WCRP C37
Poster TH69B

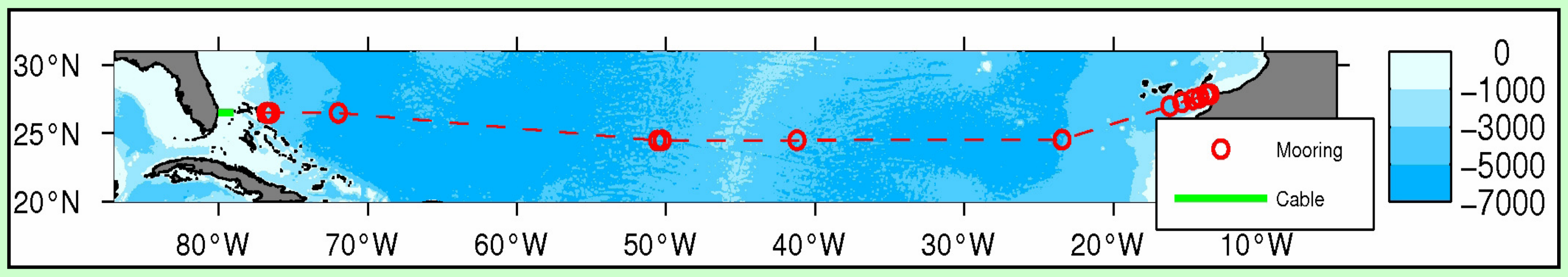
Atlantic Meridional Overturning Circulation: New estimates of Atlantic Ocean Heat Transport at 26.5°N from the RAPID-MOCHA Array

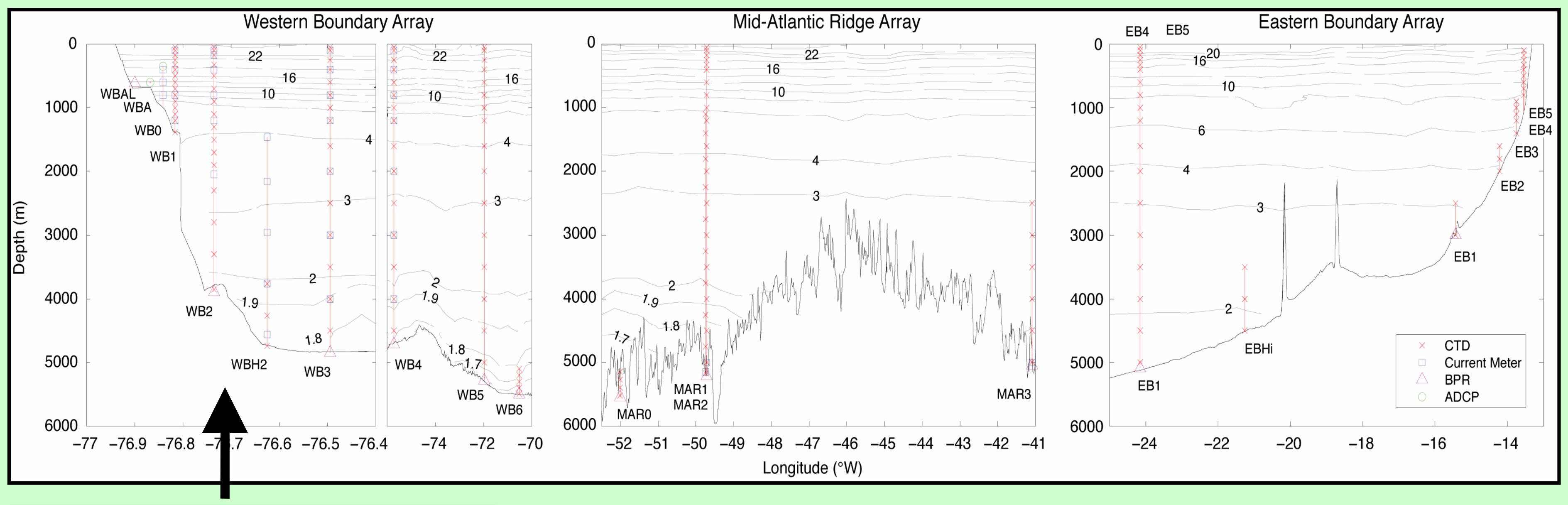
Bill Johns[1], Lisa Beal[1], Molly Baringer[3], Harry Bryden[2], Stuart Cunningham[2], Torsten Kanzow[6], Joel Hirschi[2], Jochem Marotzke[4], Chris Meinen[3], Jian Zhao[1], Brian King[2], Elaine McDonagh[2], and Ruth Curry[5]

