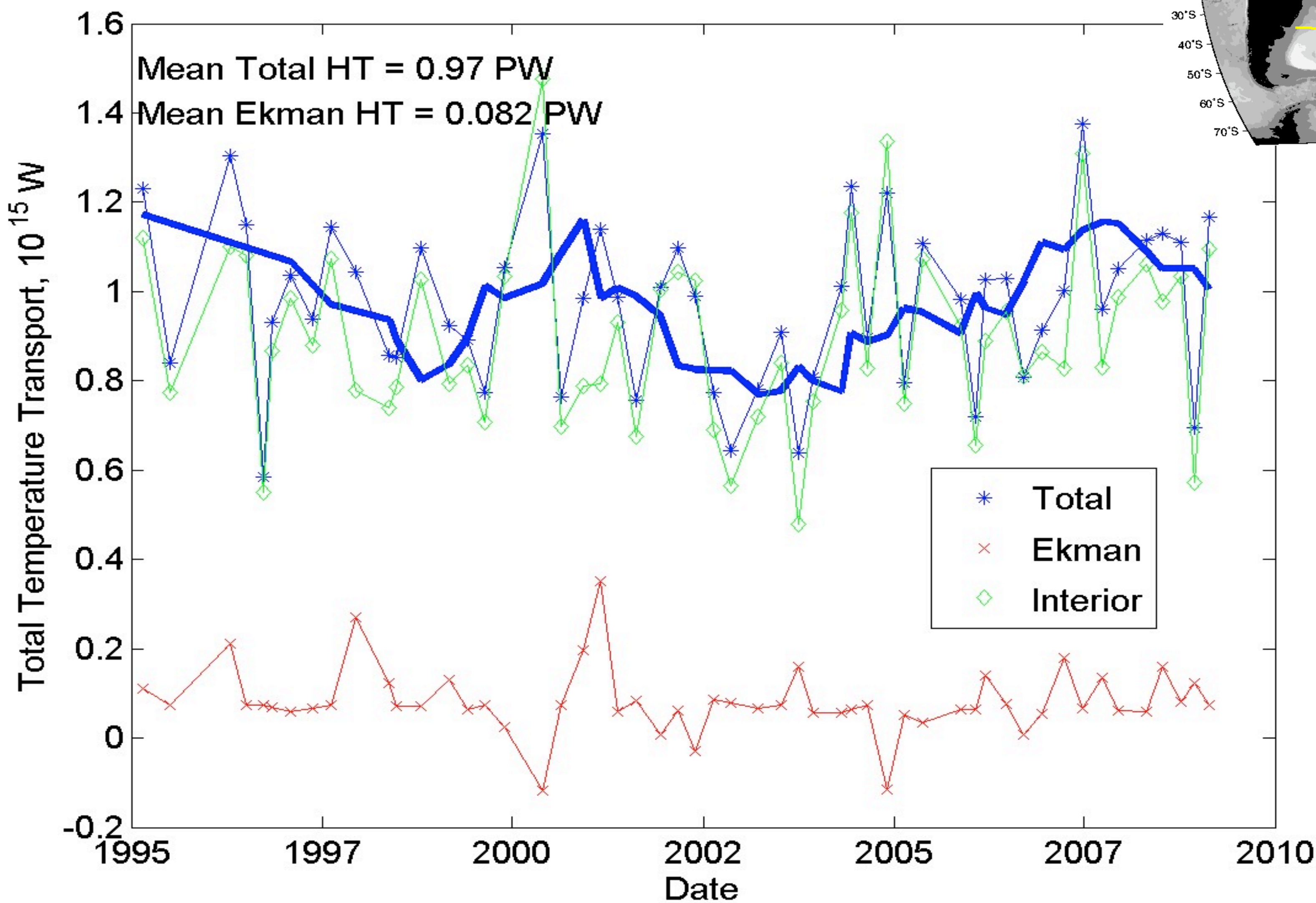


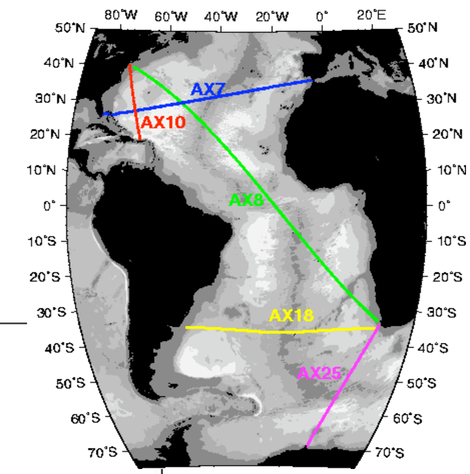


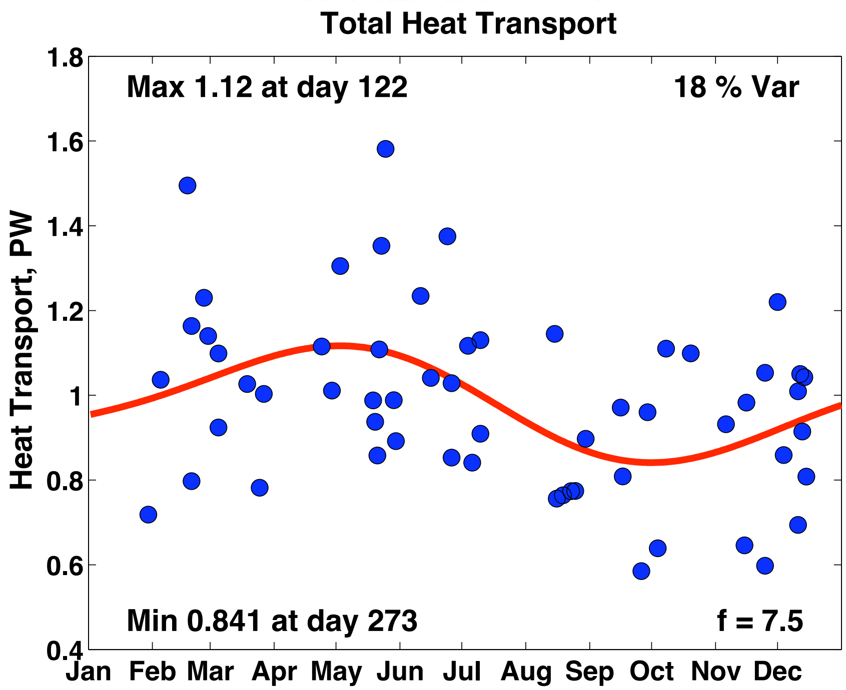

Transport:
Brazil Current
19.5 Sv at 35S
Vs
10 Sv at 24S

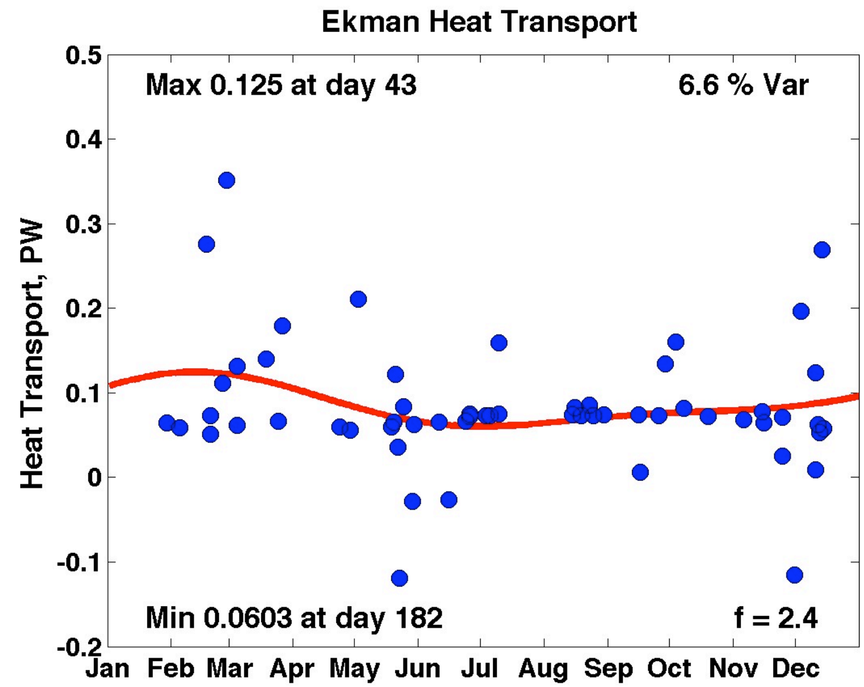
Benguela Current
23.5 Sv
Vs
20.5 Sv

# Heat Transport across 30N: Adjusted Update Time Series

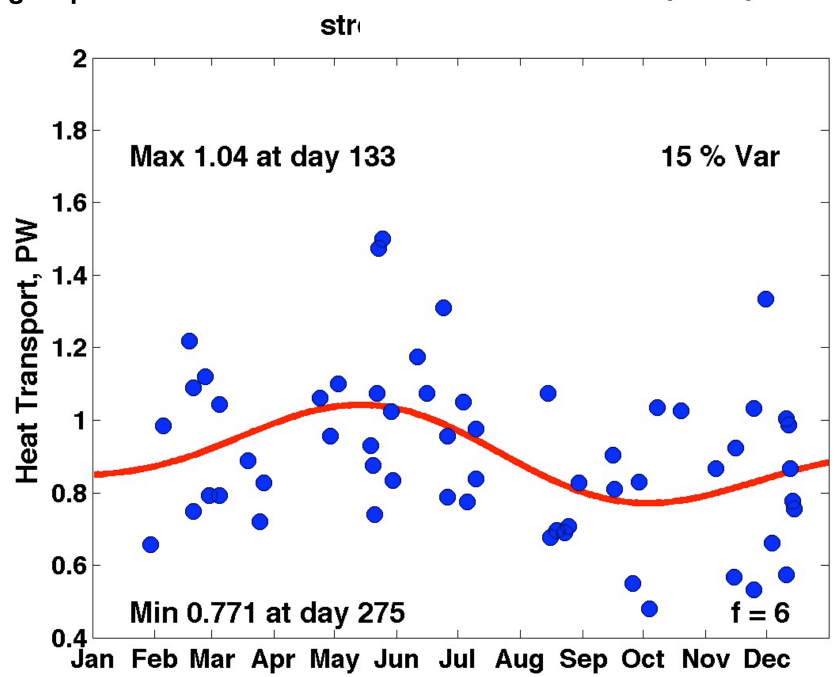


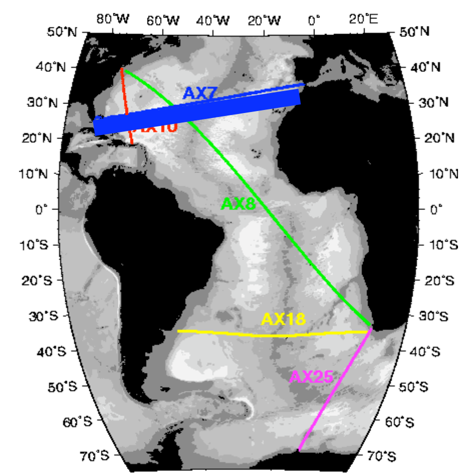





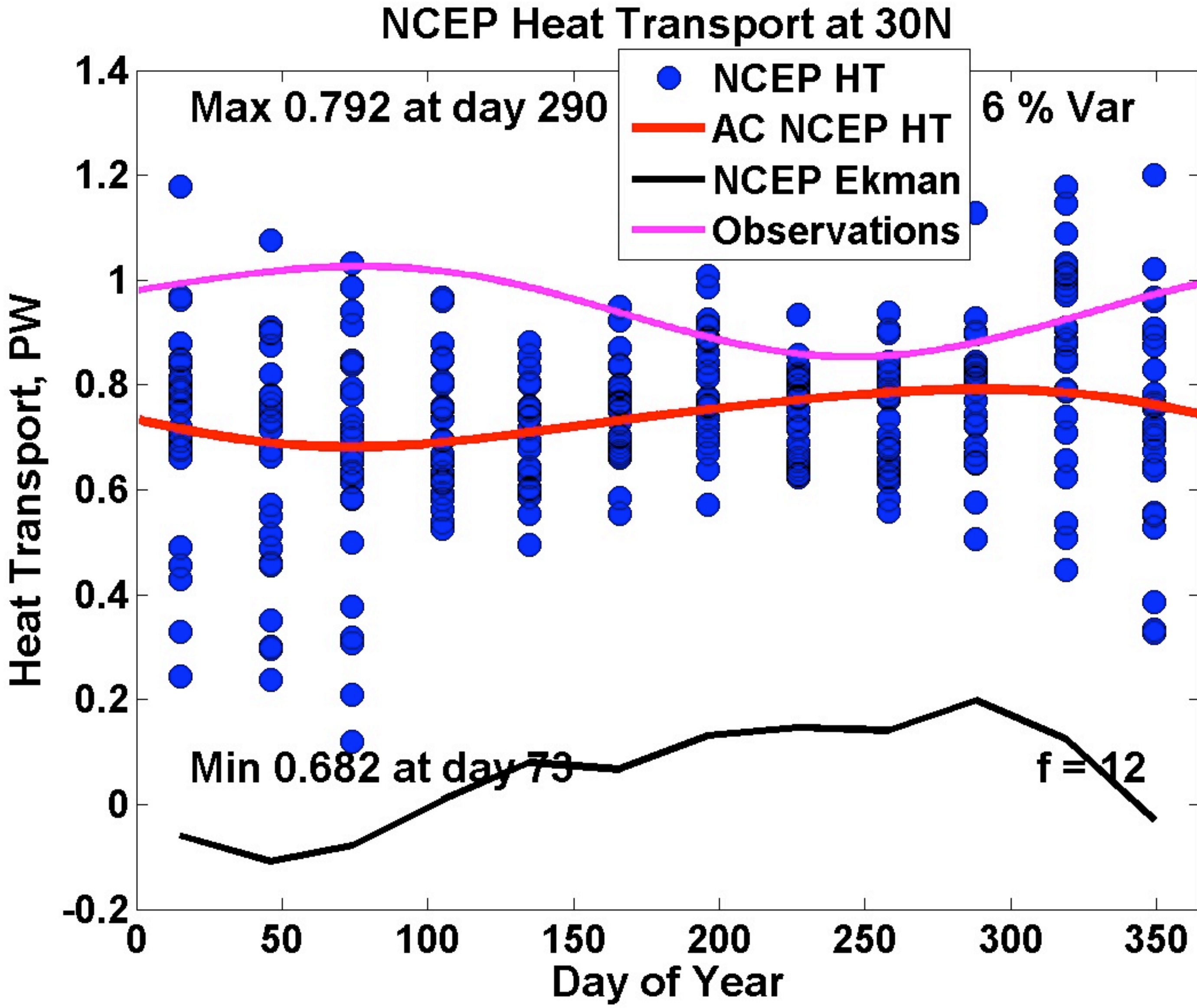



