NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre
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MERIDIONAL TRANSPORT ESTIMATES FROM THE RAPID-WAVE ARRAY

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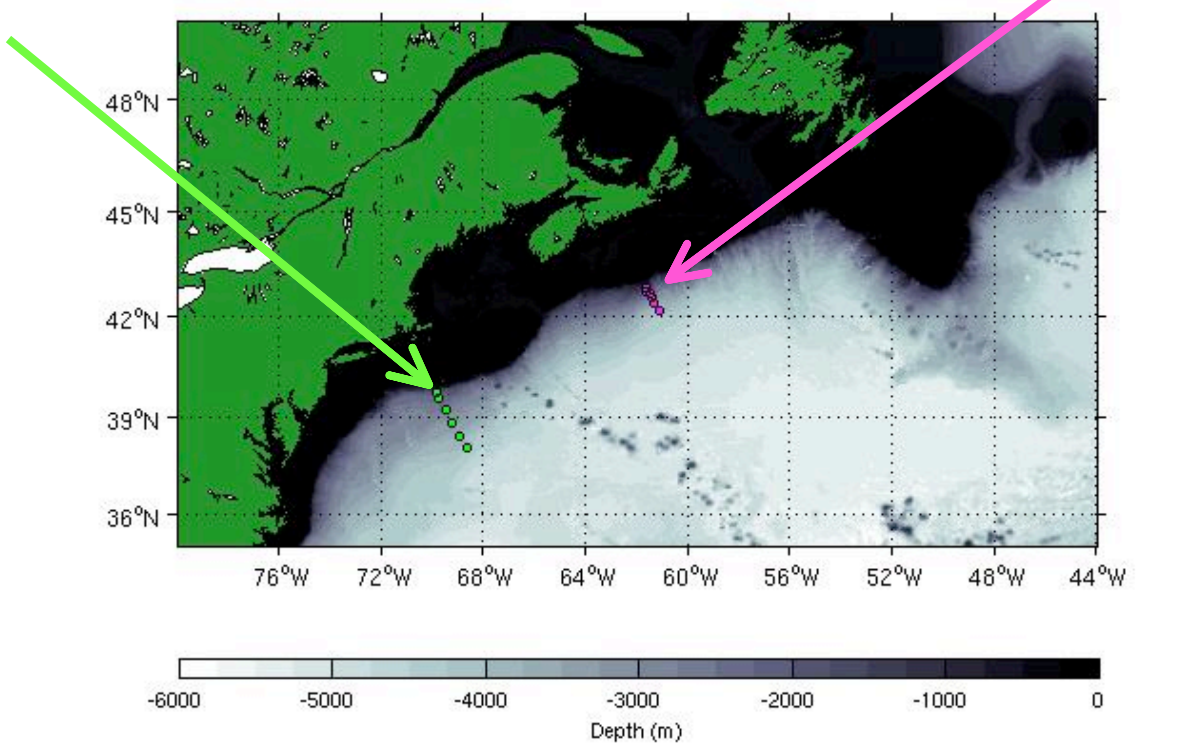
In collaboration with:
Bedford Institute of Oceanography (John Loder et al.)
Woods Hole Oceanographic Institution - Line W program (John Toole et al.)

Outline

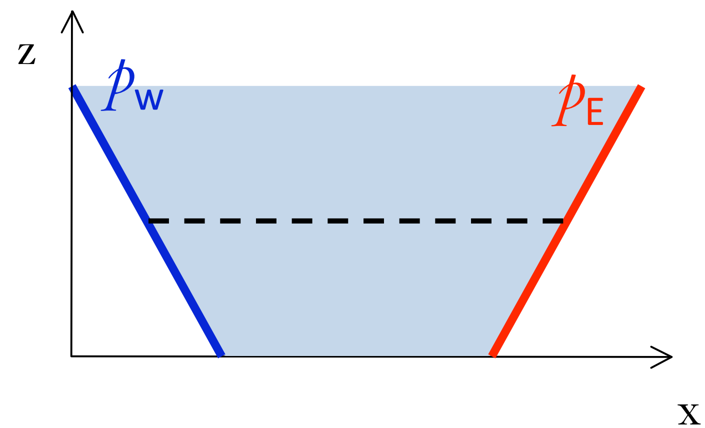
1. **Principle: pressure and transport on the western boundary**
2. **The "step" method to measure pressure**
3. **Application at the Rapid Scotia (RS) line (2008 …)**
4. **Application at line W (2004 - …)**



1. The measurement principles

Geostrophy:

$$-\rho_0 f v(x,z) \quad = \quad -\frac{\partial p}{\partial x}(x,z)$$



Define transport per unit depth: $$\int_W^E v \; dx \quad = \quad Q(z)$$

Zonal integral gives : $$\rho_0 f Q(z) \quad = \quad p_E(z) - p_W(z)$$

Transport per unit depth is the difference of pressure between East and West boundaries

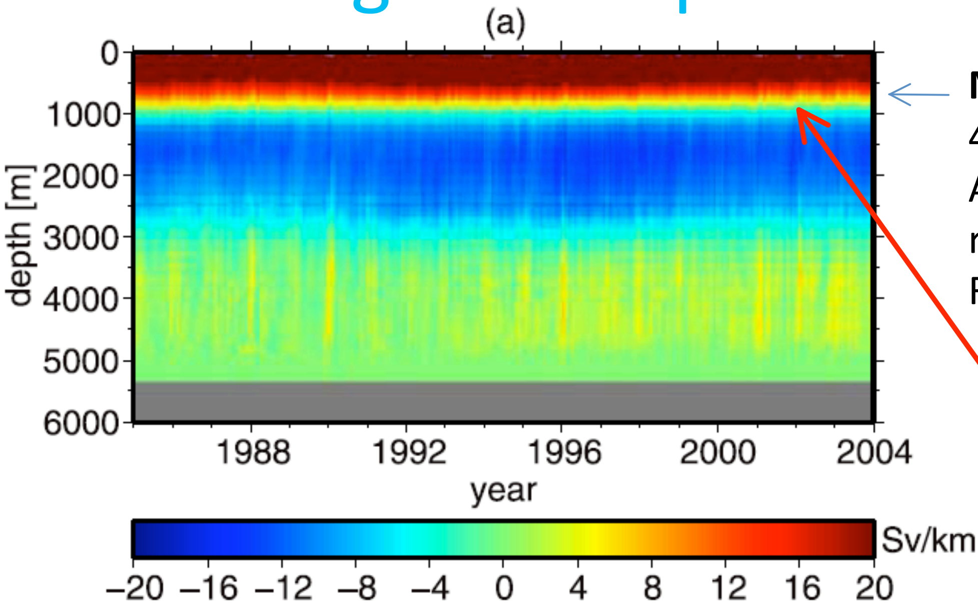
"Western" and "Eastern" contribution to zonally-integrated meridional transport

$$
\begin{aligned}
T &= \int_{-H}^{0} \frac{-p_W(z)}{\rho_0 f}\, dz + \int_{-H}^{0} \frac{p_E(z)}{\rho_0 f}\, dz \\
&= \underbrace{T_W}_{\text{"Western boundary contribution"}} + \underbrace{T_E}_{\text{"Eastern boundary contribution"}}
\end{aligned}
$$

"Western boundary contribution"

"Eastern boundary contribution"

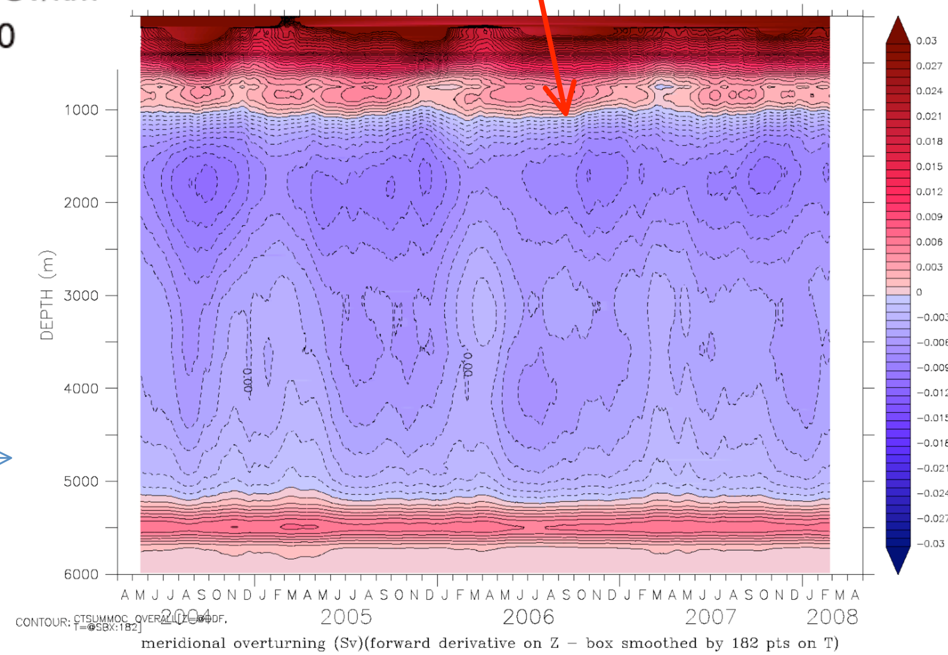
Measuring from top to bottom? 1000 m down?