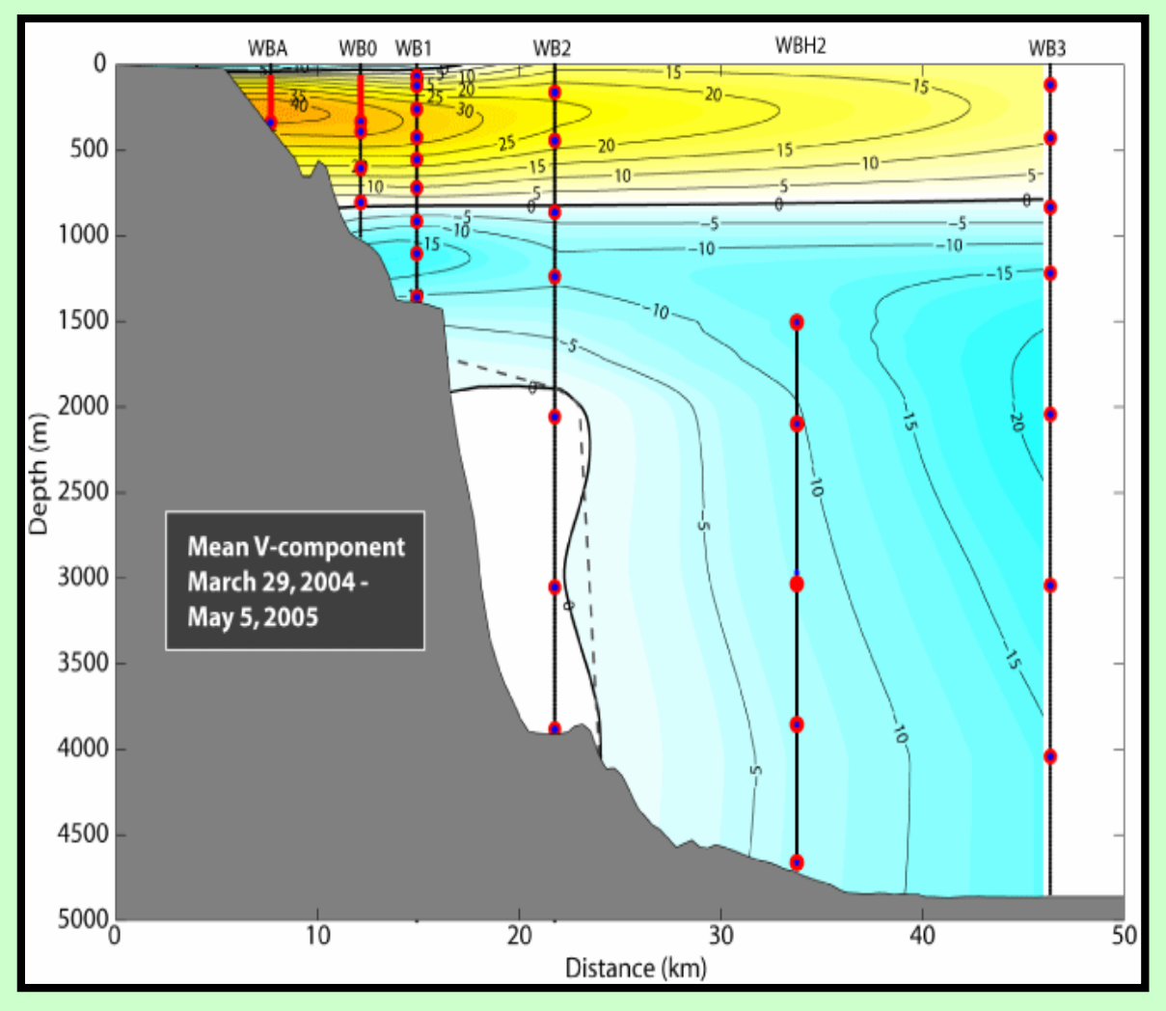
[1] Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL USA [2] National Oceanography Centre, Southampton, England [3] NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami, FL USA [4] Max Planck Institute for Meteorology, Hamburg, Germany [5] Woods Hole Oceanographic Institution, Woods Hole, MA, USA [6] IFM-GEOMAR, Kiel, Germany

Introduction

At 26ºN, the Atlantic ocean circulation carries about 1.3 PW (1 PW = 10^{15} W) of heat northward. This is approximately 70% of the net poleward heat flux carried by the global oceans and 25% of the total heat flux by the ocean and the atmosphere at this latitude (Ganachaud and Wunsch, 2003). The most recent assessment from coupled climate models (IPCC 4th Assessment Report; Meehl et al, 2007) is that greenhouse warming will lead to a decrease in the strength of the Atlantic MOC by 25% in the next century (Schmittner et al, 2005). This will presumably lead to a similar decrease in the Atlantic meridional heat transport, unless compensated by increased gyre or eddy circulations. Here, continuous estimates of the oceanic meridional heat transport in the Atlantic are derived from the RAPID-MOCHA (Rapid Climate Change – Meridional Overturning Circulation and Heatflux Array) observing system deployed along 26.5°N since 2004. The time-mean meridional heat transport (MHT) during 2004-2010 was 1.28 ± 0.13 PW, consistent with previous direct estimates, but with a substantially reduced uncertainty compared to one-time estimates from hydrographic sections. The MHT estimates available from the array provide an important benchmark for indirect estimates derived from surface climatologies and residual methods, and for comparison with climate models. These results update the previous results reported by Johns et al. (2011, *JCLIM*) based on the first four years of observations.







The Array

The mid-ocean array includes 18 moorings concentrated in three clusters: at the western boundary off Abaco, Bahamas, at the eastern boundary off Morocco, and over the Mid-Atlantic ridge. These mooring provide the relative geostrophic current profiles across the western and eastern basins through continuous T/S profile measurements. The Florida Current transport is monitored by voltage measurements from a subsea telephone cable, which is calibrated by 6-10 ship sections per year. Transports in the western boundary layer off the Bahamas are derived from direct current meter measurements. The interior barotropic flow is inferred by enforcing a mass balance on 10-day time scales.

Method

The basin-wide meridional heat transport (MHT) is derived by combining temperature transports (relative to a common reference) from: (1) the Florida Current in the Straits of Florida, (2) the western boundary region offshore of Abaco, Bahamas, (3) the Ekman layer (derived from ECMWF wind stresses), and (4) the interior ocean monitored by dynamic height moorings. The interior eddy heat transport arising from spatial covariance of the velocity and temperature fields is estimated from ARGO observations across the mid-ocean region.

