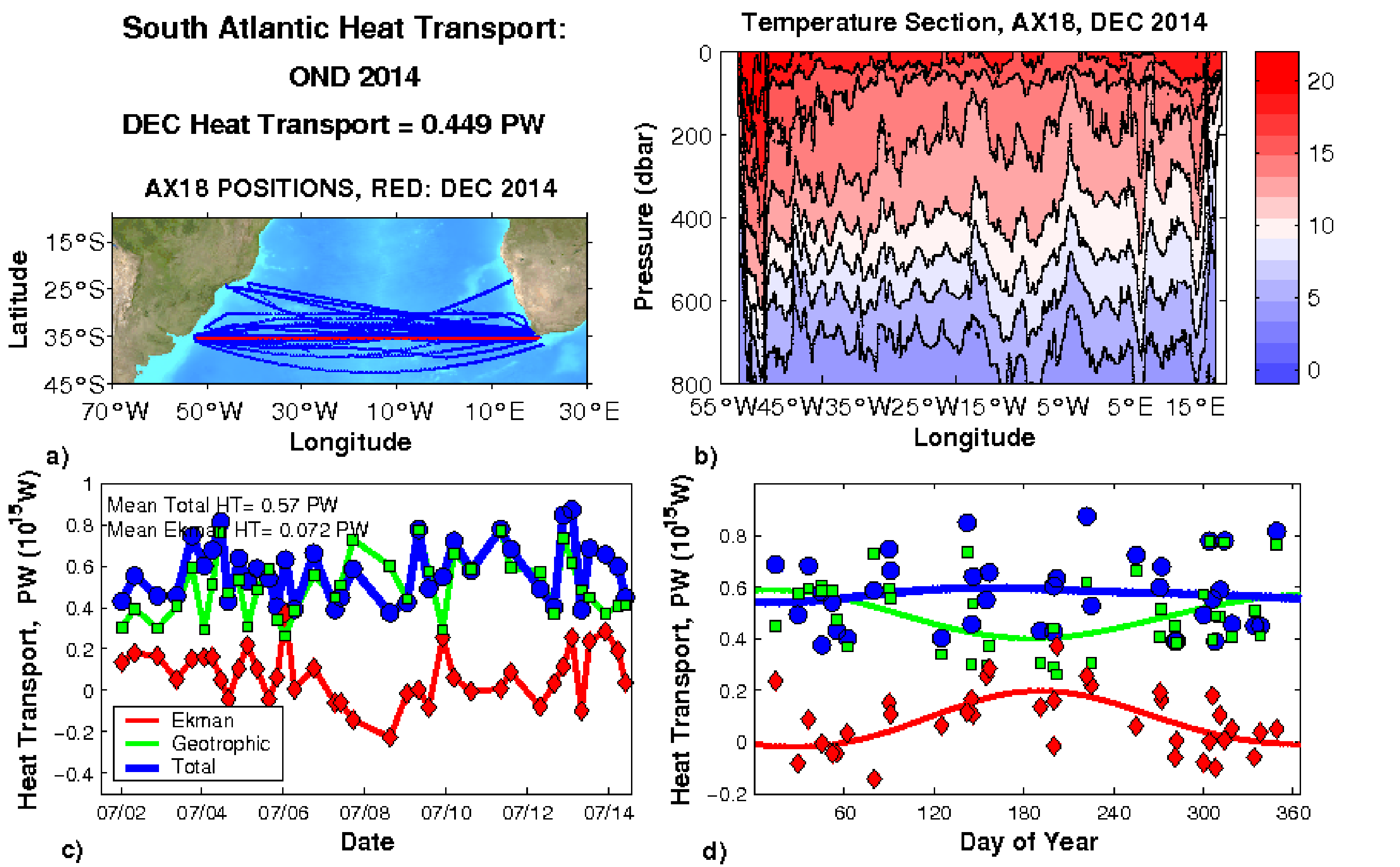
Assessing the meridional overturning and heat transport uncertainties derived from the AX18 XBT transect along 34°S

Marlos Goes

Goes, M., M. Baringer, G. Goni, 2015: The impact of historical biases on the XBT-derived meridional overturning circulation estimates at 34S, Geophys. Res. Lett., in-press

Goes, M., G. Goni, S. Dong, 2015 An optimal XBT-based monitoring system for the South Atlantic Meridional Overturning Circulation at 34S, J. Geophys. Res., 120.

February 17, 2015



The Atlantic MOC is formed by the northward surface flow of warm waters and by the southward deep flow of cold waters, resulting in a net heat transport to the north called Meridional Heat Transport (MHT).

http://www.aoml.noaa.gov/phod/goos/xbtscience/mht_products.php

Assumptions in the AX18 transect

Observational Assumptions:

- **Salinity**
- **Bottom temperature**
- **Geostrophic velocity**
- **Zonal resolution**
- **Time sampling**

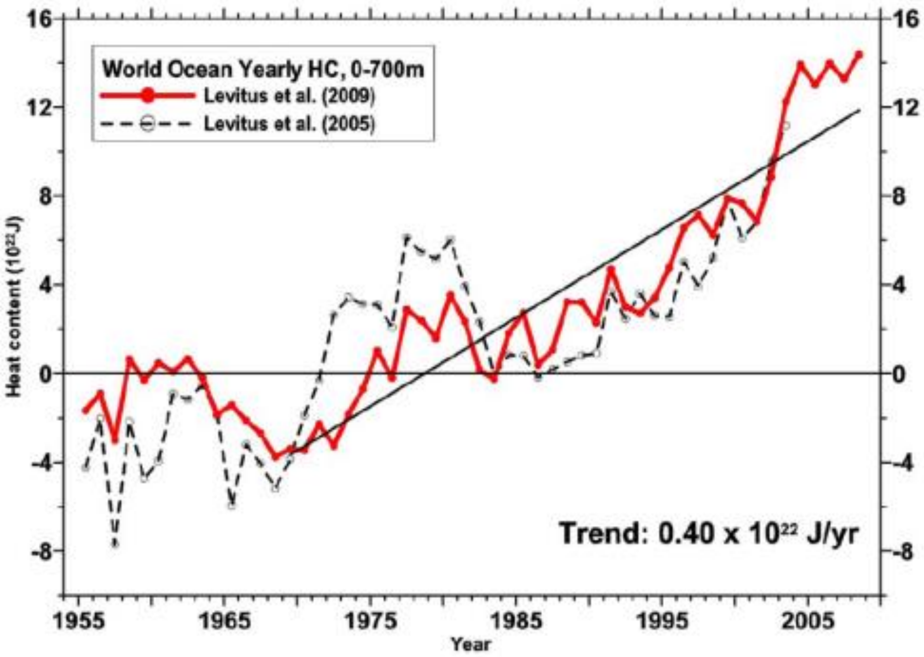
- To date, only Baringer and Garzoli (2007) have estimated some of the uncertainty resulting from the underlying XBT-based observational system methodological assumptions to measure meridional heat transport across 34°S.

- No sensitivity tests have yet been performed to derive an optimal AX18 sampling strategy, and to assess the uncertainty in volume and heat transports associated with observational and computational methodologies across 34°S.

Objectives

- The uncertainty **horizontal sampling** along the AX18.
- The uncertainty in **temporal sampling** to capture the seasonal variability of the MOC and MHT in the region.
- The uncertainties derived from the **salinity and deep temperature** estimation.
- Potential improvements to the assumptions made regarding the **reference level** to resolve the barotropic mode.
- The impacts of historical **XBT measurement biases**.

What is the impact of XBT measurement biases on the meridional overturning and heat transport?



Since the XBT data are the largest proportion of the dataset, significant World Ocean warming is artifact when time periods before and after introduction of XBT are compared. *Gouretski and Koltermann (2006).*

Model Description

HYCOM Global Analysis (GLBa0.08)

- Outputs every 7 days of 7-day means
- Period: June 2007 to May 2013.
- Mercator grid between 78°S and 47°N (1/12° resolution)
- 32 vertical layers.
- Surface forcing is from Navy Operational Global Atmospheric Prediction System (NOGAPS) and includes wind stress, wind speed, heat flux (using bulk formula), and precipitation.
- Assimilates altimetry, SST, available in-situ vertical temperature and salinity profiles from XBTs, ARGO floats and moored buoys.