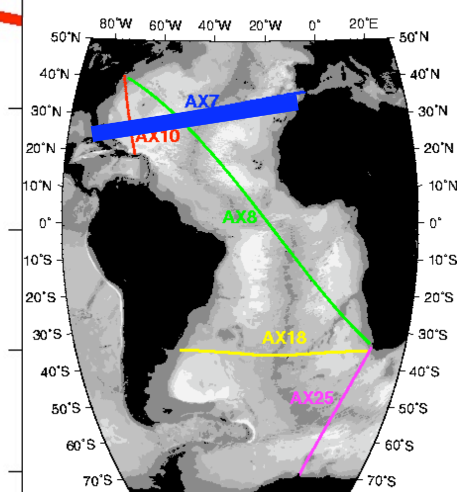

# Heat Transport across 30N: Seasonal Components are in phase



# Heat Transport across 30N (AX7): Seasonal Cycle of NCEP out of phase with observations

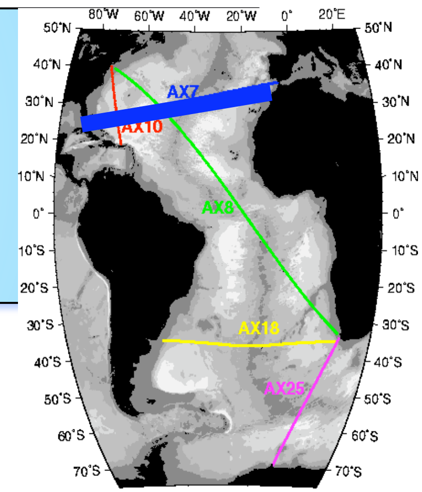


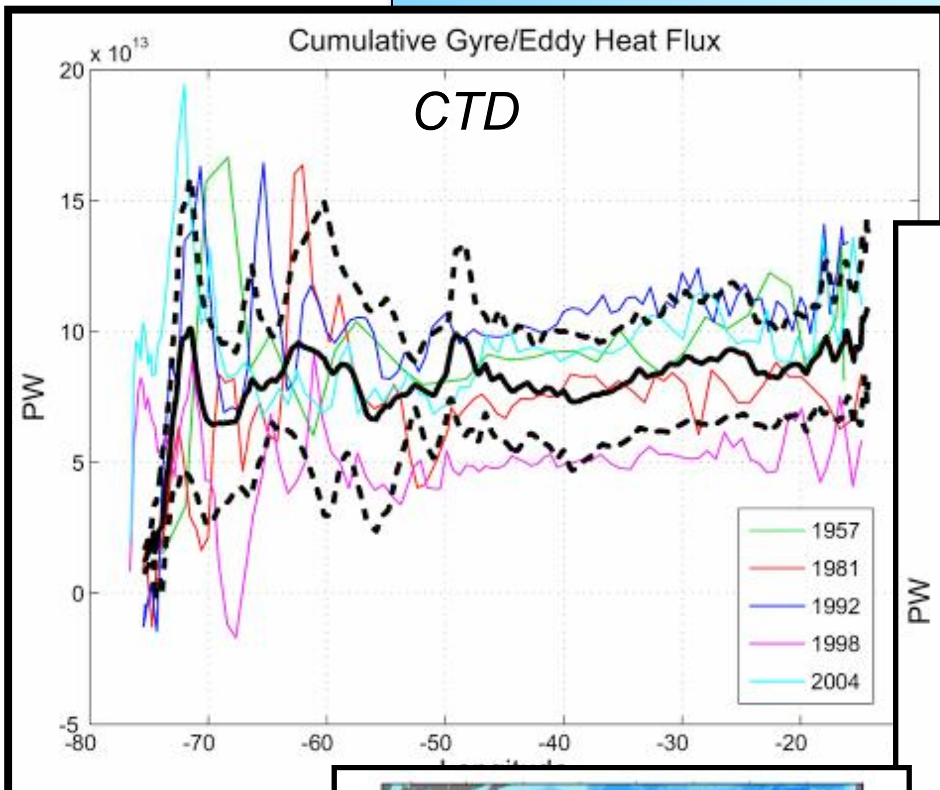



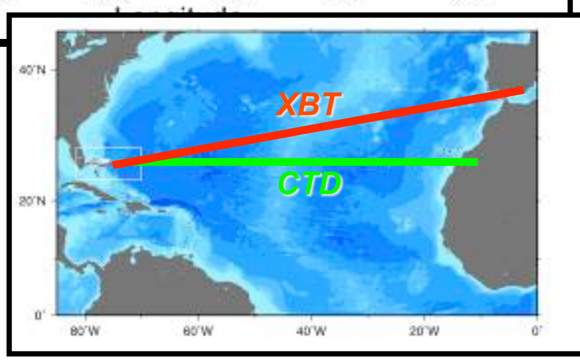
# Gyre/eddy Heat Transport

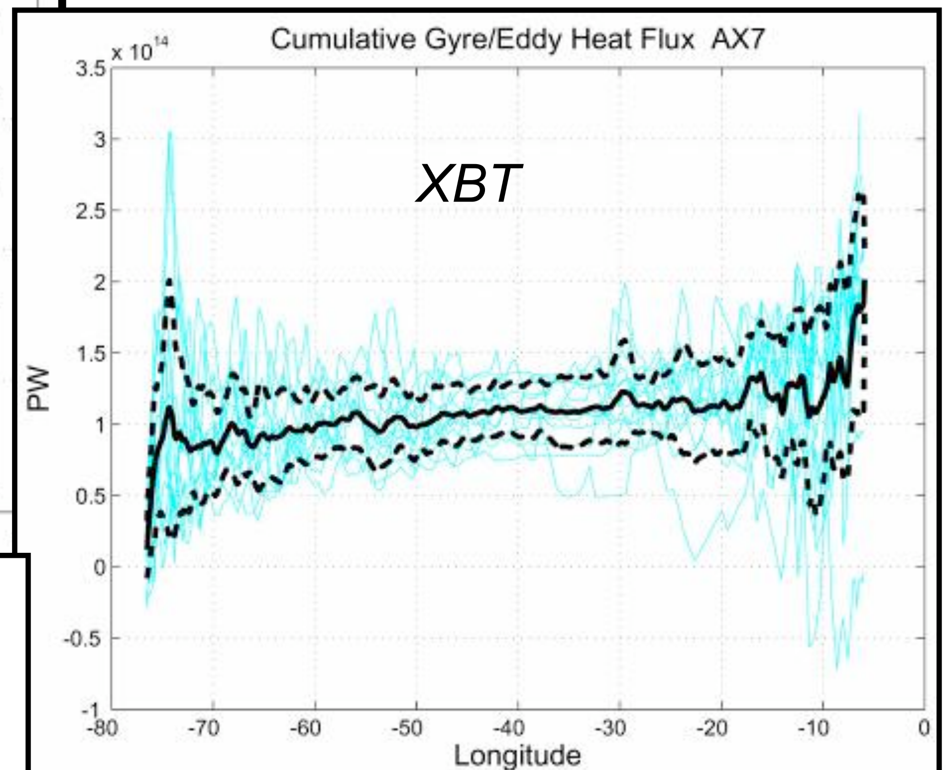
$$Q_{gyre/eddy} = \iint \rho c_p \, v'\theta' \, dx \, dz$$