Meridional Heat Transport: $Q_{TOT} = \iint \rho c_p \, v\theta \, dx\, dz$

$$Q_{TOT} = Q_{FC} + Q_{EK} + Q_{WB} + Q_{INT} + Q_{EDDY}$$

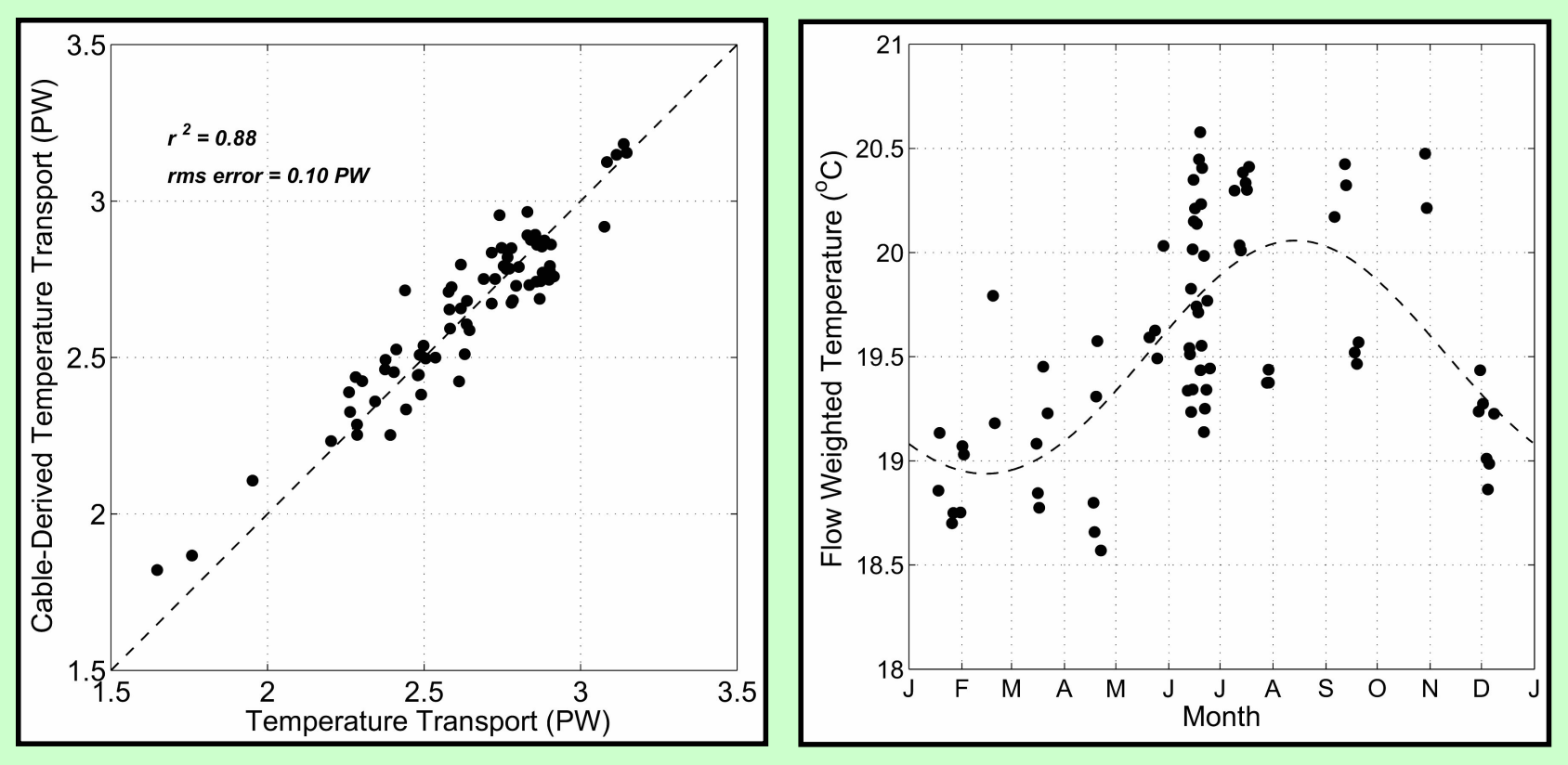
Q_{FC} → Cable transport (daily) • Seasonally varying flow-weighted Florida Straits temperature (Shoosmith et al., 2005)

Q_{EK} → ECMWF Interim wind stress (daily) • Reynolds SST (daily)

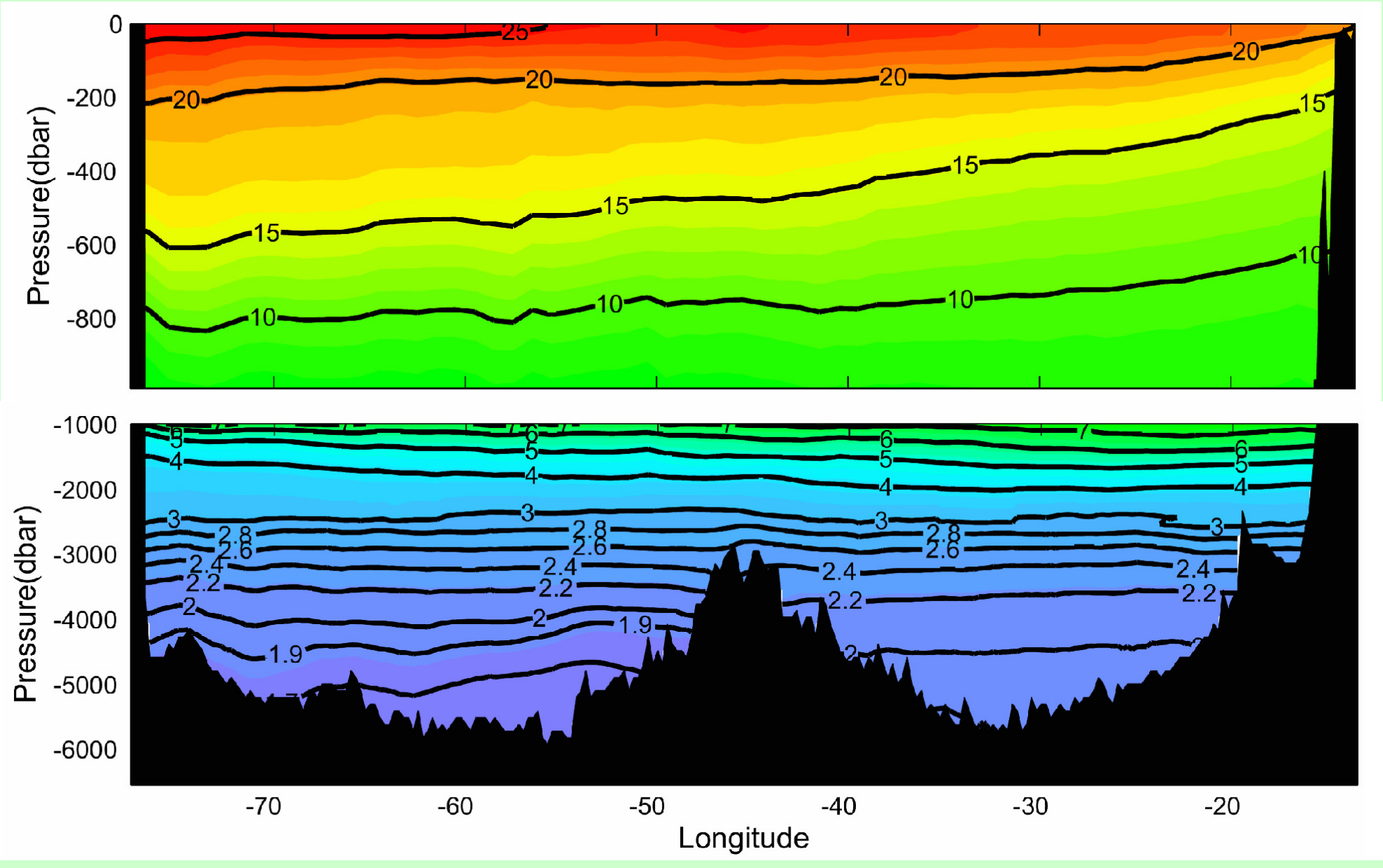
Q_{WB} → Directly calculated from moored CM's/thermistors in Abaco western boundary array (daily)