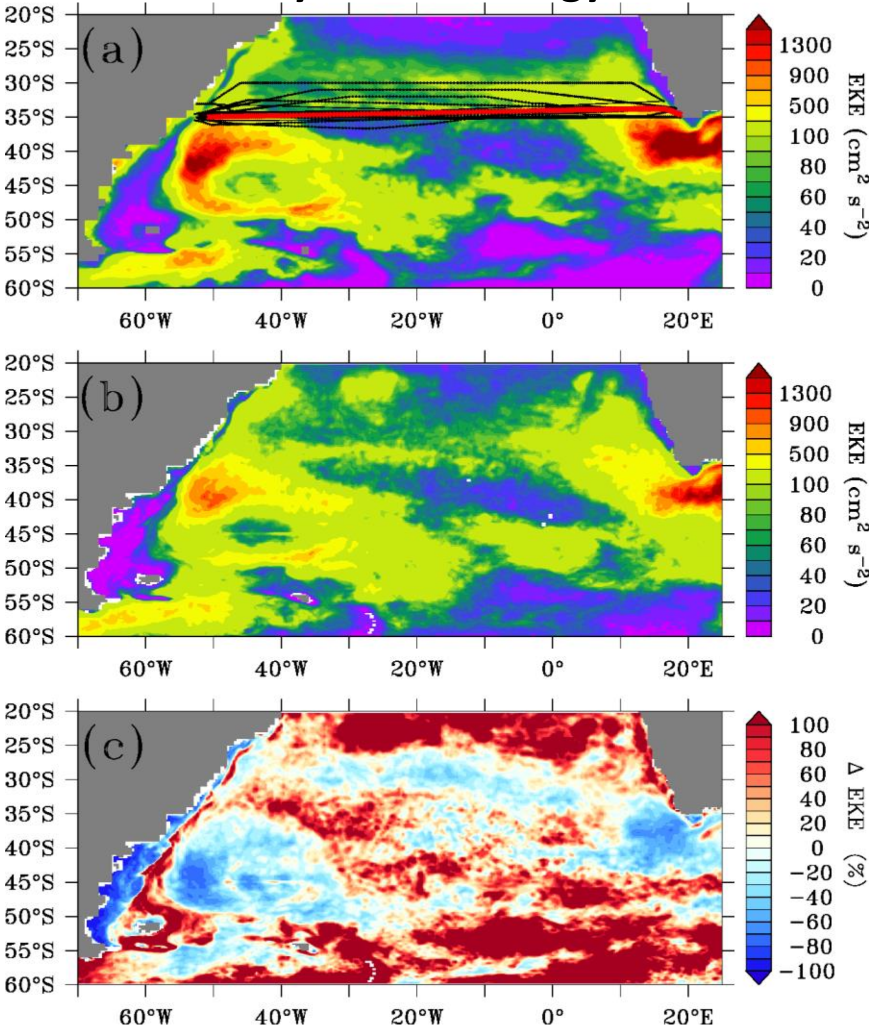
Model Energetics

Eddy Kinetic Energy

AVISO

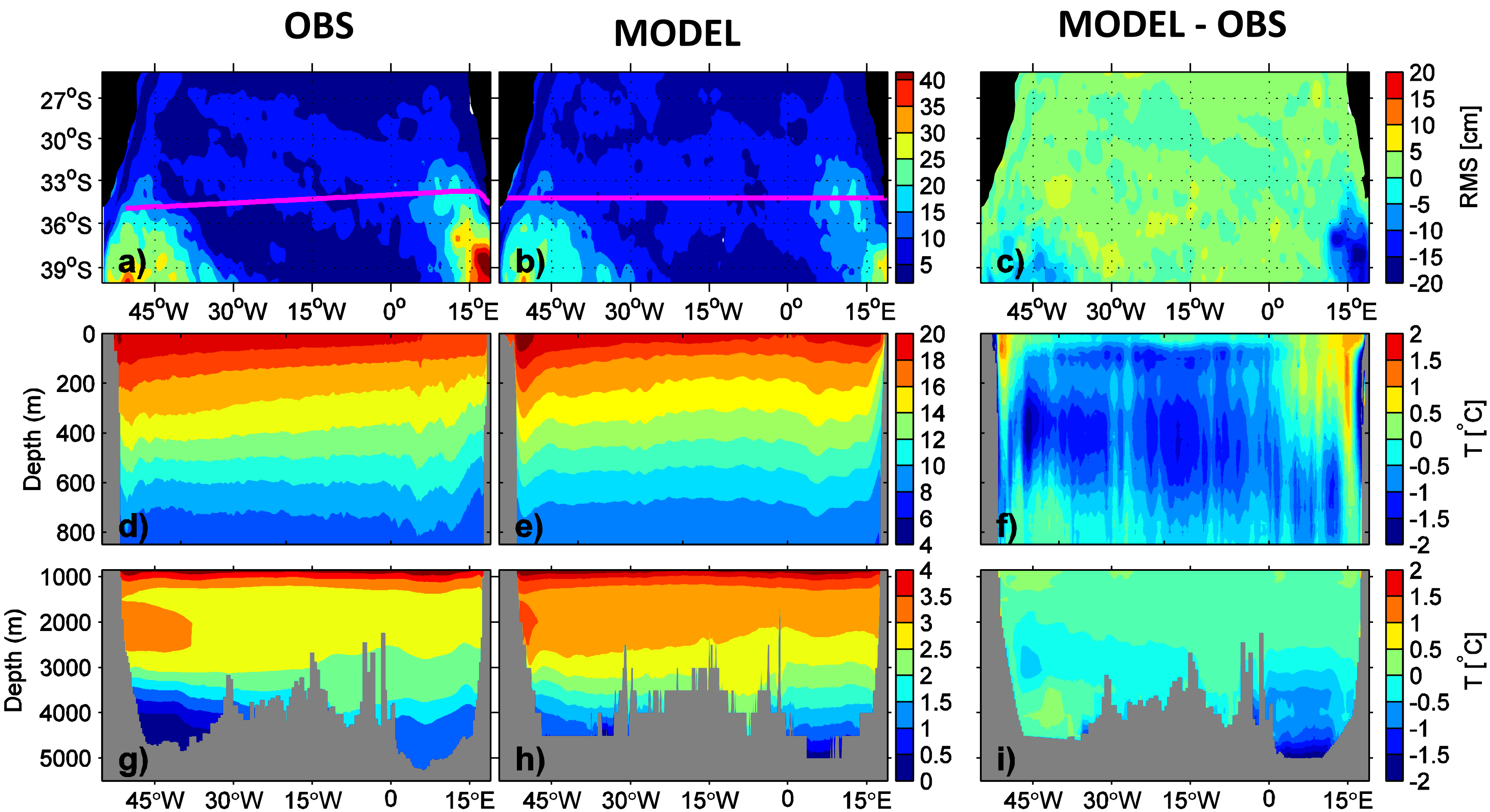
HYCOM

HYCOM – AVISO



- Regional features compare well with observations.
- Model variability generally underestimated in hi-EKE regions, and overestimated in lo-EKE regions.

Model Mean Stratification



Simulating the AX18 transect

Salinity

- 0 - 800m: T-S lookup table
- 800m - bottom: Climatology padding

Temperature

- 800m-bottom: Climatology padding

Geostrophic Velocity

- Reference level: $\sigma_2 = 37.09$ Kg/m^3

Time Sampling: Quarterly

Spatial Sampling: 25 km in the boundaries, 50 km in the interior

Velocity Reconstruction

- Velocity decomposition:

$$v(x,z) = \underbrace{\frac{1}{H}\int_{-H}^{0} v(x,z)\,dz}_{\text{Barotropic}} + \left[\underbrace{v_E(x,z) - \frac{1}{H}\int_{-H}^{0} v_E(x,z)\,dz}_{\text{Ekman}}\right] + \underbrace{v_{sh}(x,z)}_{\text{Vertical Shear}} + \underbrace{\varepsilon}_{\text{Residual}}$$

Vertical Shear component :

$$v_{sh} = v_g - \overline{v_g}$$

Geostrophic velocity:

$$v_g = -\frac{g}{\rho_0 f}\int_{zref}^{z} \frac{\partial \rho(x,z)}{\partial x}\,dz + v_{ref}(\mathrm{x})$$

Each component of the reconstructed velocities is compensated by a depth uniform return-flow (Jayne and Marotzke, 2001) to allow zero mass transport across the section

Meridional Transport

- Volume transport (AMOC) Streamfunction:

$$PSI = \int_{xE}^{xw} \int_{-H}^{z} v(x,z)\,dx\,dz$$

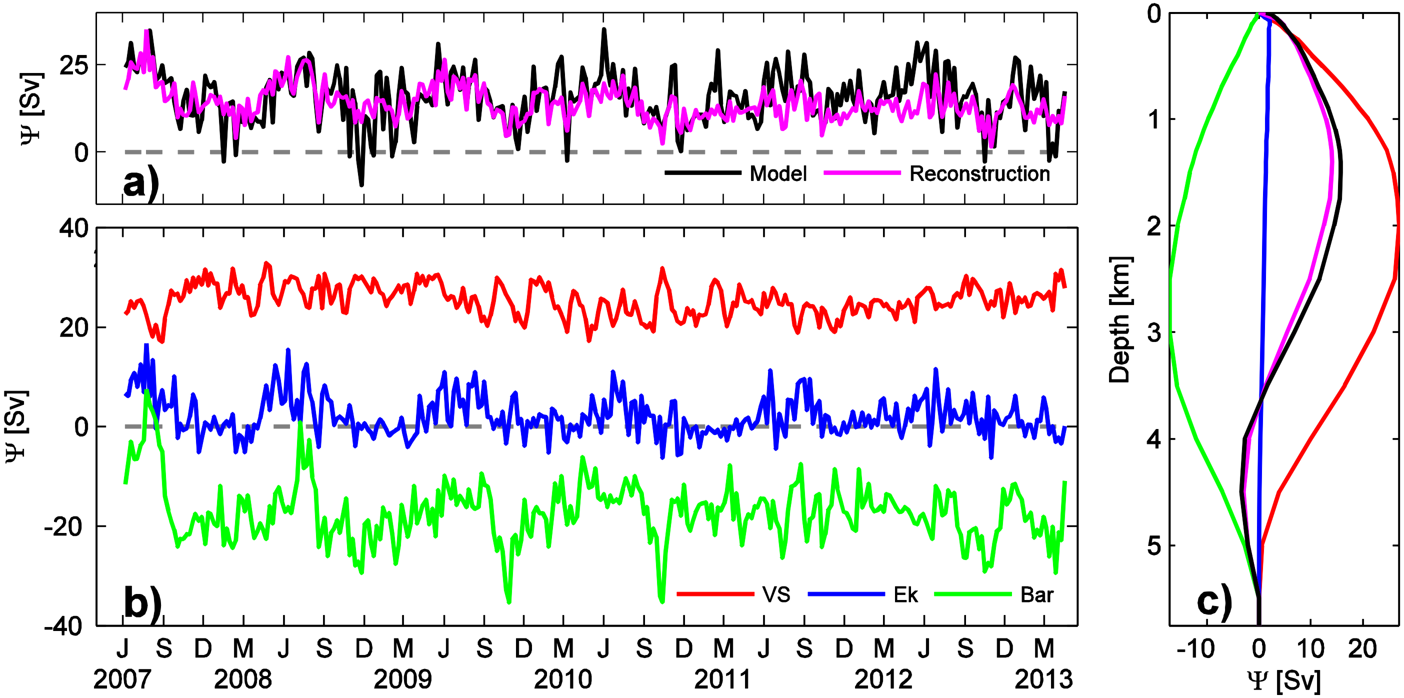
- AMOC strength:

AMOC strength = max(abs(PSI))

- Meridional Heat transport:

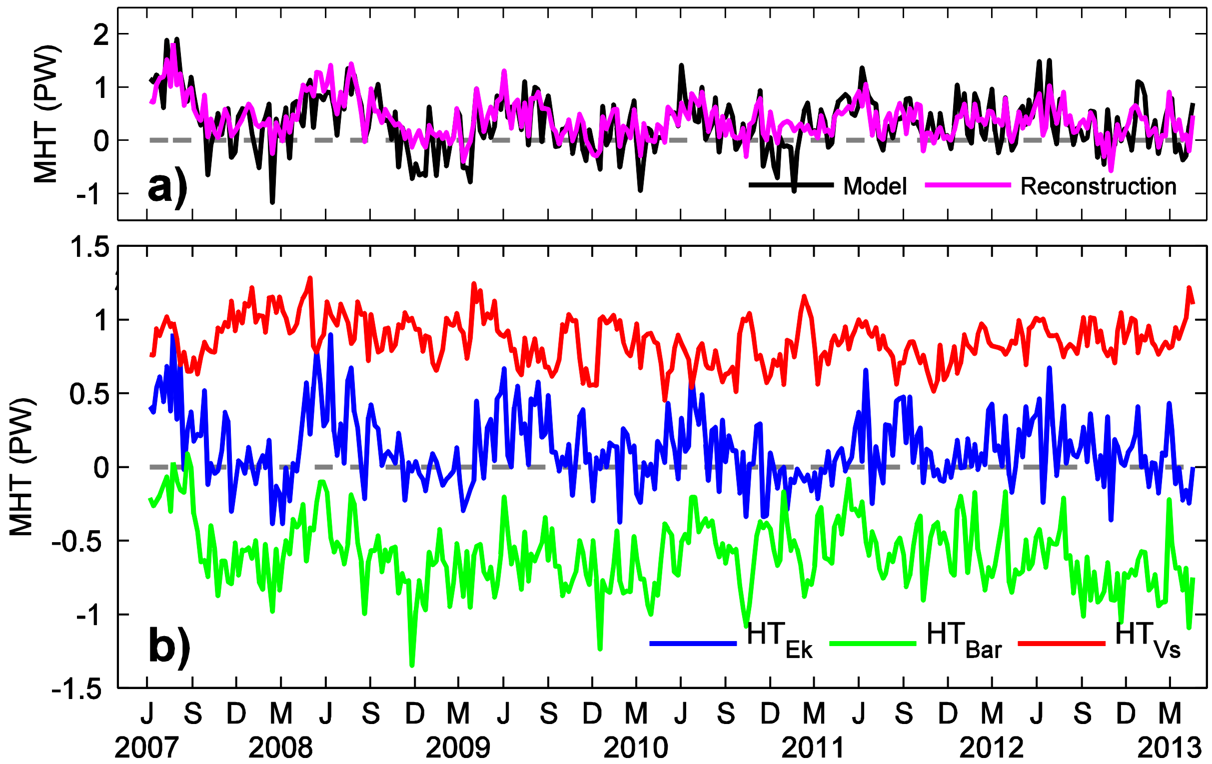
$$MHT = \rho_0 c_p \int_{-H}^{0} \int_{xE}^{xW} v(x,z) T(x,z)\,dx\,dz - \rho_0 c_p M_y \langle [T] \rangle$$