~ 0.10 ± 0.03 PW

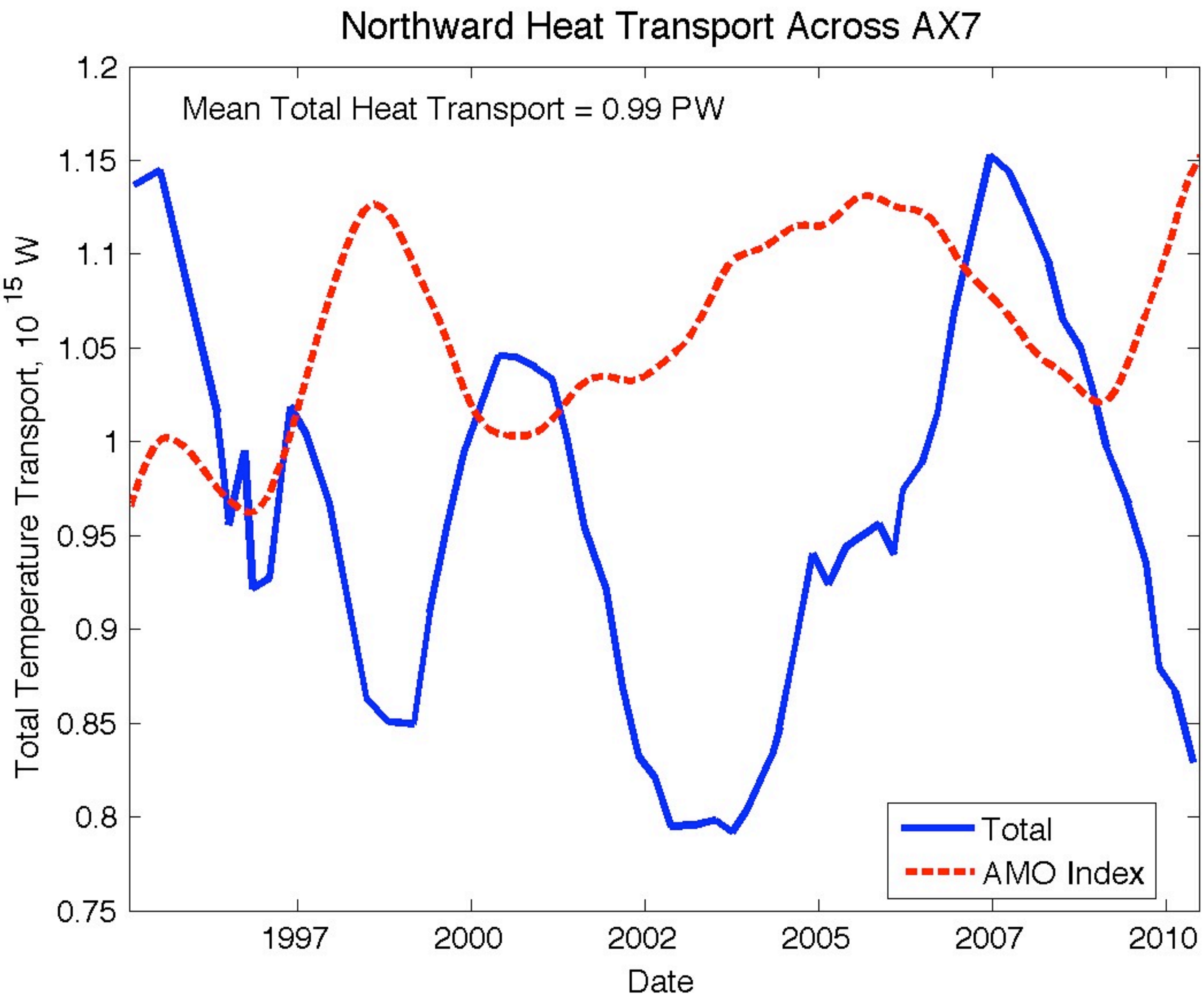


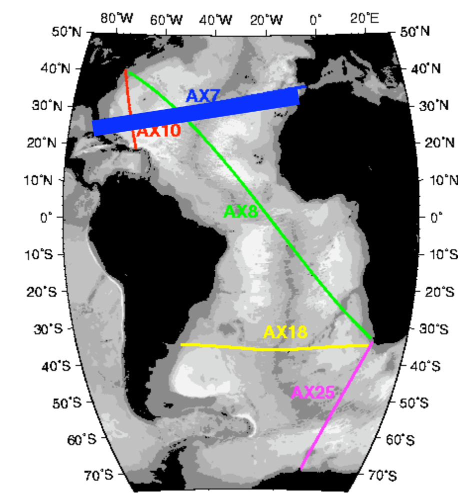



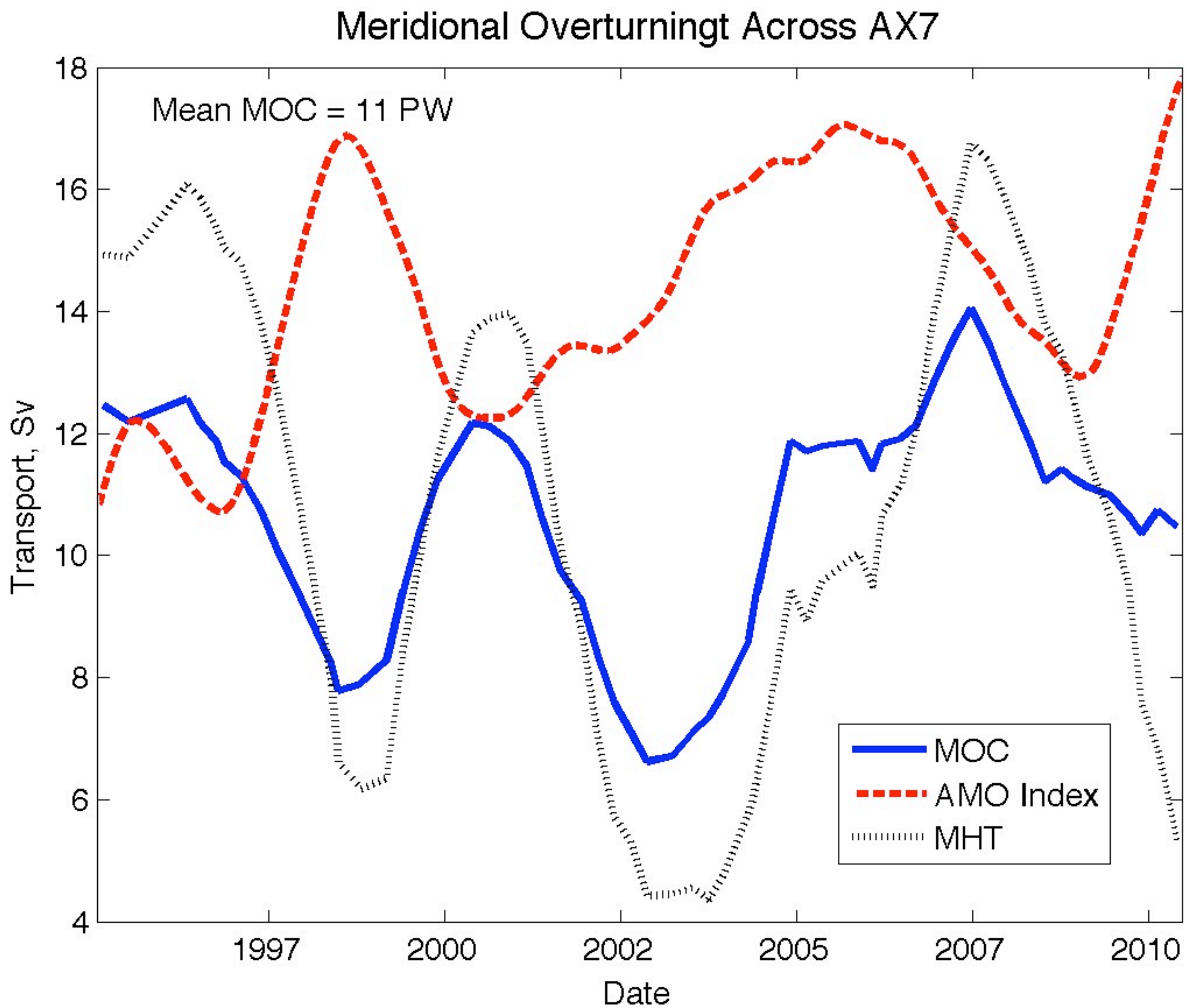



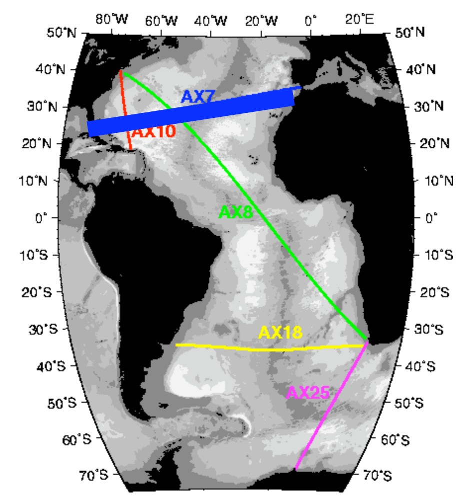
# Heat Transport across 30N (AX7): Out of phase with Atlantic Multidecadal Oscillation



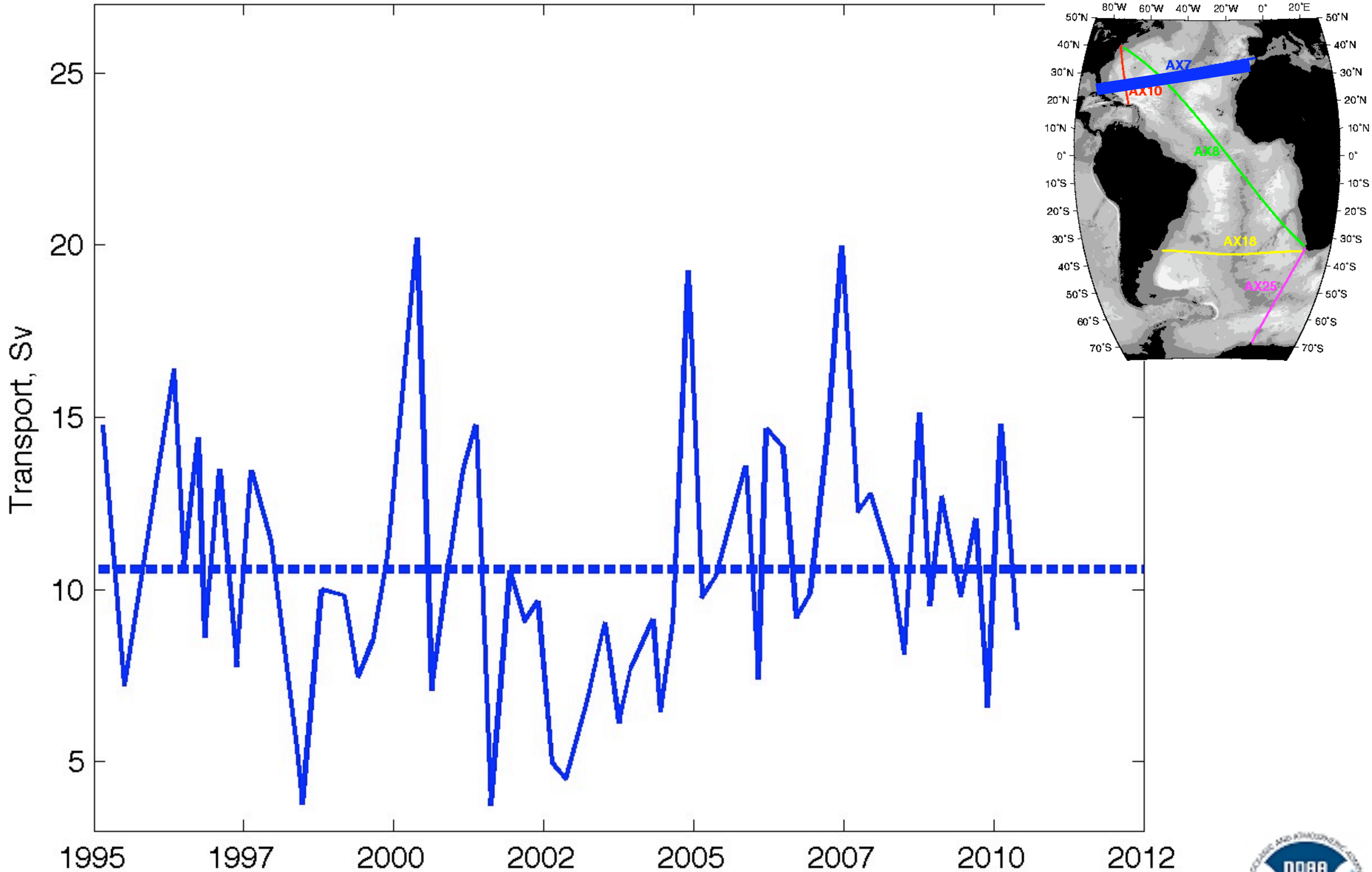



# Meridional Overturning Circulation across 30N (AX7): Strongly Correlated with Heat Transport

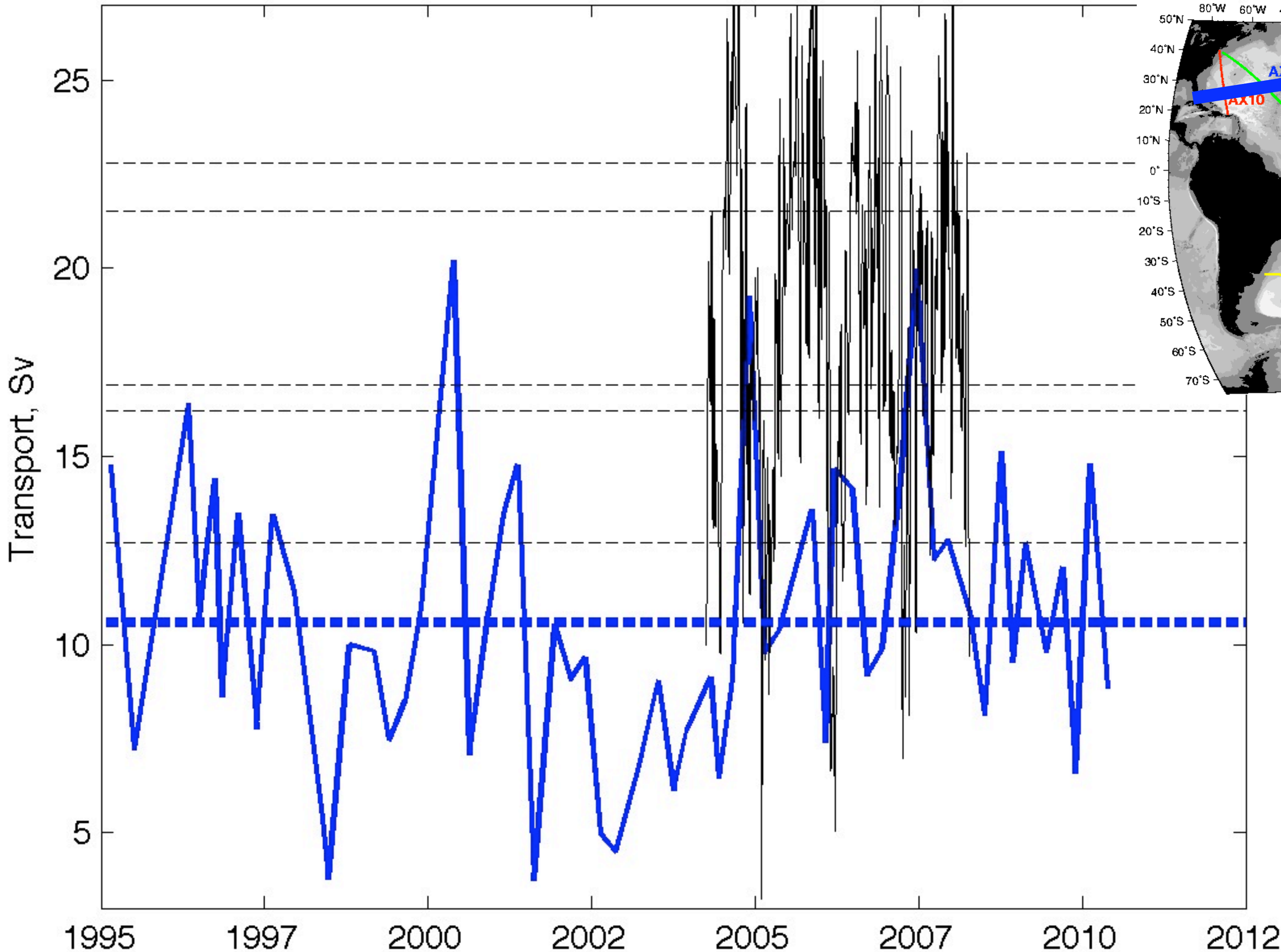


# Meridional Overturning Circulation across 30N (AX7):

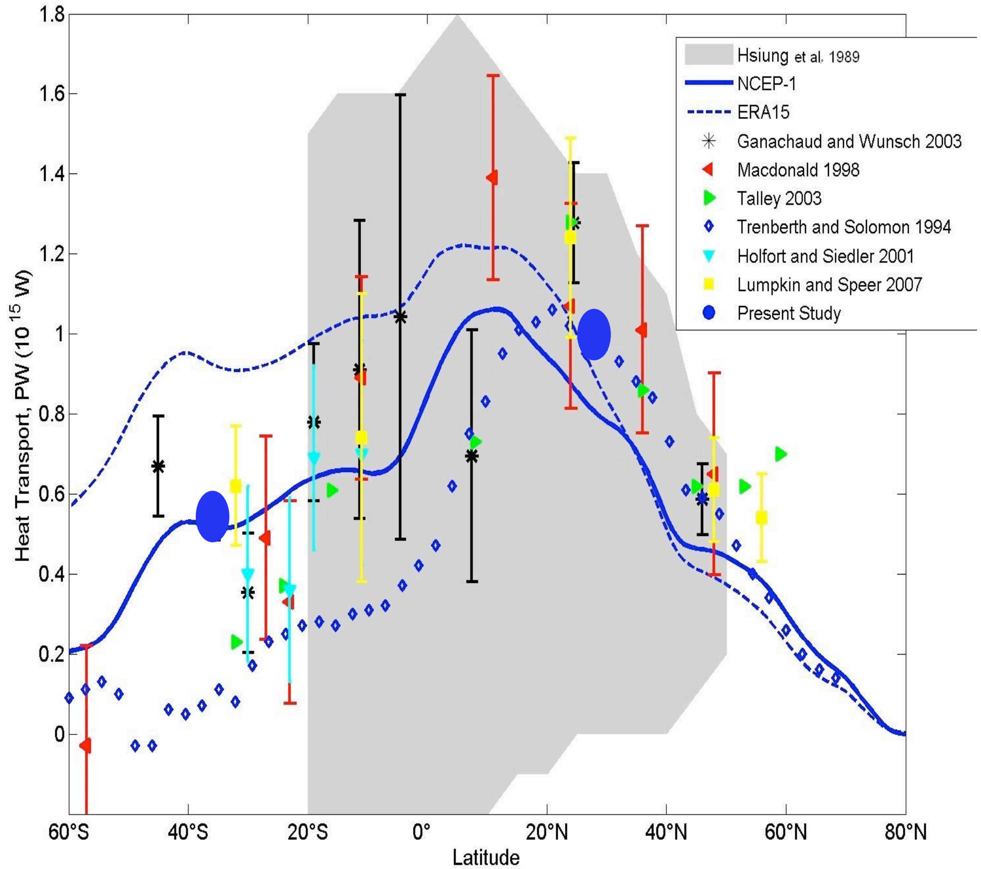


# Meridional Overturning Circulation across 30N (AX7):



# Conclusions

- Annual mean (1995-2010) heat transport AX7 (approximately 30N) = 0.97 PW with a standard deviation of +/- 0.21 PW.




•Annual mean (2002-2010) heat transport AX18 (approximately 35S) = 0.53 PW with a standard deviation of +/- 0.15 PW.

•The heat transport mean and variability is dominated by the geostrophic heat transport, especially in the North Atlantic.