Q_{INT} → Zonally-averaged interior transport profile from geostrophic moorings (daily) • Zonal mean interior temperature profile from merged ARGO/Hydrobase analysis (10 day average)

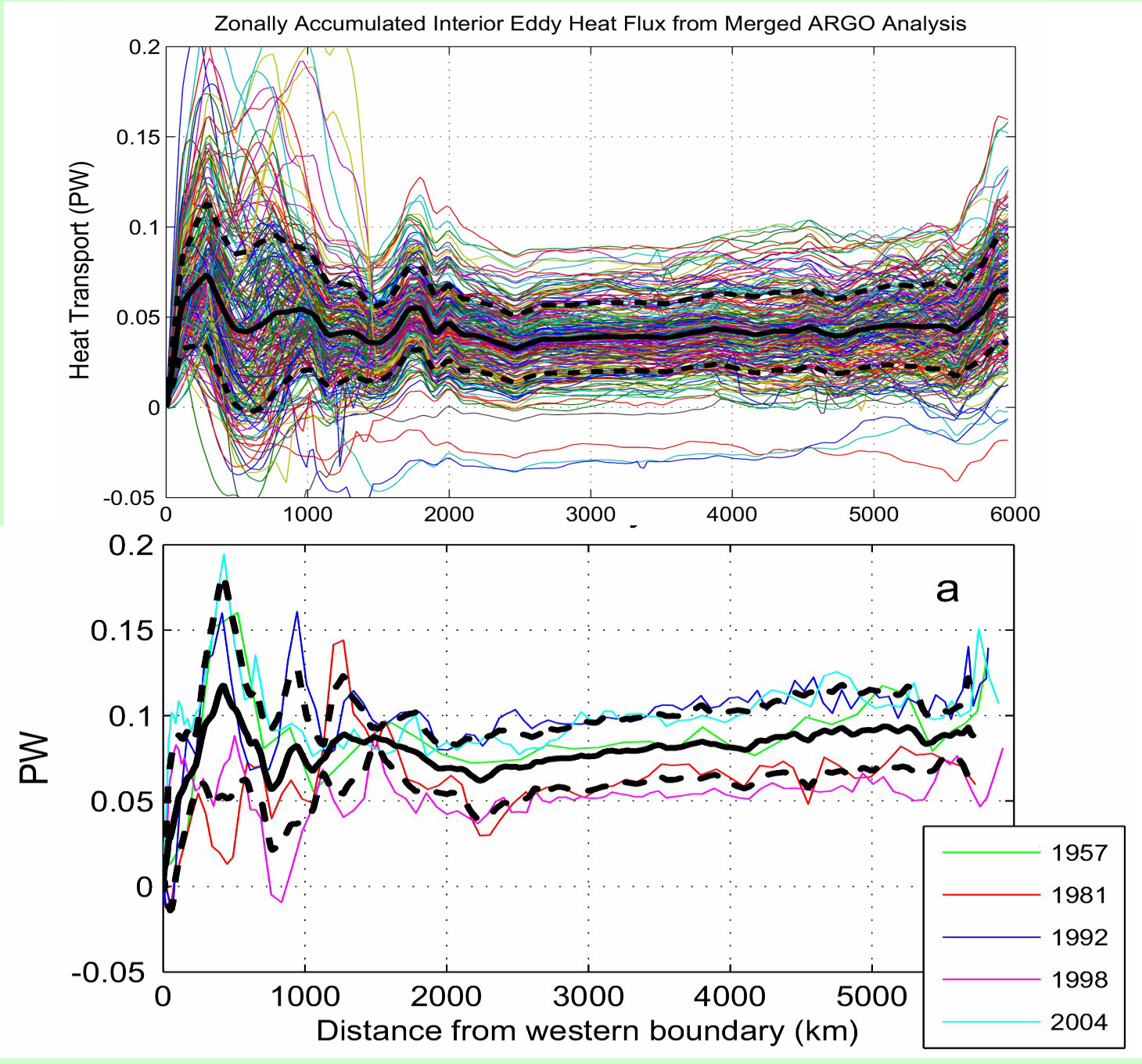
Q_{EDDY} → Contribution due to spatially correlated v,θ variability across the interior, from ARGO analysis: $Q_{EDDY} = \iint \rho c_p \, v'\theta' \, dx\, dz$



Cable-derived Florida Current temperature transport vs. calibration sections (left), and seasonal cycle of the Florida Current flow-weighted temperature (right)



Merged ARGO/Hydrobase interior temperature climatology for the 26.6°N line. The merged analysis at 10-day intervals is used in estimating Q_{INT}.