Reconstructed AMOC



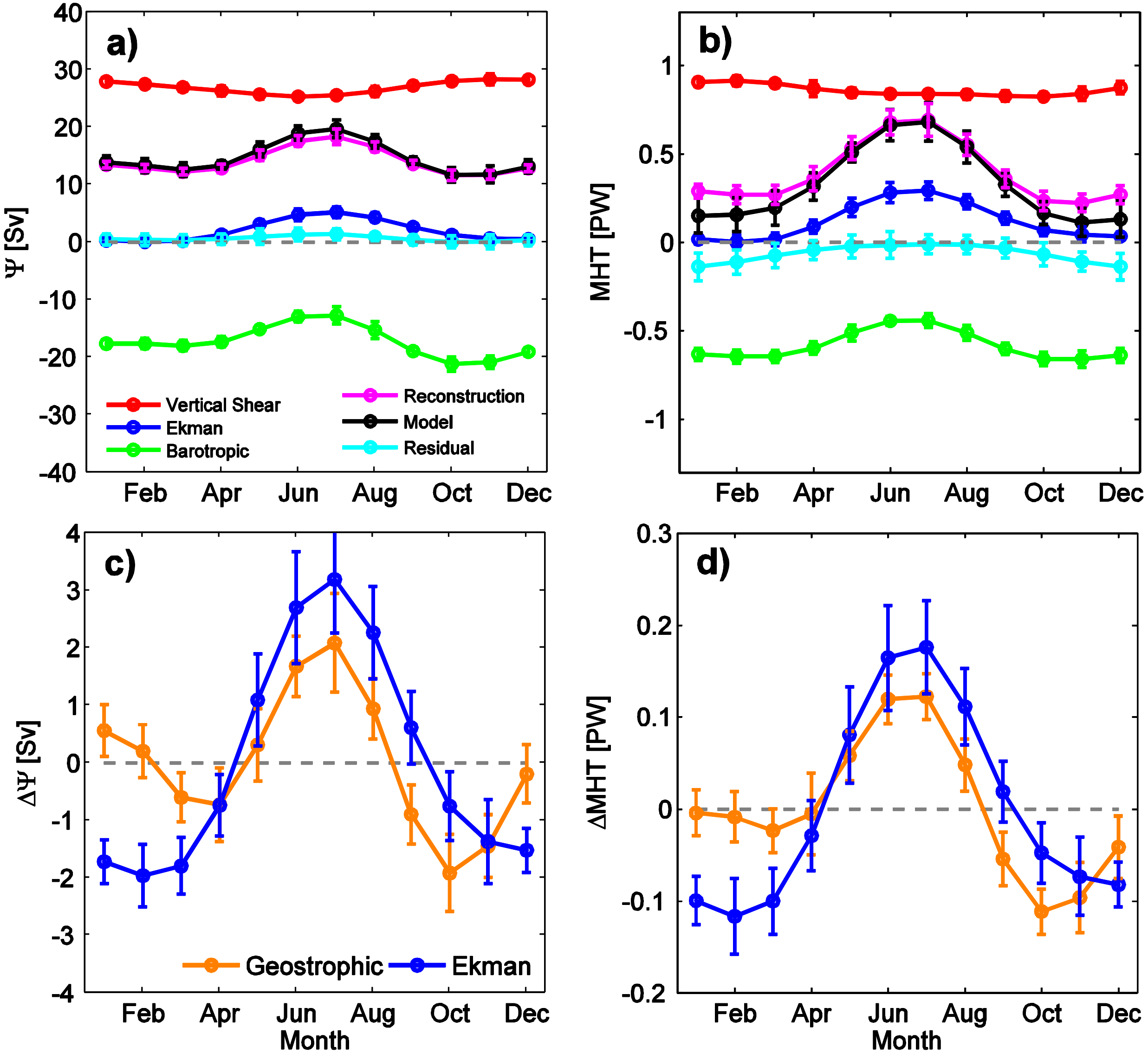
Component	HYCOM	Dong et al. (2009)
Total	15.1 ± 6.8 Sv	17.9 ± 2.2 Sv
Geostrophic	12.6 ± 3.2 Sv	15.7 ± 2.6 Sv
Ekman	2.0 ± 4.0 Sv	2.2 ± 2.0 Sv

Reconstructed MHT



Component	HYCOM	Garzoli et al. (2013)
Total	0.33 ± 0.5 PW	0.55 ± 0.14 PW
Geostrophic	0.21 ± 0.2 PW	~ 0.45 ± 0.1 PW
Ekman	0.12 ± 0.24 PW	0.08 ± 0.2 PW

Monthly Climatologies

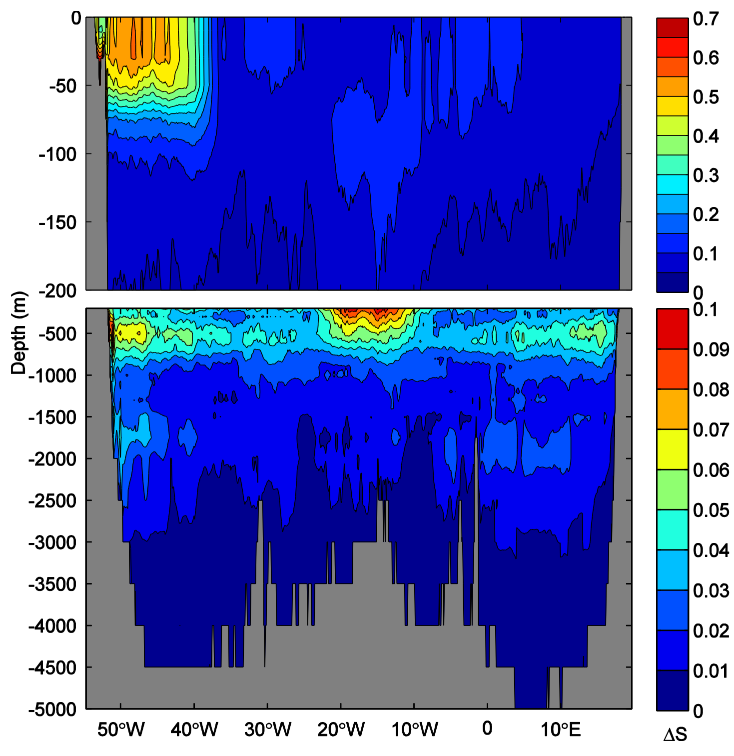


1st and 2nd harmonics are fitted to the time series.

In-phase relationship between the Geostrophic and Ekman transports.

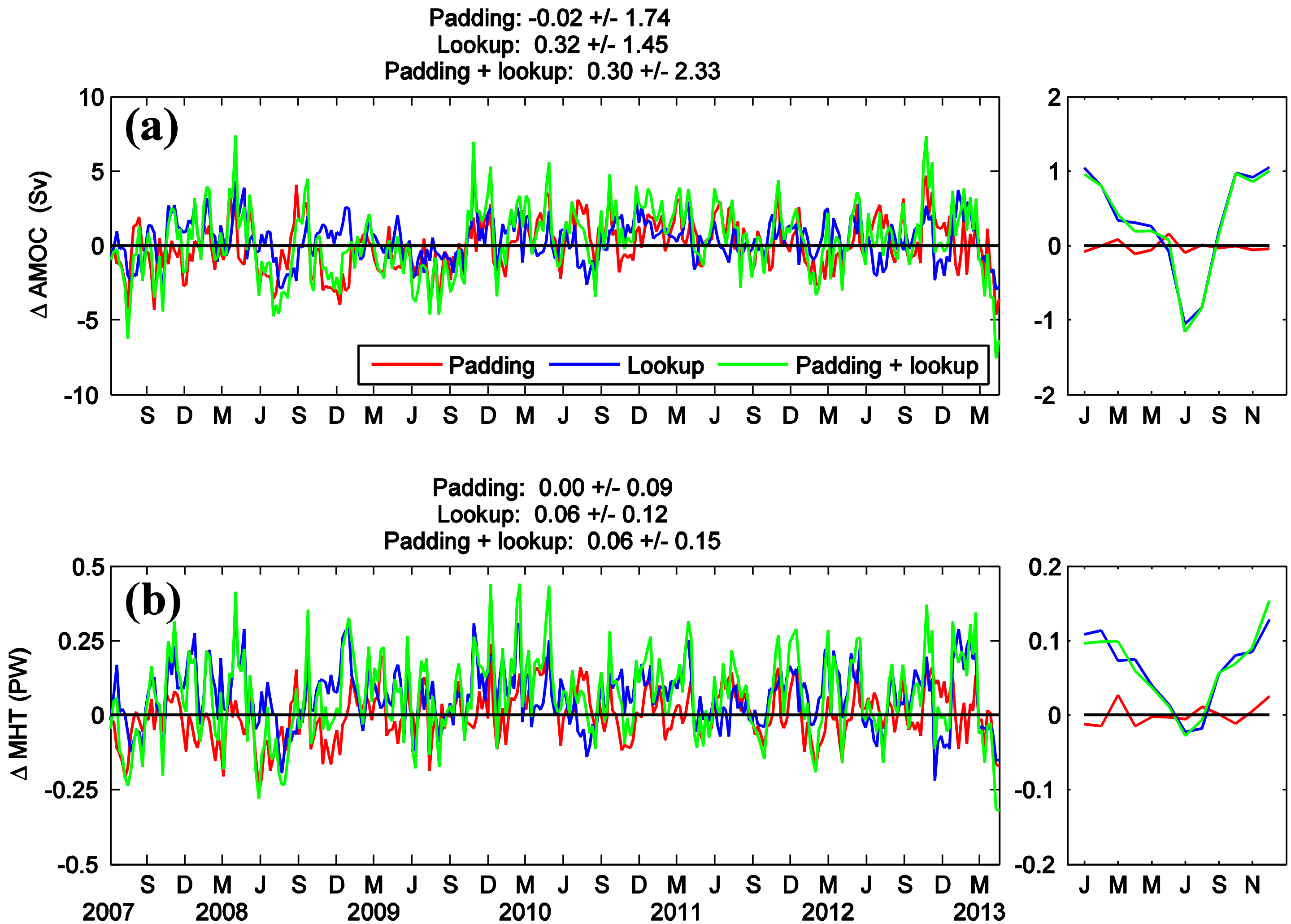
Effect of Salinity and Deep temperature estimates

- **Lookup method**: An annual T-S relationship is estimated for the model at 1° of longitude. Salinity is regressed to temperature at each depth.
- **Padding method**: Climatological values of temperature and salinity are estimated for depth below 800 m.



Salinity RMS is proportional to the seasonal variability in the lookup method.

Effect of Salinity and Deep temperature estimates



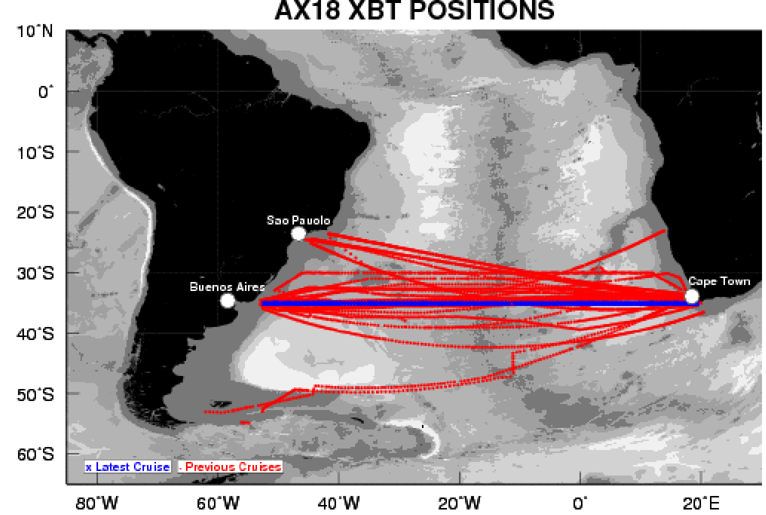
Time Sampling

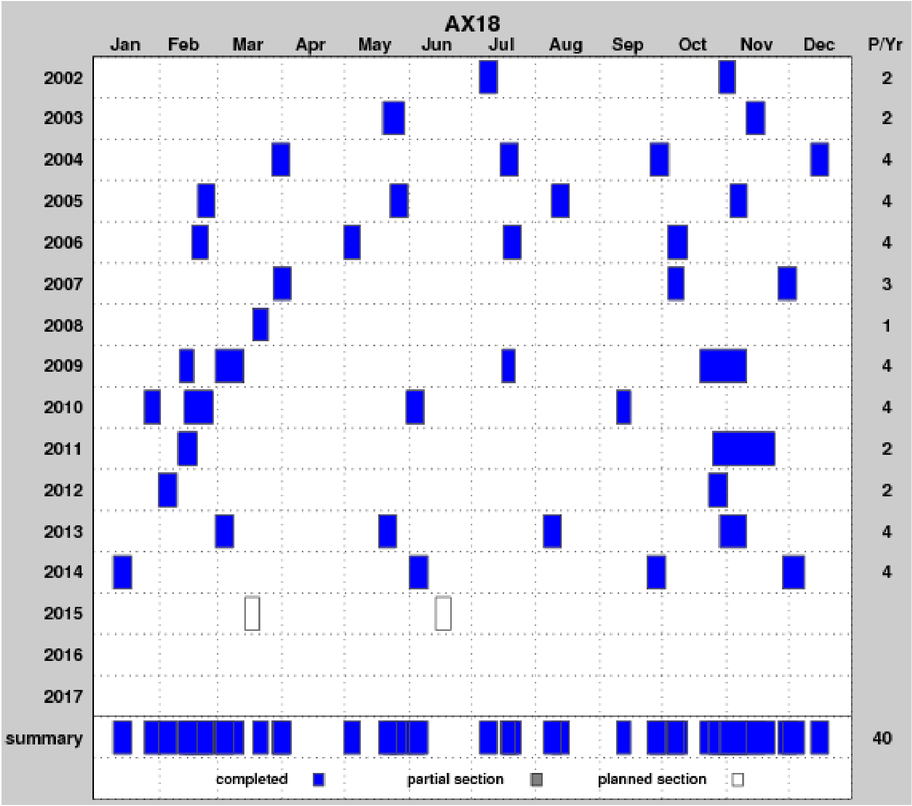
- Is a quarterly sampling of the AX18 array enough to capture the seasonal variability in the region?