•Geostrophic variability may play a bigger role than previously suggested by models (which models may not simulate correctly)

# Conclusions (continued)

• In the North Atlantic the annual mean MOC transport = 10.6 Sv with a standard deviation = +/- 3.8 Sv, which is much lower than other estimates at 24-26N.

•Short term variability is large:  ranging from 0.58 to 1.58 PW HT and from 3.7 to 20.2 Sv.

•Seasonal cycle emerging… the annual cycle appears to be small, but significant (about 15-20% of the variance).

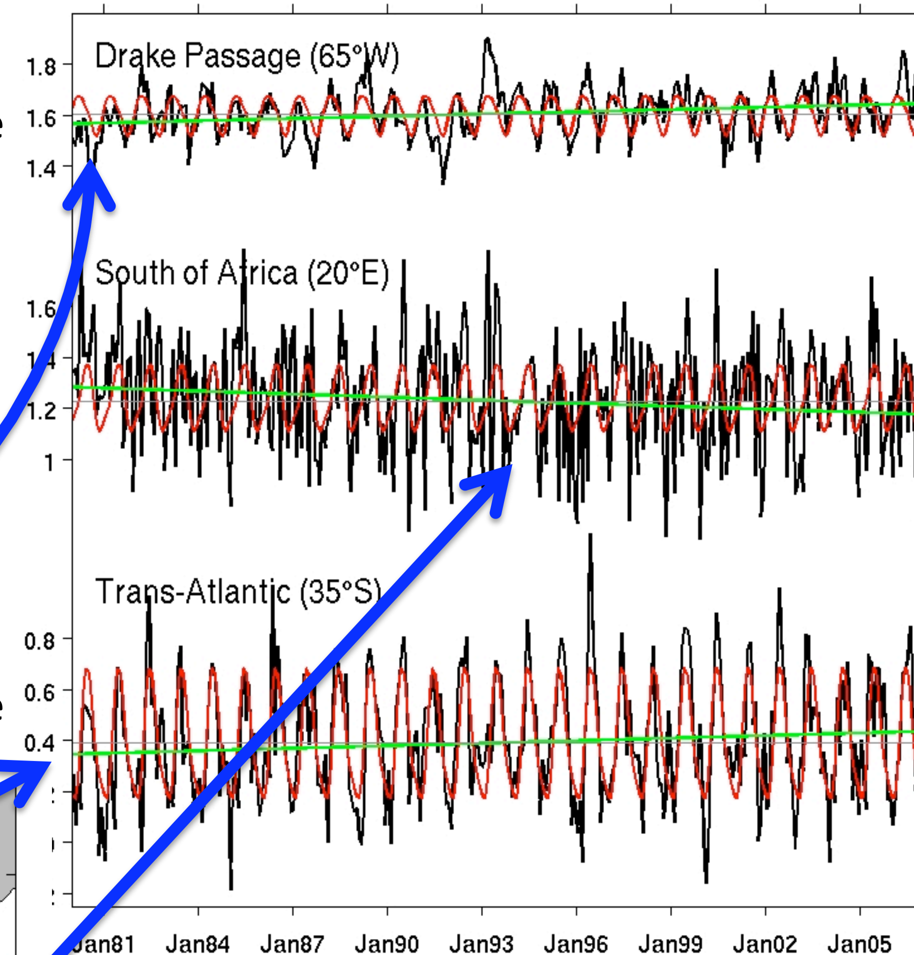
•MOC dominated by FC and interior ocean while for the MHT Ekman transport becomes more import.

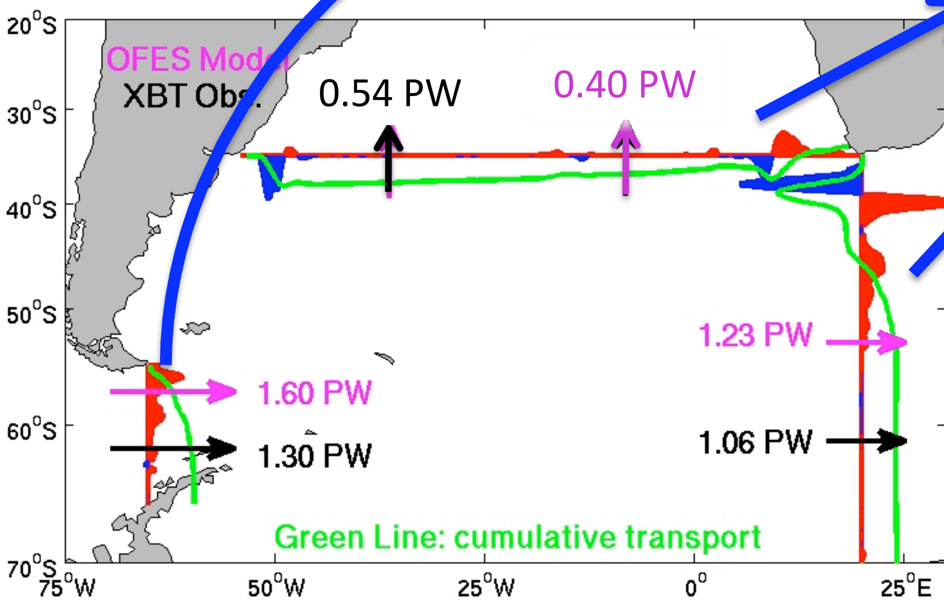
# Heat Transport in the South Atlantic Box bounded by 3 high density XBT transects

+0.032 PW/decade

-0.036 PW/decade

+0.031 PW/decade




- Surface Heat Fluxes decreasing
- Heat Content tendency constant

Annual and semi harmonic fit

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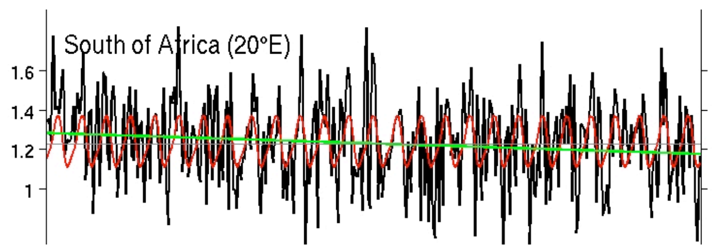
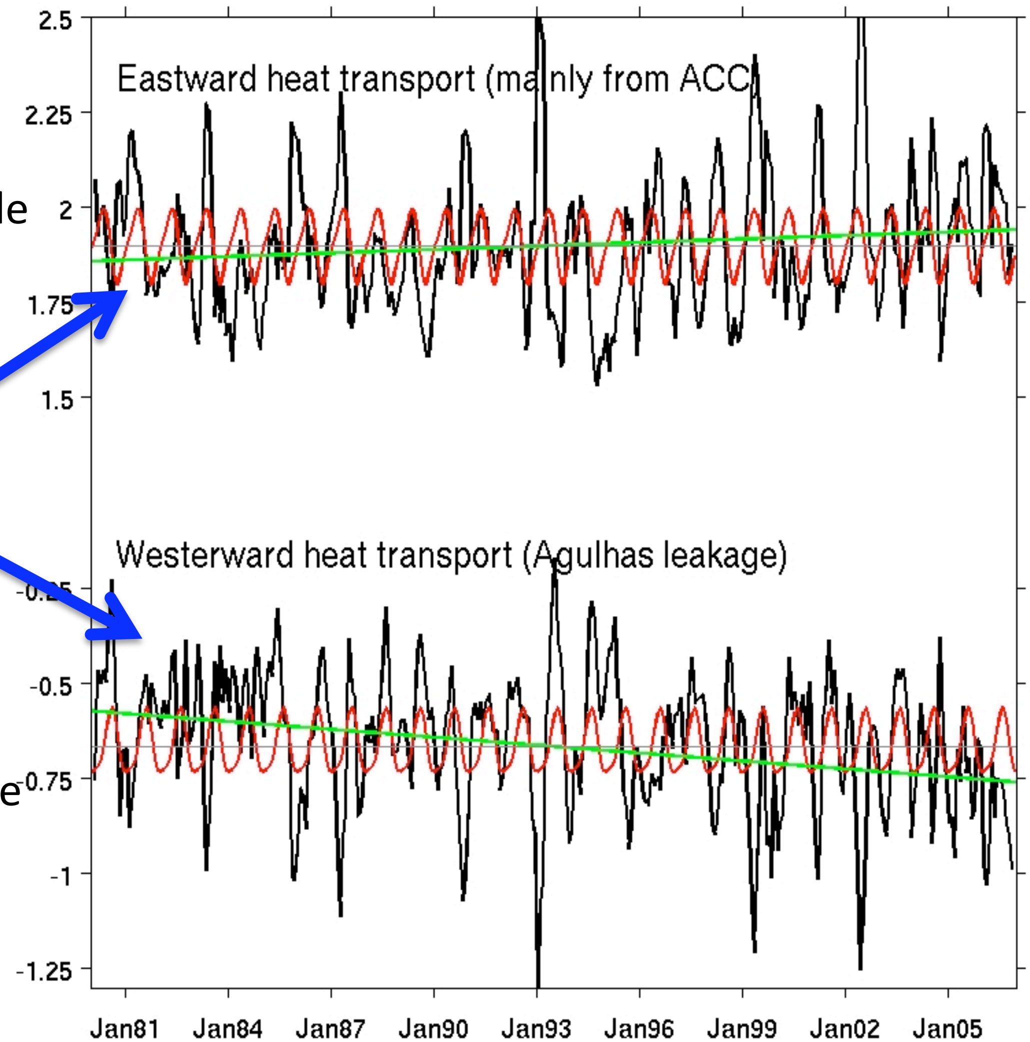
South of Africa Decomposed




0.03 PW/decade




-0.07 PW/decade

d HC/dt = Q – divergence of heat

Half of this increasing trend supplies the increasing trend along 35S
Half goes to providing more heat to atmosphere (decreasing Q over time)