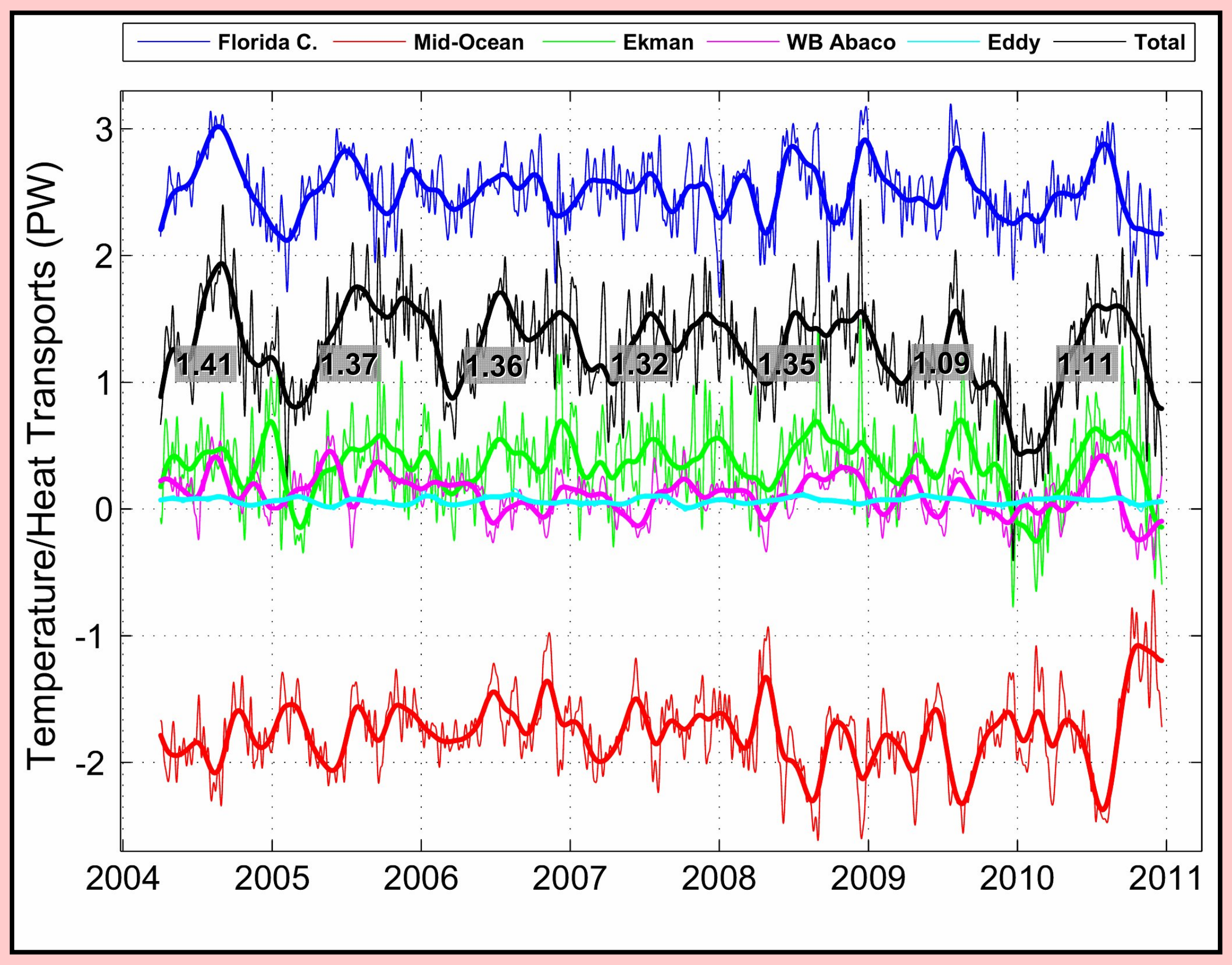


Interior ocean eddy heat flux (Q_{EDDY}) derived from 10-day ARGO analyses (top), compared to results from five trans-Atlantic hydrographic sections at 24°-26.5°N (bottom).

The Heat Transport Time Series

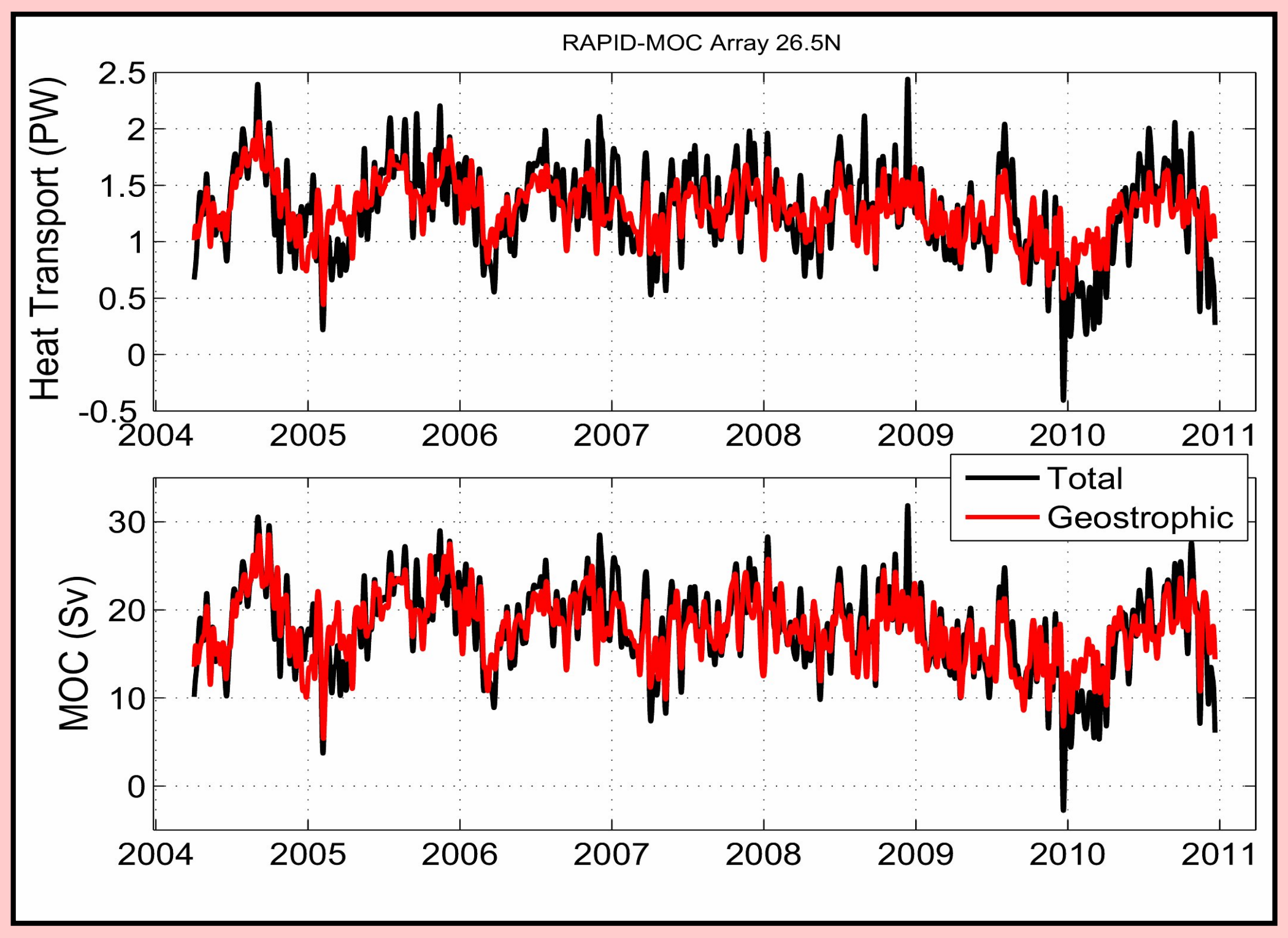
The net heat transport shows variations of nearly ± 1 PW about its 2004-2010 mean value of 1.28 PW. Year-to-year variability is relatively small during the first 5 years of the time series (2004-2008), but a large anomaly occurred in 2009-2010, resulting in much lower mean heat transports of ~1.1 PW during those years. This anomaly was driven in large part by reduced Ekman transports associated with a strong negative NAO anomaly in winter 2009-2010, which recurred again in winter 2010-2011 (***see poster TH71B***).