To investigate how the time sampling affect the detection of the AMOC/MHT seasonal cycle, we test two uncertainty parameters:

i) The number of years sampled (0-15 years)

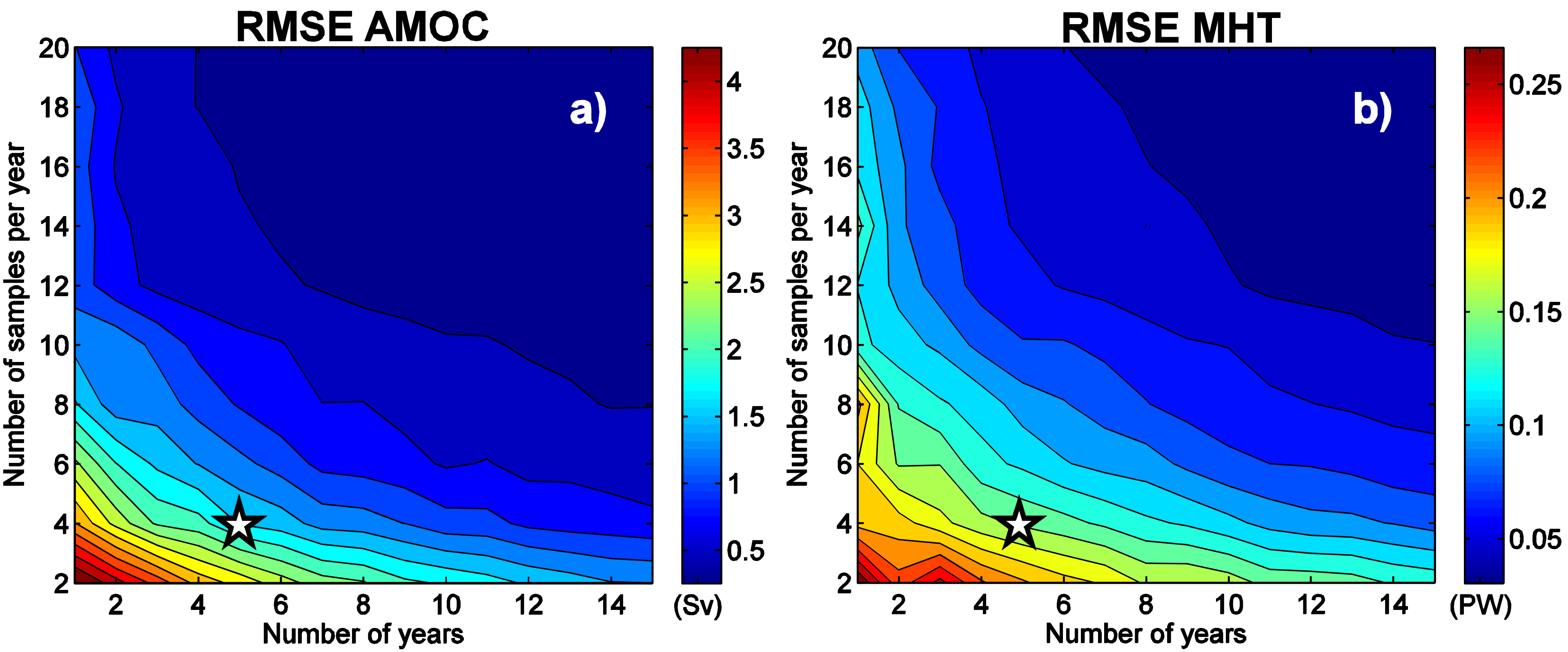
ii) The number of samples per year (2 – 20 samples/yr)





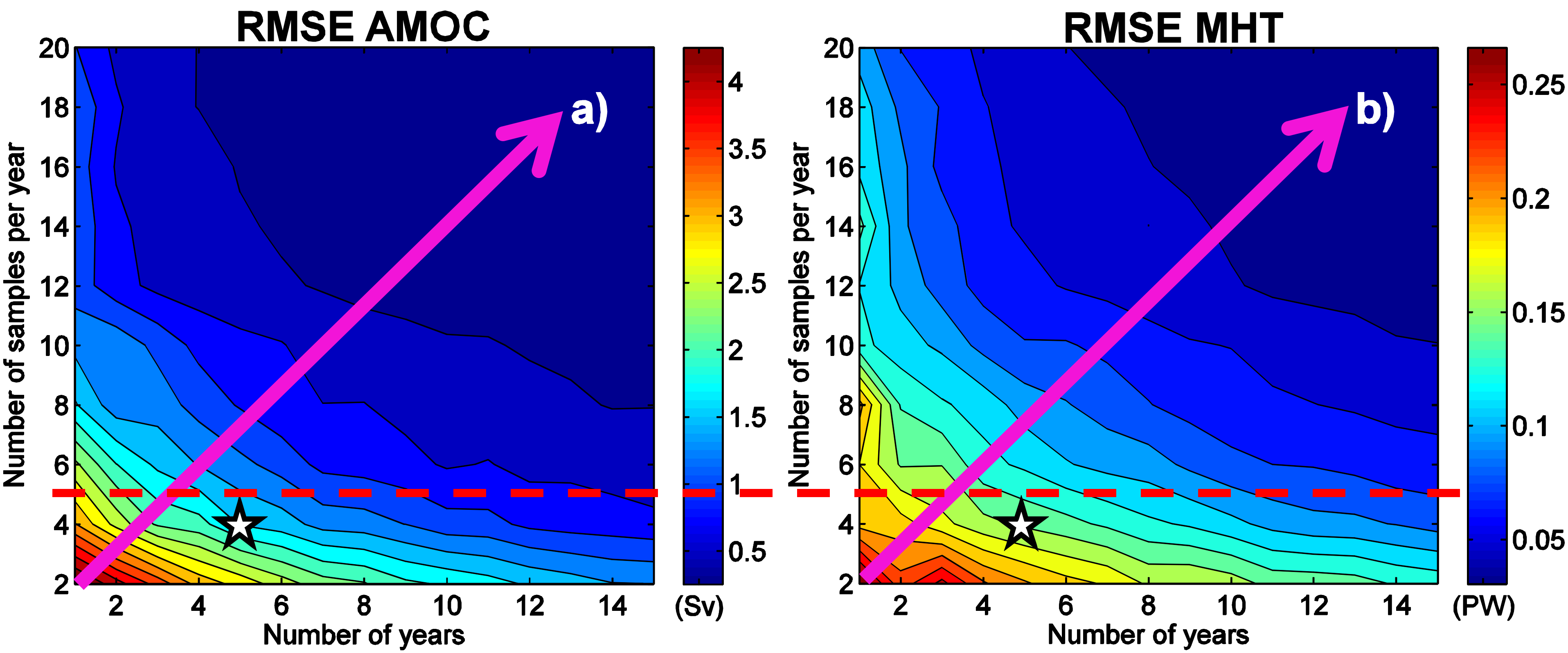
http://www.aoml.noaa.gov/phod/hdenxbt/ax_home.php?ax=18

Time Sampling



- The time series are resampled to a total of 100 years.
- For each parameter settings, a stretch of the resampled time series is selected and subsampled by the number of samples/year.
- The 1st and 2nd harmonics are calculated for each realization.
- The steps 2 and 3 are performed 400 times, and the RMS of the reconstructed AMOC strength and MHT are calculated.

Time Sampling



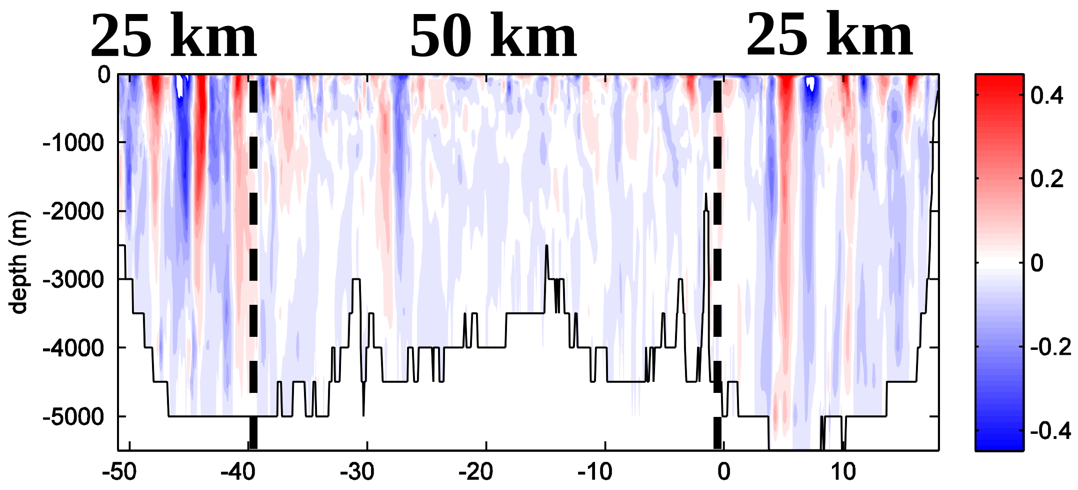
Sampling	AMOC	MHT
5 years/ 4 x year	±1.7	±0.15
12 years/ 4 x year	±1.4	±0.13

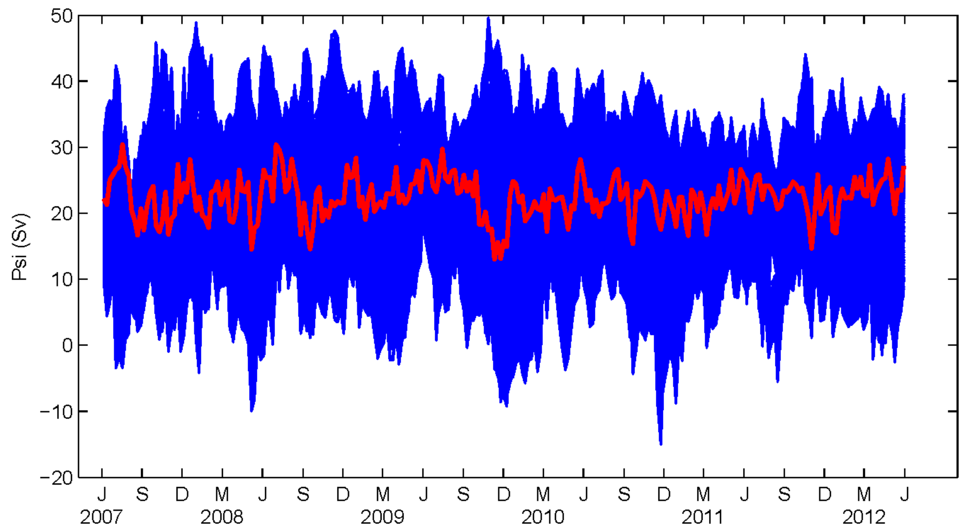
Operational constraints prevents increase in the number of samples/year

Spatial Sampling

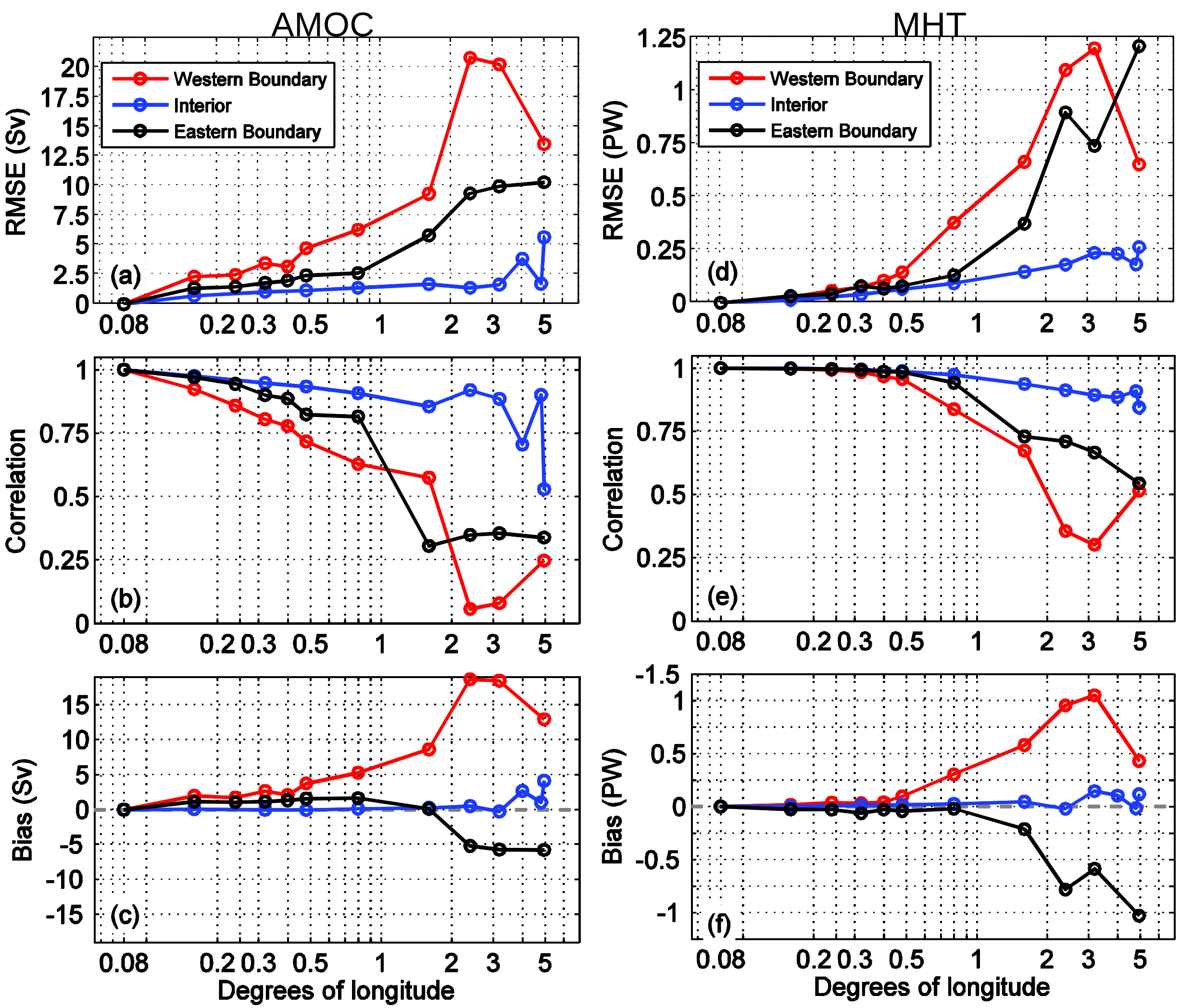
How the zonal resolution affects the reconstruction of the AMOC?

- Divide de domain into 3 regions: western, interior, and eastern.
- Generate for each region 10 different sampling spacing.
- Calculate how the RMSE, bias and correlation vary from the reconstructed field at every grid point.



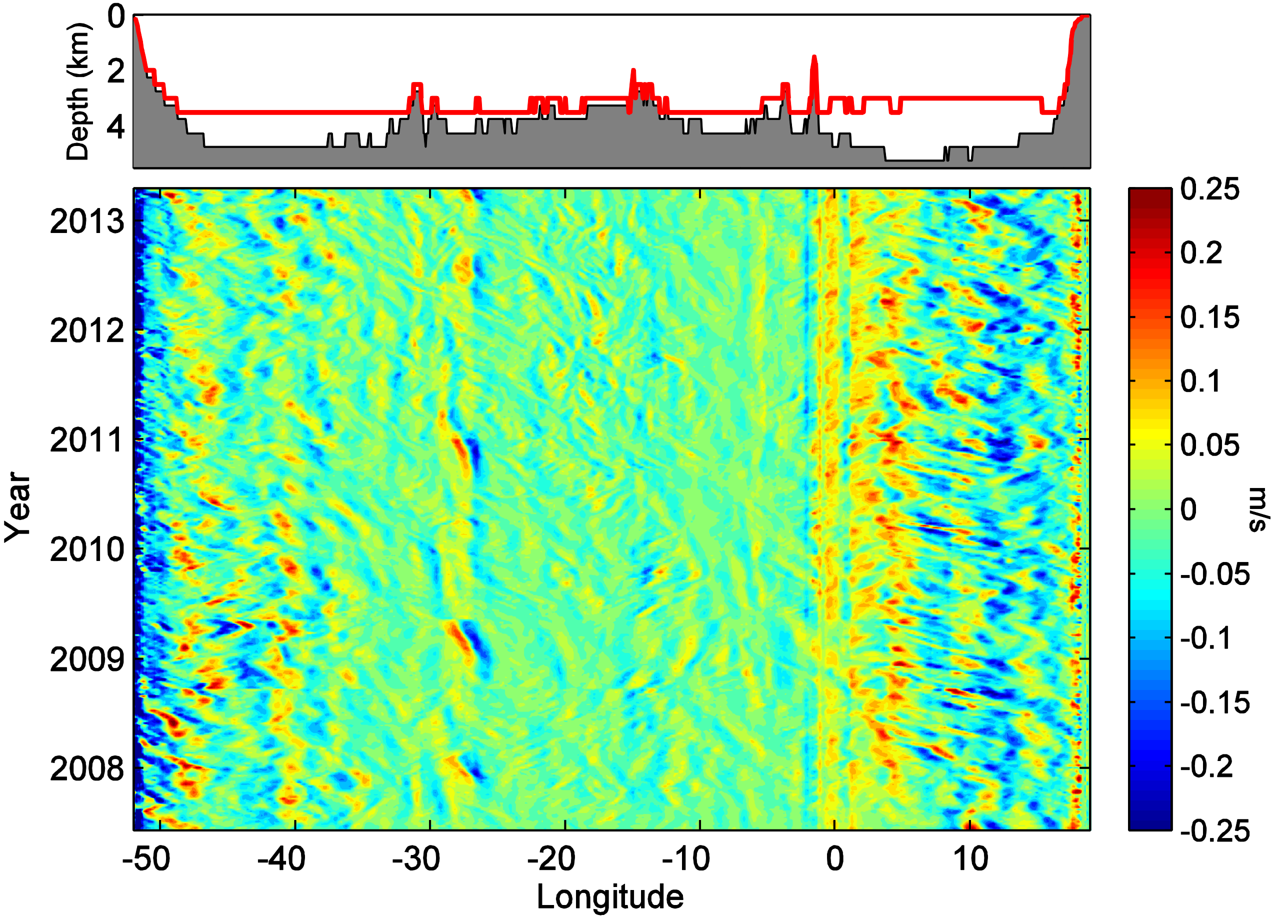


Spatial Sampling



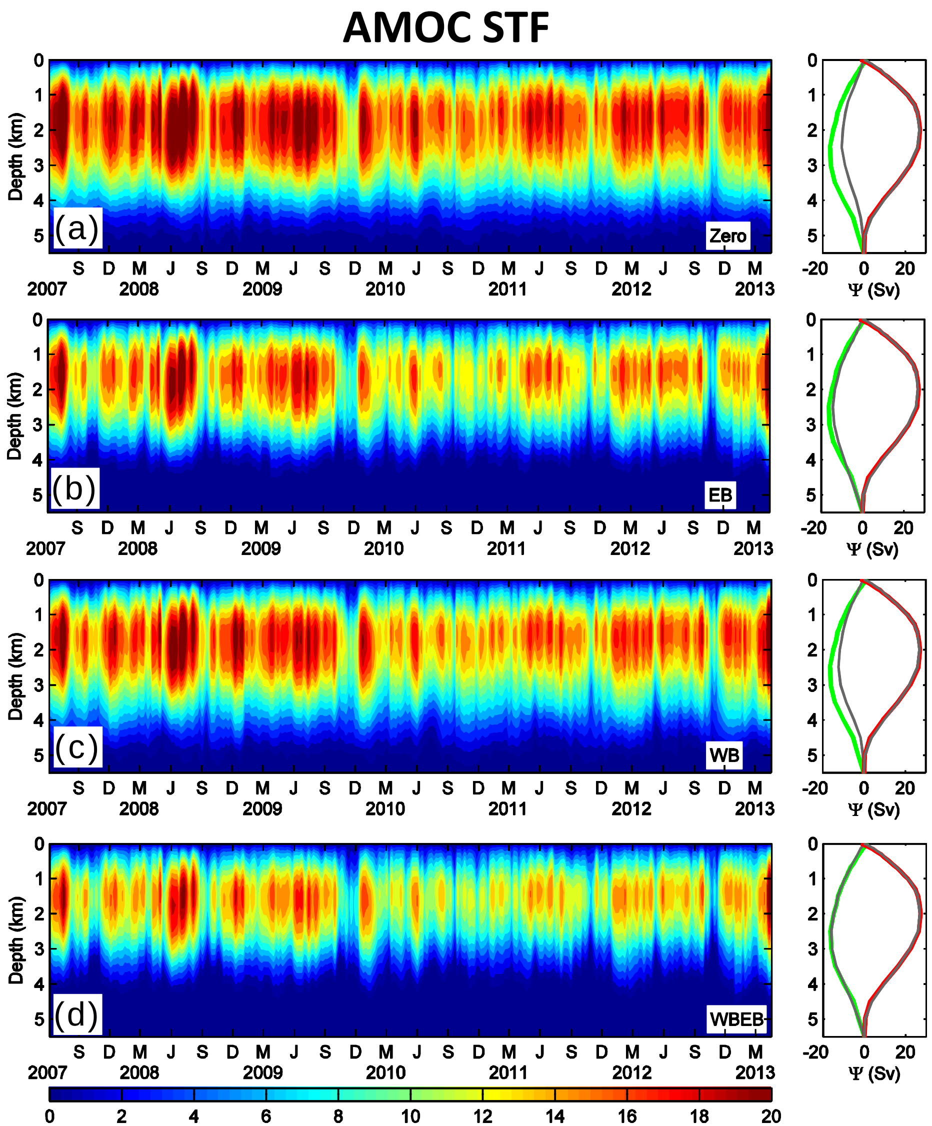
Region	AMOC	MHT
Interior (50km)	-0.1±1.1	0.01±0.06
East (25 km)	1.0±1.4	-0.03±0.04
West (25 km)	1.7±2.4	0.03±0.06

Barotropic velocities in the model



Barotropic velocities are strongly influenced by bathymetry

MOC sensitivity to the reference velocity



Barotropic
Vertical Shear
Reconstruction

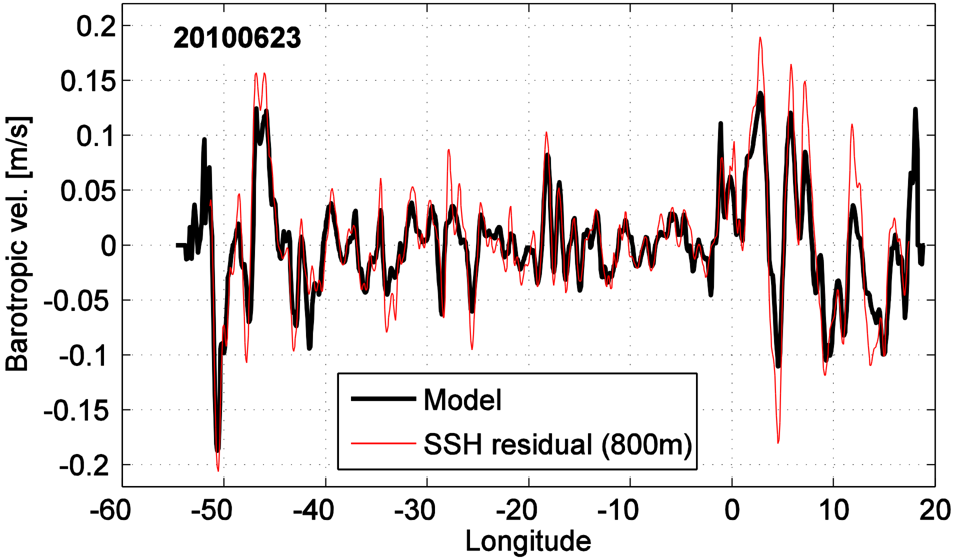
Vref	Bias(Sv)	RMS (Sv)
Zero	5.7	4.4
East	2.0	4.3
West	4.0	4.5
East + West	0.3	4.4

Test how the knowledge of climatological reference velocities affect the AMOC.

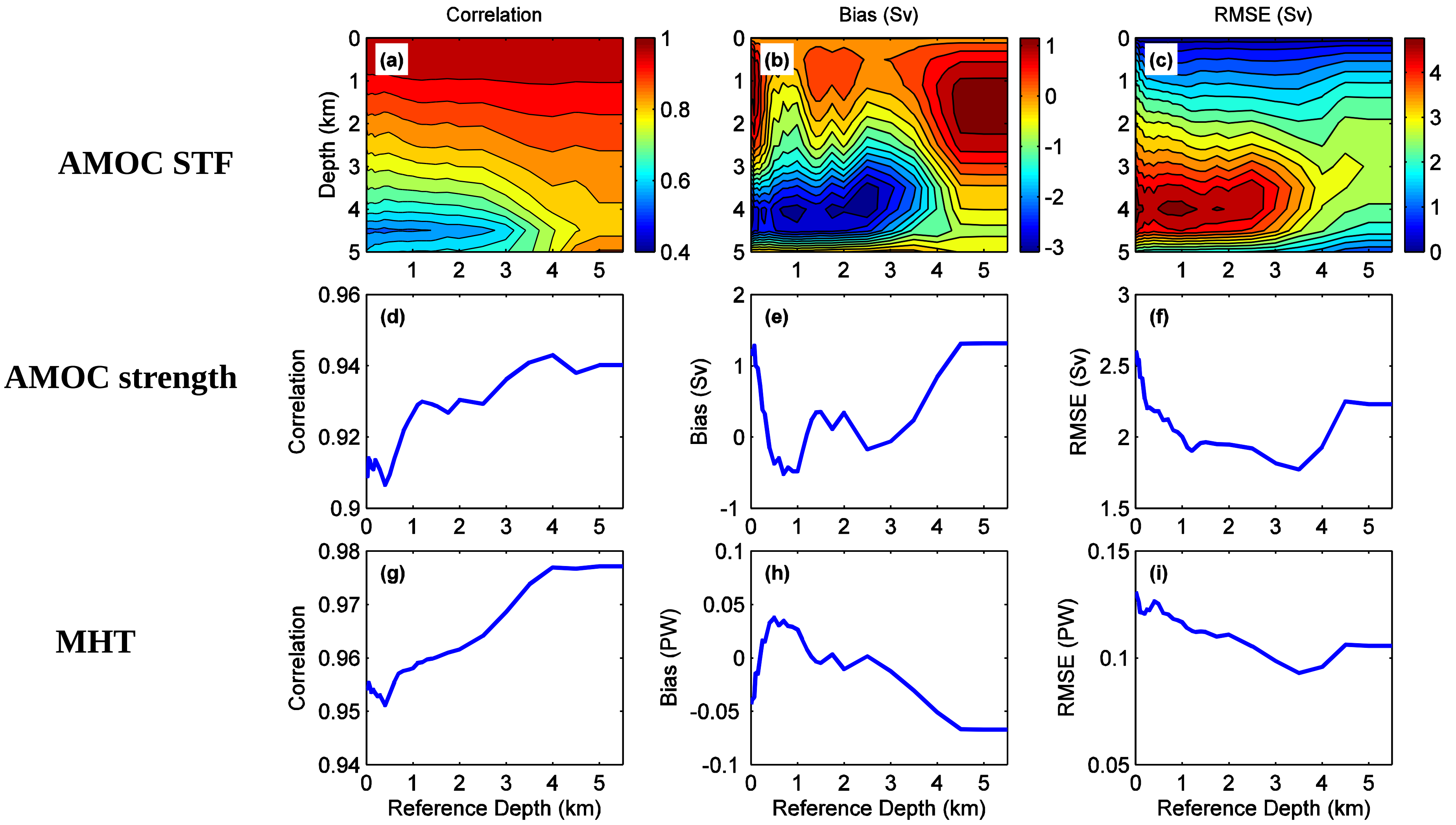
Alternative for Barotropic Velocity Estimation Using Altimetry and Hydrography

- Using the hydrostatic relation, the total sea level (SSH) can be accurately related to bottom and atmospheric (Patm) pressure, plus the steric contribution [Park and Watts, 2005].
- Guinehut et al. (2006) estimated the barotropic component of the flow as the SSH – DynH(700m) residual.

We test how the [SSH-DynH(z)] residual contributes to improvements in the AMOC/MHT at various reference depths.



Reference velocity estimated from the SSH-residual method



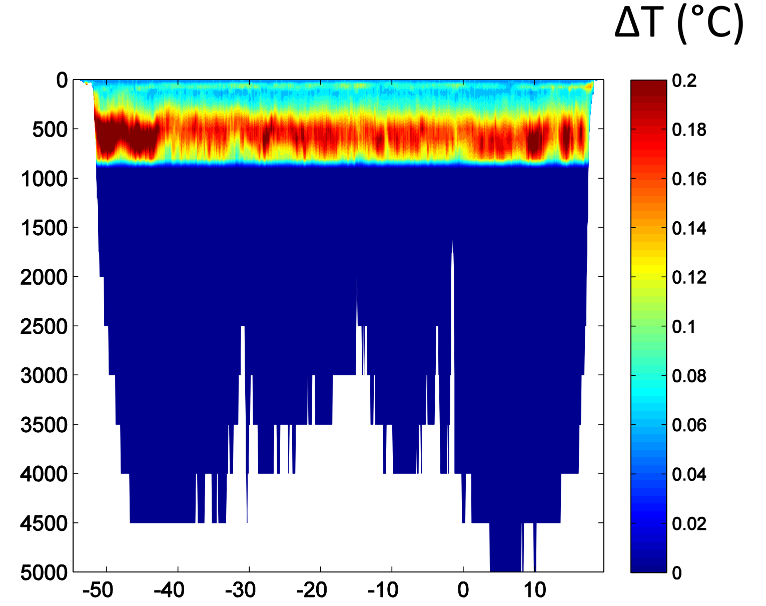
Error estimates for AMOC and MHT

Source	AMOC (Sv)	Meridional Heat Transport (PW)	
	Present	Present	B&G
Upper ocean salinity	0.32 ± 1.4	0.06 ± 0.12	0.03
Deep climatology below 800 m	−0.02 ± 1.7	0.0 ± 0.09	0.15
Mass imbalance	0.9 ± 3.8	−0.02 ± 0.06	0.02
Nonsynopticity	0.2 ± 4.1	0.01 ± 0.25	
Ageostrophic eddies (non-Ekman)	0.6 ± 5.5	−0.06 ± 0.32	0.05
Quarterly sampling	0 ± 1.7	0 ± 0.15	
Unresolved western shelf transport	−0.6 ± 0.8	10−8	0.01
Unresolved eastern shelf transport	0.15 ± 0.4	10−8	0.01
Western horizontal resolution (25 km)	1.7 ± 2.4	0.03 ± 0.06	
Eastern horizontal resolution (25 km)	1.0 ± 1.4	−0.03 ± 0.04	
Interior horizontal resolution (50 km)	−0.1 ± 1.1	0.01 ± 0.06	
Western reference velocity	4.0 ± 4.5	0.06 ± 0.16	0.02
Eastern reference velocity	2.0 ± 4.3	0.10 ± 0.14	
Reference level depth	0.6 ± 1.8	−0.04 ± 0.09	0.05

Last column shows the biases estimates of Baringer and Garzoli [2007, Table 3].

How XBT measurement errors affect the AMOC and MHT estimates?

RMS error for the 34S temperature section



➢Typical errors found in XBT measurements are:

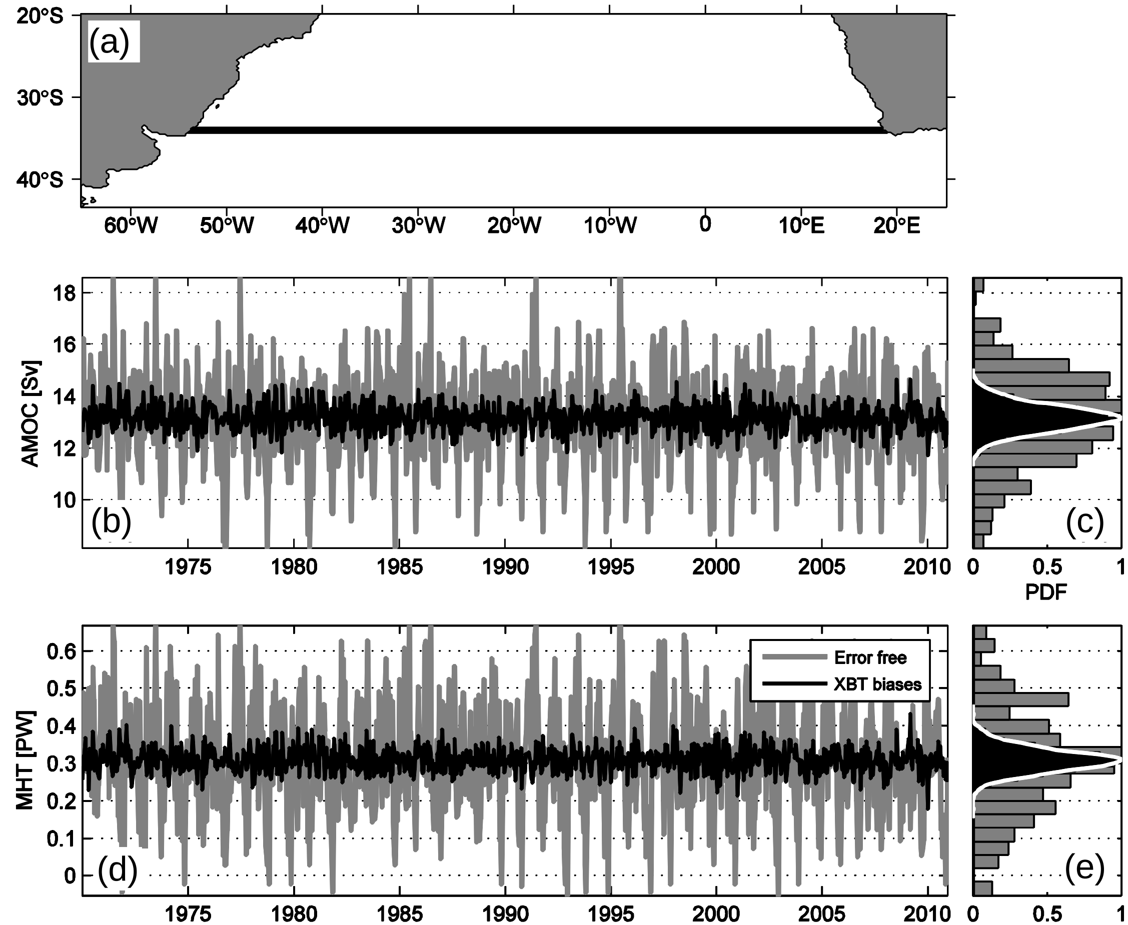
Type of error	Order of Magnitude	Source
Temperature accuracy (T0)	T0 ≈ ±0.2°C	Probe-to-recording device, (static) calibrations in laboratory, wire de-reeling
Depth offset (Z0)	Z0 ≈ ±5m.	Wave height variability, entry velocity and angle of the probe
Depth linear bias (Zd)	Zd ≈ 2% of depth	Pure FRE error

Sensitivity of Meridional transport to XBT measurement biases

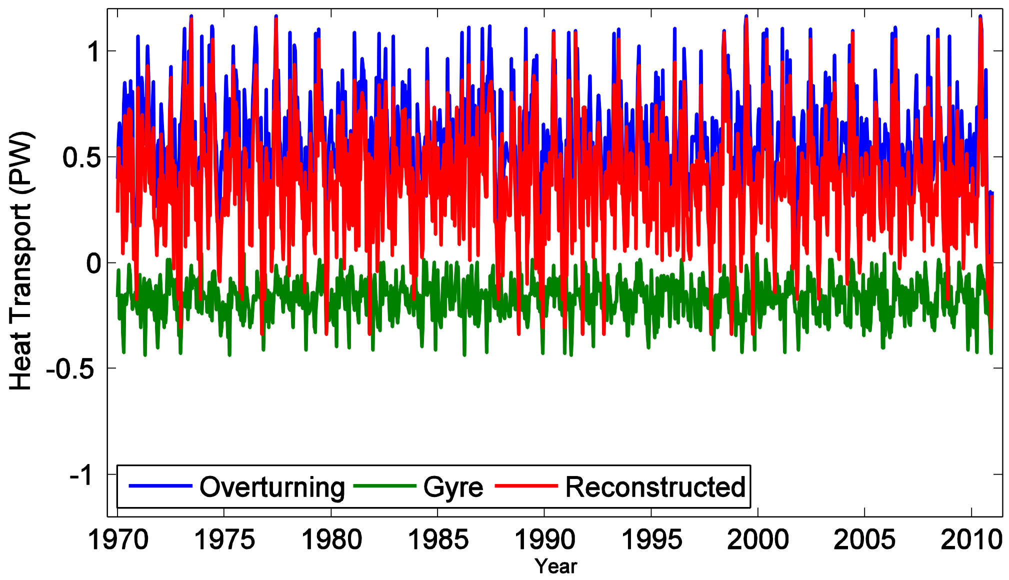
The resampled timeseries from HYCOM is used to produce CONTROL time series of the AMOC and MHT since 1970.

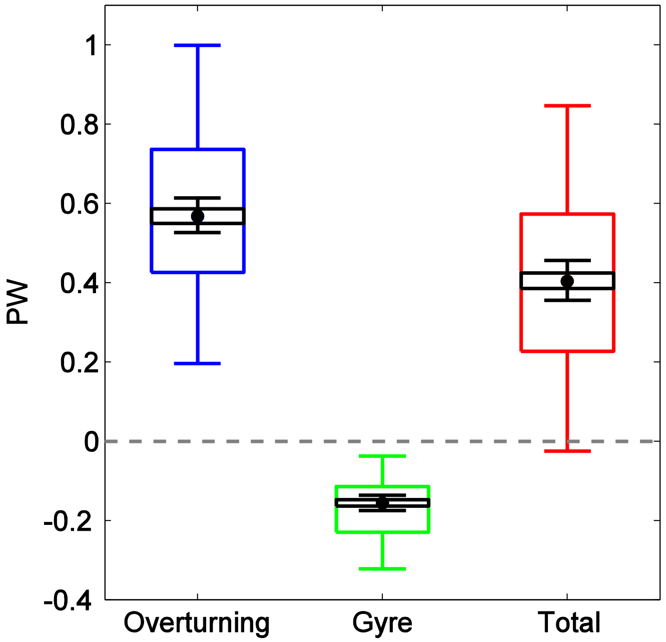
Manufacturing tolerance biases are applied and residuals are estimated.

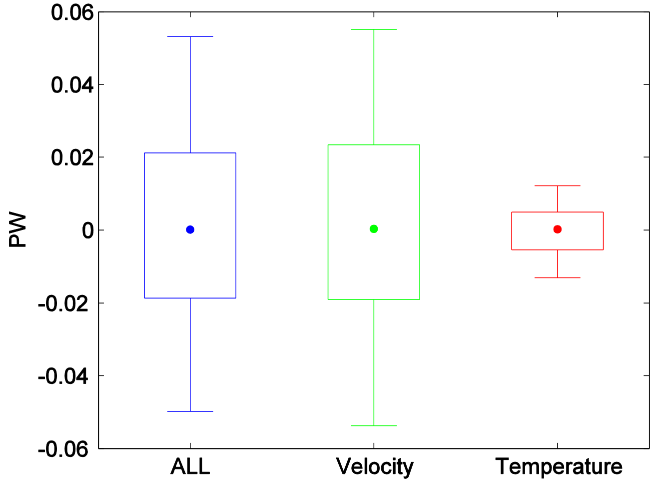
The errors associated with XBT measurement biases account for **3% (0.38 Sv)** and **8% (0.025 PW)** of their mean values, for the AMOC and MHT, respectively



XBT biases on MHT dynamic properties







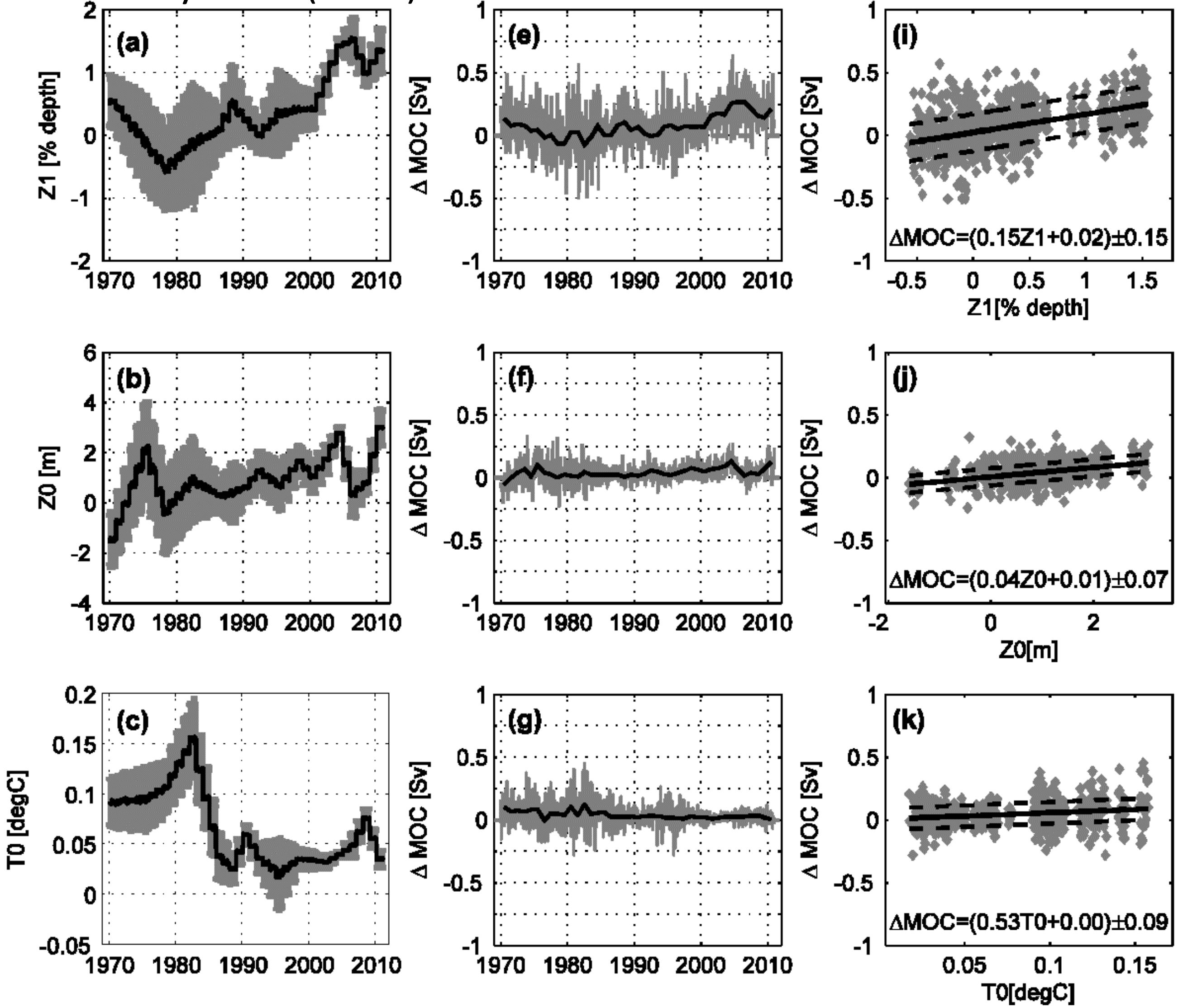
MOC sensitivity to historical XBT bias parameters

Cowley et al. (2013)

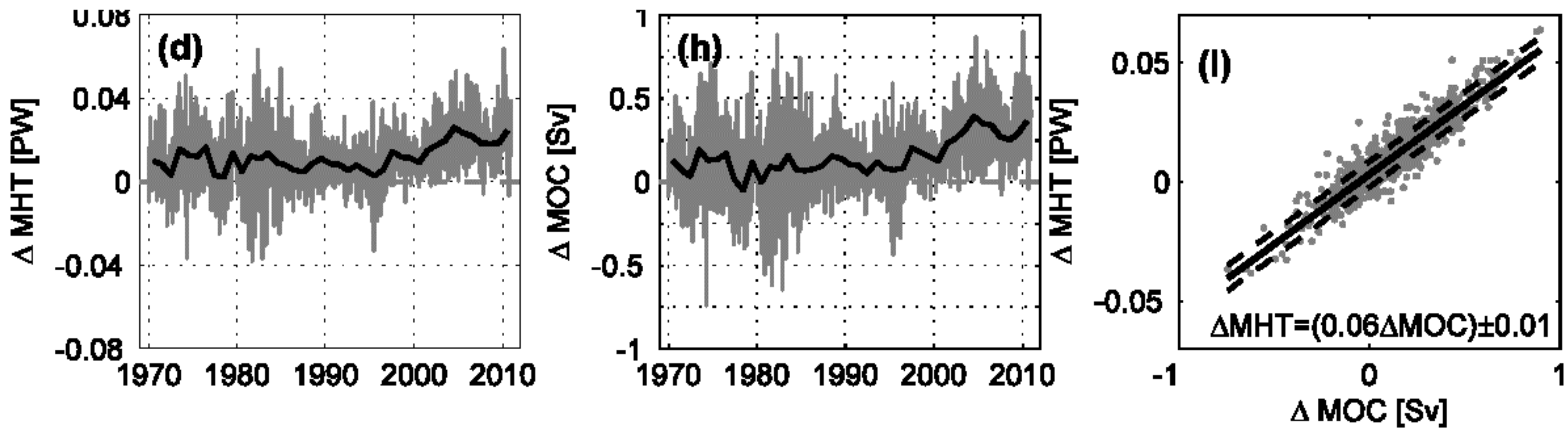
Depth linear bias

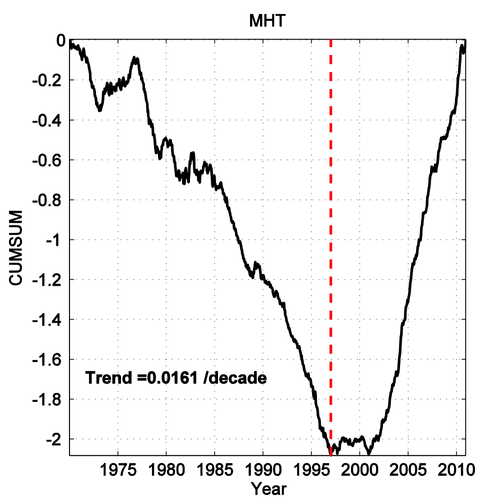
Depth offset

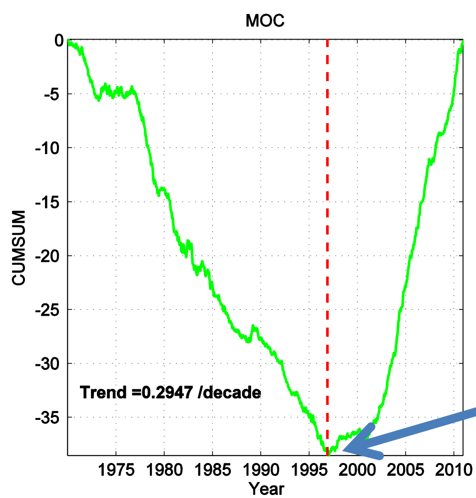
Temperature offset



Total XBT measurement bias



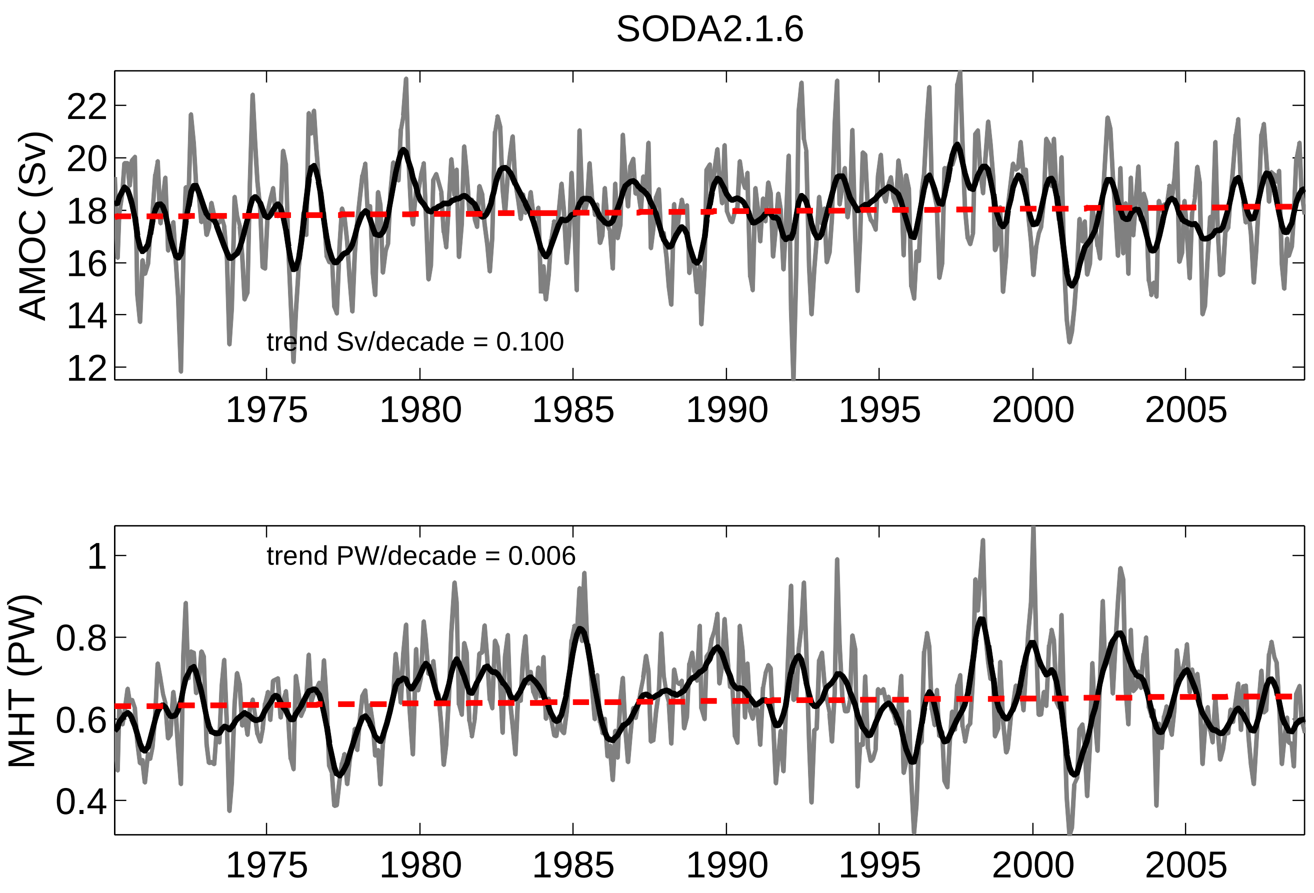




Historical XBT biases produce trends of 0.3 Sv/decade and 0.02 PW/decade since the 1990s.

Sippican changed factory to Mexico

Historical AMOC and MHT trends in SODA

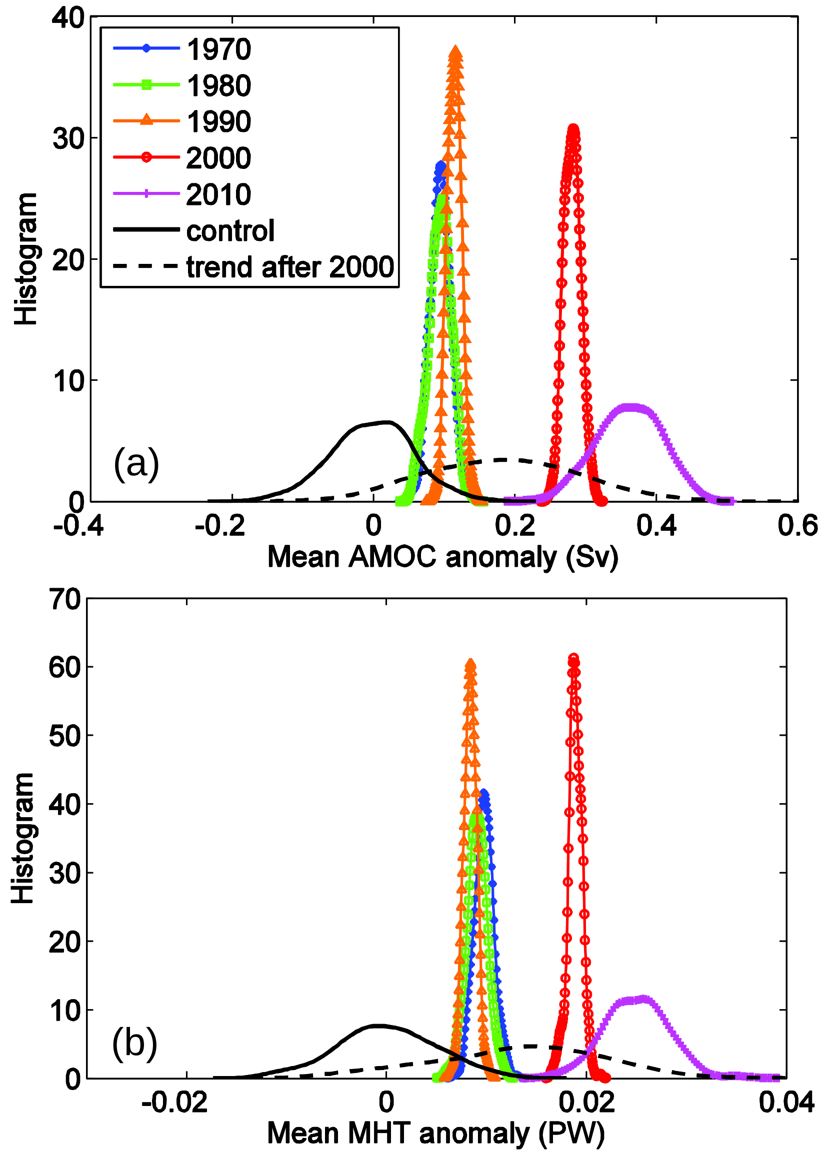


Mean decadal AMOC and MHT biases resulting from historical XBT biases

Bootstrapping is performed to estimate the mean AMOC and MHT biases and associated standard errors for each decade.

The distribution of the mean biases due to XBT after 2000 are statistically different than the CONTROL.

The XBT biases should be corrected for long term AMOC/MHT monitoring.



Conclusions

- Current **quarterly sampling** causes an average RMS error of ±1.7 Sv and ±0.15 PW in the climatological AMOC and MHT estimates, respectively. Due to operational constraints, it is desirable to conduct continuous realizations at current quarterly sampling for at least 15 years.
- The current **spatial sampling** seems to be adequate to capture most of the variability of the meridional transports, although the western boundary resolution still shows large AMOC bias at the present sampling (1.7 ± 2.4 Sv). An increase in the western boundary sampling to 20 km would improve the accuracy of the current AMOC calculations by ~1 Sv.
- The effect of **T-S padding and salinity estimation** from the T-S lookup table in the upper 800 m are also small in comparison to the other components. However, seasonal biases in the annual climatology can produce AMOC monthly biases of as much as 1 Sv. Salinity from other measurements, such as Argo, can produce monthly climatologies of T-S relationships, which would in principle avoid these seasonal biases.

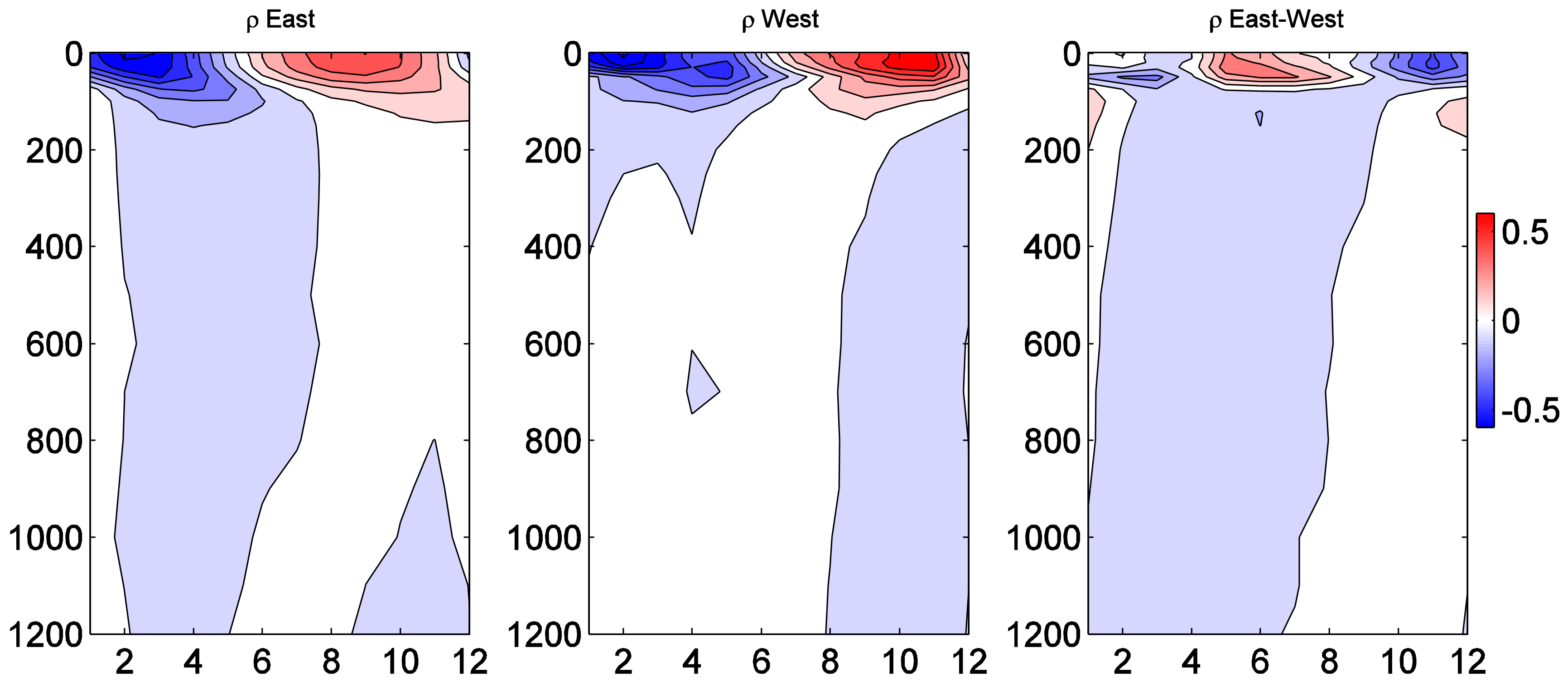
Conclusions

- The **barotropic mode** is likely to be the most significant source of error in the AMOC and MHT calculations due to the extensive continental shelf along 34°S. The best location for a level of no motion is around 3700 m, approximately the depth of kg m^{-3}. However, errors are on the order of 5.7 ± 4.4 Sv for the AMOC and 0.17 ± 0.16 PW for MHT if a level of no motion is used in kg m^{-3}. Using at least climatological values as the reference velocities in both boundaries is necessary to reduce the AMOC and MHT mean biases to $\sim 0.3 \pm 4.4$ Sv and 0.02 ± 0.14 PW, respectively.

- The use of **satellite altimetry/hydrography** observations is a good alternative for barotropic component of the AMOC/MHT. We show that errors in the barotropic mode estimation using the non-steric component of altimetry are 0.6 ± 1.8 Sv and -0.04 ± 0.09 PW, an improvement of up to 90% in the bias and 60 % in the RMS in comparison to the commonly used level of no motion at kg m^{-3}.

THANK YOU

Density and density differences



Time Sampling