Meridional transport per unit depth Q(z) at 42°N in Ocean Circulation and Climate Advanced Modelling project model (**OCCAM**), run at NOC (Southampton)
From Bingham and Hughes (2008)

Zero crossing of Q(z) is at ~ 1000 m

From 26.5°N data ; 3-month averaging window



2. The "step" method: (because bottom pressure recorders are unreliable on climatic time scales)

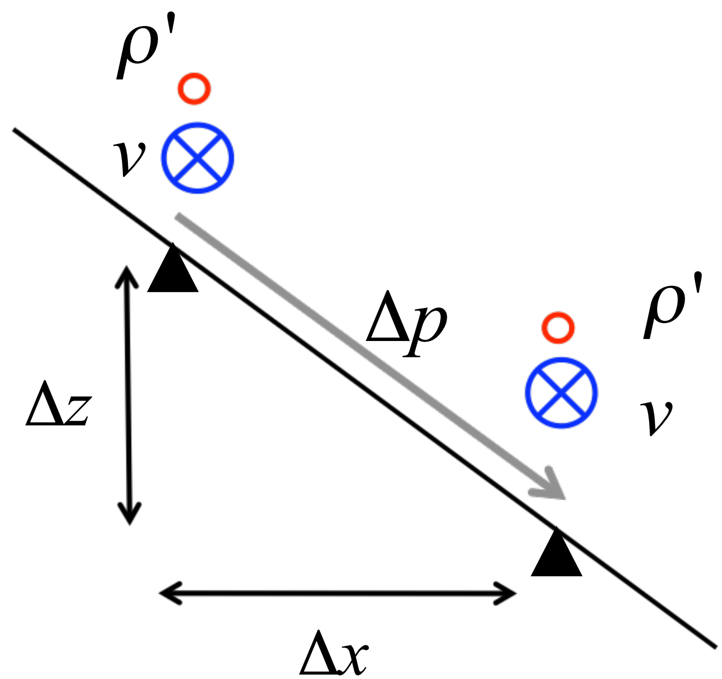
a. Measure pressure along slope from in-situ velocity and density data

$$\Delta p = \frac{\partial p}{\partial x}\Delta x + \frac{\partial p}{\partial z}\Delta z$$

$$= \rho_0 f v \Delta x + \rho' g \Delta z$$

Pressure gradient from geostrophic velocity

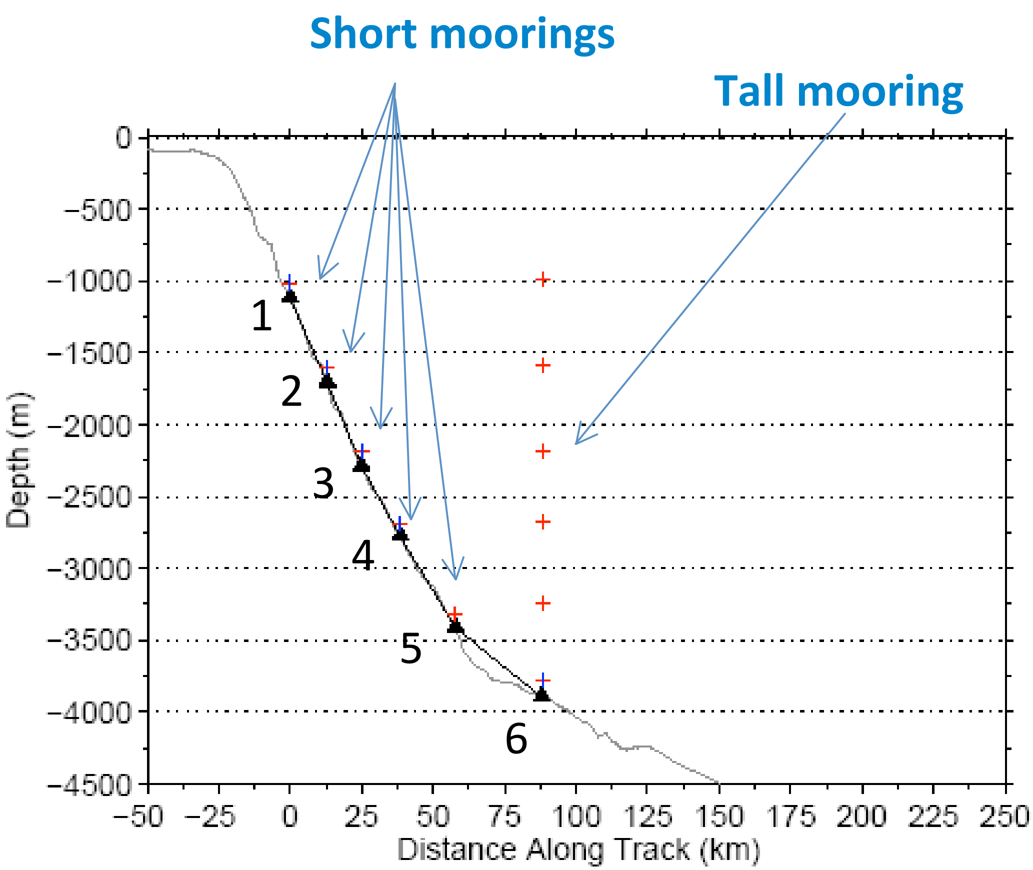
Pressure gradient from density anomalies



b. Use pressure differences to step along the slope
to obtain pressure anomalies relative to first depth (here 1000 m):

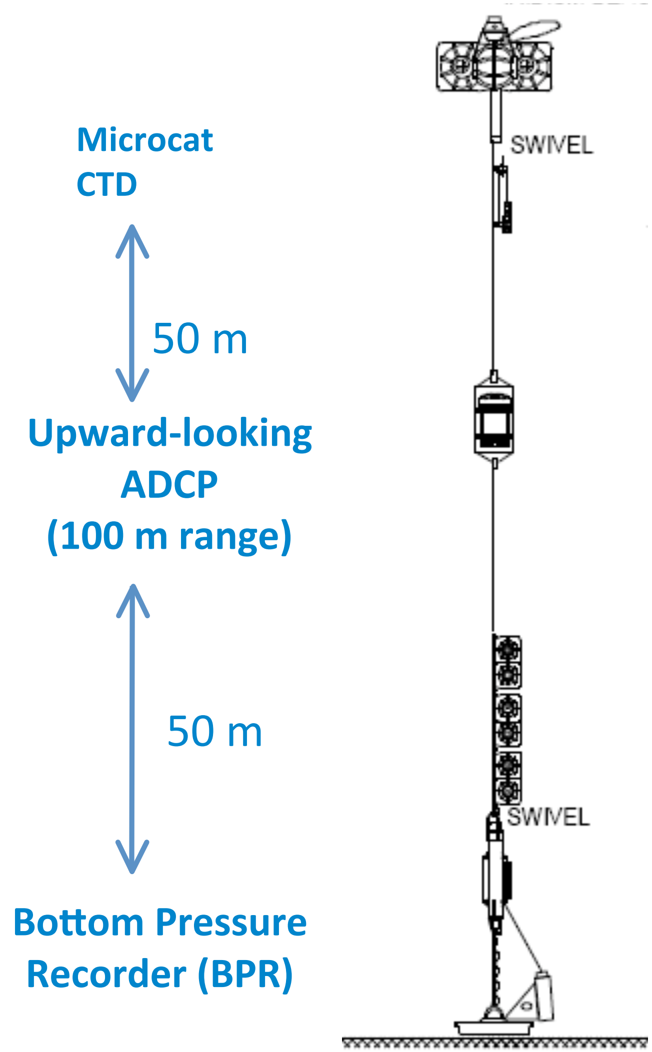
$$p'_1 = 0,\ p'_2 = p'_1 + \Delta p_{12},\ p'_3 = p'_1 + \Delta p_{12} + \Delta p_{23}, \ldots$$