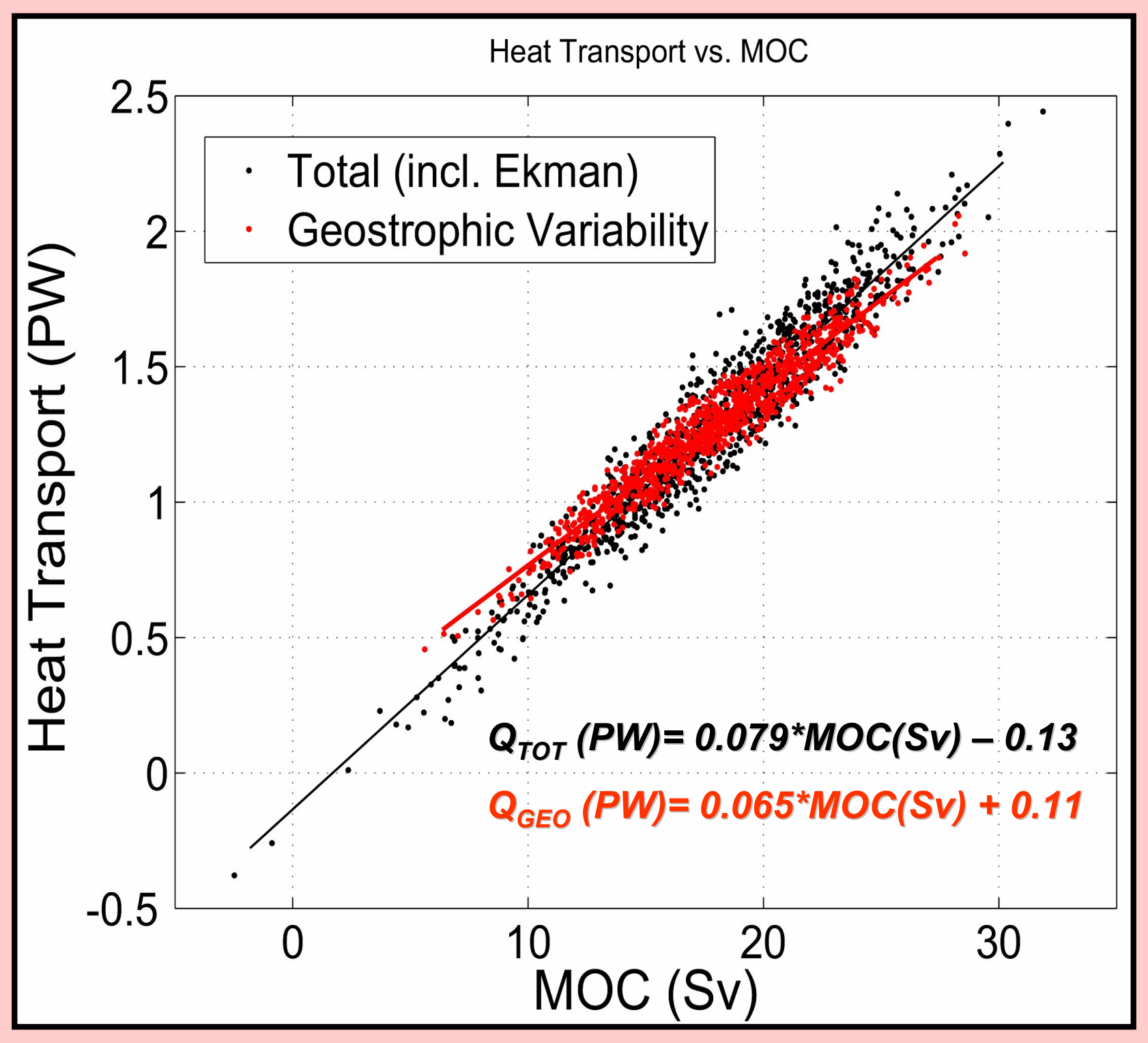
Year to year variations in the heat transport can be resolved to within an accuracy about 0.17 PW by the array. The 2009 and 2010 values are individually not statistically distinct from the prior years. However, the 2-year mean from 2009-2010 (1.1 ± 0.11 PW) is statistically different from the mean of the prior 5 years (1.35 ± 0.08 PW) at the 1σ level.