D HC/dt is constant (linear trend increasing heat content +/ 0

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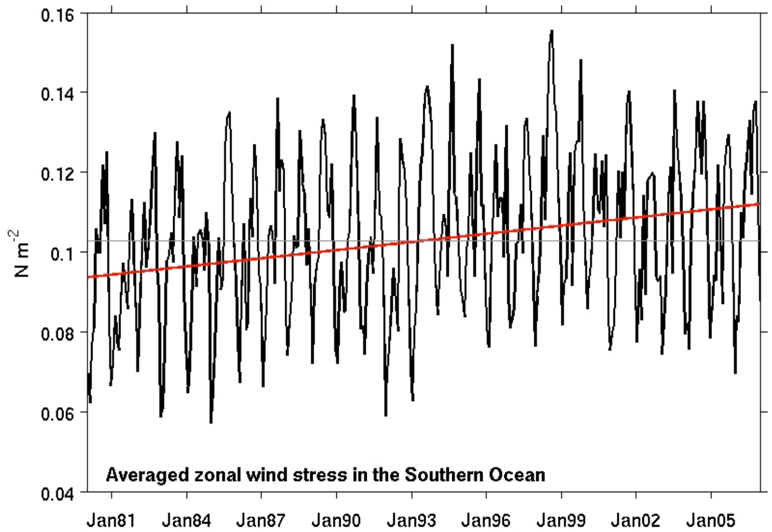
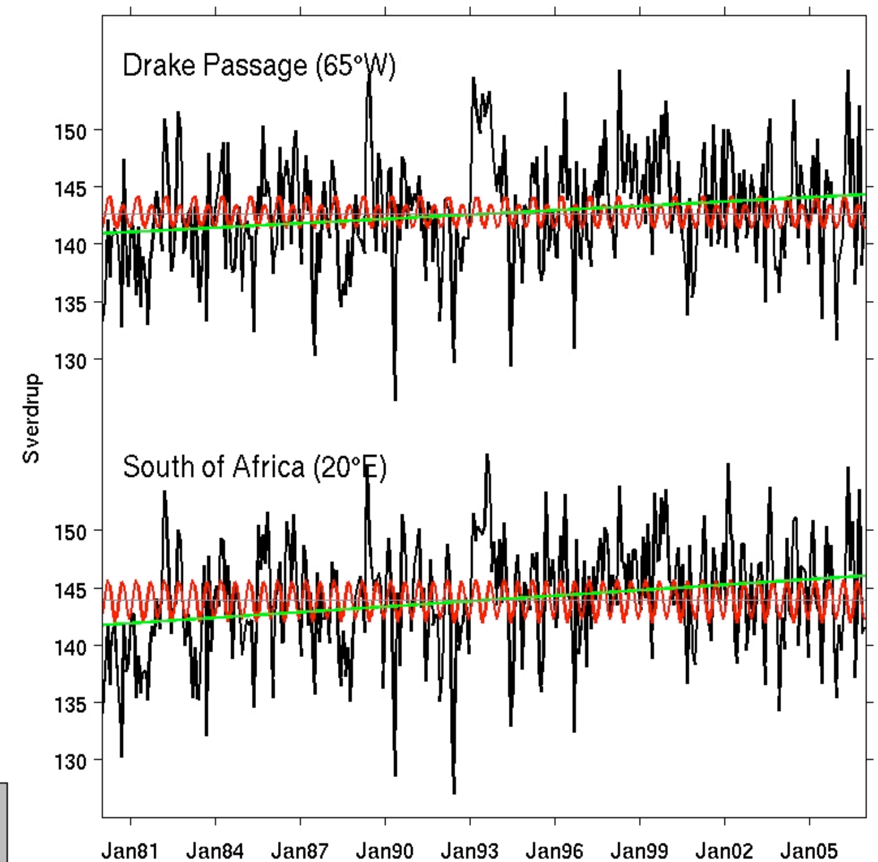
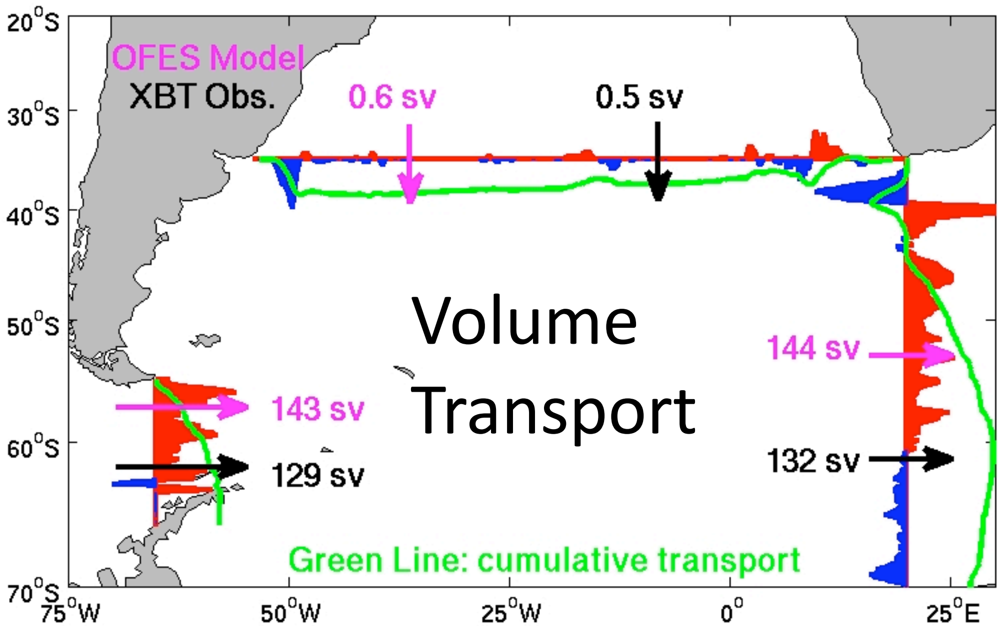
Zonally average wind stress increasing




Southern Annual Mode strengthening and shifting southward

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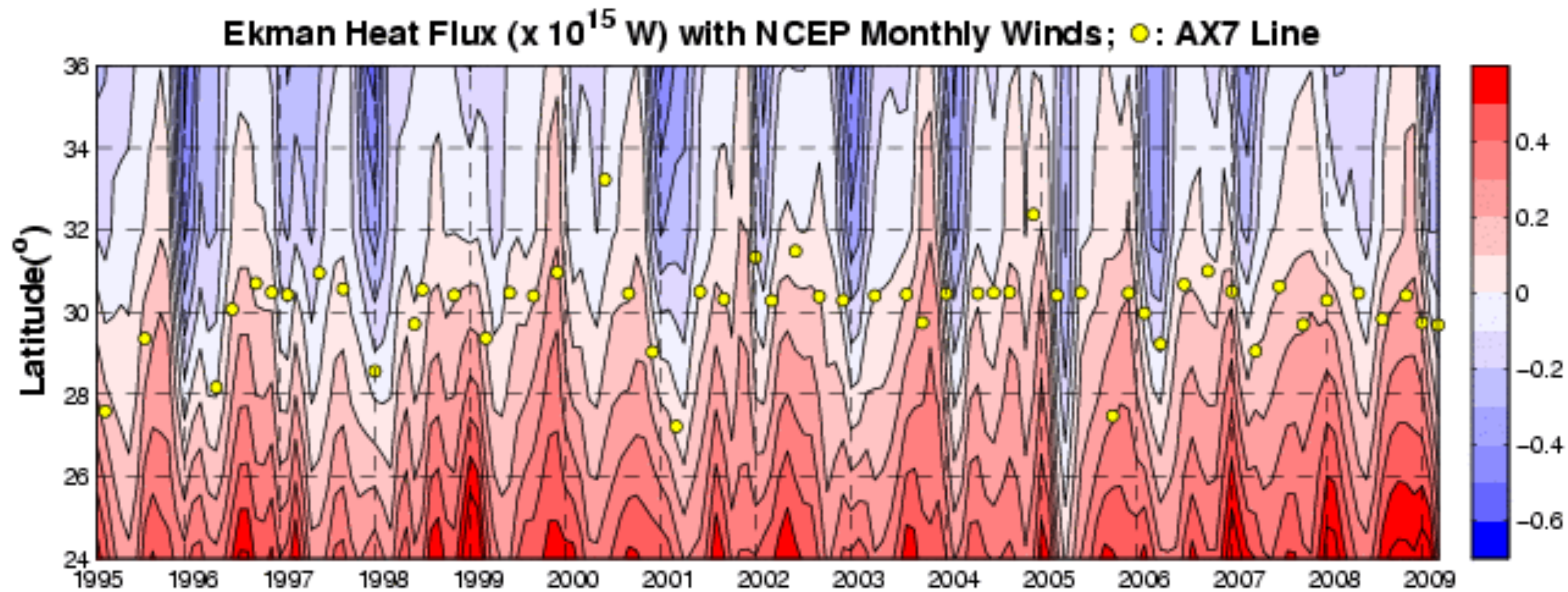
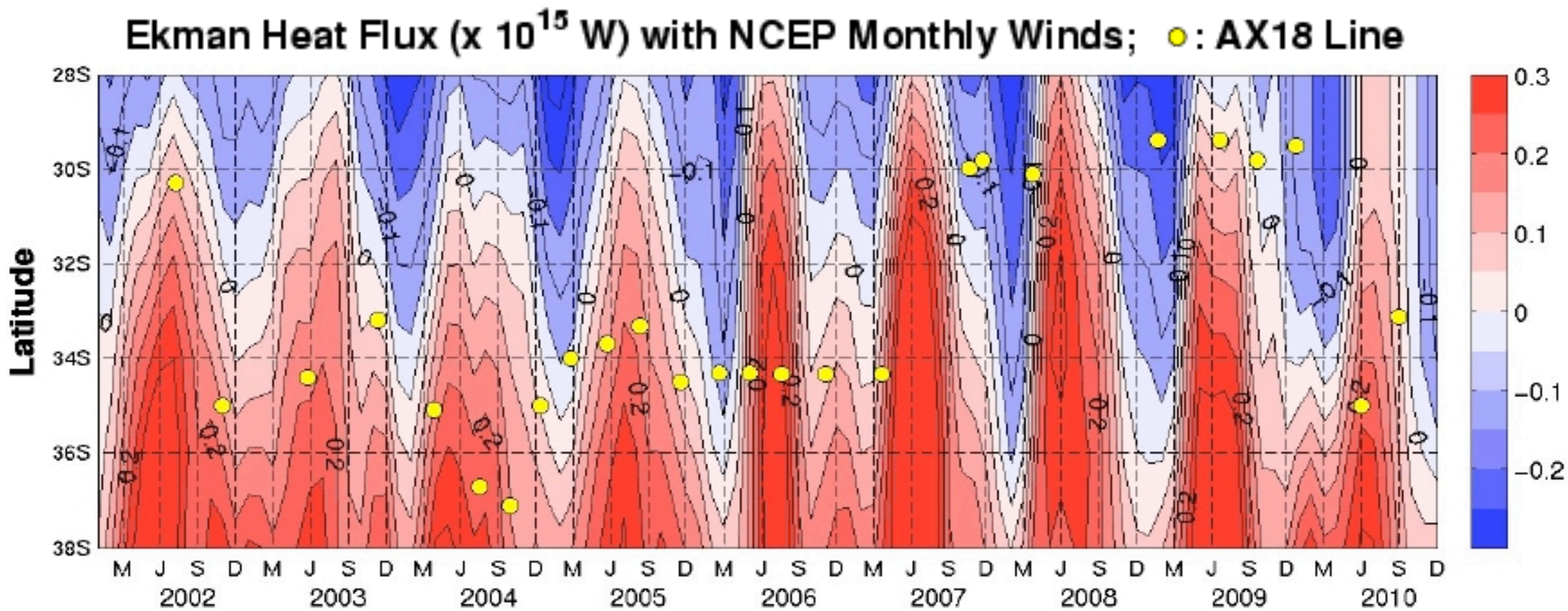
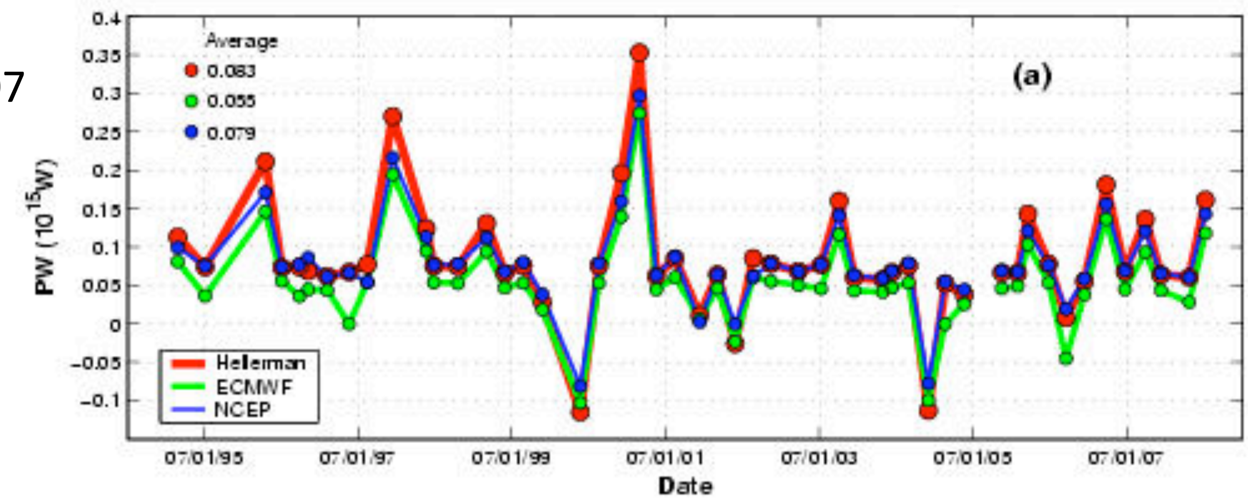

Ekman Heat Flux (x 10^15 W) with NCEP Monthly Winds; ○: AX7 Line
Latitude(°)
36
34
32
30
28
26
24
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
0.4
0.2
0
−0.2
−0.4
−0.6


Ekman Heat Flux (x 10^15 W) with NCEP Monthly Winds; ○: AX18 Line
Latitude
28S
30S
32S
34S
36S
38S
M J S D
2002
2003
2004
2005
2006
2007
2008
2009
2010
0.3
0.2
0.1
0
−0.1
−0.2

Greatest Difference 0.07 PW

Average
0.024 PW

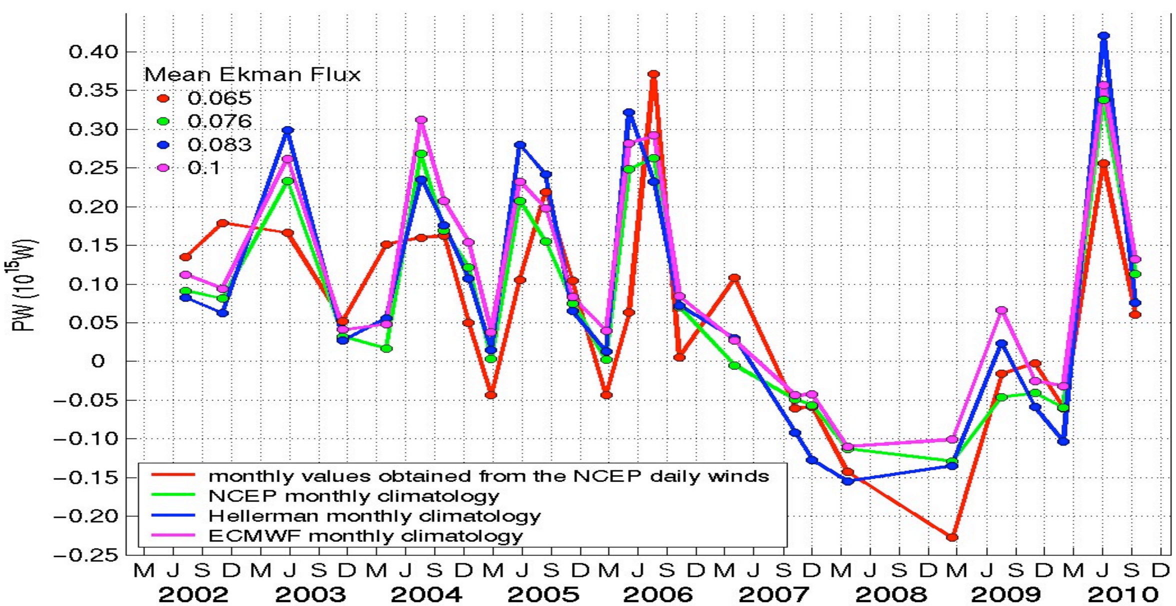
## North Atlantic: AX7




Greatest Difference 0.2 PW

Average
0.06 PW

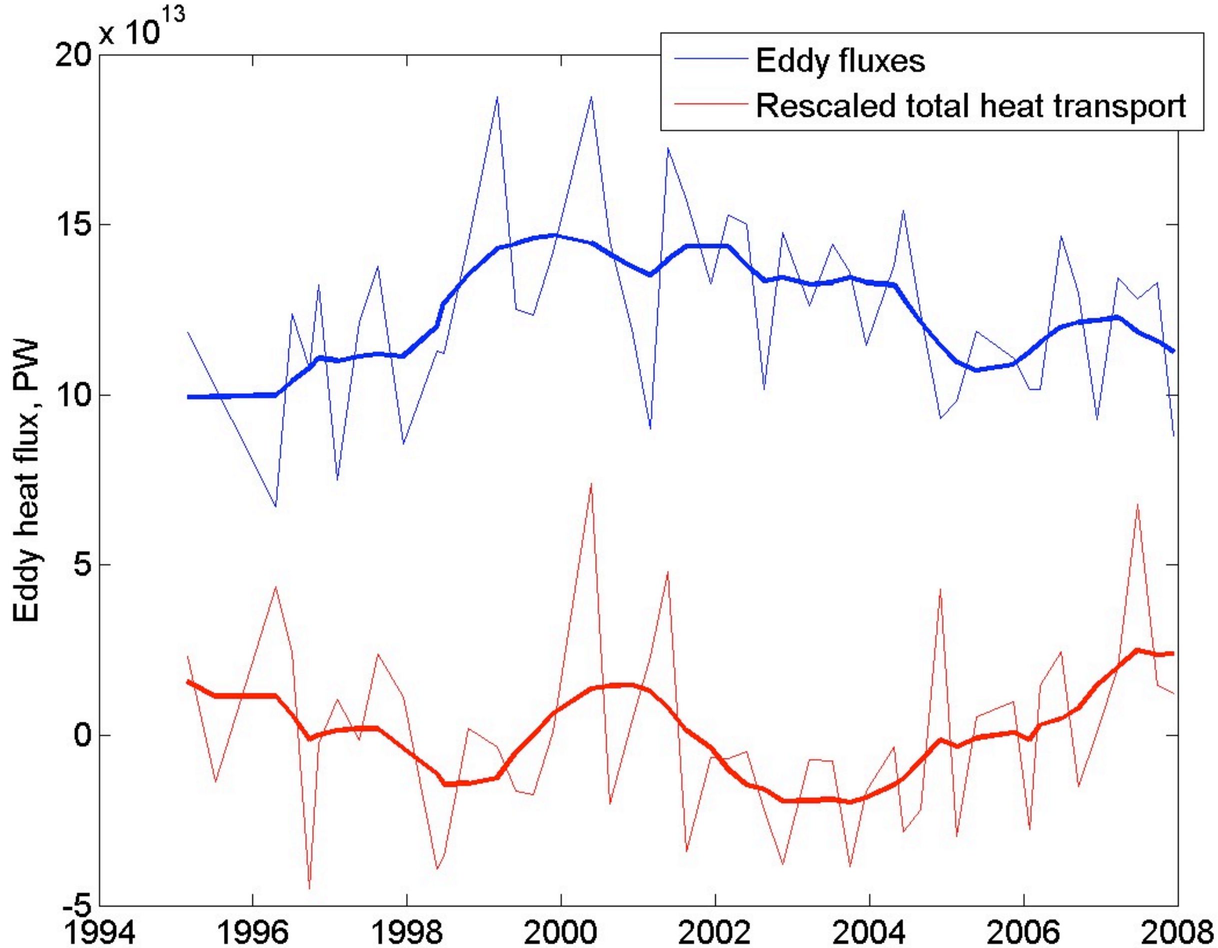
## South Atlantic: AX18



# Interannual Variability of Eddy Fluxes

Subannual variability as large as 0.05 PW

Interannual variability as large as 0.025 PW



# North Atlantic: Ax7