The wind stress drives the coherence of the North Atlantic Meridional Overturning Circulation on seasonal and longer time scales

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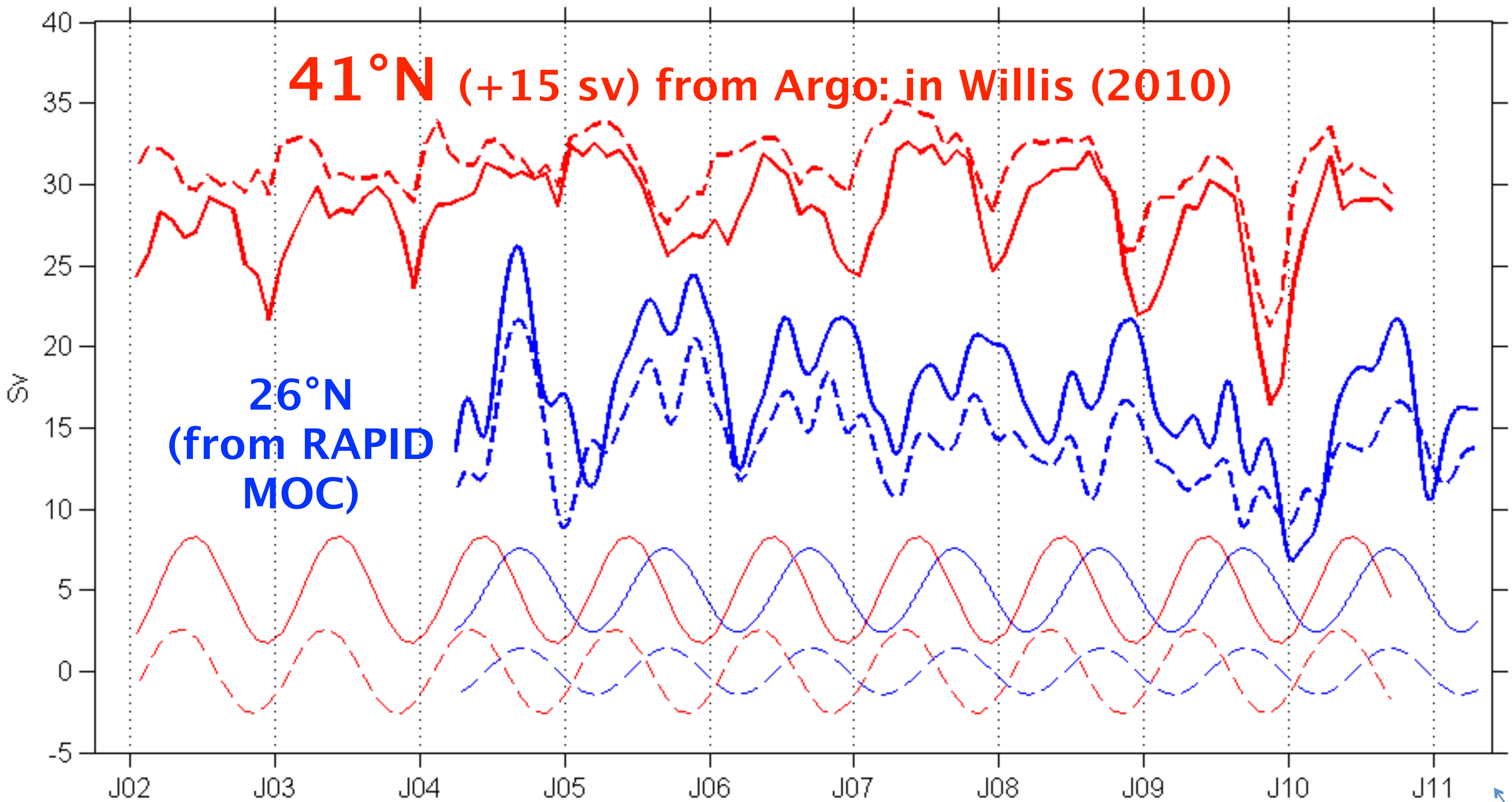
NERC Rapid WAVE project in collaboration with :
Woods Hole Oceanographic Institution – Line W program (John Toole)
MOVE Project at Scripps Institution of Oceanography (Uwe Send)

MOC strength at two latitudes:



- - - - - Geostrophic —— Total = Geo. + Ekman

Fits to
annual frequency

See e.g Kanzow et al. 2007, Kanzow et al. 2010, Johns et al. 2011, McCarthy et al. 2012, Mielke et al. 2012

Goals of study:

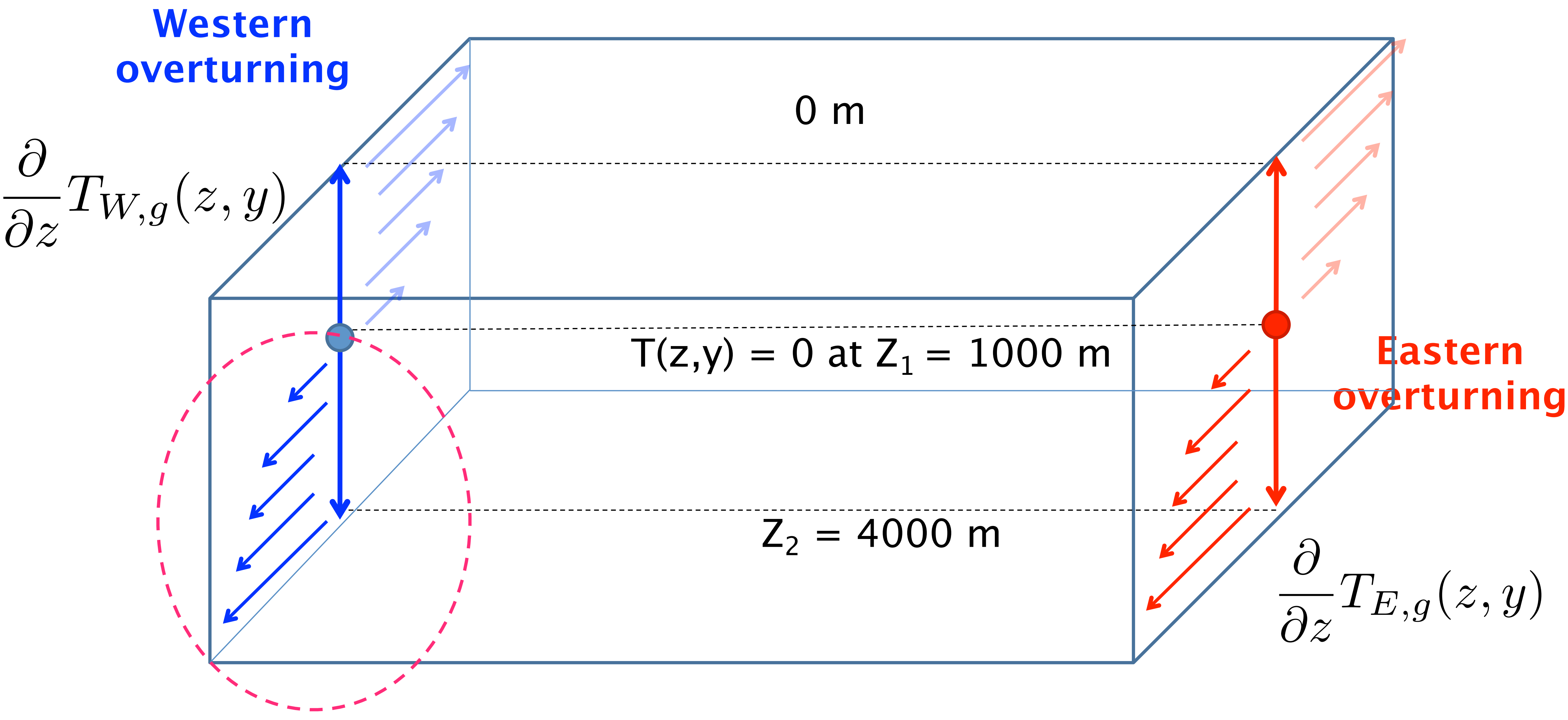
1. Derive a quantity from observations which is representative of the MOC in the North Atlantic ocean

2. Study the meridional coherence of overturning processes in the North Atlantic: role of wind forcing?

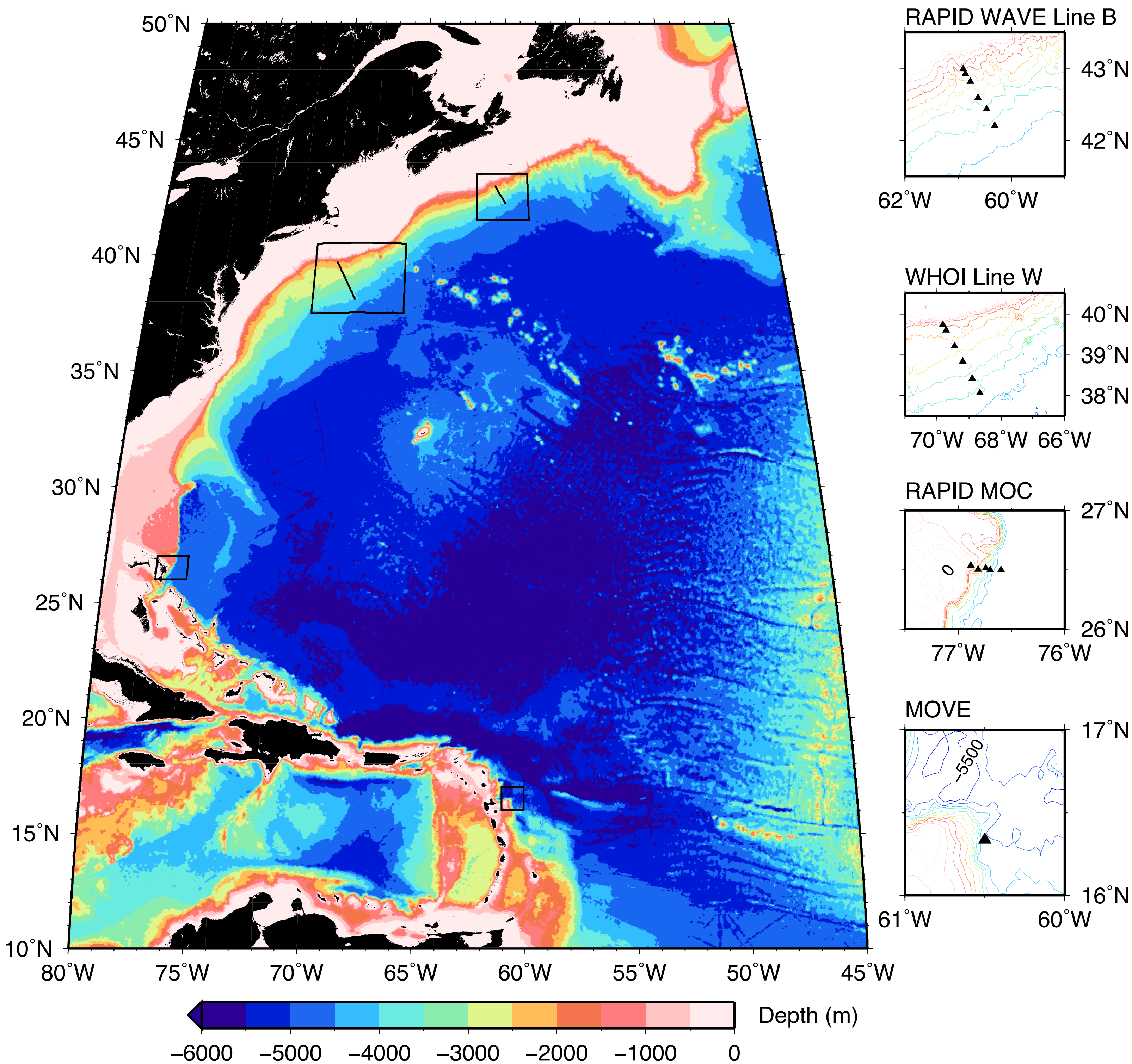
Eastern and western overturning transports below 1000 m

$$T_g(z,y) = \int_W^E \rho v_g \, dx$$: zonally integrated meridional geostrophic transport

$$\frac{\partial}{\partial z} T_g(z,y) = \frac{1}{f}\frac{\partial}{\partial z}[p_E(z,y) - p_W(z,y)] = \frac{\partial}{\partial z} T_{E,g}(z,y) + \frac{\partial}{\partial z} T_{W,g}(z,y)$$



4 arrays to obtain western overturning transports below and relative to 1000 m:



RAPID WAVE array
Line B/Line RS
(NOC/BIO)

Hughes et al. (2013)
Elipot et al. (2013)

WHOI Line W array

Toole et al .(2011)

RAPID MOC/MOCHA
array
RSMAS/AOML/NOC

Rayner et al. (2011)

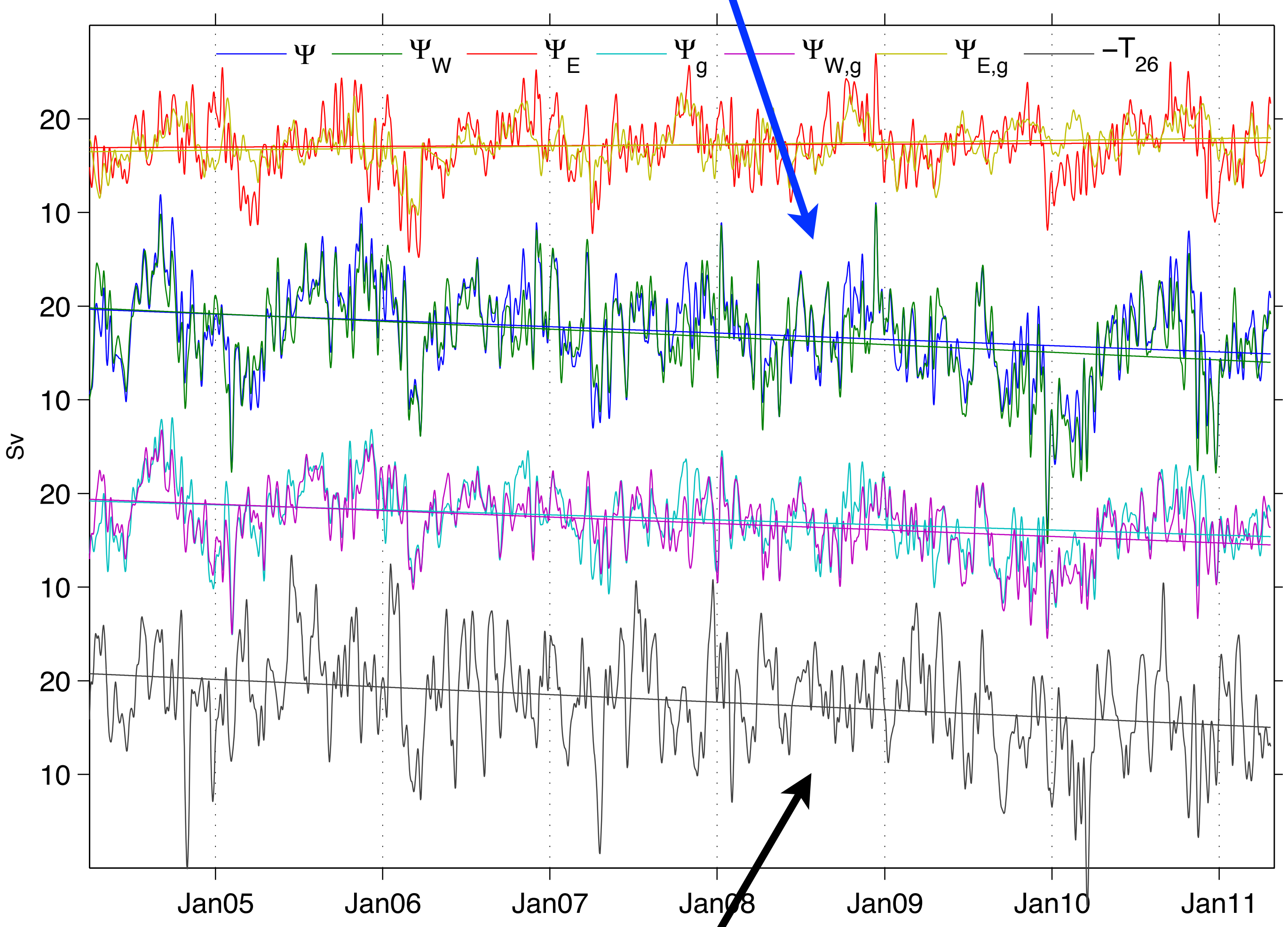
MOVE array
(SIO)

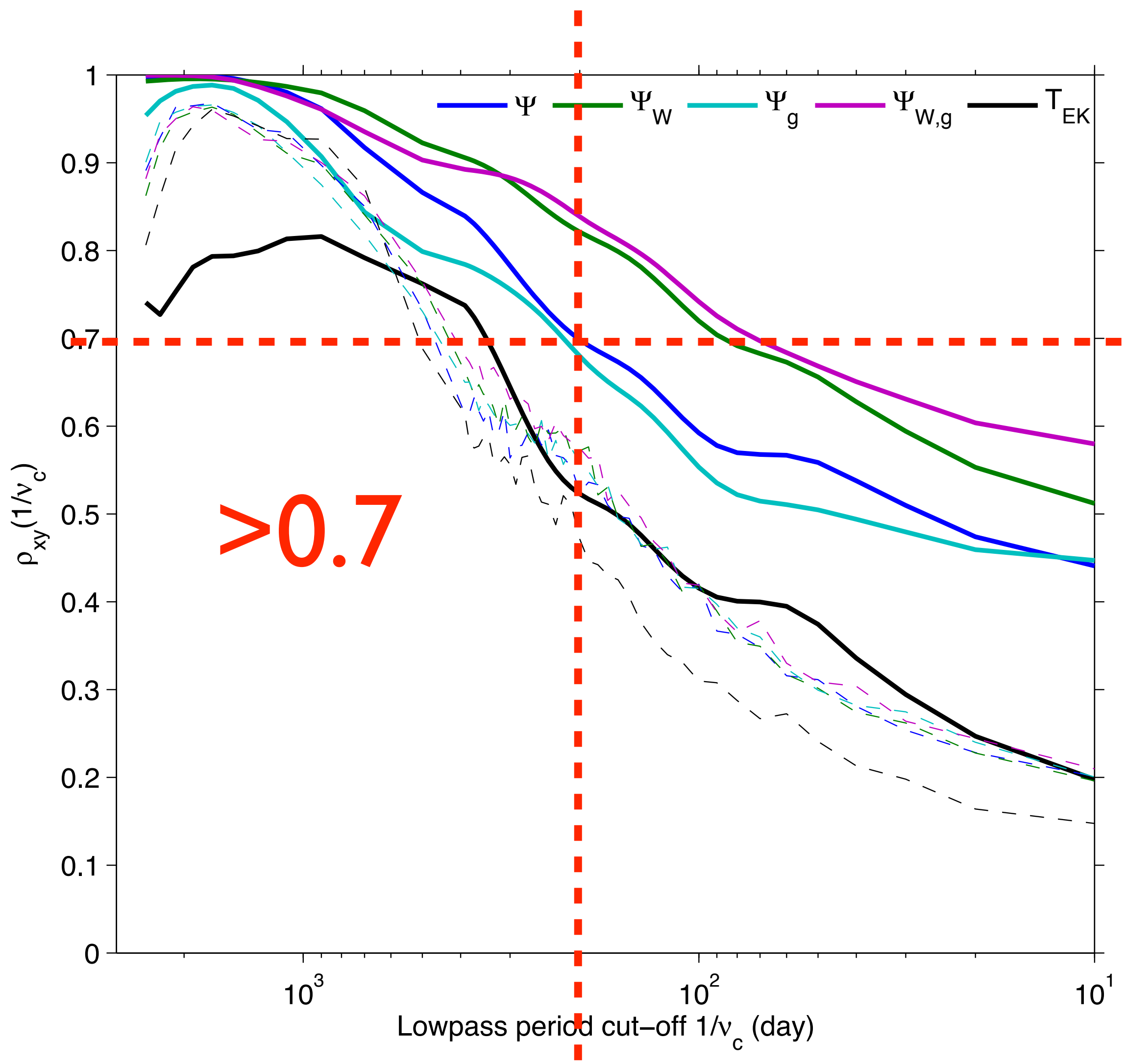
Send et al. (2011)

Overturning transport below 1000 m and MOC at 26°N?

"MOC" transport

Correlation



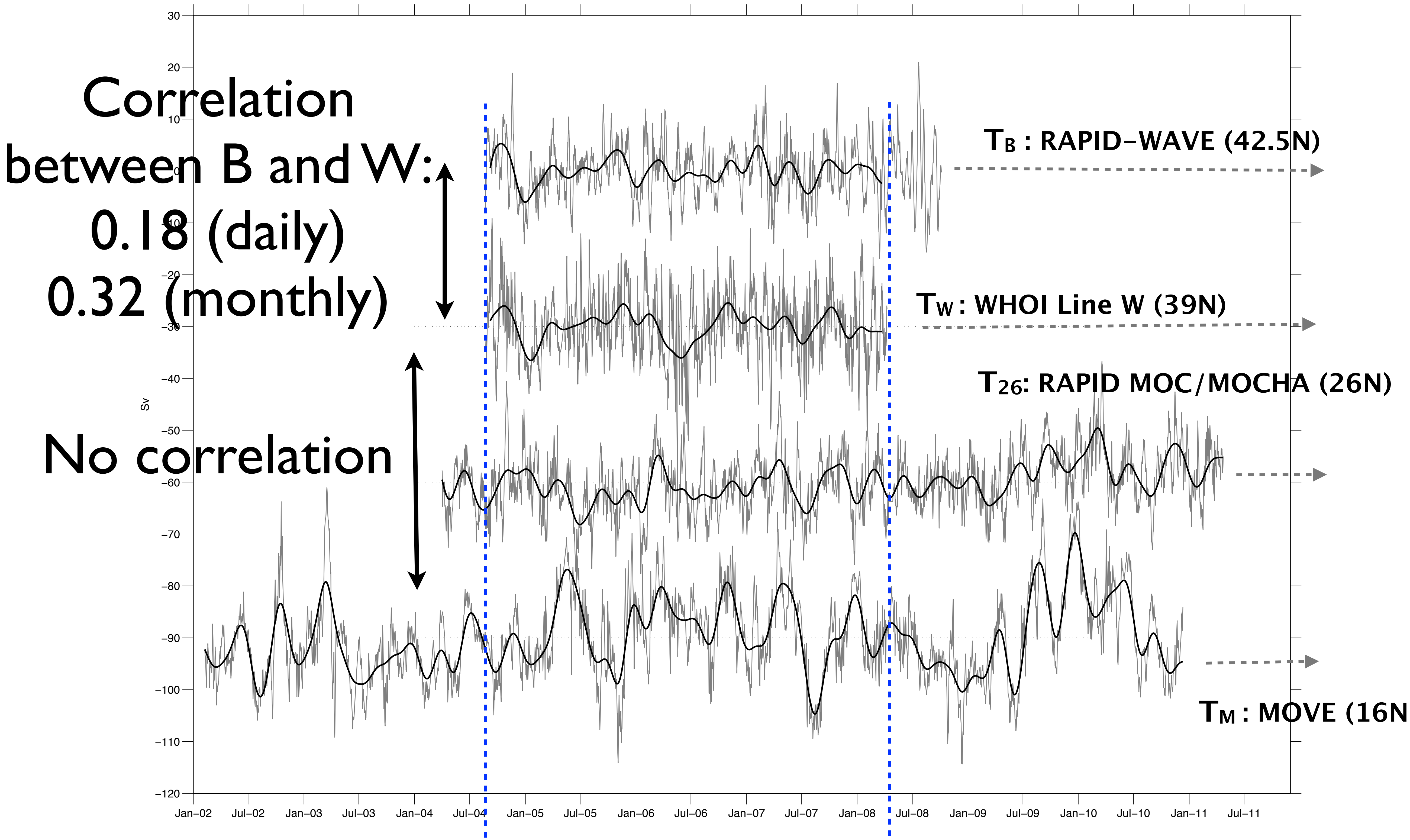


Negative of overturning transport below and relative to 1000 m (T_{26})

~ 6 months

In "*Ocean bottom pressure data capture the North Atlantic Meridional Overturning Circulation and its meridional coherence*" Elipot et al. 2013 (in revision for JPO)

So, 4 time series of overturning transport below 1000 m ...



Study from 22 August 2004 to 8 April 2008 : 3.7 years

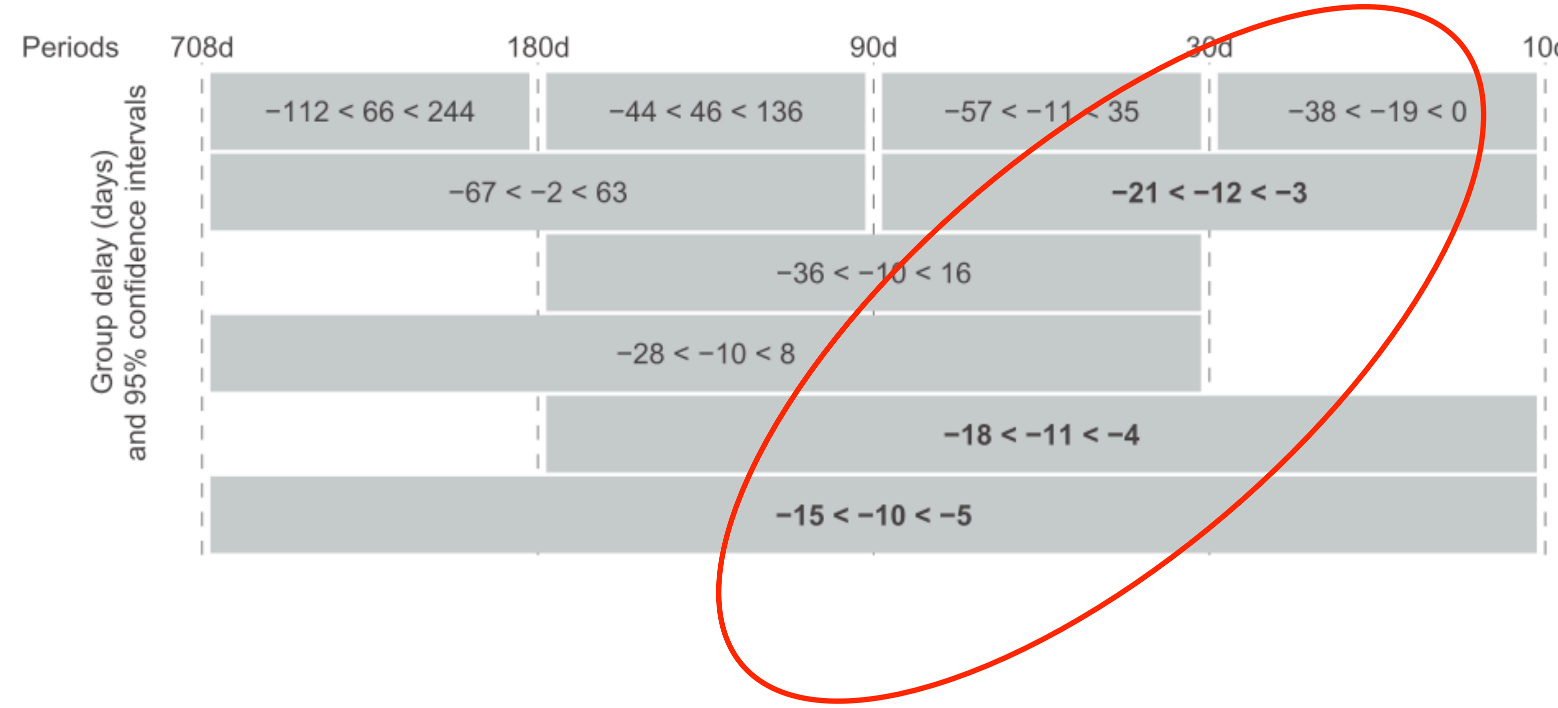
Elipot et al (2013), *J. Phys. Oceanogr.*:

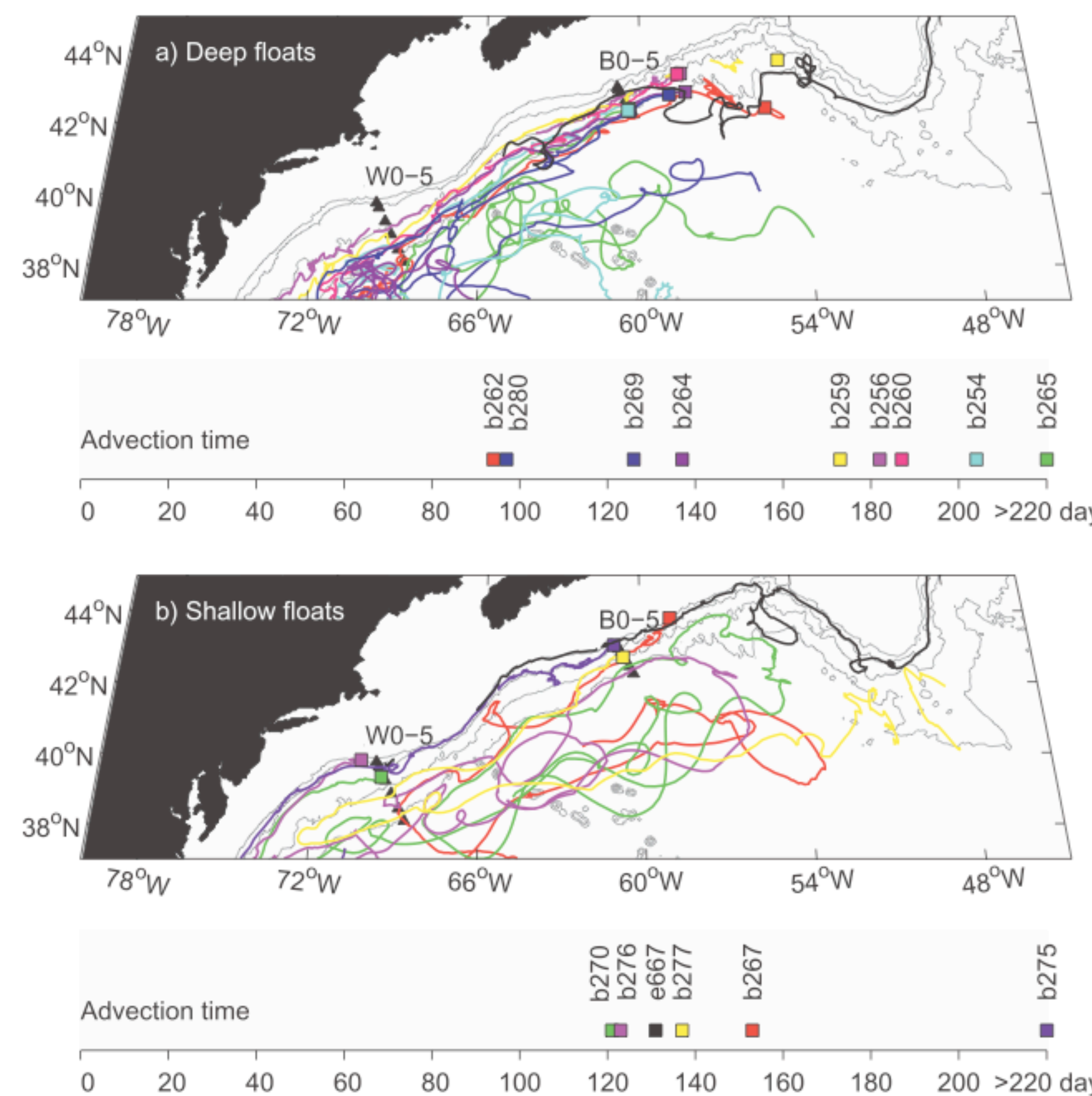
Evidence for boundary waves propagation at time scales < 3 months between Lines B and W at ~ 1 m s^{-1}

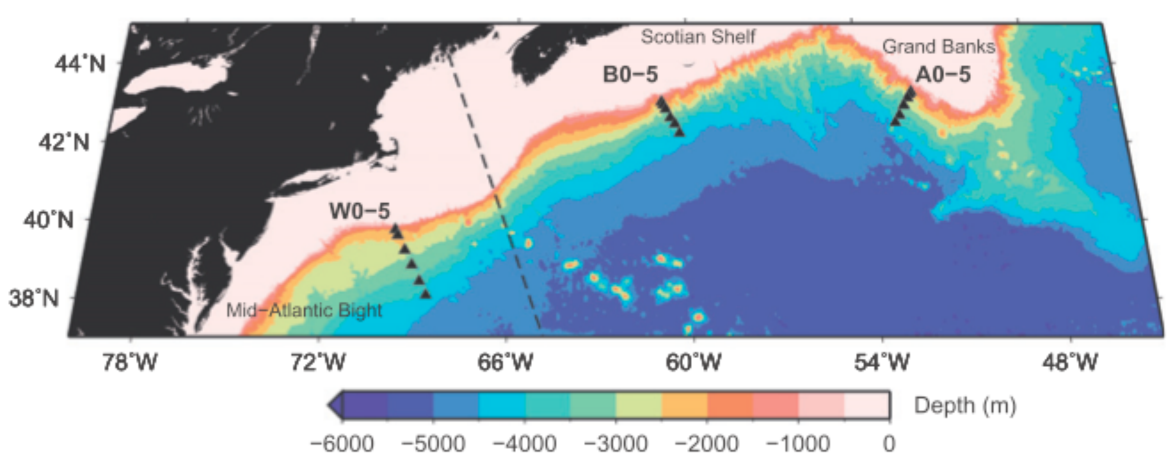
<u>Outstanding question:</u>

How does one explain overturning coherence at time scales longer than 3 months?

From RAFOS floats: NOT advection by DWBC

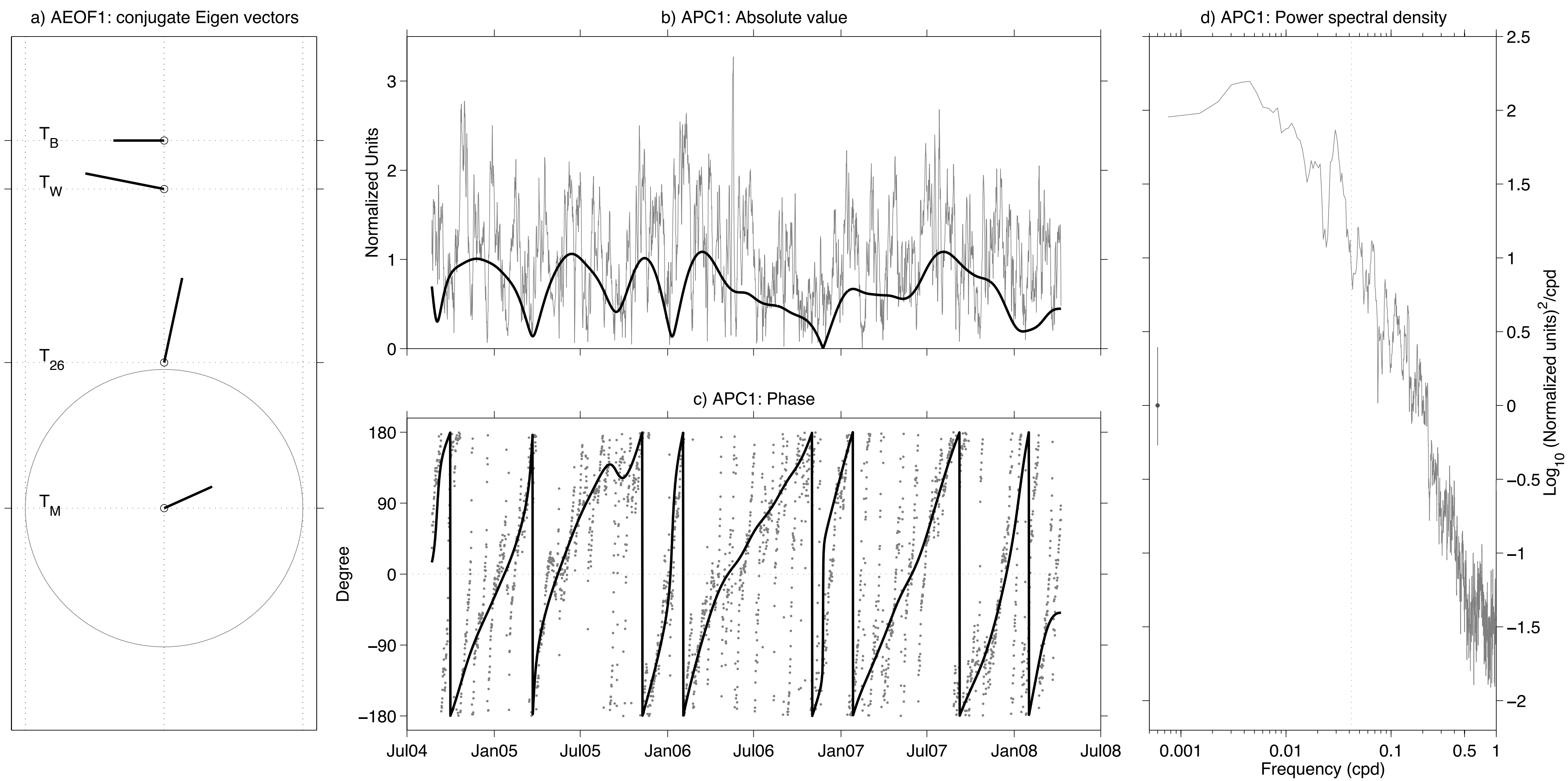






Analytic (complex) EOF analysis

First mode: AEOF1: 36% of the covariance



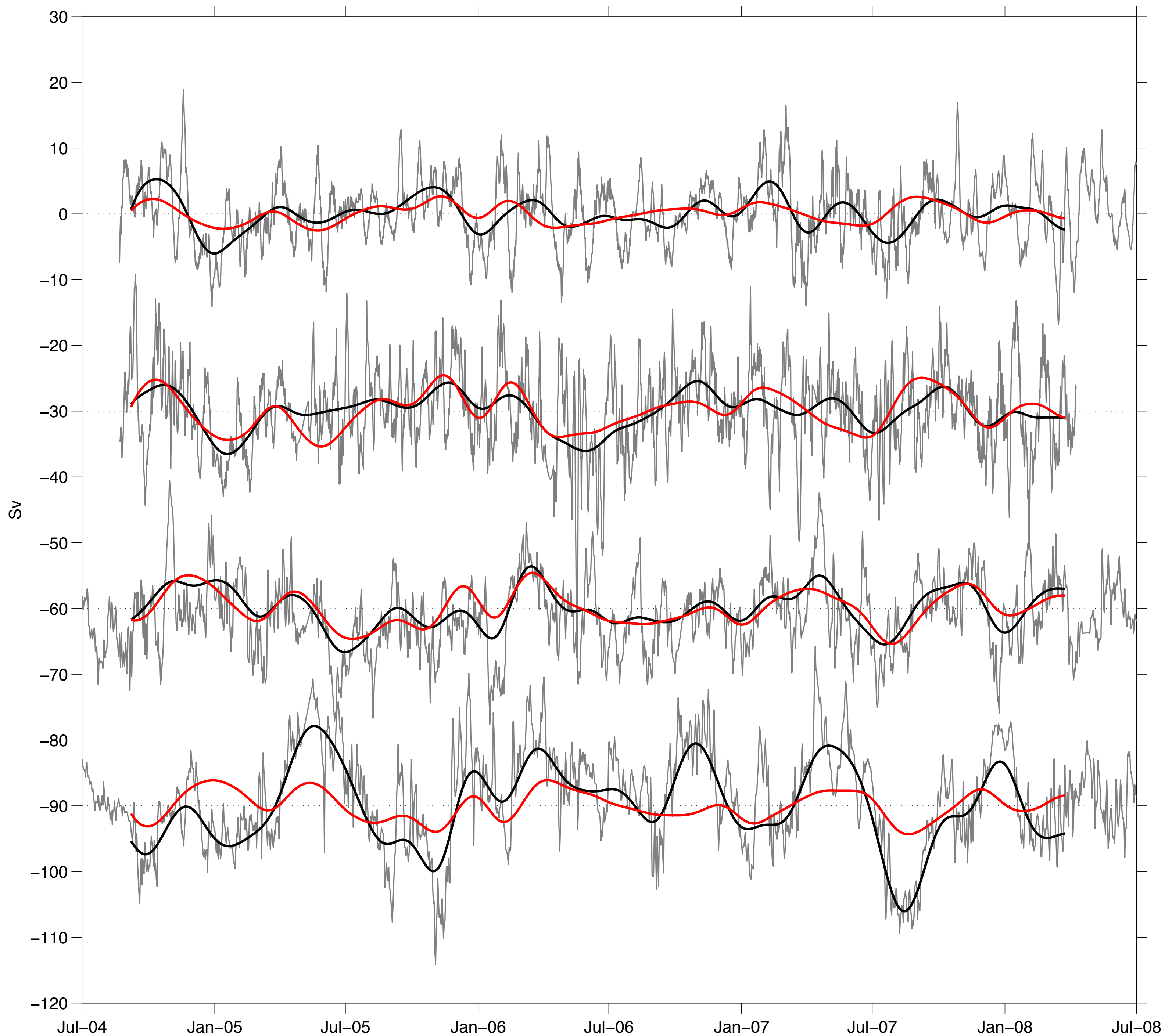
Eigen vectors

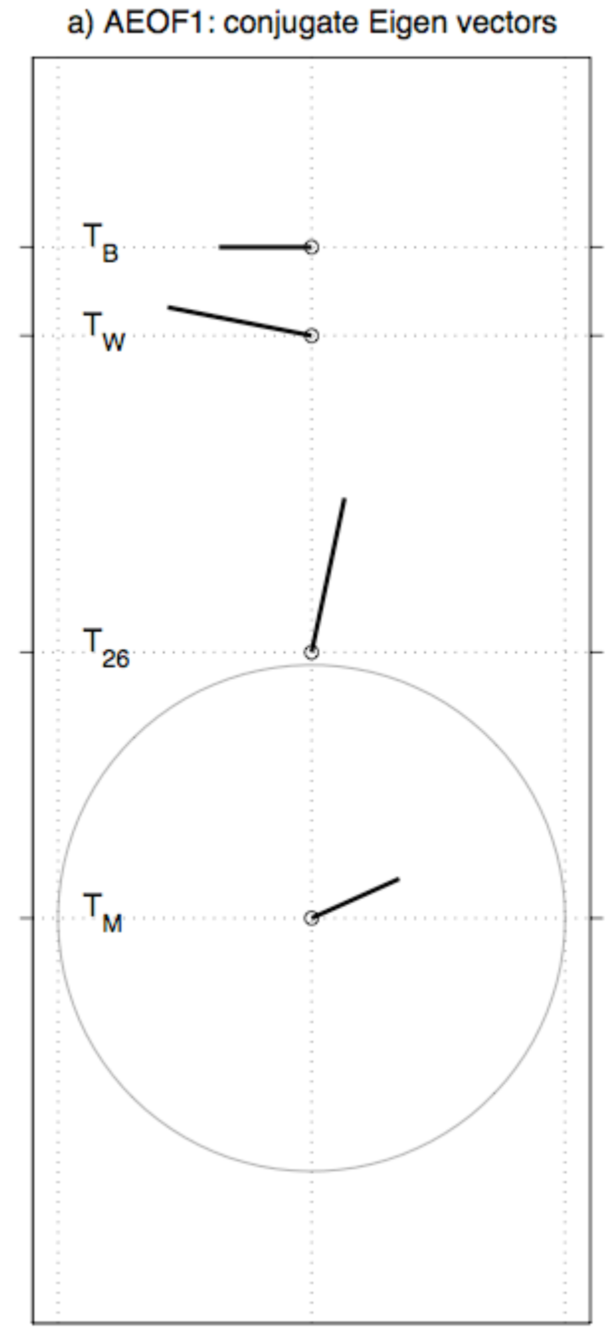
Principal Component time series

"Red" spectrum for this mode

→ <u>dubious wave interpretation</u>

Analytic EOF1: projection on time series





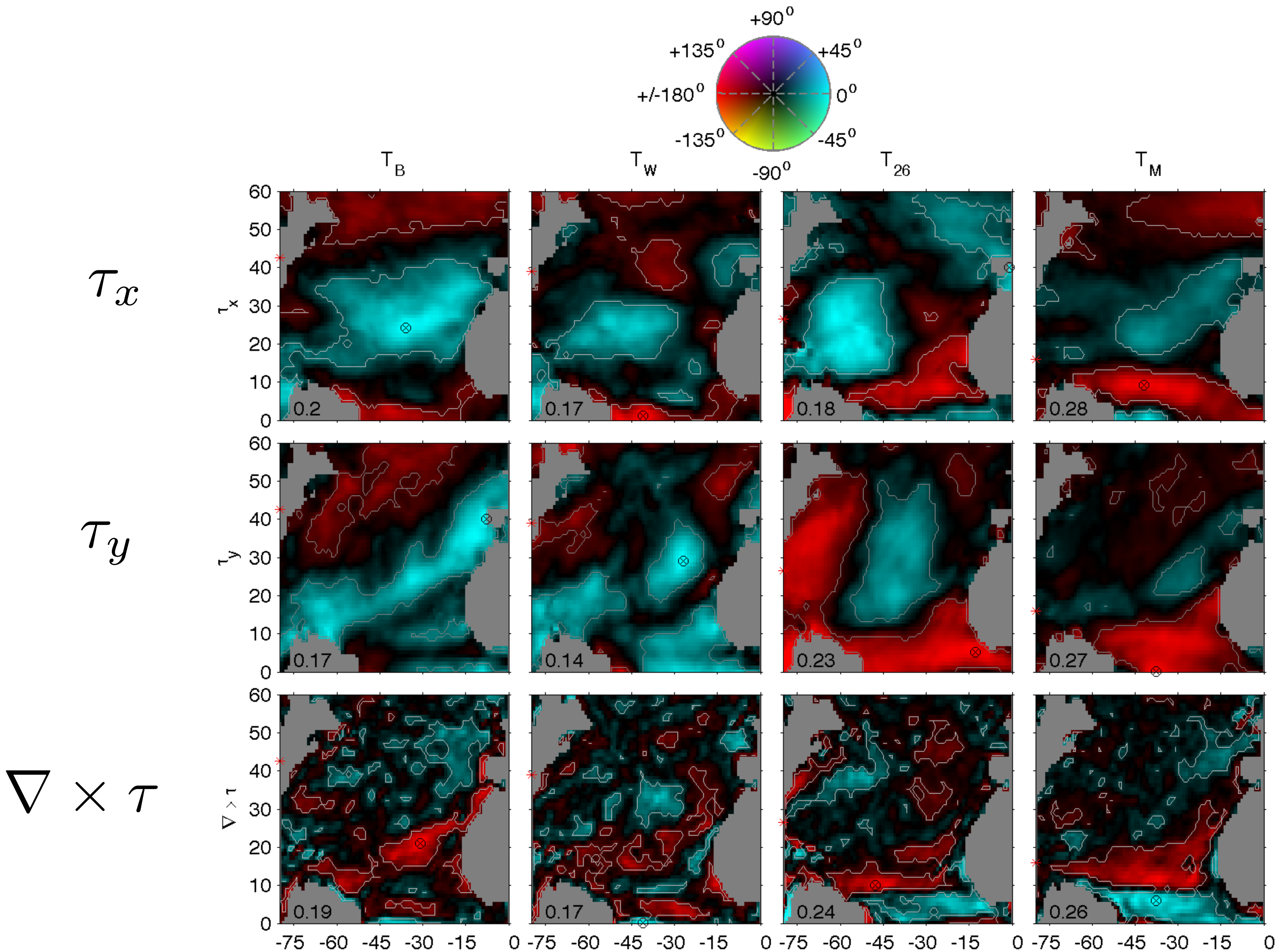
3-month lowpass

3-month lowpass AEOF1

Variance explained (12h-step):

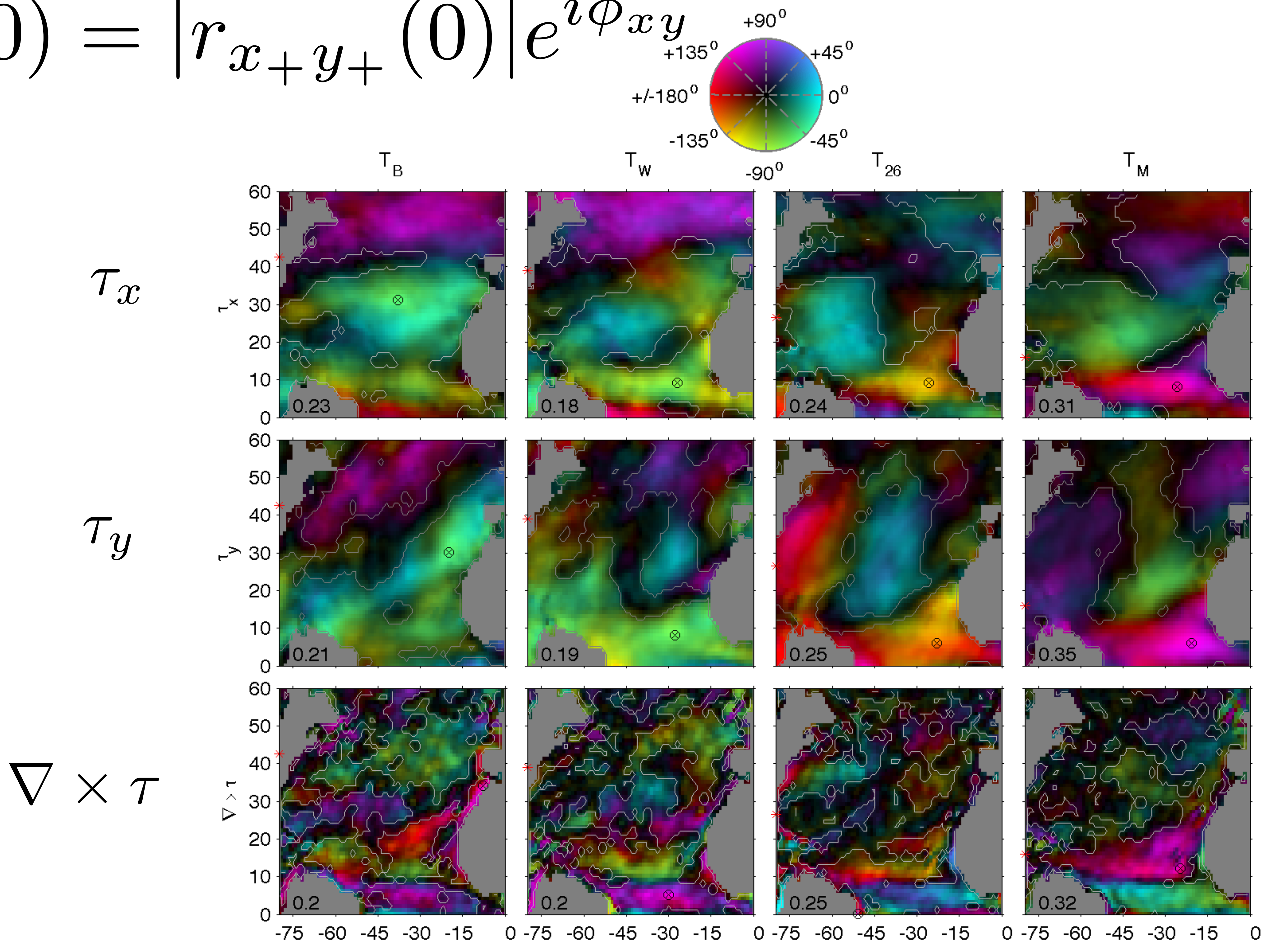
	T_B	T_W	T_{26}	T_M
$AEOF1(\%)$	19	48	56	21

Correlation of transports with wind stress Cartesian components and wind stress curl:



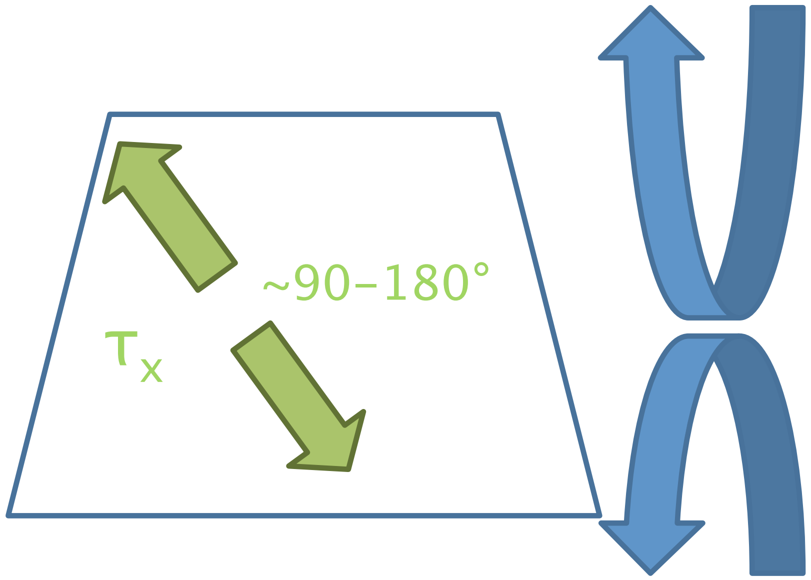
Analytic correlation of transports with wind stress Cartesian components and wind stress curl:

$$r_{x_+y_+}(0) = |r_{x_+y_+}(0)|e^{i\phi_{xy}}$$

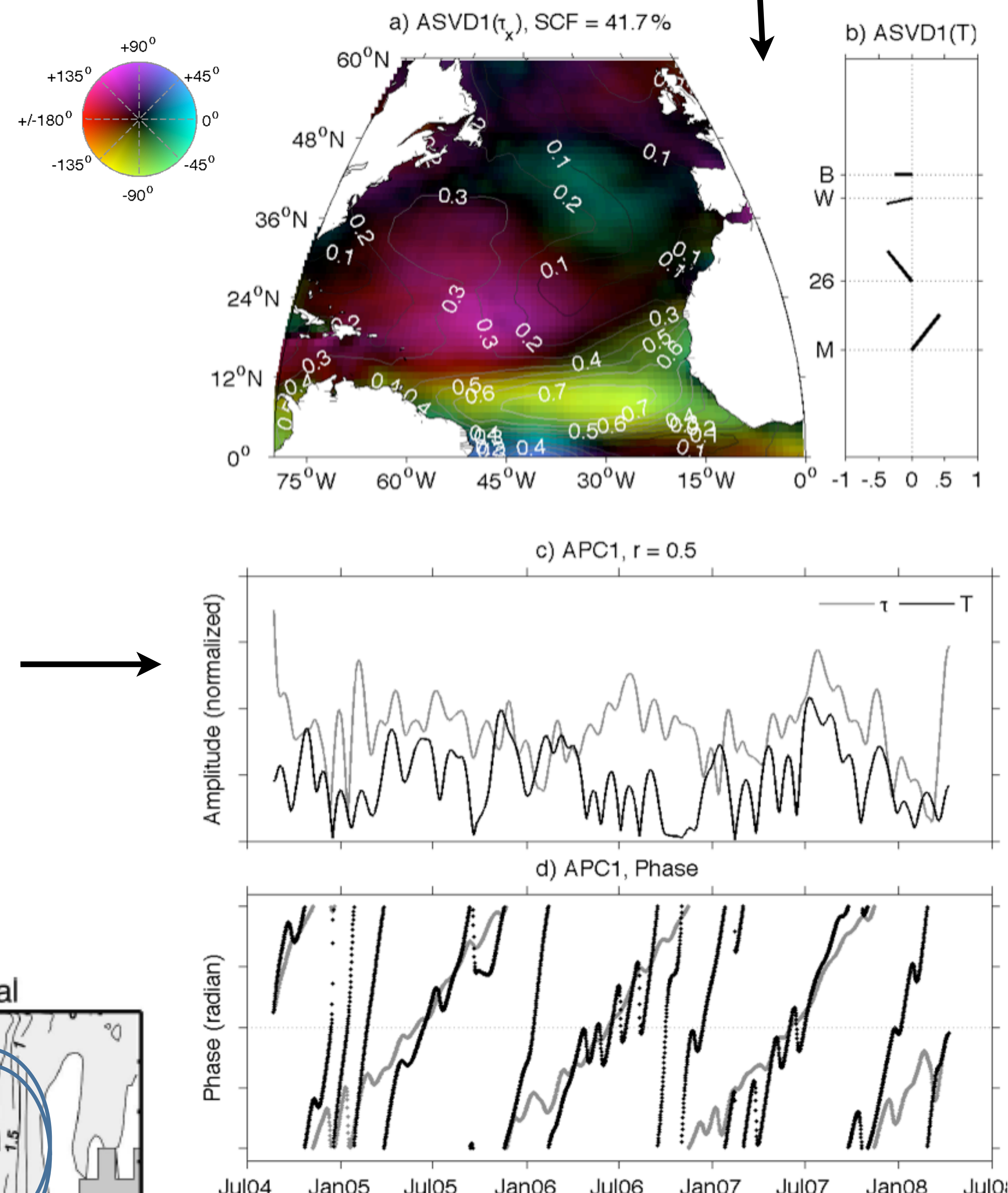


First mode of correlation between transports and wind stress: ASVD1

Singular Vectors



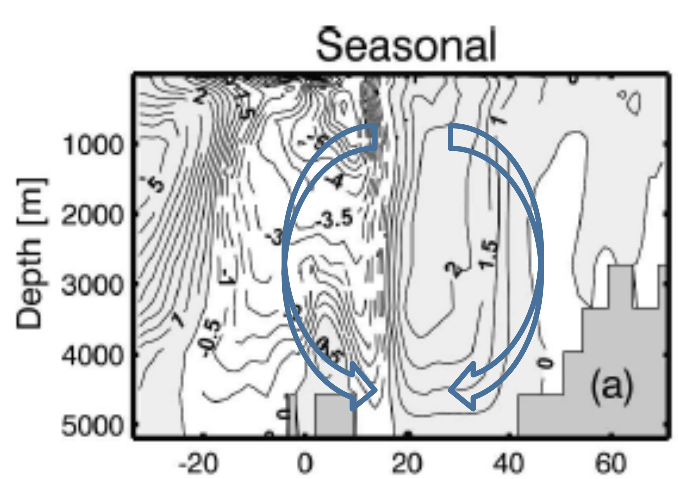
opposing oceanic overturning cells



Principal Component time series:
APC1 (τ) APC1 (T)

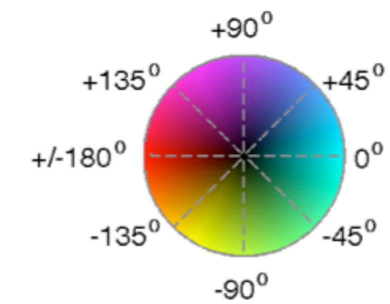
Coupling coefficient: r = 0.50

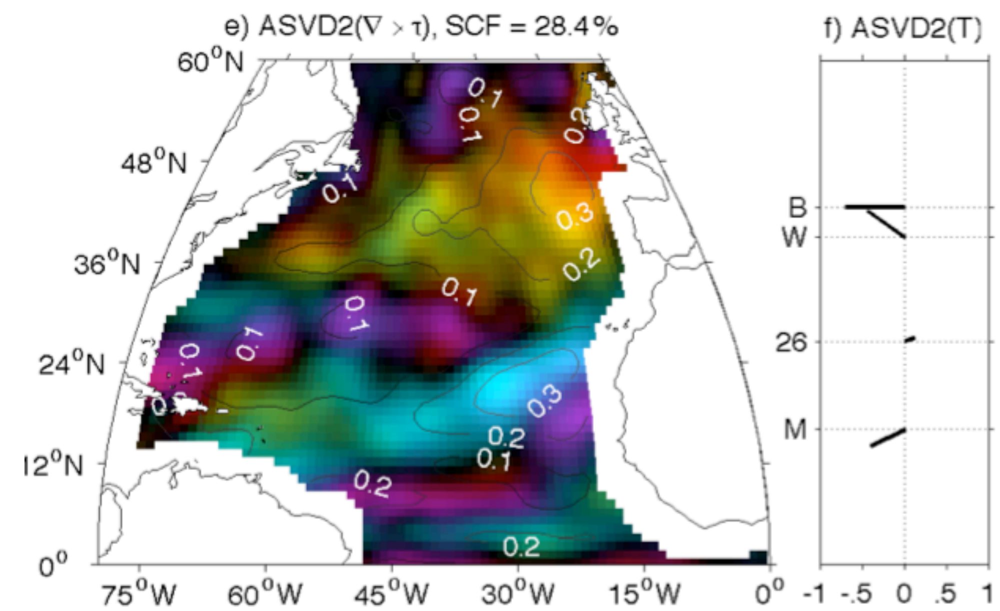
Sime et al. (2006):
Mean seasonal anomaly
in MOC diagnosed
in HadCM3



Second mode of correlation between transports and wind stress curl: ASVD2

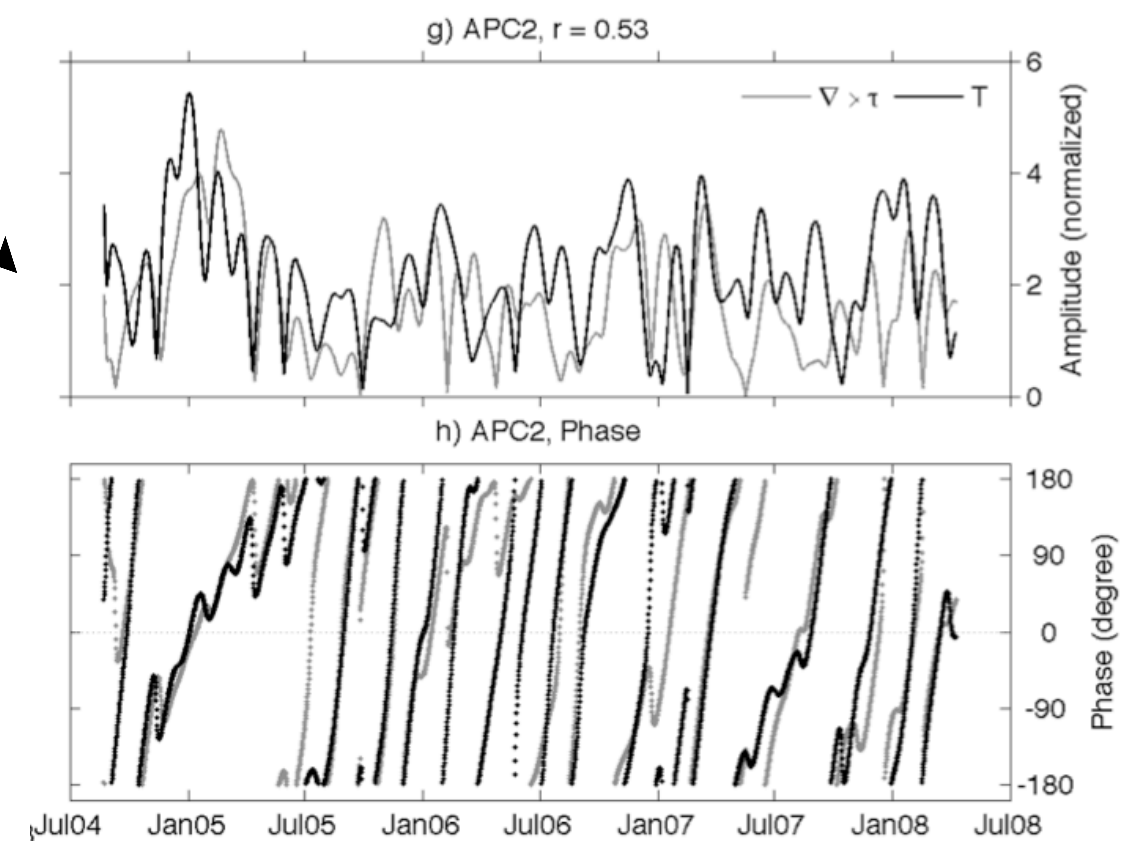
Singular Vectors



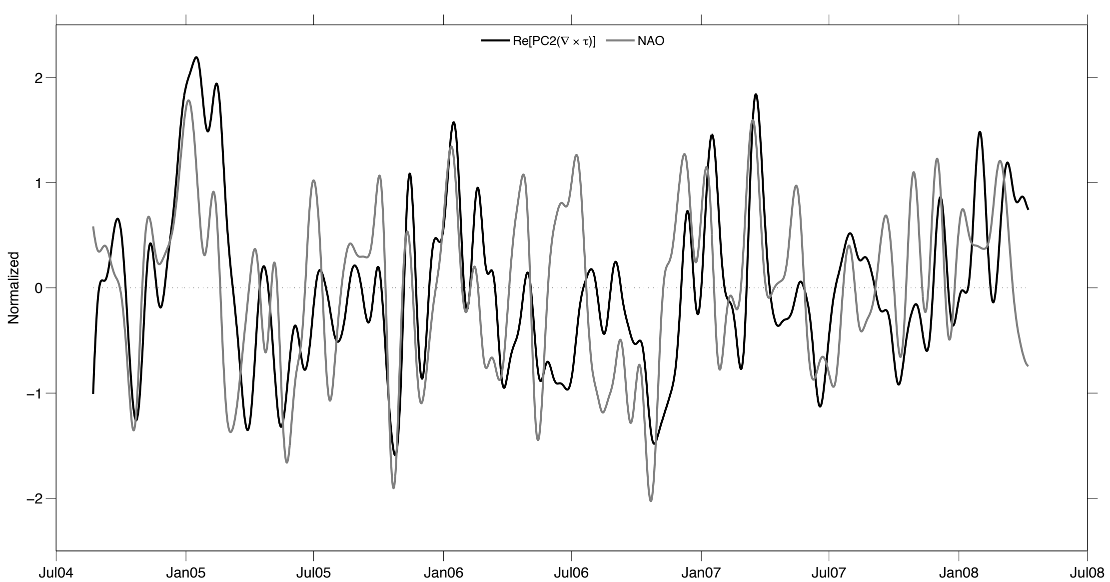


Principal Component time series:
APC1 (curl τ) APC1 (T)

Coupling coefficient: r = 0.53



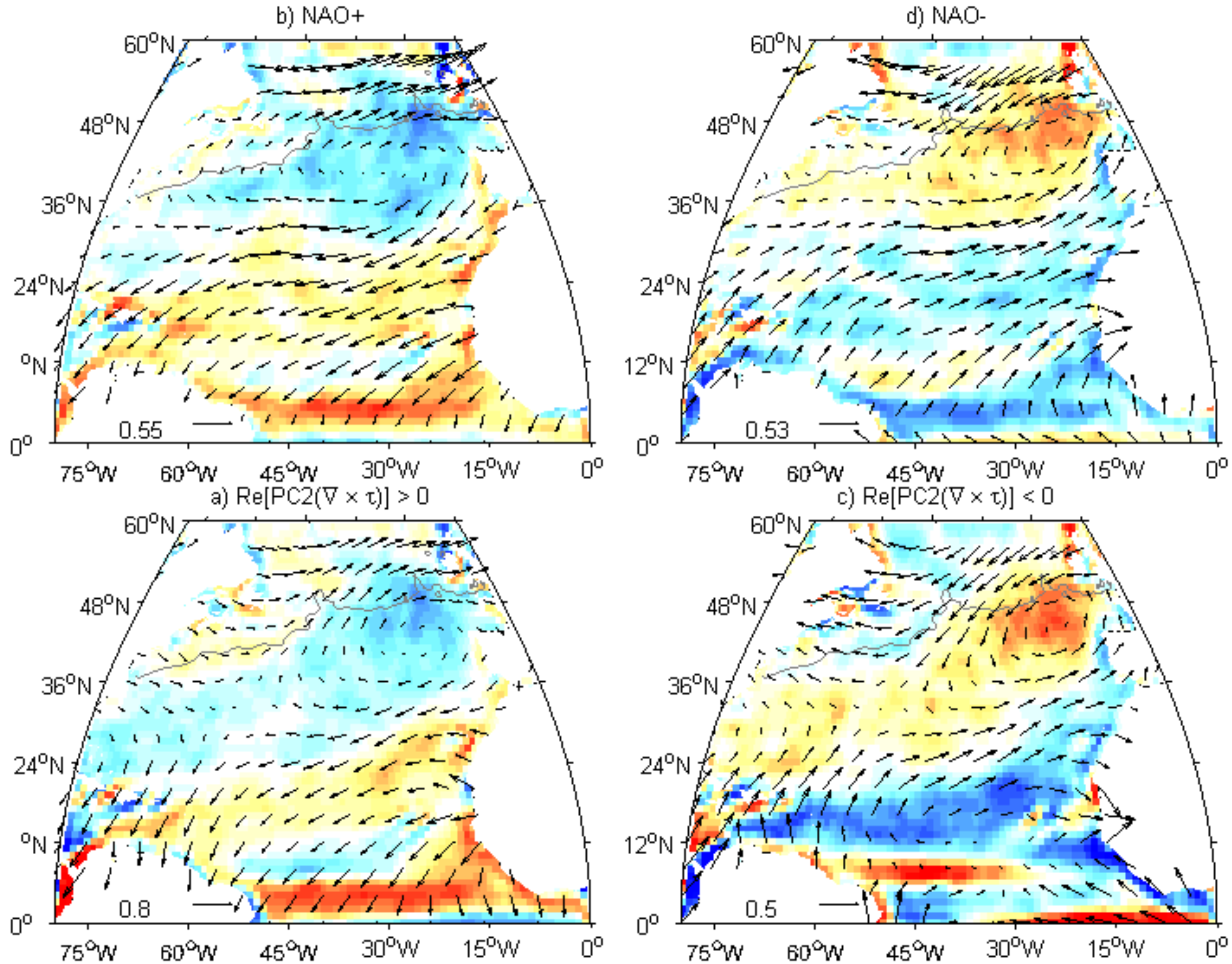
Correlation of mode with NAO index: 0.38



Wind stress and curl changes associated with ASVD2:

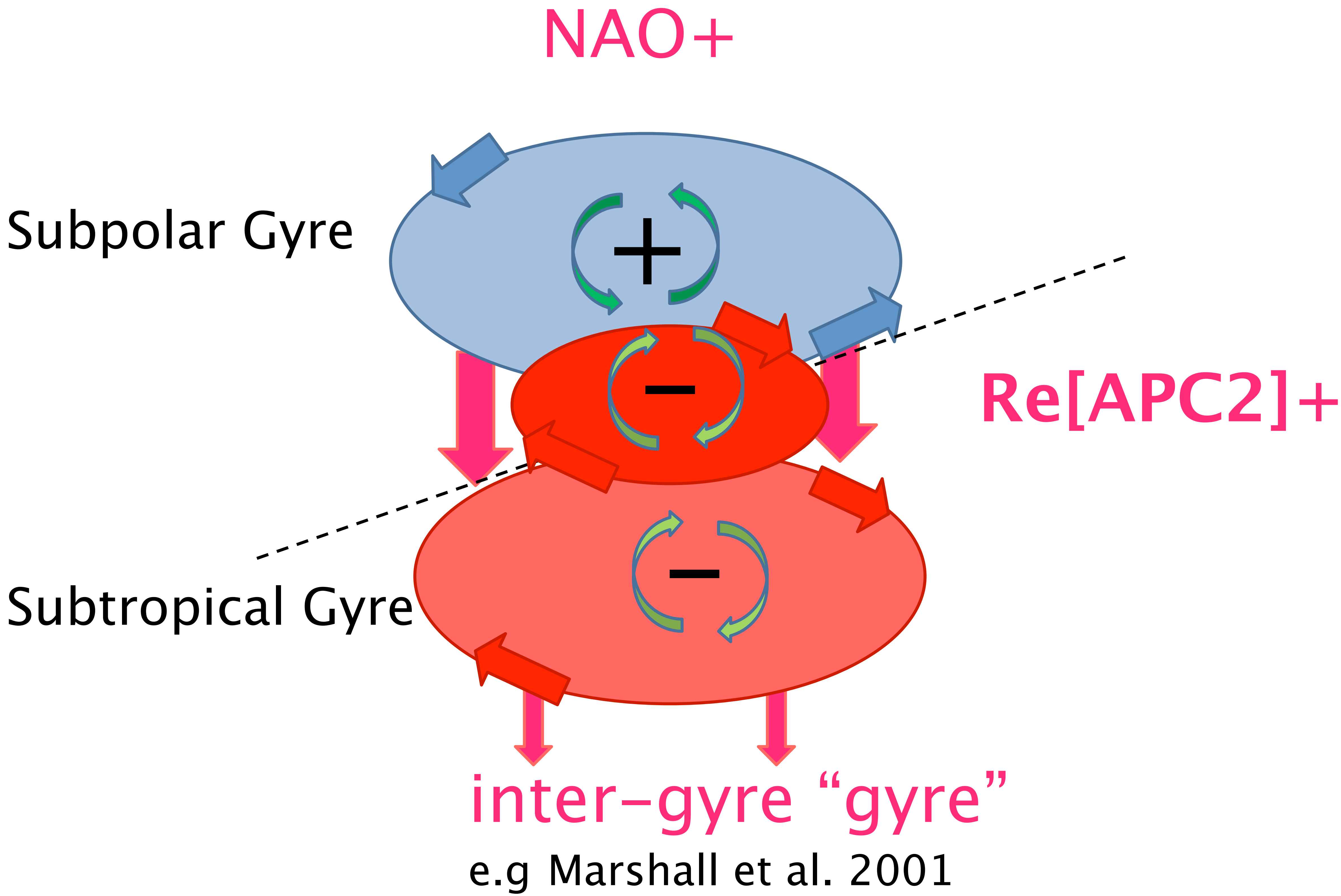
NAO phases →

Positive or negative Re[APC(curl stress)] →

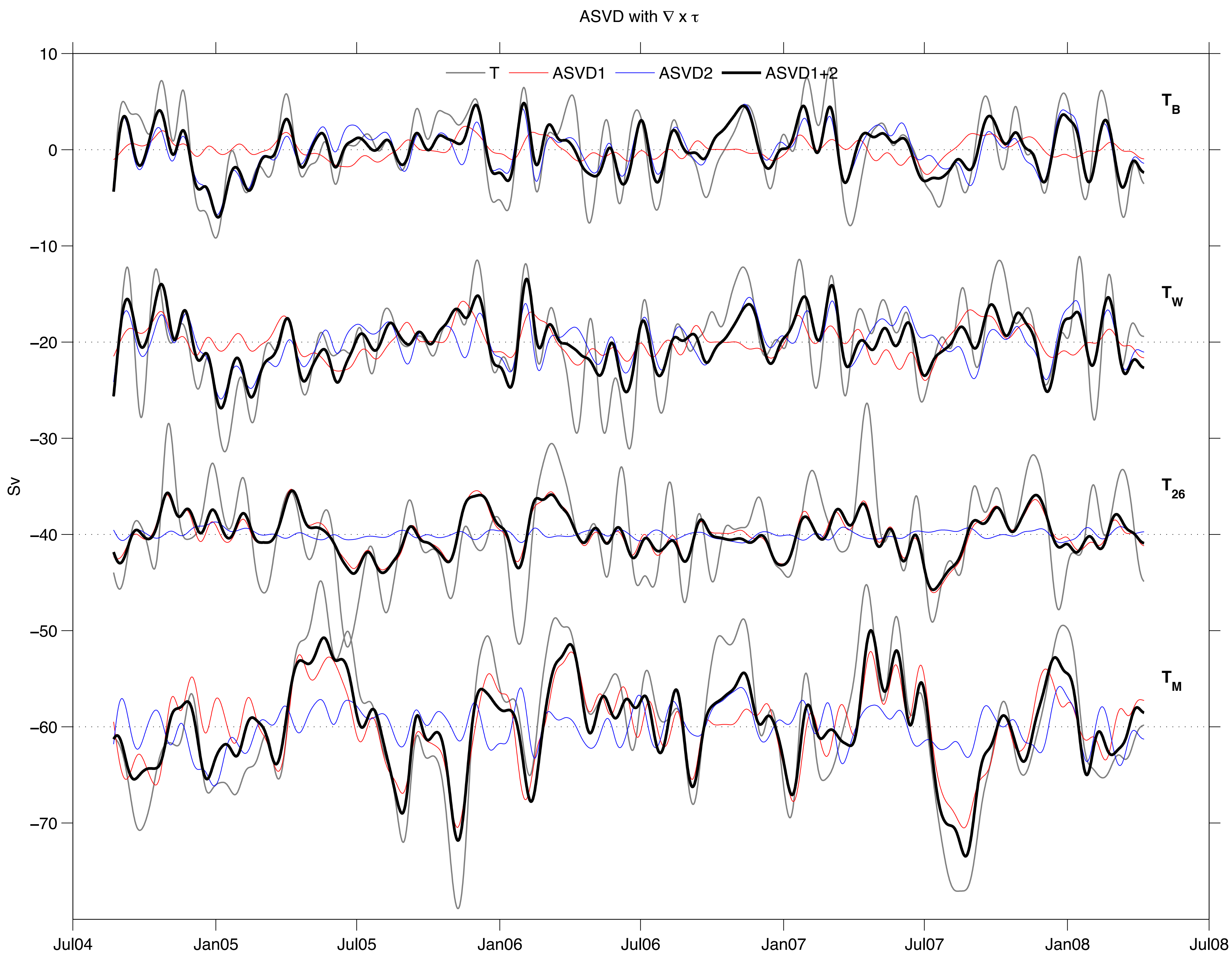


Composite anomalies of normalized wind stress curl (shading) and normalized wind stress vector (arrows)

Mechanism for deep overturning transport fast response to ASVD2?



Summary of wind covariance analysis: ASVD1 & ASVD2 for overturning transport time series



Total amount of variance explained by AEOF and wind stress curl modes:

	T_B	T_W	T_{26}	T_M
AEOF1 (%)	19.1	47.9	55.7	20.6
$\nabla \times \boldsymbol{\tau}$				
SVD1	9.4	20.7	45.7	59.4
SVD2	56.6	39.2	6.1	14.2
SVD1+SVD2	63.4	54.5	49.6	80.0

Summary

- 4 time series of western overturning transport below and relative to 1000 m at 42ºN, 39ºN, 26ºN, and 16ºN
- Time series are representative of geostrophic overturning processes on semi-annual and longer time scales
- Evidenced semi-annual and longer periods covariability between transports
- 1st mode of variability with near annual & semi-annual phase cycle associated with basin-wide Ekman forcing
- 2nd mode of variability related to large-scale NAO-like wind pattern

Thank you

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