Ekman and Geostrophic Heat Transport Variability

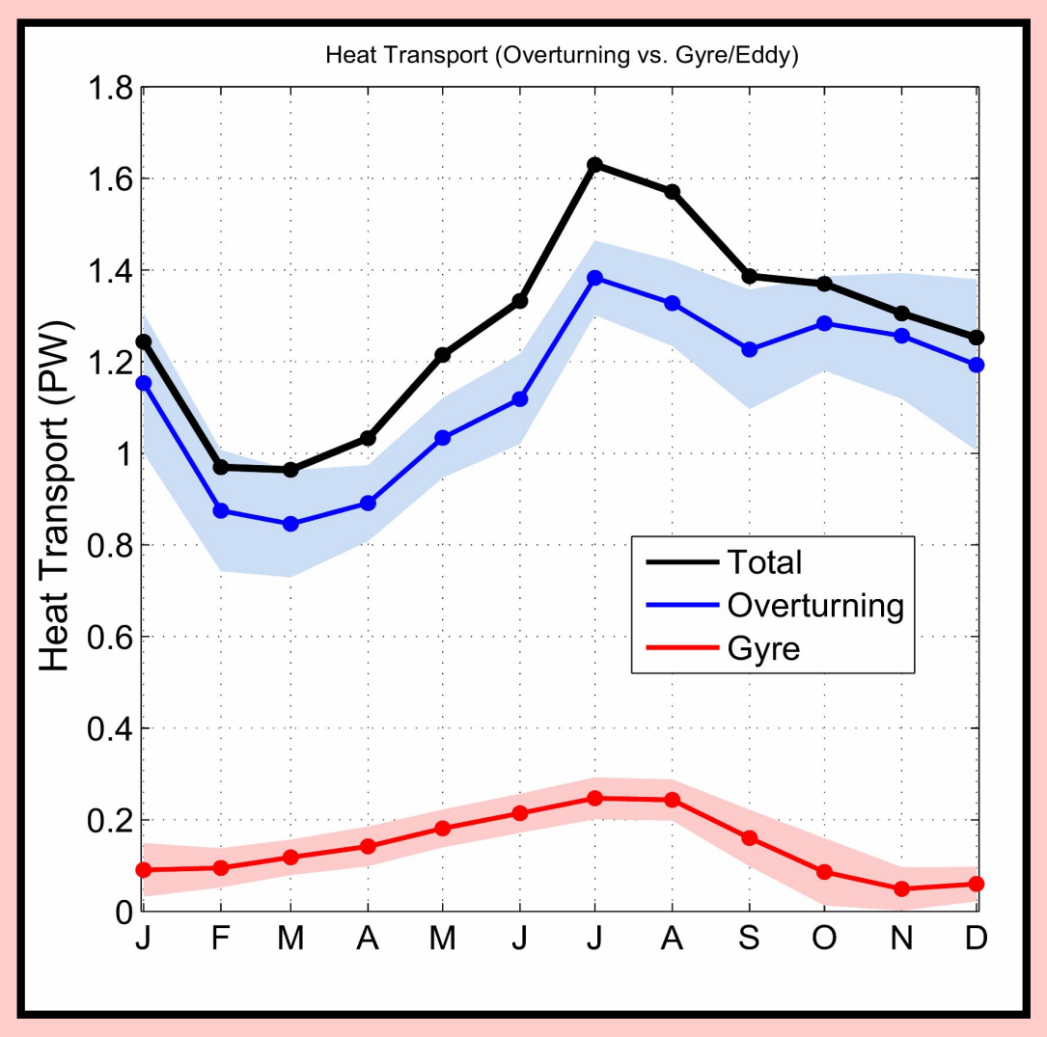
The heat transport variability can be divided into a component related to Ekman transport and a component related to the basinwide geostrophic circulation. Much of the shorter term variability is due to Ekman heat transport, but the geostrophic heat transport contributes significantly to the seasonal cycle of the MHT as well as partly to the weak MHT in 2009-2010. Regression of the MHT against the MOC variability shows a high correlation (r = 0.94) for both the total MHT and geostrophic heat transport.