3. The Rapid Scotia (RS) line

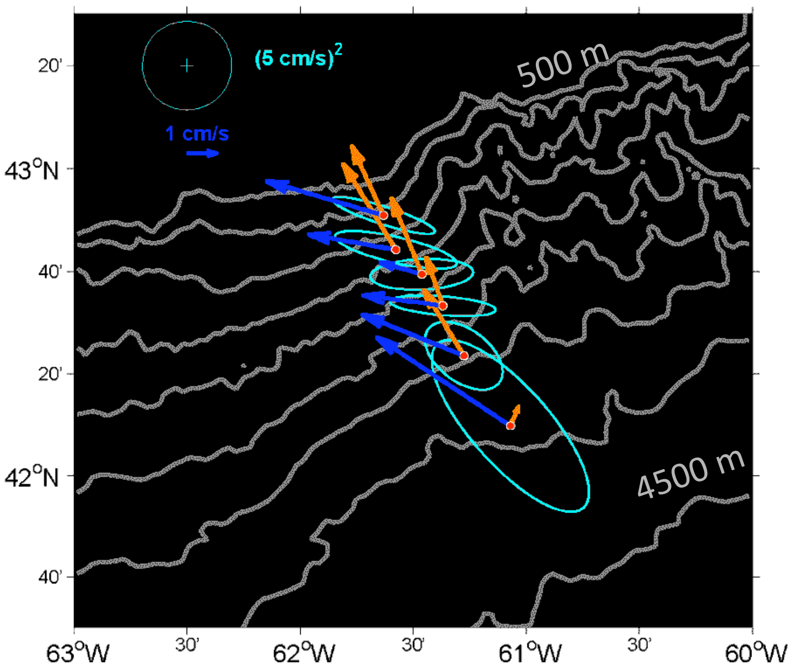


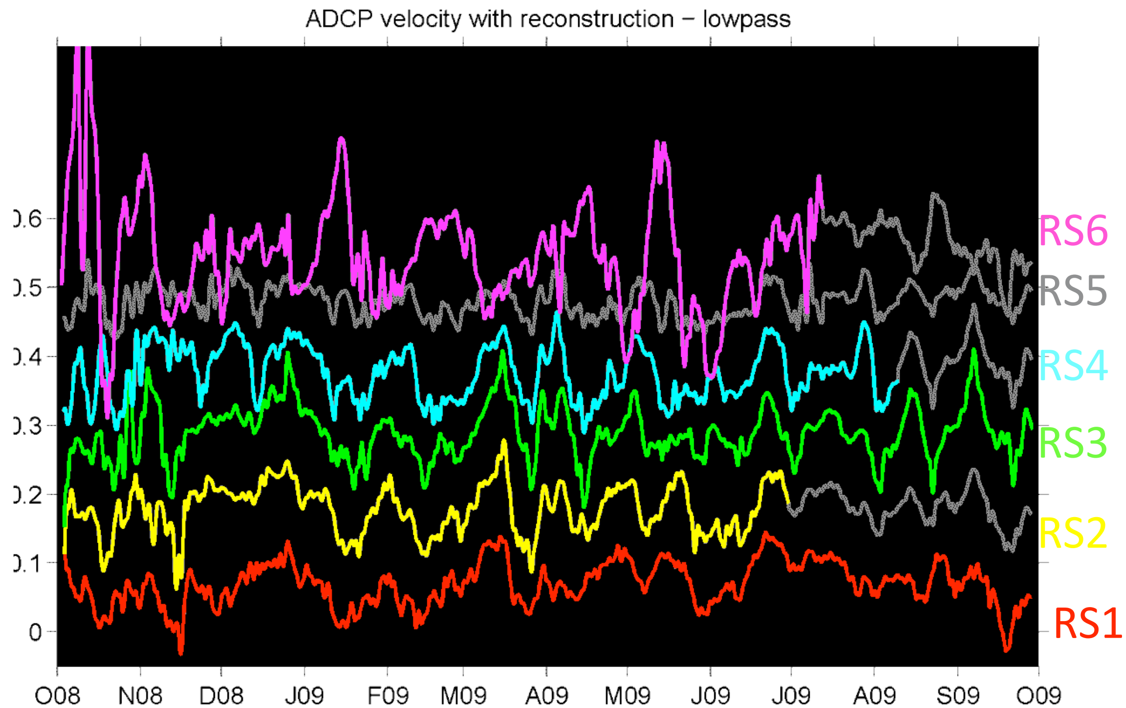
Bottom pressure recorder (**Δ**), microcat CTD (+) and ADCP (|)

Short mooring diagram:



RS line velocity data





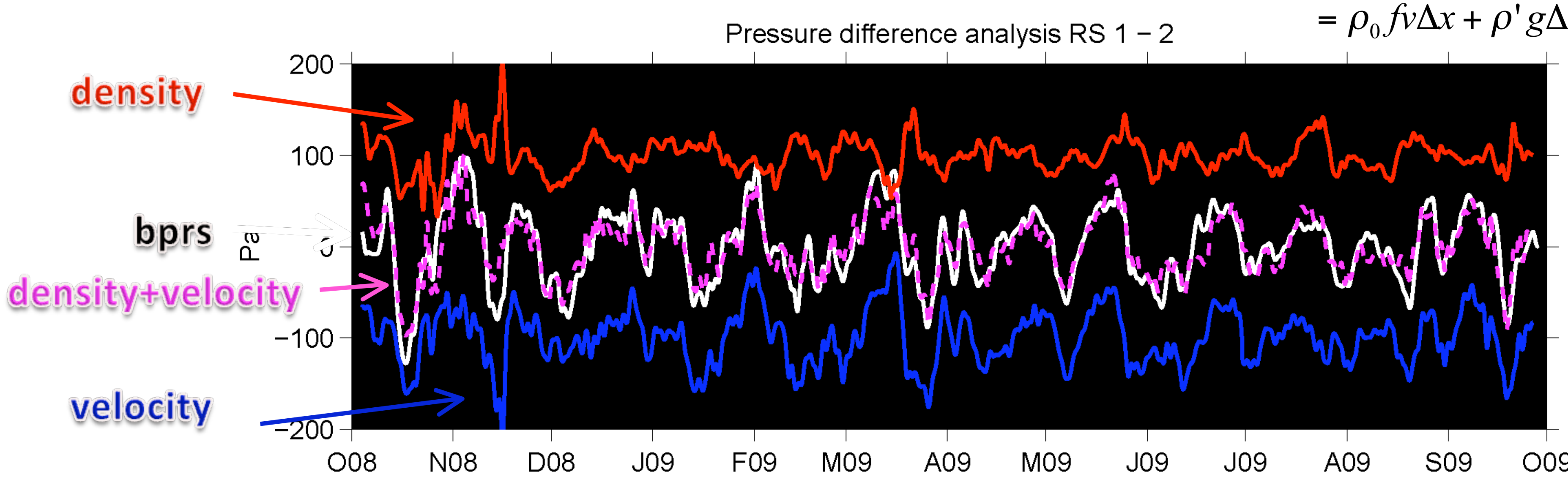
- Mean flow
- Bathymetry gradient
- Variance ellipses

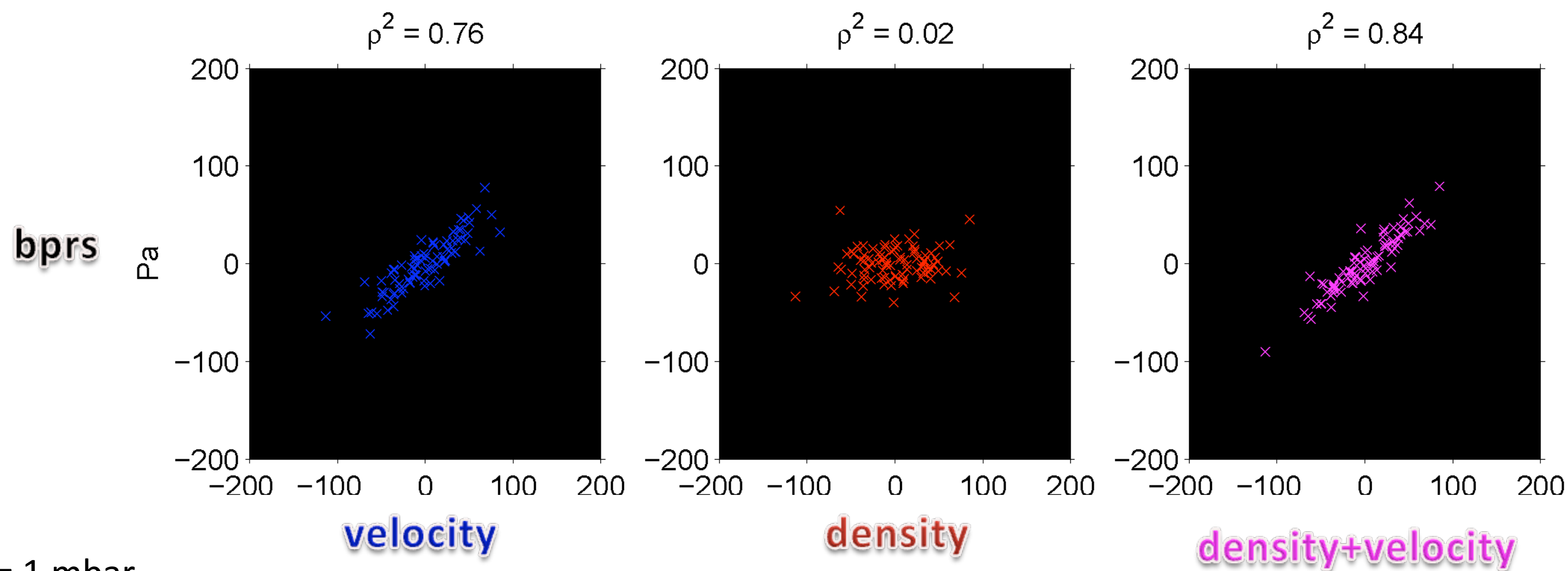
Velocity component perpendicular to gradient of bathymetry

Validation of the "step" method at RS line

$$\Delta p = \frac{\partial p}{\partial x}\Delta x + \frac{\partial p}{\partial z}\Delta z$$

$$= \rho_0 f v \Delta x + \rho' g \Delta z$$

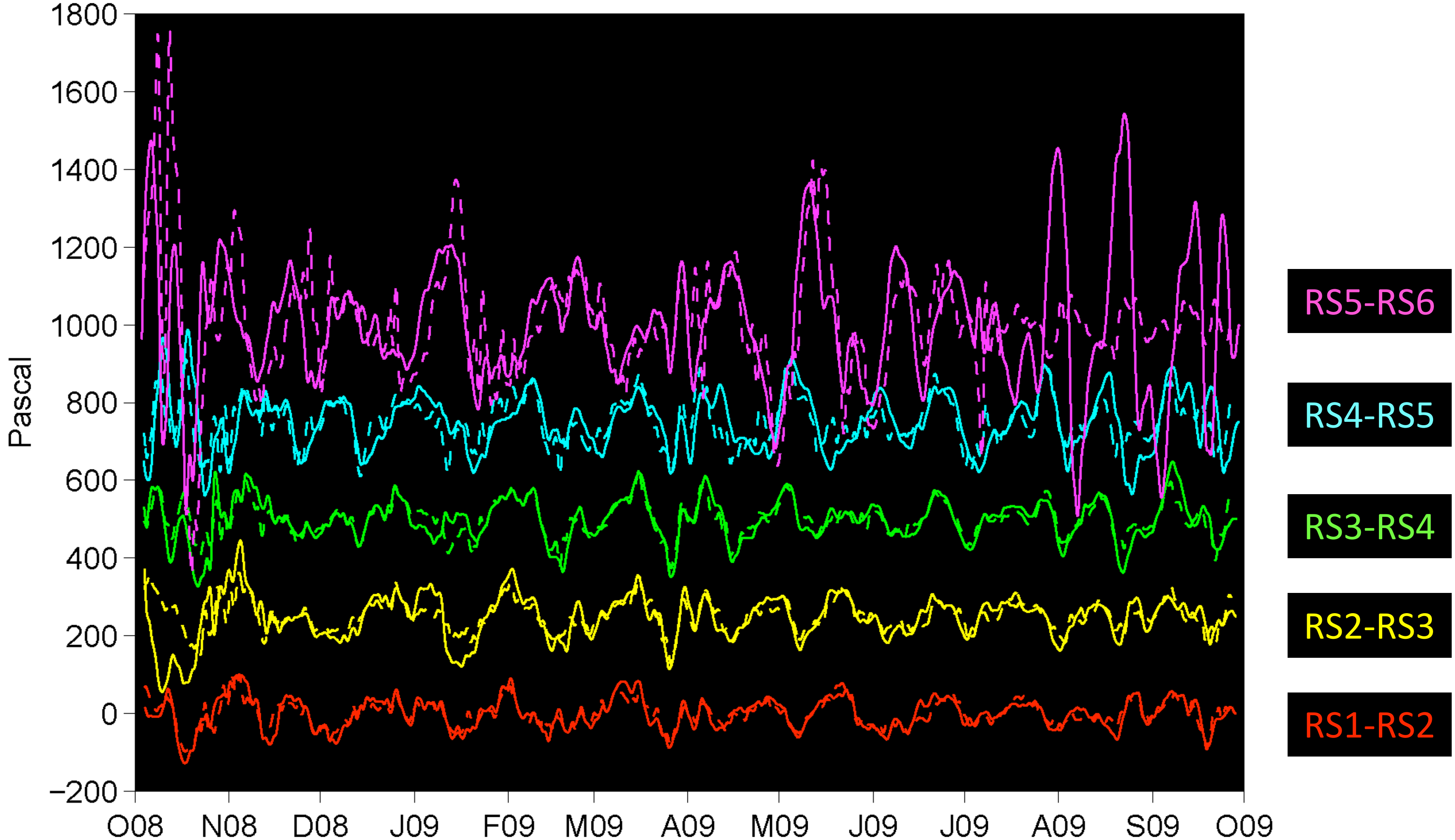




100 Pa = 1 mbar

BPRs (—) and step-derived (---) pressure differences

Band-passed between 50- and 2-day periods

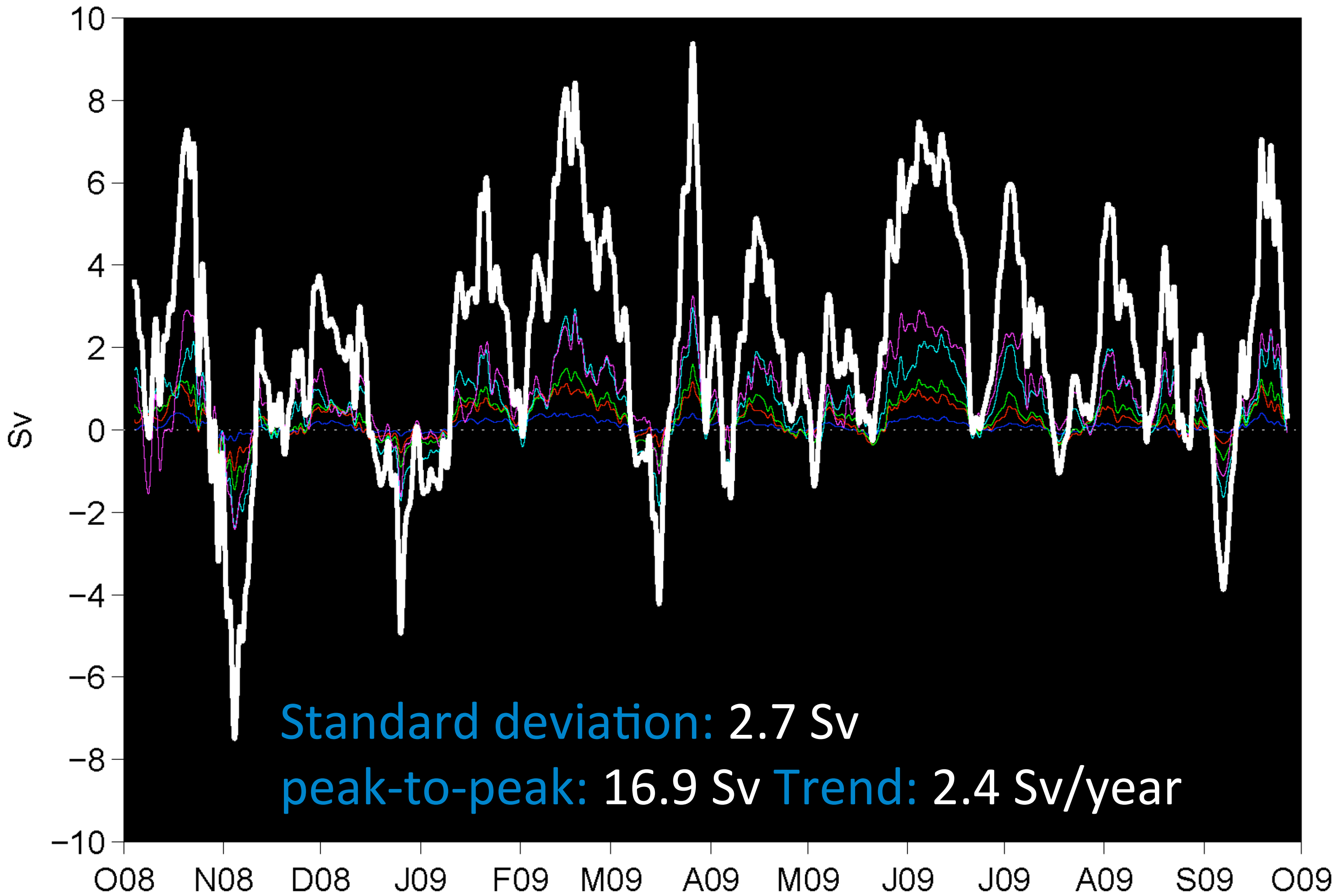


100 Pa = 1 mbar

Transport at RS line (42°N)

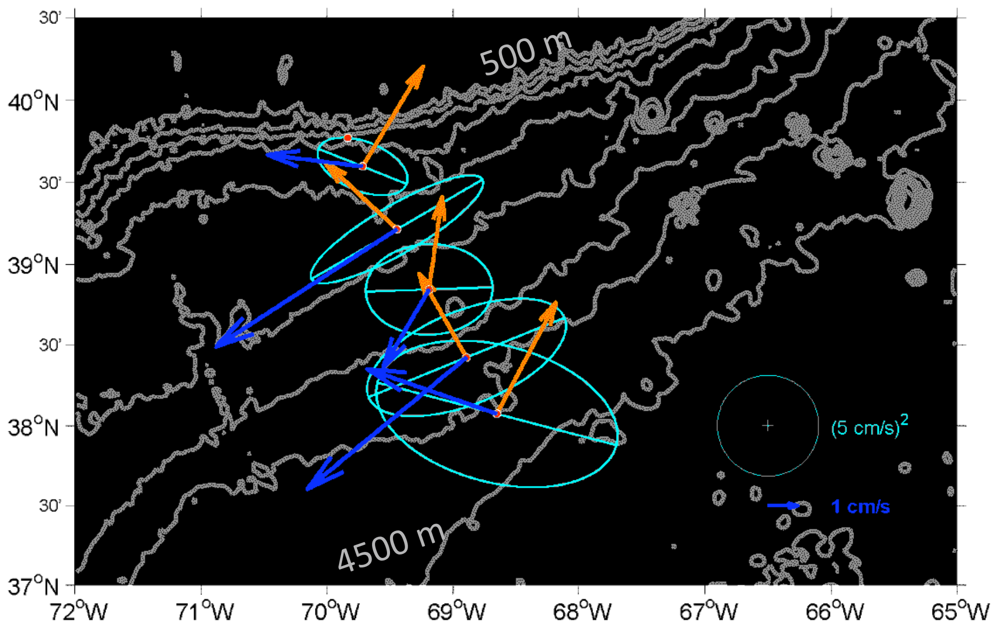
(below and relative to ~1100 m)

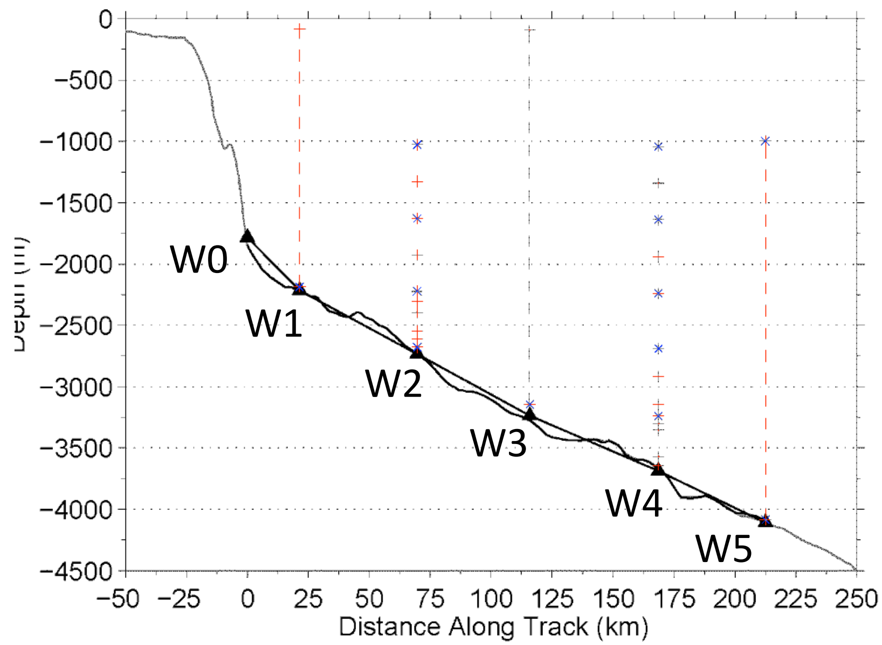
$$T'_W = \int_{z=-4000}^{z=-1000} \frac{-p'_W(z)}{\rho_0 f} \, dz$$



Line W

(2004 - ongoing)

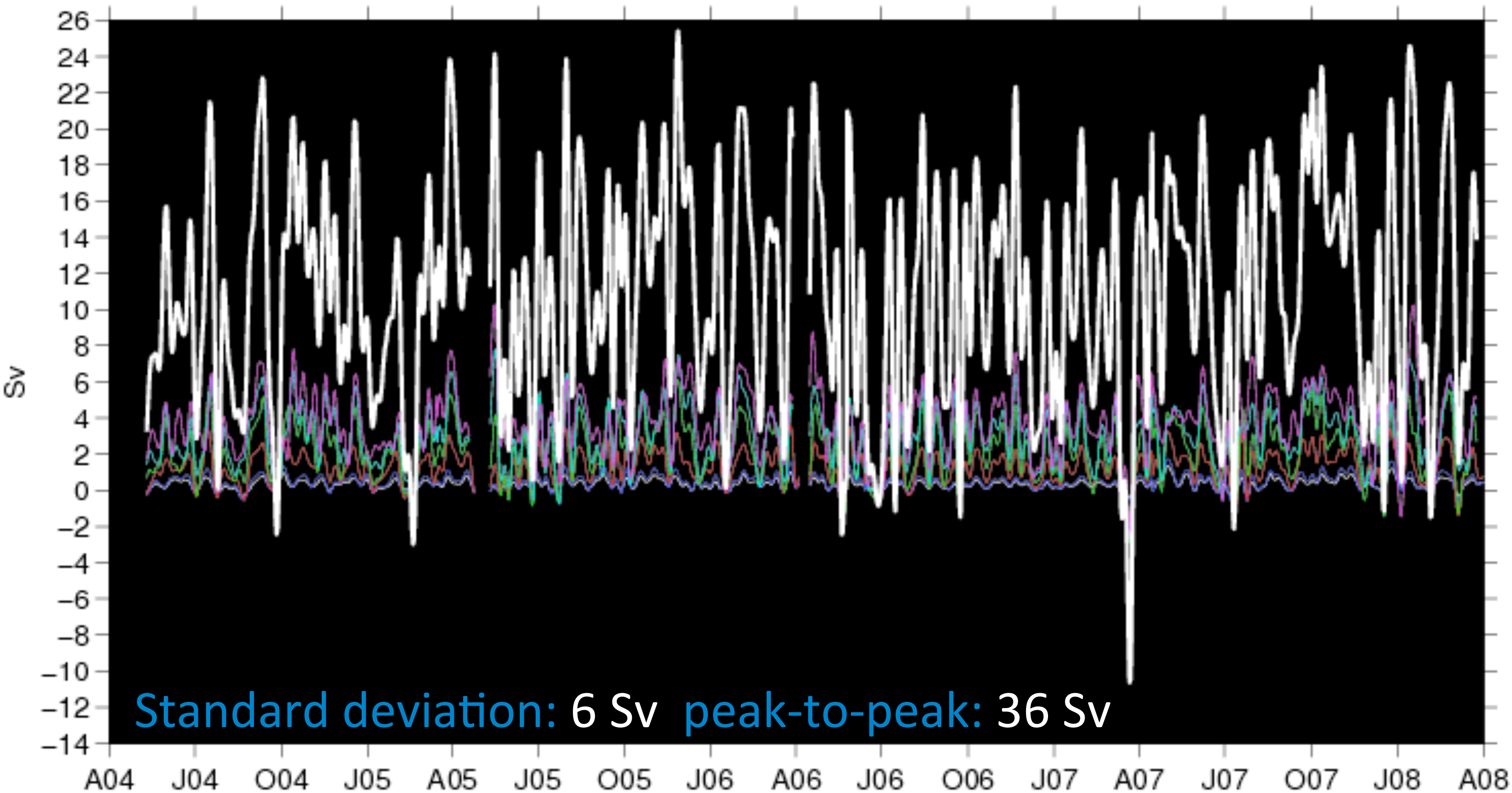




- Mean bottom flow
- Bathymetry gradient
- Variance ellipses

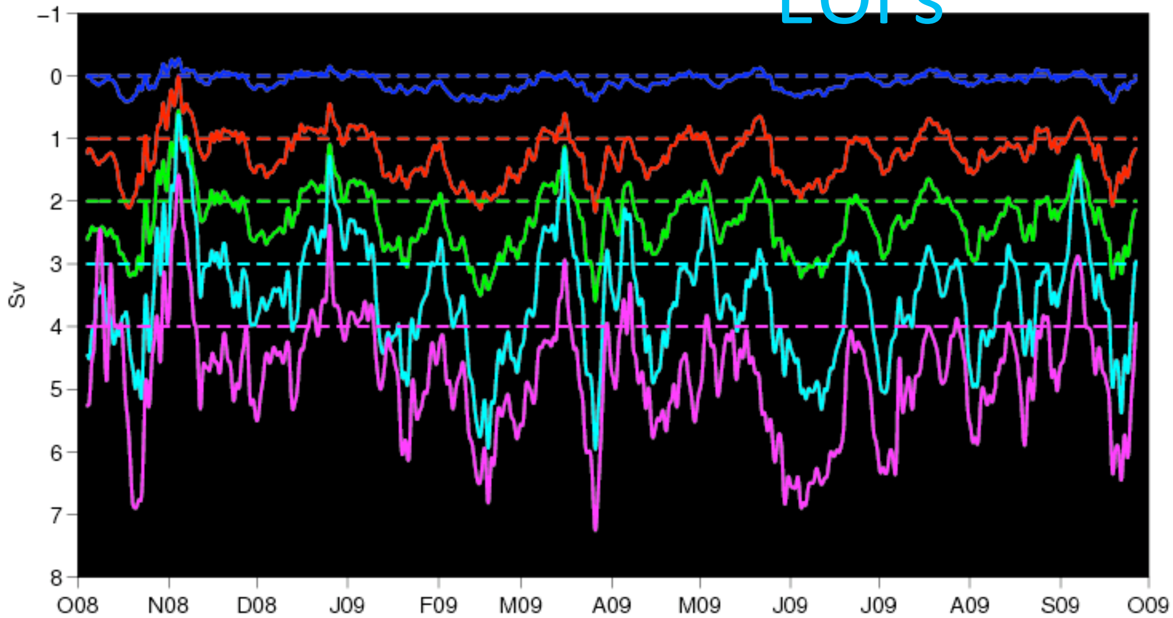
•Bottom pressure recorder (Δ), microcat CTD (+) , VACM (x), MacLane profiler (|)

Transport at line W (below and relative to ~1000 m)

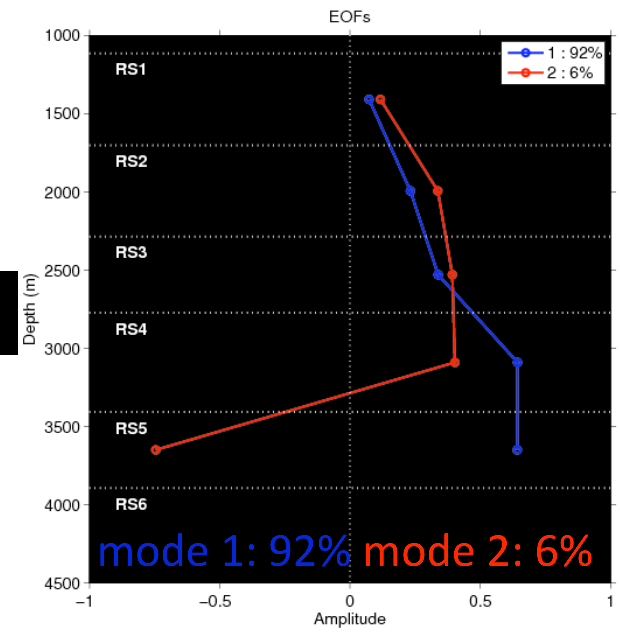


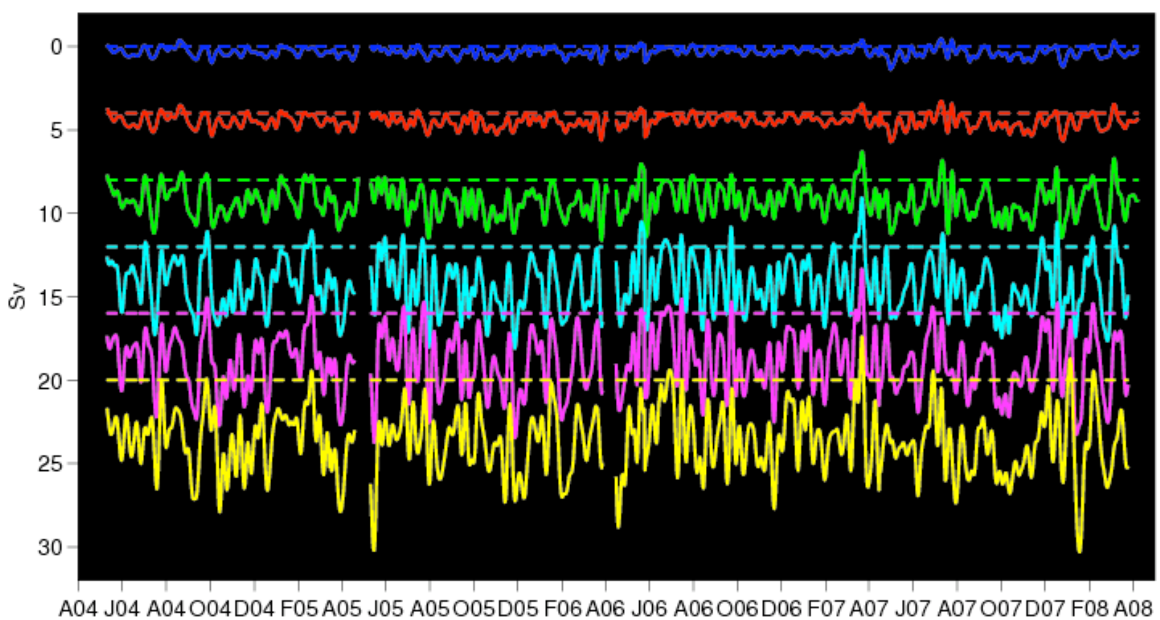
$$T'_W = \int_{z=-4000}^{z=-1000} \frac{-p'_W(z)}{\rho_0 f}\, dz$$

Vertical structure of transports: layers and EOFs

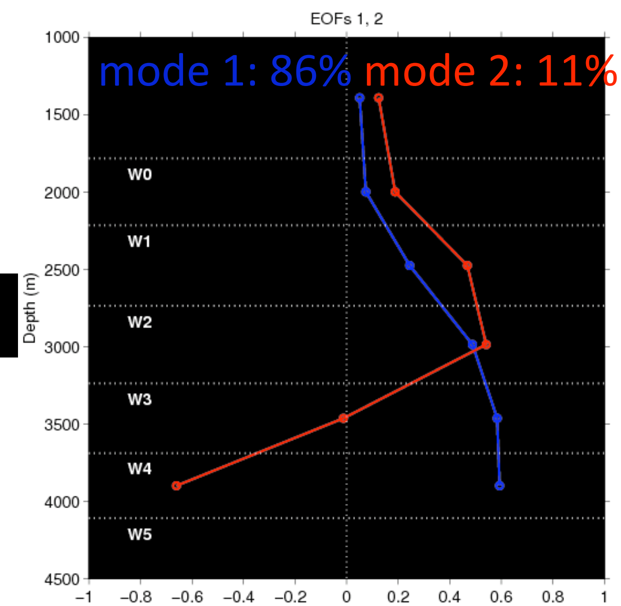


RS

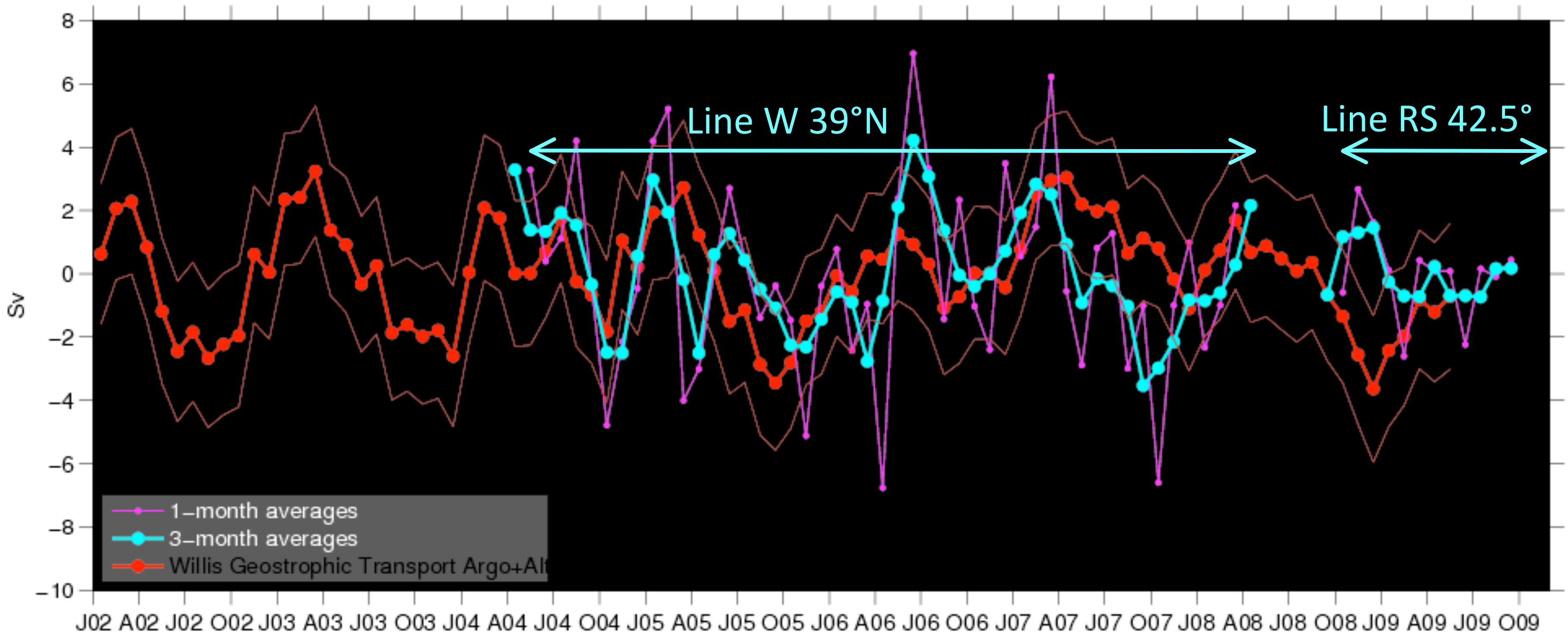




W



Comparison with Willis (2010) ARGO+Altimetry upper 1000 m geostrophic transport anomalies (40 – 41.5°N)



Willis (2010)'s northward geostrophic total transport anomaly

Southward geostrophic "western contribution" transport anomaly (3-month)

1-month average

With W transport, correlation is 0.30, significant at 95%

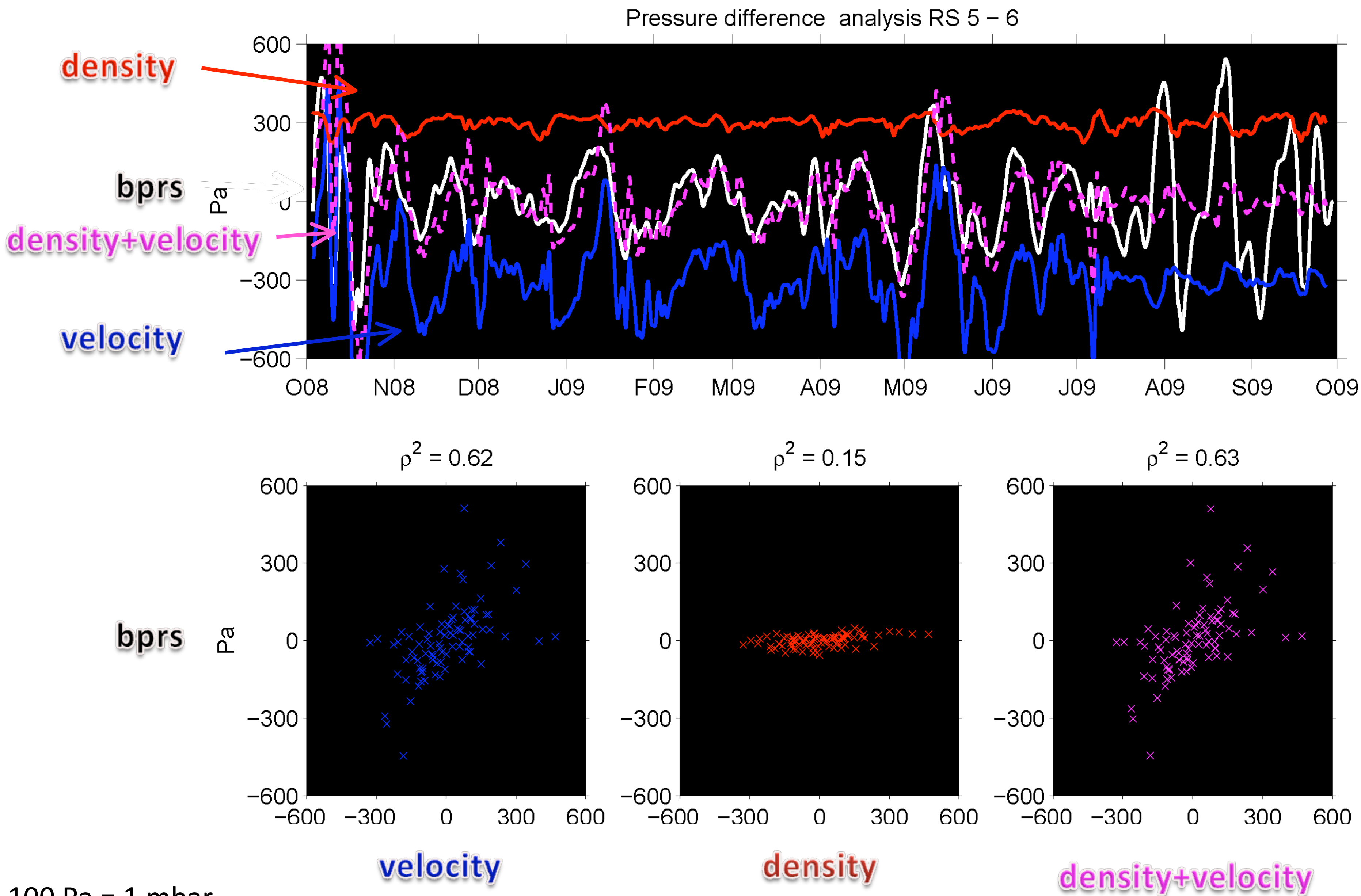
Summary

- Step method is shown to work for reconstruction of pressure on sloping boundary;
- Transport vertical structures are comparable at lines W and RS;
- Estimates are comparable to Willis (2010)' overturning;
- Affordable method for long-term monitoring of MOC variability

What's next?

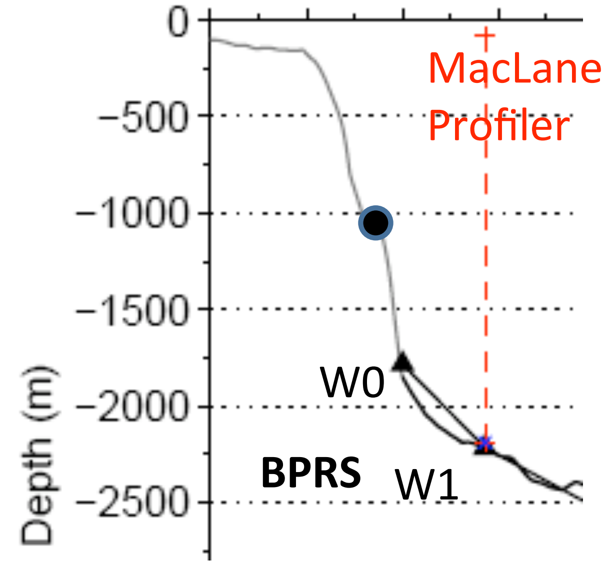
- Uncertainty estimates;
- Assess importance of pressure on Eastern boundary at 42°N (RAPIDO program); link to 26.5°N
- Coherence with transport at 26.5°N?
  Model studies show that MOC inter-annual (or more) variability differs between North Atlantic subtropical and subpolar gyres (see Bingham et al. 2007)
- This method is an option for MOC monitoring; it is a simple add-on to DWBC monitoring systems
- Involvement in US AMOC subpolar gyre initiative?

“Step” method between RS5 (3400 m) and RS6 (3900 m)

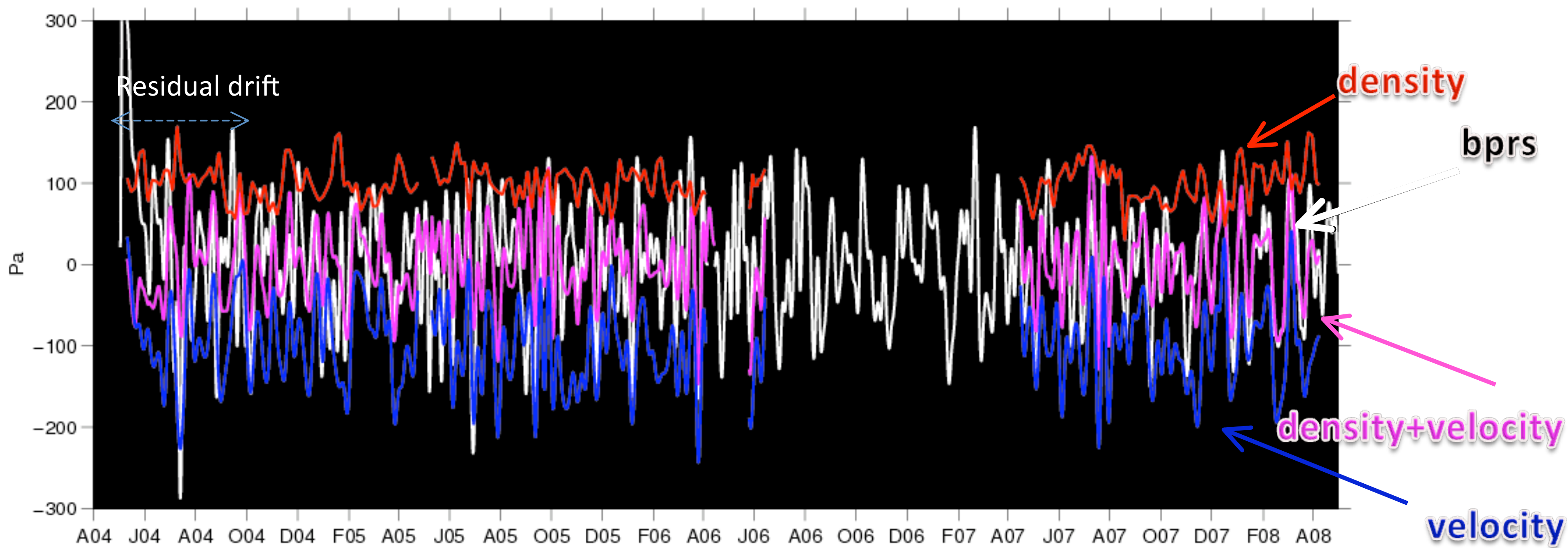


100 Pa = 1 mbar

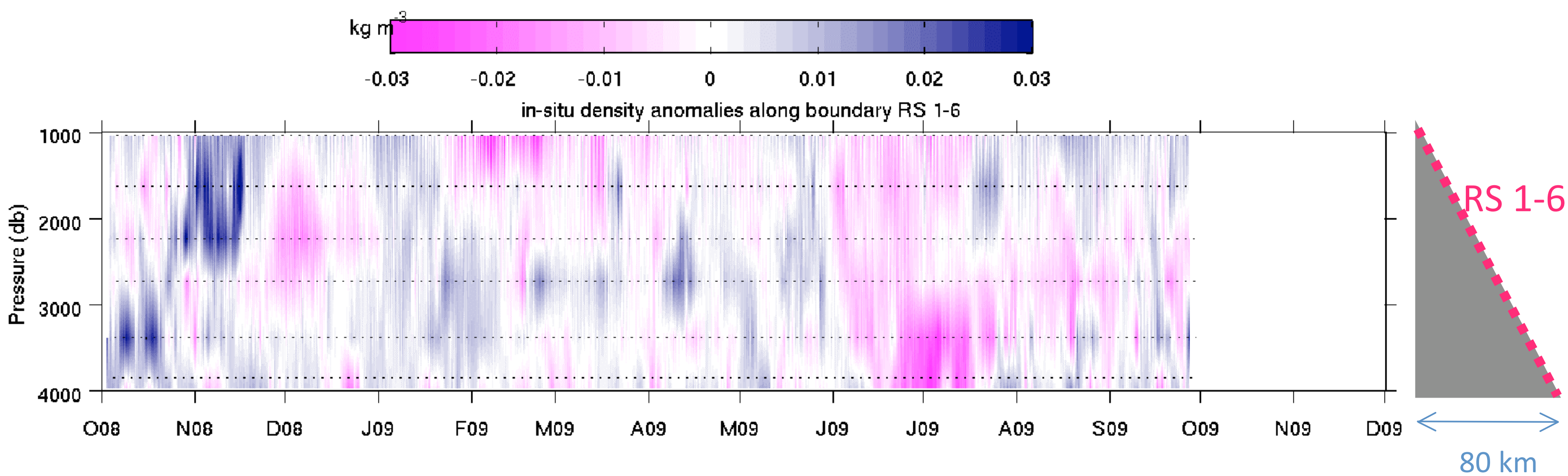
Step method applied at line W

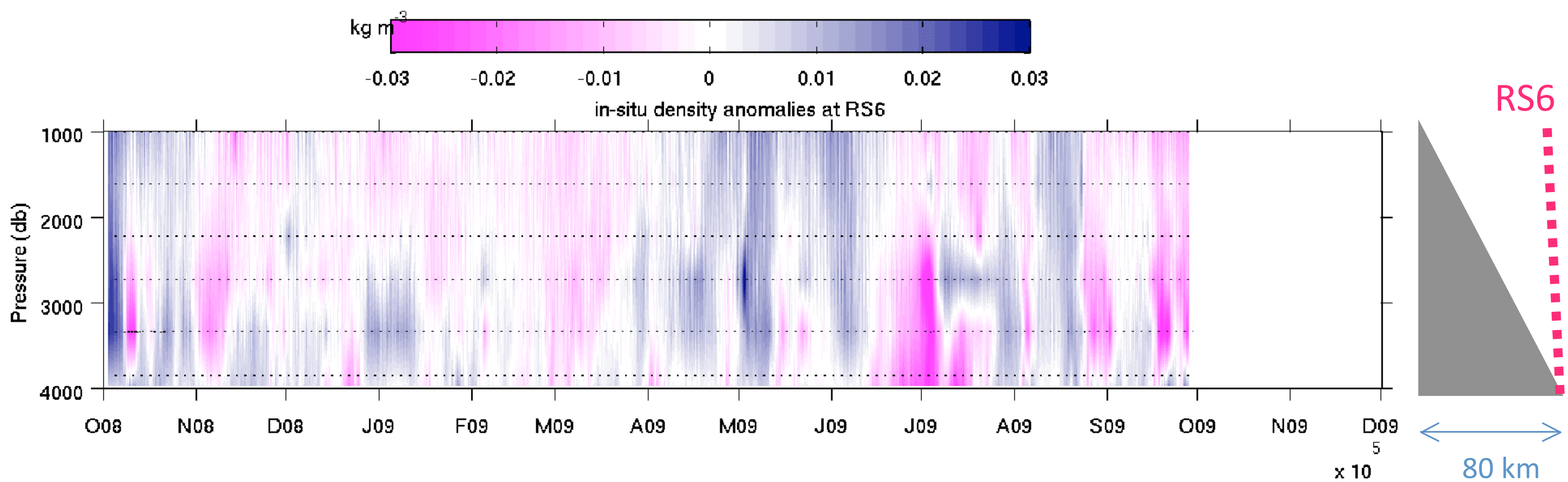


- Validated between sites W0 and W1
- Extended from 1000 m to ~4000 m

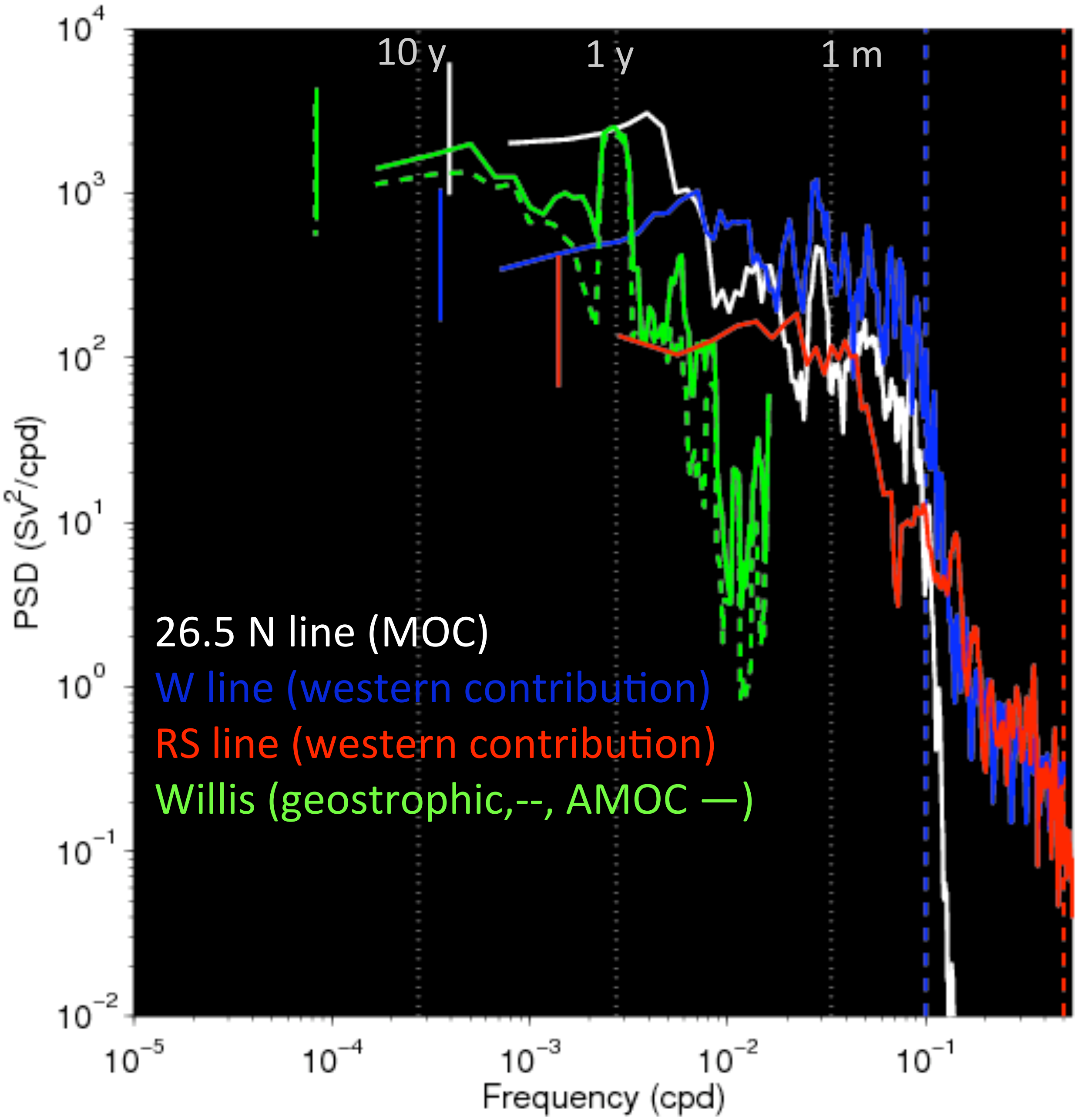


In-situ density anomalies at RS line along the slope and east of slope





Transport spectra



Multi-taper spectral estimates

RAPIDO BPRS deployment

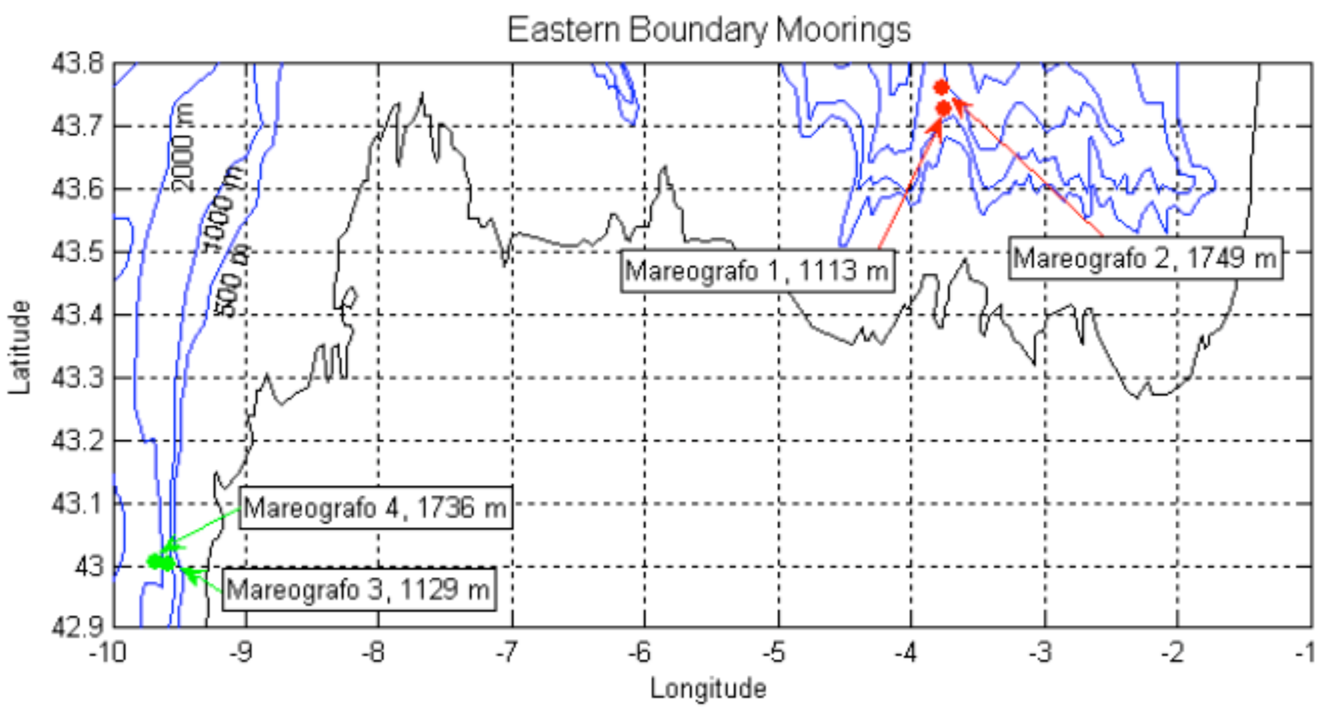


Figure 1. Locations and depths of the four BPR moorings deployed during RADPROF0809. Red: BPR deployments in the Santander line. Green: BPR deployments in the Finisterre line.

The vertically integrated pressure signal

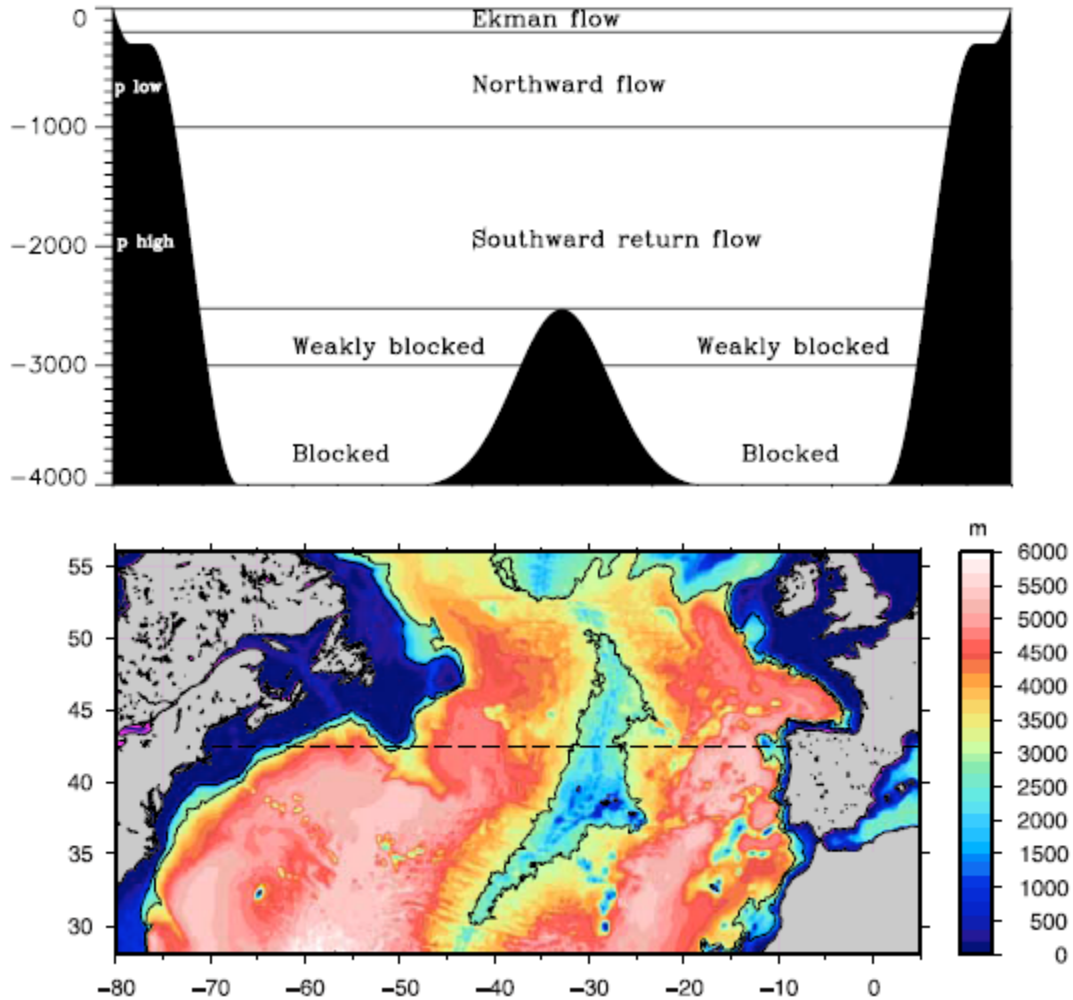
$$\bar{p} = \frac{1}{H}\int_{z=-H}^{z=0} p(z)\ dz$$

$$p'(z) = p(z) - \bar{p}$$

Residual pressure

Subtracting $\overline{p}$ removes mean hydrostatic pressure, high frequency bassin modes and uniform net flow which is not an overturning

Intervening topography



In **Determining North Atlantic meridional transport variability from pressure on the western boundary: A model investigation**
R. J. Bingham and C. W. Hughes (2008)