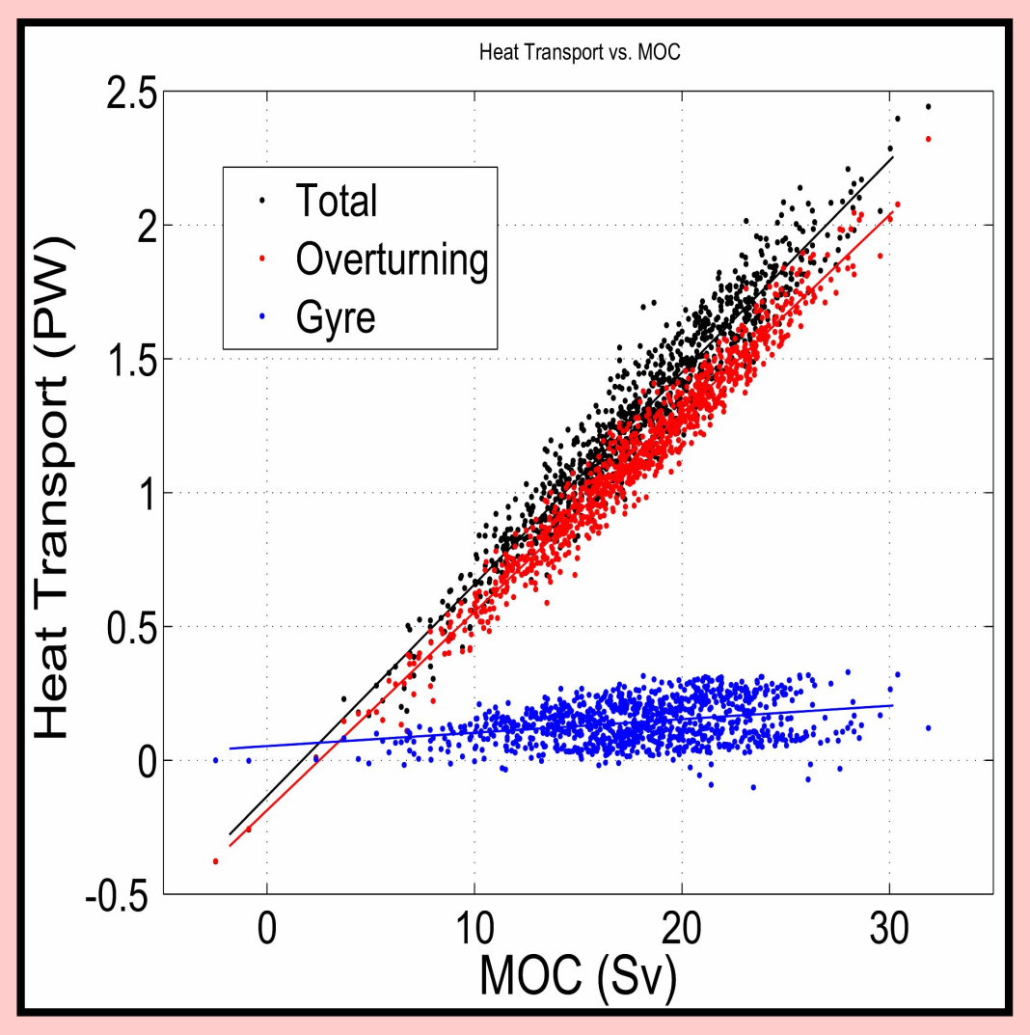




Overturning and Gyre Heat Transport

The total heat transport can also be broken down into an "overturning" component, associated with the zonal mean circulation, and the "gyre" heat transport associated with temperature and velocity anomalies relative to the zonal mean (Bryan, 1982). The total MHT shows a significant seasonal cycle of ±0.3 PW, with a maximum in summer and minimum in spring. Most of the seasonal cycle is from the overturning component, which accounts for 90% of the net heat transport. The overturning heat transport is highly correlated with the MOC; the gyre component is virtually independent of it.





Comparison With Other Estimates

The mean MHT of 1.28 ± 0.13 PW at 26.5°N is consistent with previous direct estimates from hydrographic sections and inverse models. Other estimates derived from residual radiation balances [at right: ECMWF and NCEP, Trenberth et al. (2001); TF08, Trenberth and Fasullo (2008)], air-sea flux climatologies [LY09, Large and Yeager (2009)], and coupled models (CM2.1 from GFDL; CCSM4 from NCAR) tend to provide lower estimates, often below the lower error bound of the RAPID estimate.

Recent Direct Estimates at 24-26°N	Heat Transport (PW)
Lumpkin and Speer (2007)	1.24 ± 0.25
Ganachaud and Wunsch (2003)	1.27 ± 0.15
Lavin et al. (1998)	1.27 ± 0.26
Molinari et al. (1990)	1.21 ± 0.34

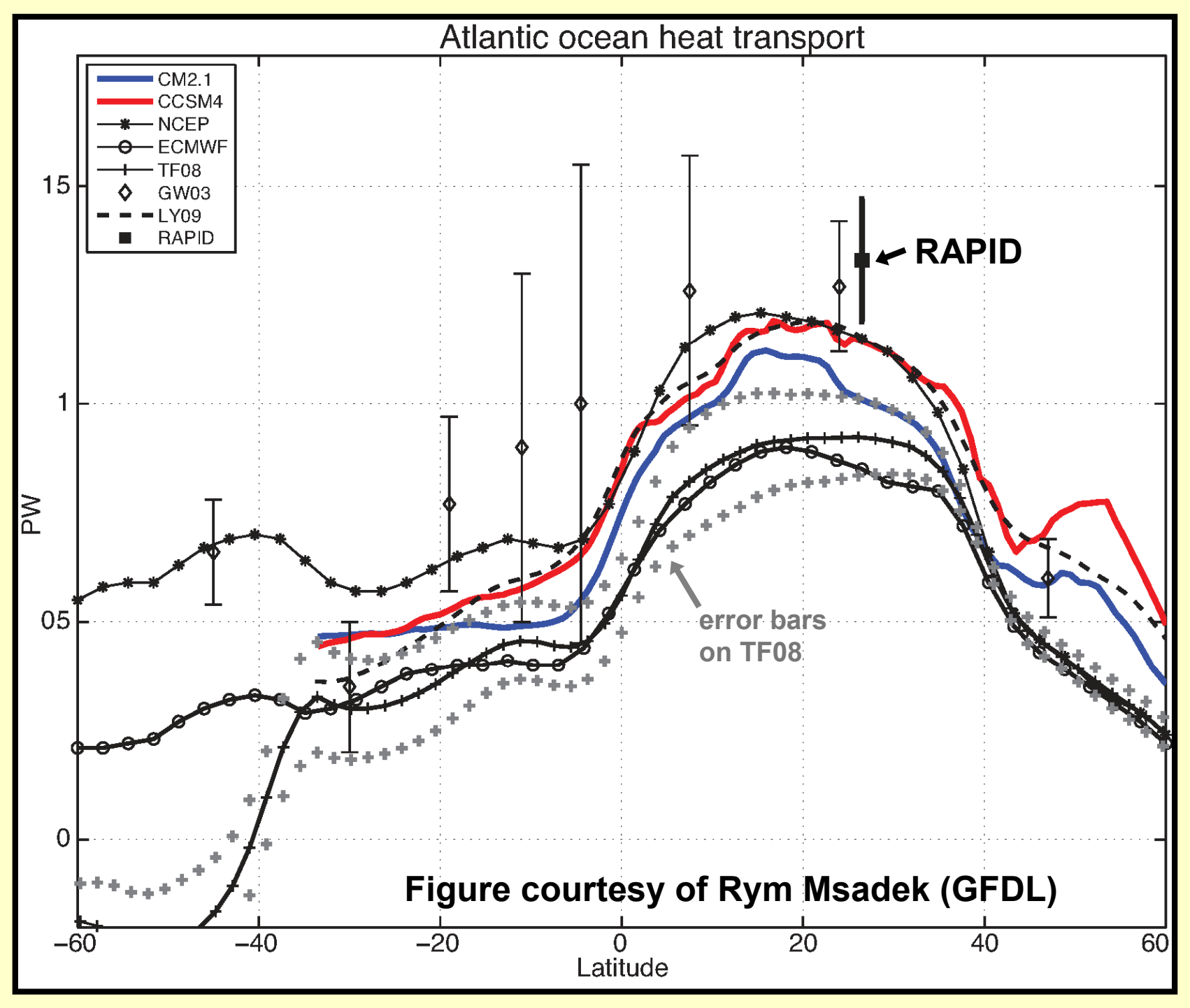


Figure courtesy of Rym Msadek (GFDL)

Acknowlegment: Support for RAPID-MOCHA is provided by the U.S. National Science Foundation, the U.S. National Oceanic and Atmospheric Administration, and the U.K. National Environmental Research Council.

Corresponding Author: Bill Johns (bjohns@rsmas.miami.edu)
Project website: http://www.rsmas.miami.edu/users/mocha

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE