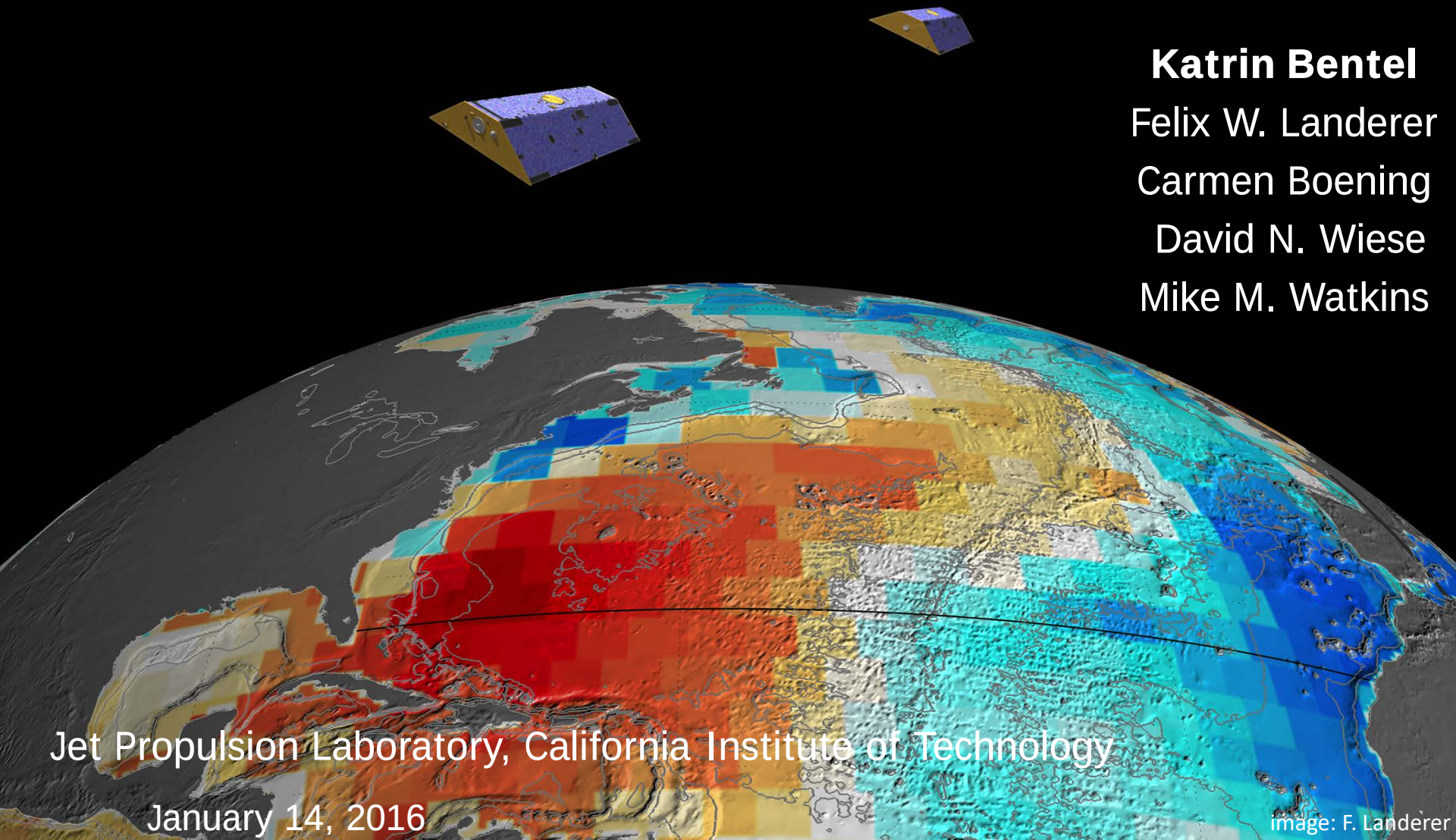
Can Atlantic overturning circulation variability be observed with GRACE?

Katrin Bentel
Felix W. Landerer
Carmen Boening
David N. Wiese
Mike M. Watkins

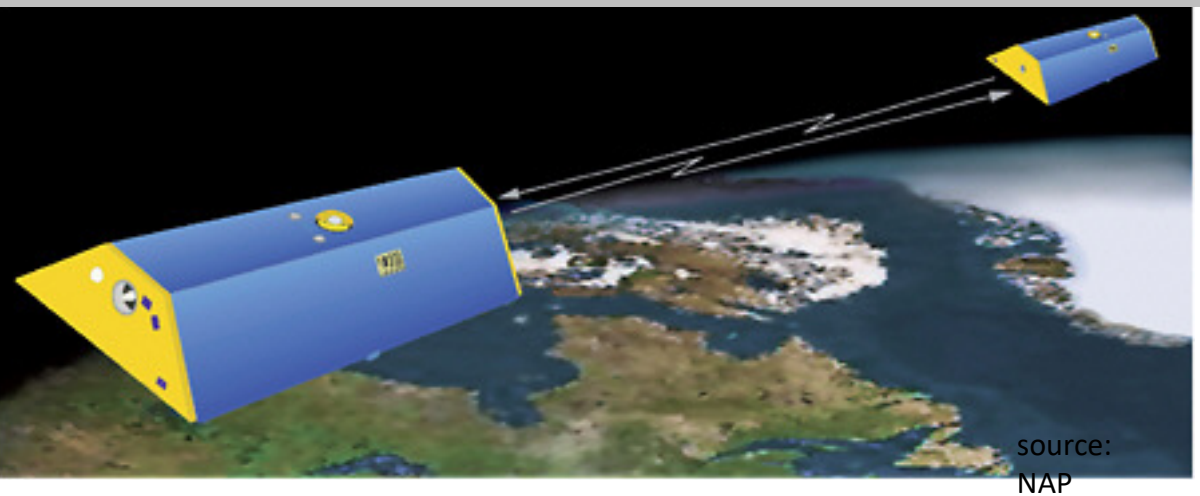


Jet Propulsion Laboratory, California Institute of Technology

January 14, 2016

image: F. Landerer

GRACE (Gravity Recovery and Climate Experiment)

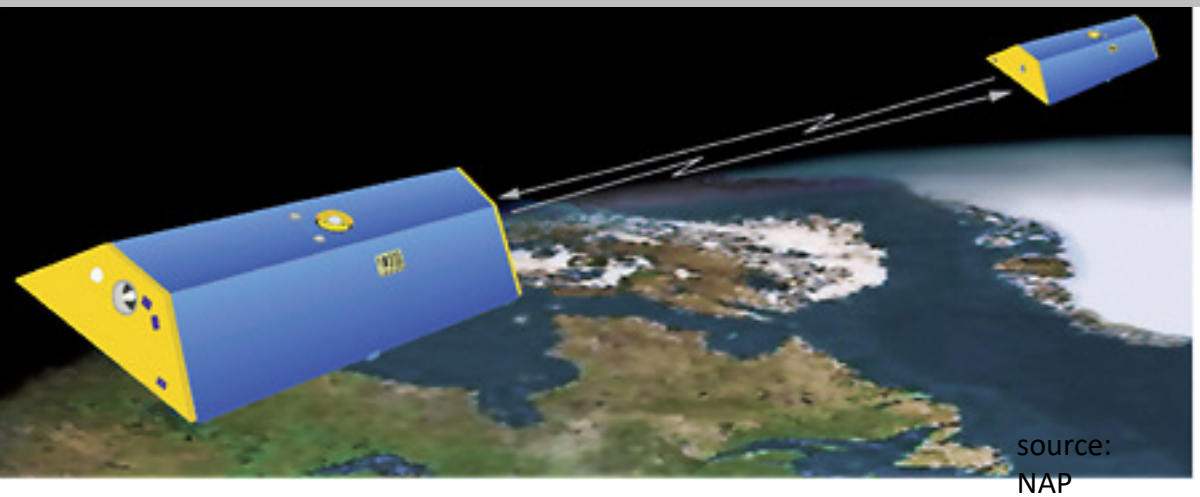


source: NAP

- Distance between satellites ~220 km

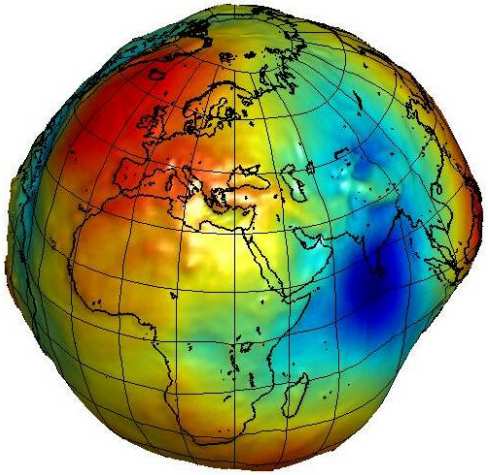
Measured by microwave ranging instrument with accuracy of 1 µm (human hair ~50µm)

GRACE (Gravity Recovery and Climate Experiment)

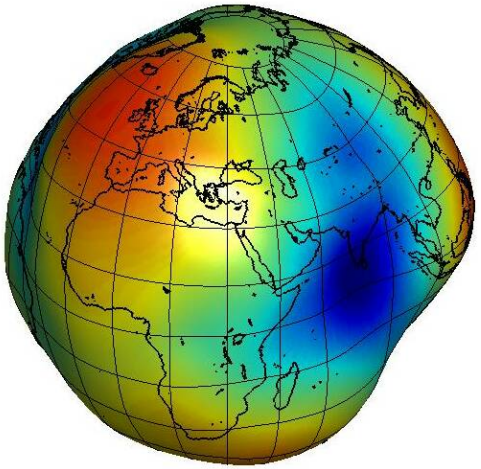


- Distance between satellites ~220 km
- Polar orbit, ~ 400 km altitude

geoid at surface

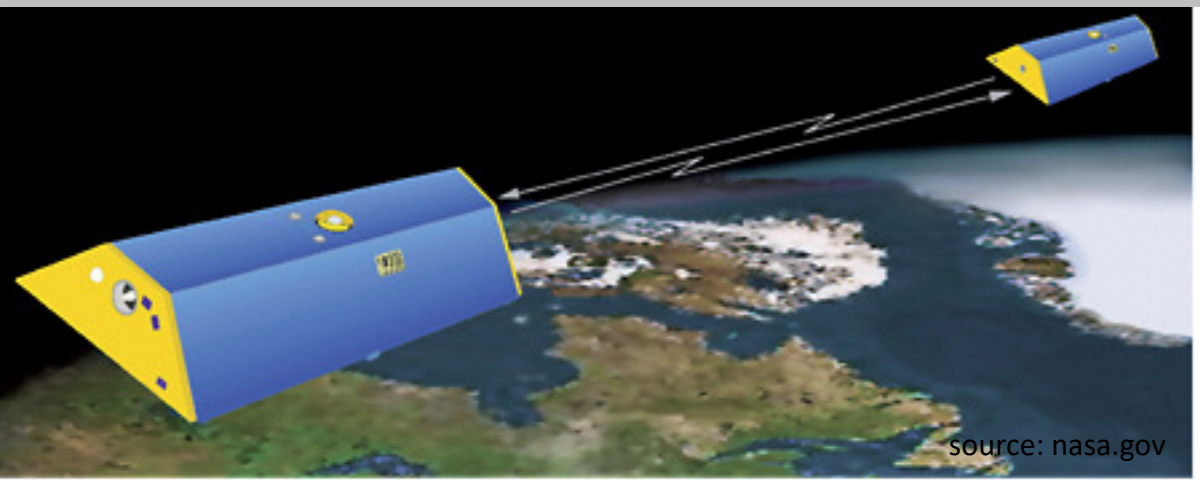


dampening of small features



geoid at 500 km

GRACE (Gravity Recovery and Climate Experiment)



- Distance between satellites ~220 km
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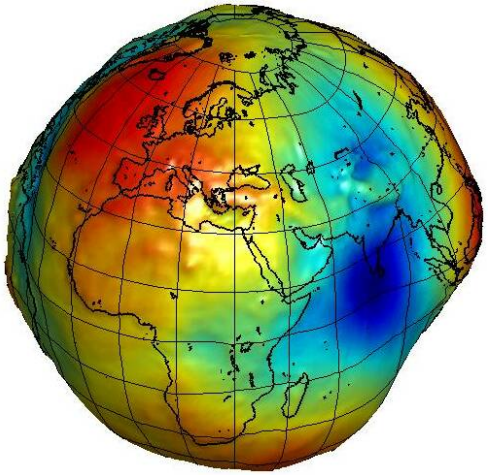
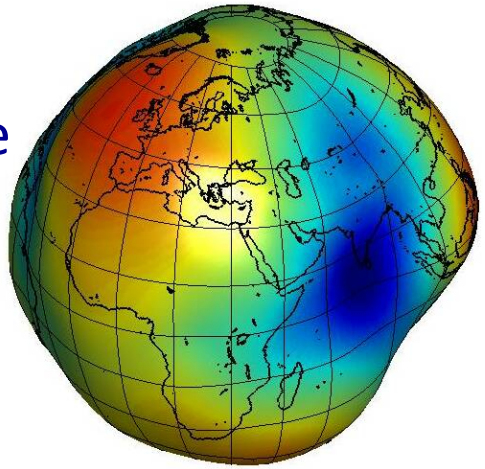
geoid at surface

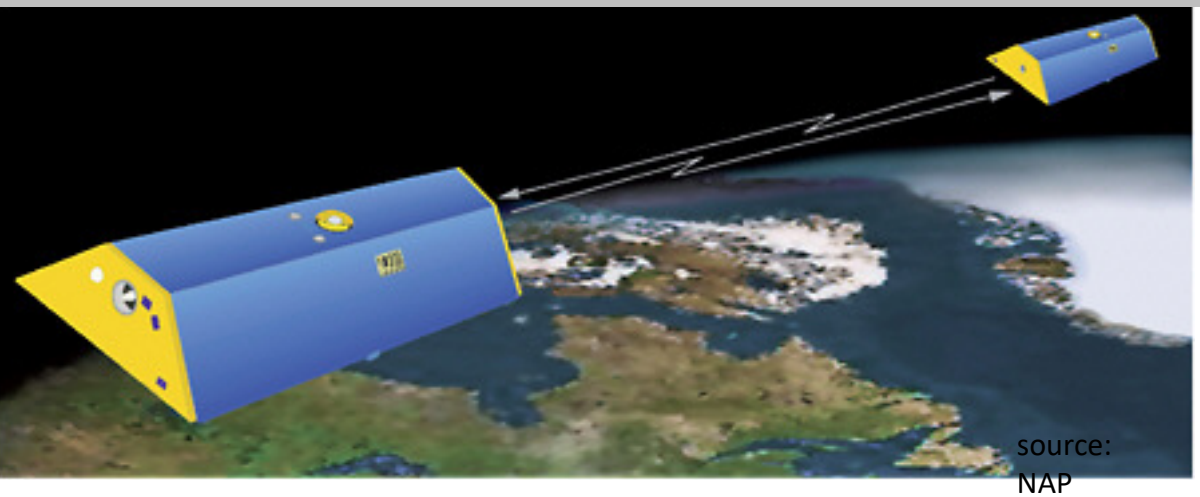


amplification of observation noise



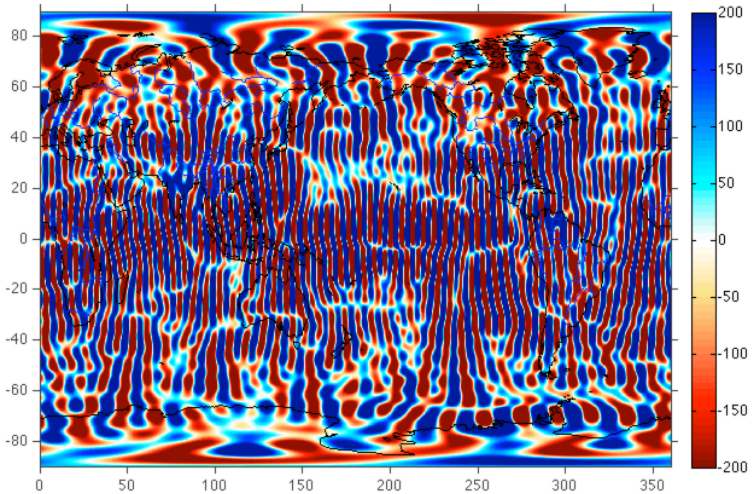
geoid at 500 km

GRACE (Gravity Recovery and Climate Experiment)

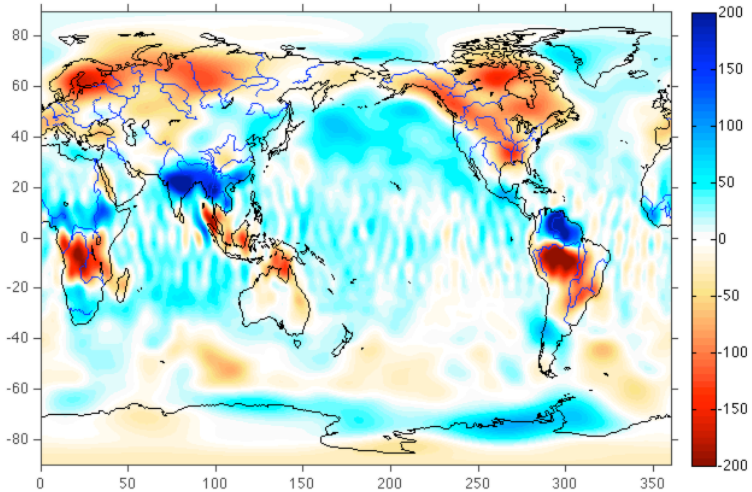


- Distance between satellites ~220 km
- Polar orbit, ~ 400 km altitude
- Monthly gravity field solutions

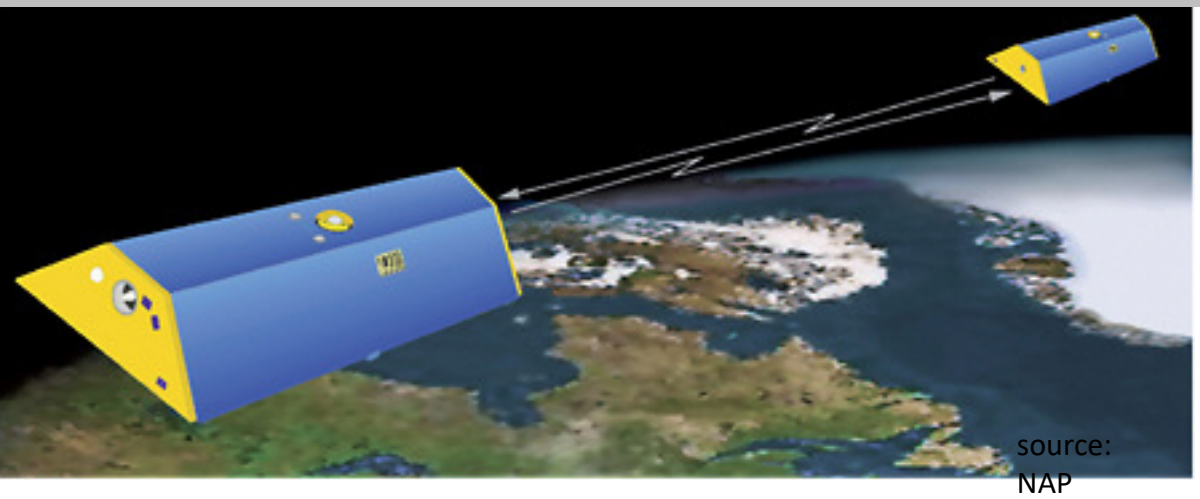
Unfiltered GRACE observations



Conventional filters



GRACE (Gravity Recovery and Climate Experiment)



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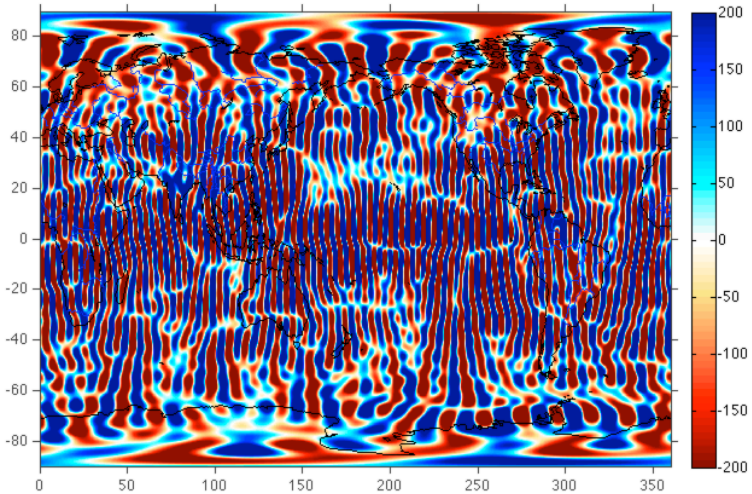
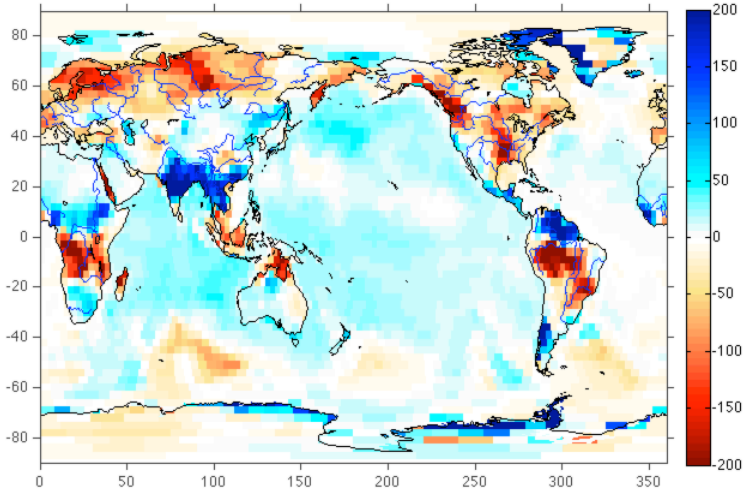
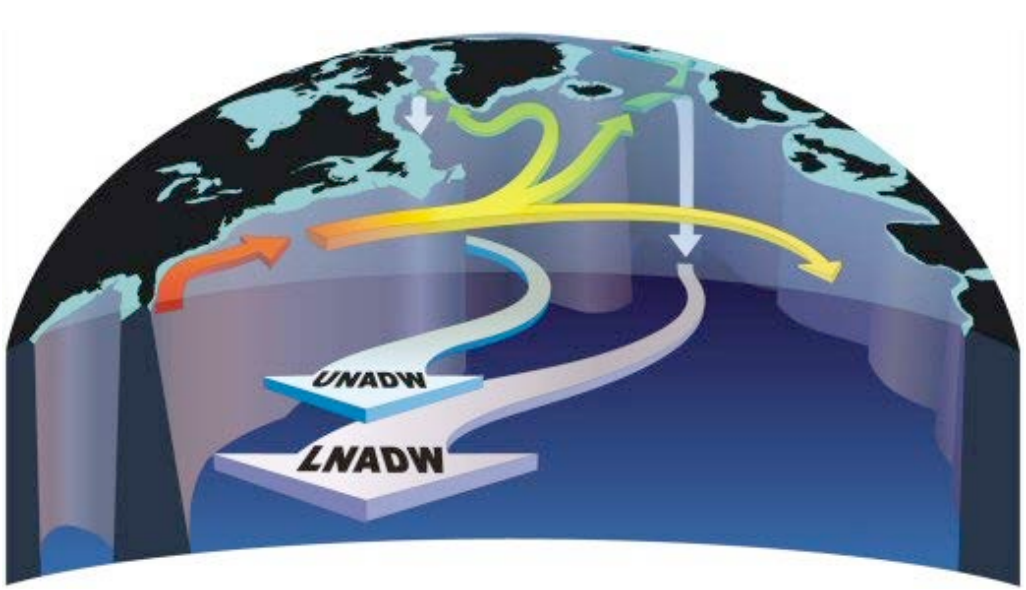


JPL mascon solution



GRACE (Gravity Recovery and Climate Experiment)

AMOC (Atlantic Meridional Overturning Circulation)

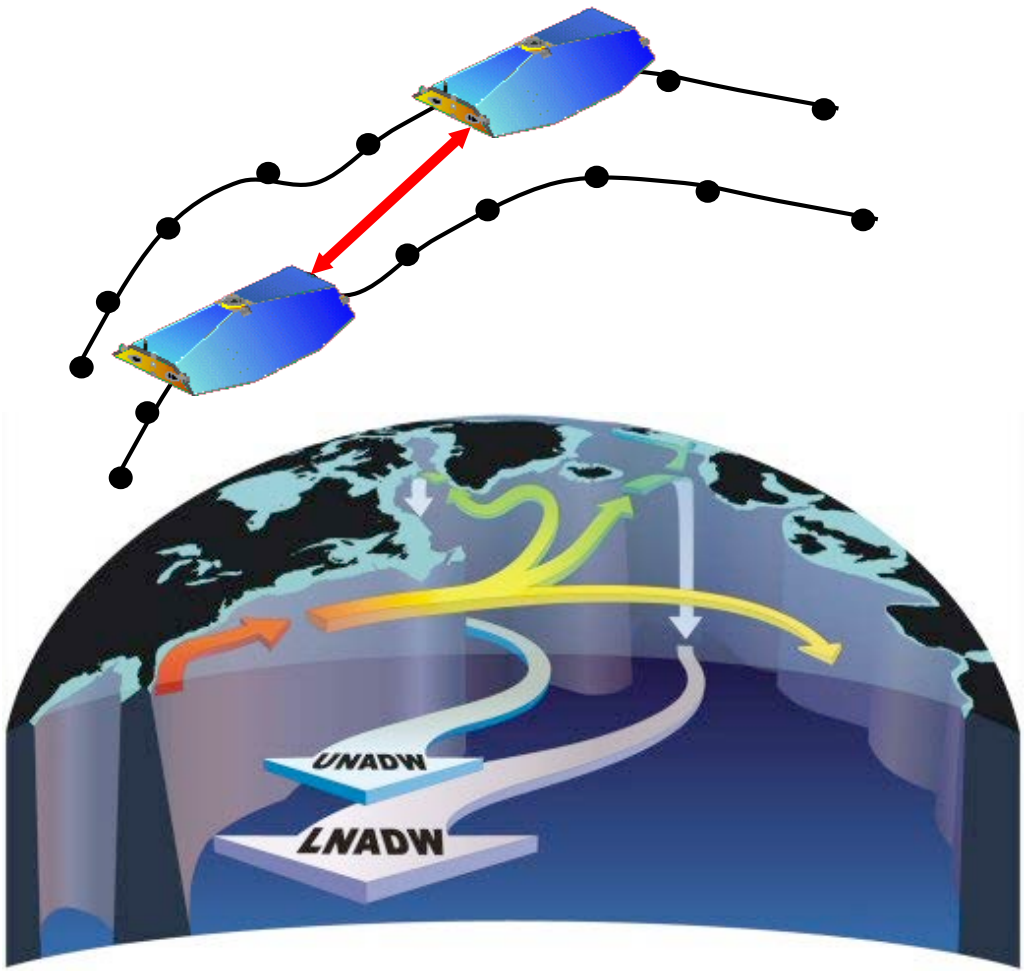


source: RAPID/NERC

- upper layers:
  - warm northward transport
- deeper layers:
  - cold southward transport

+/- AMOC anomaly: direct impact on surface temperatures in Europe / Northern Asia

Observing AMOC variability with GRACE



source: RAPID/NERC

- upper layers:
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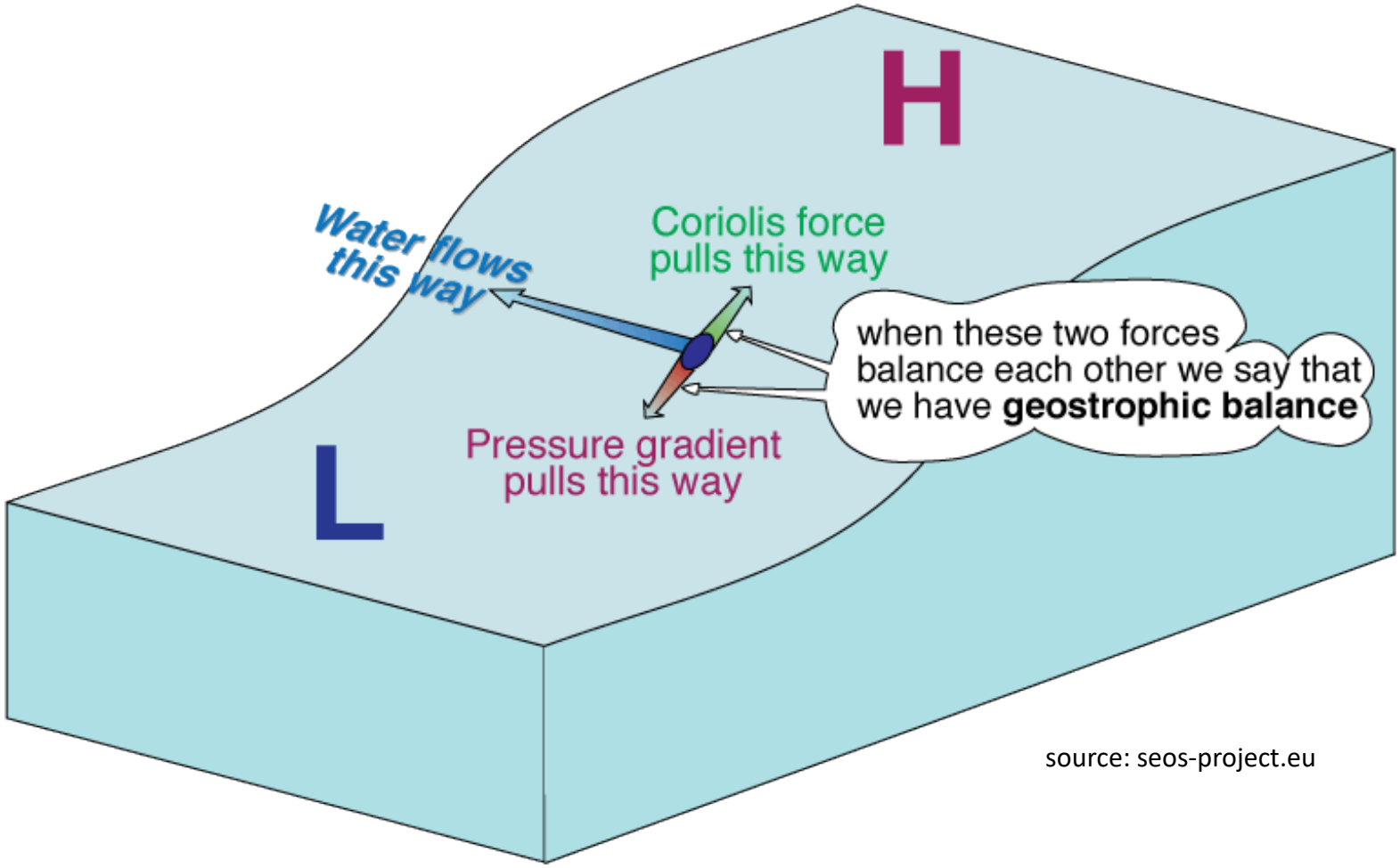
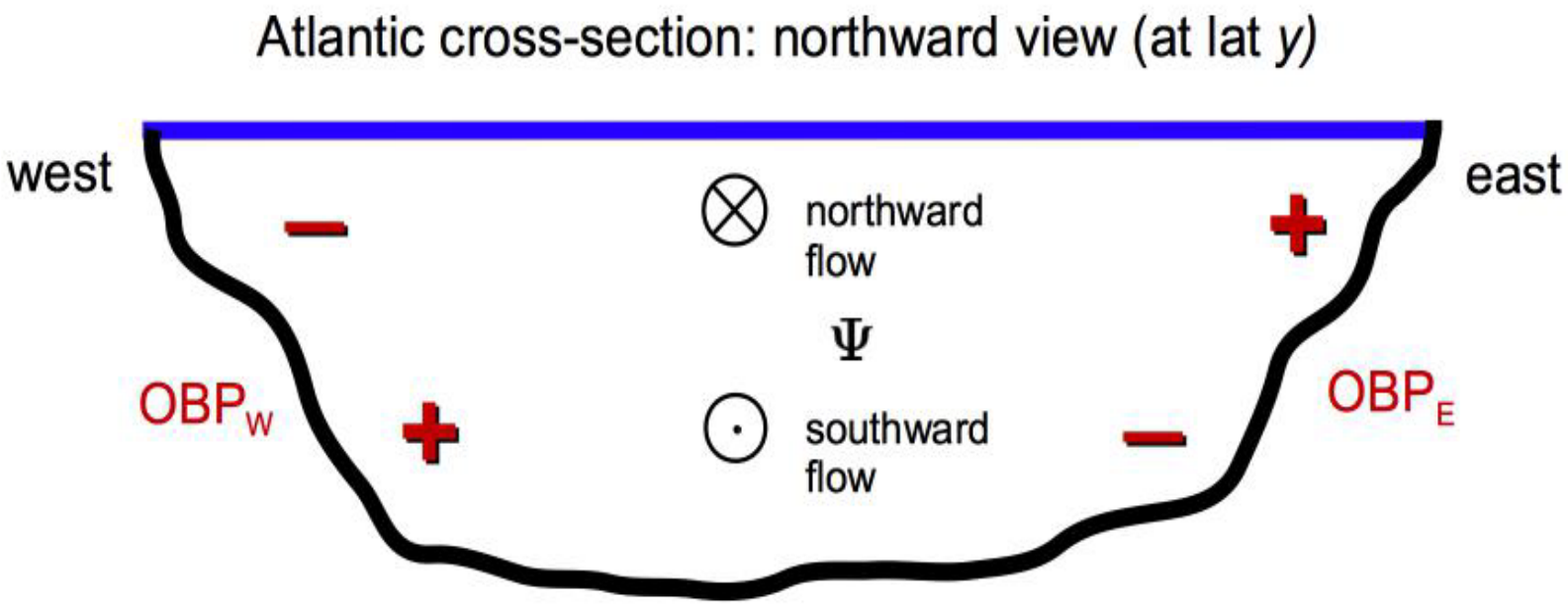
+/- AMOC anomaly: direct impact on surface temperatures in Europe / Northern Asia

Observing AMOC with GRACE: geostrophic balance



source: seos-project.eu

Geostrophic flow and OBP (ocean bottom pressure)



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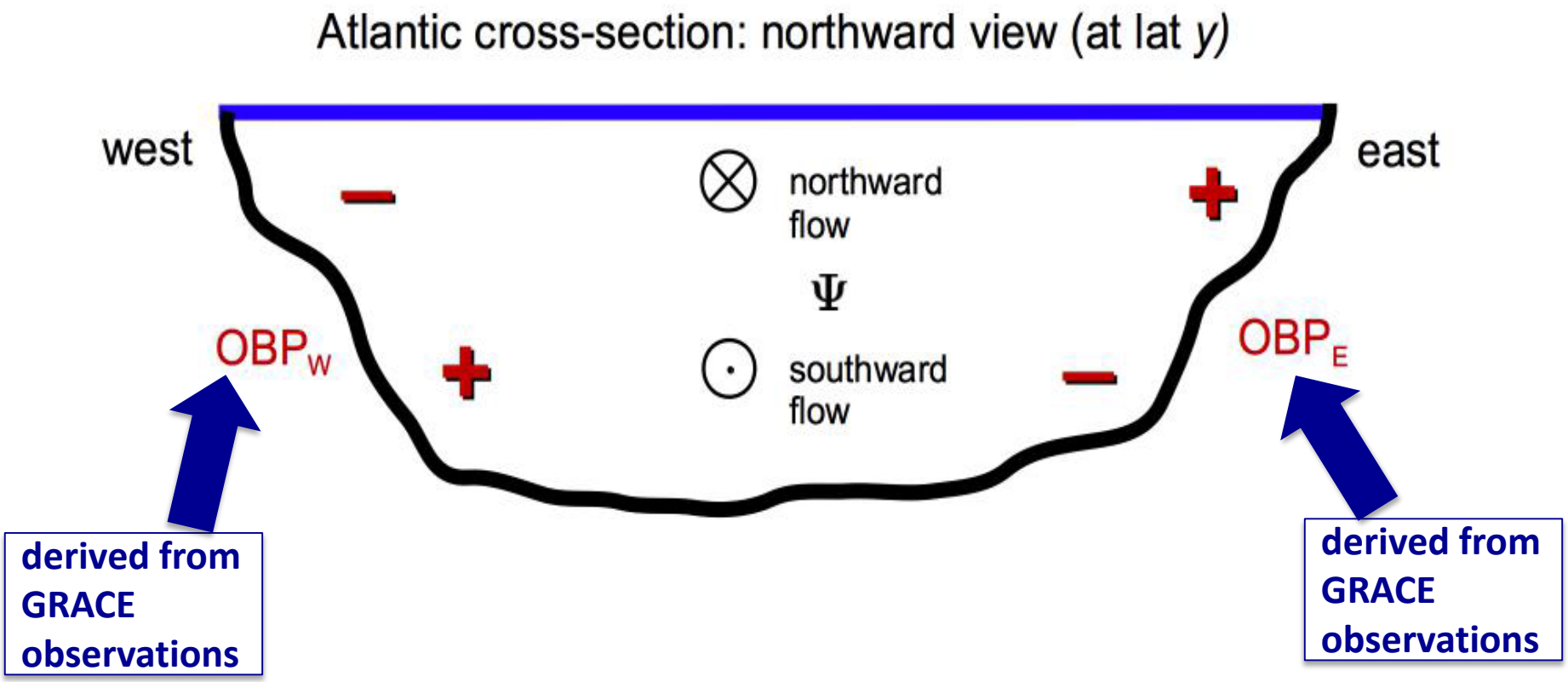
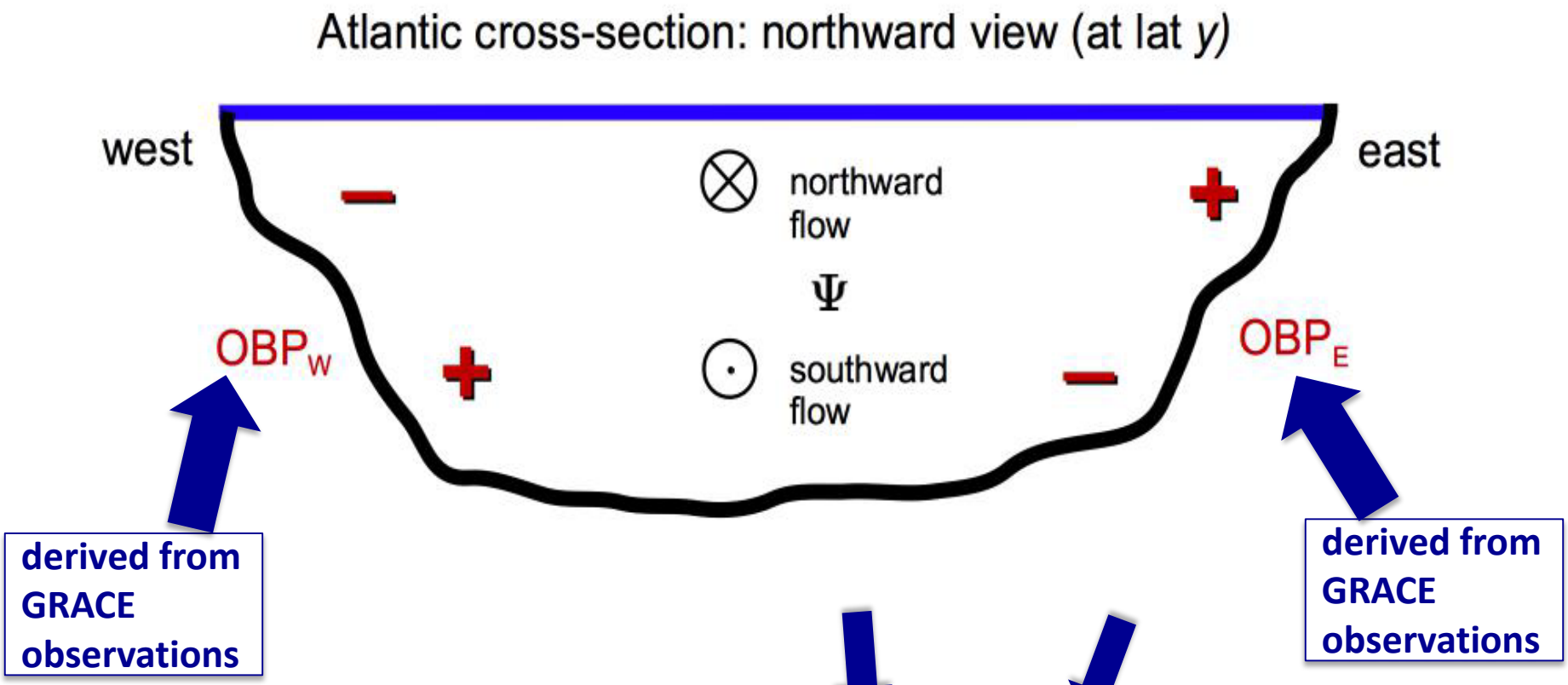
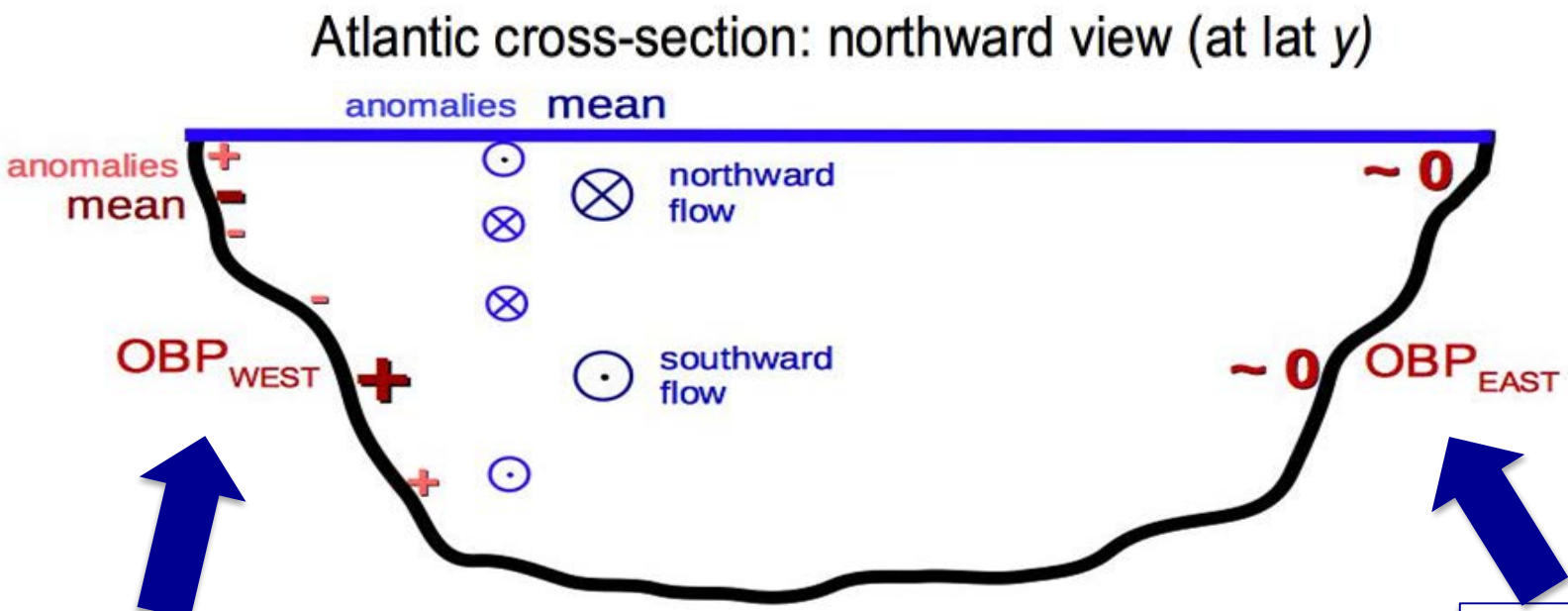


Geostrophic flow and OBP (ocean bottom pressure)



$$\Psi(y,z) = \frac{1}{\rho_0 f}\int_{z_1}^{z_2}(OBP_E - OBP_W)dz$$

Geostrophic flow and OBP (ocean bottom pressure)

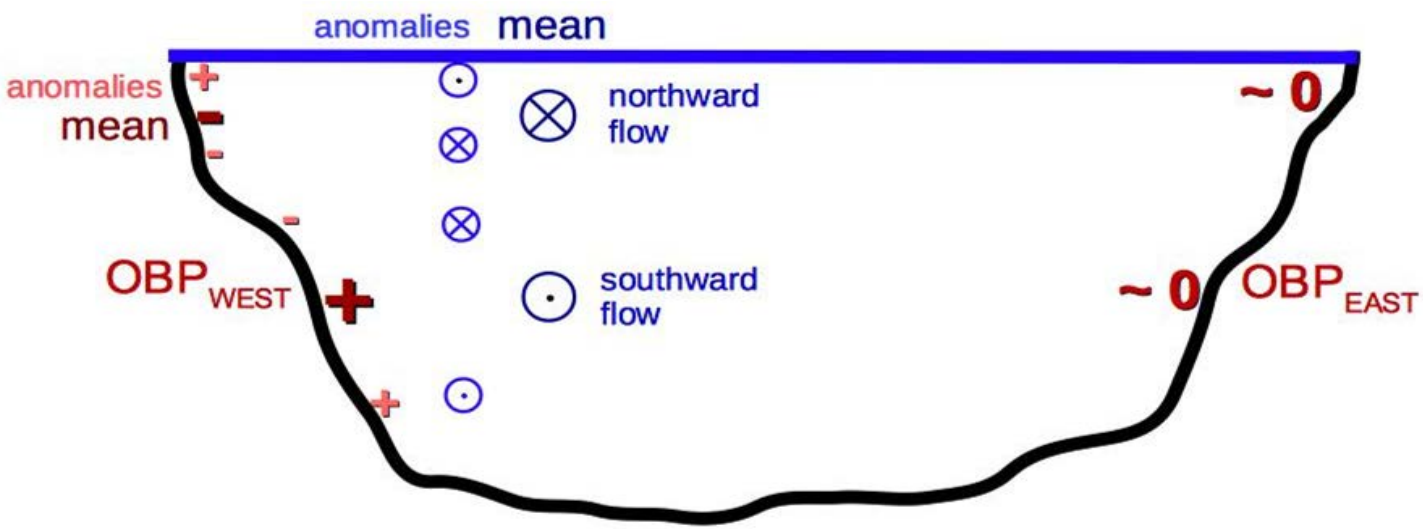


derived from GRACE observations

derived from GRACE observations

$$\Psi(y,z) = \frac{1}{\rho_0 f}\int_{z_1}^{z_2}(OBP_E - OBP_W)dz$$

A) Validate method with ECCO2 ocean state estimate



ECCO2 gives

- meridional velocities v_y
- OBP -> synthetic observations, smoothed to GRACE resolution

$$\Psi(y,z) = \int_E^W \int_{z_1}^{z_2} v_y \; dz \, dx$$

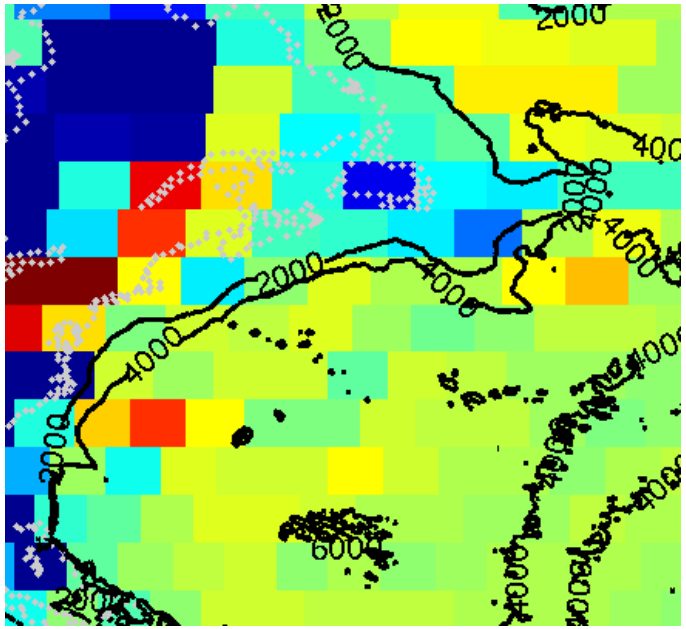
"model truth"

$$\Psi(y,z) = \frac{1}{\rho_0 f} \int_{z_1}^{z_2} (OBP_E - OBP_W) dz$$

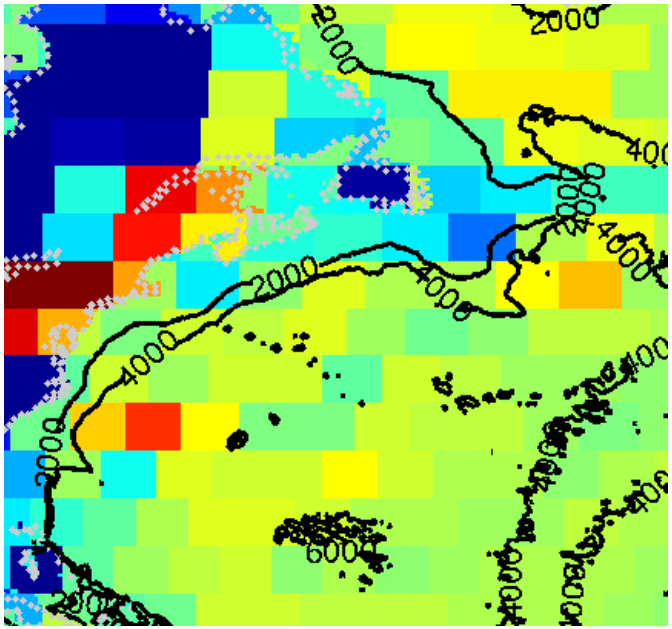
A) Validate method with ECCO2 ocean state estimate

- Need to correct for hydrology leakage:
  -> CRI (coastline resolution improvement) for JPL mascons:
- Quality of AMOC recovery is latitude (i.e.bathymetry) dependent
  -> avoid steep basin slopes
- Deep transport layer favorable for GRACE observations

mascons without CRI



mascons with CRI



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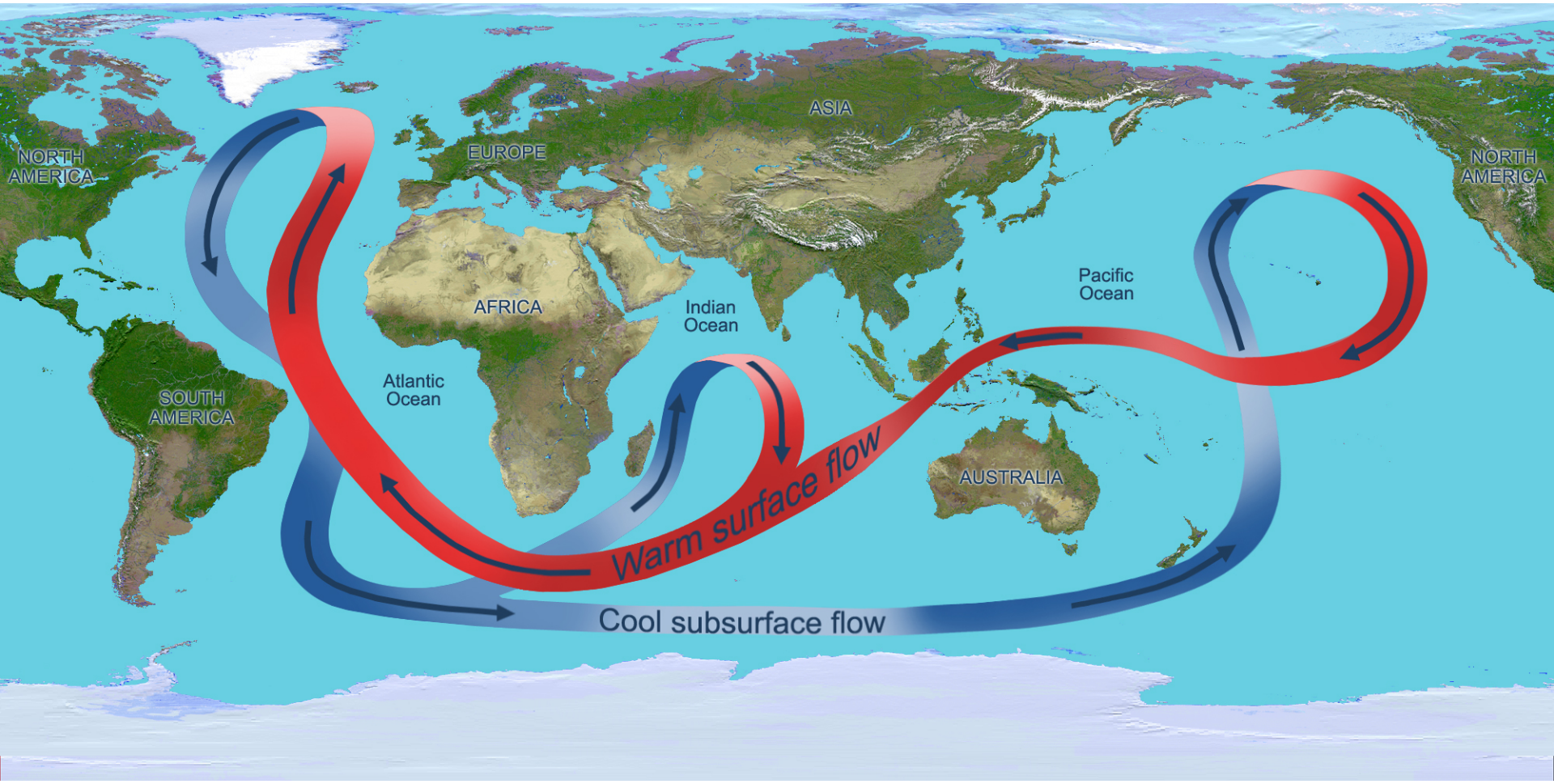
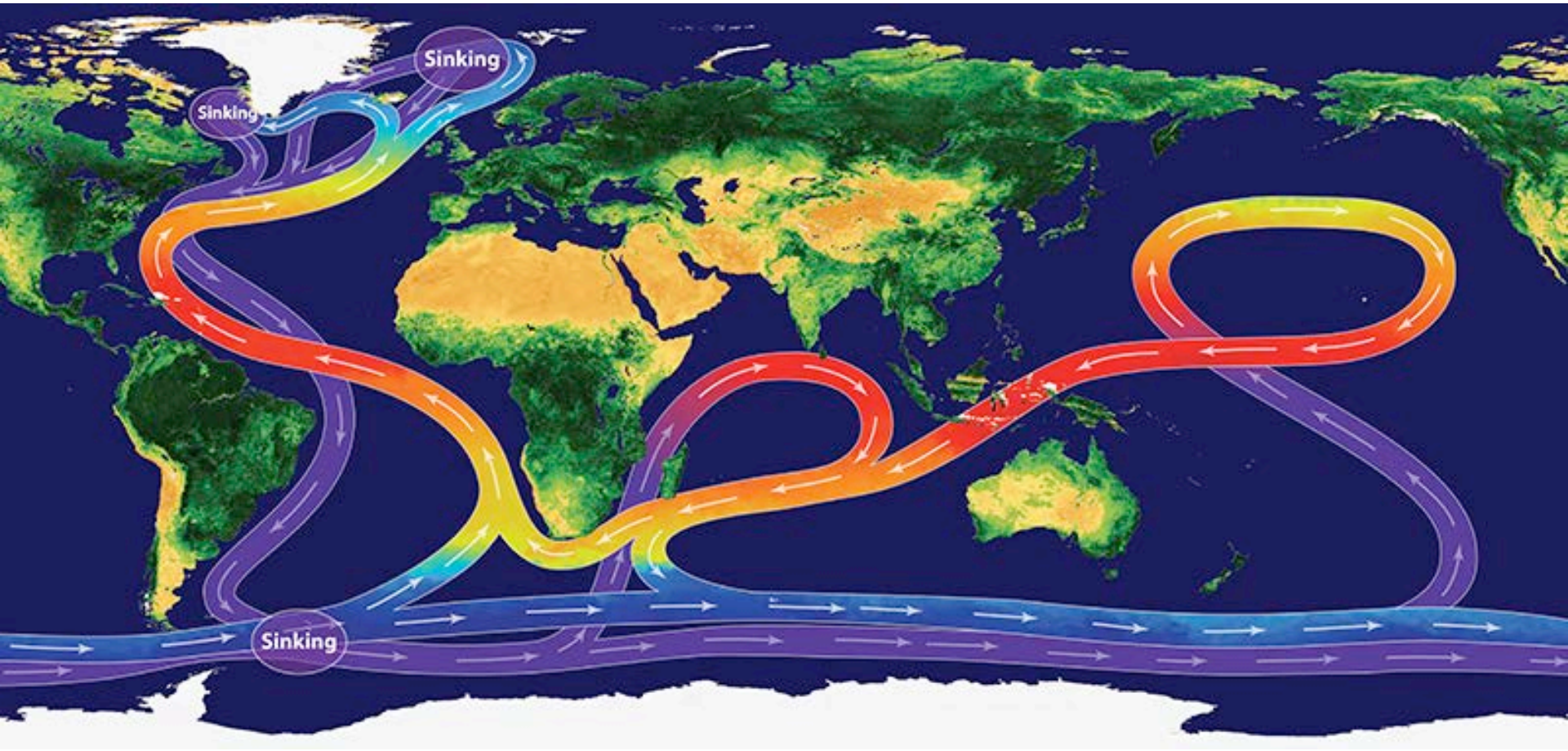
Bentel, Landerer, Boening (2015), Monitoring Atlantic overturning circulation and transport variability with GRACE-type ocean bottom pressure observations – a sensitivity study
Ocean Sci., 11, 953-963

Challenging the Conveyor Belt



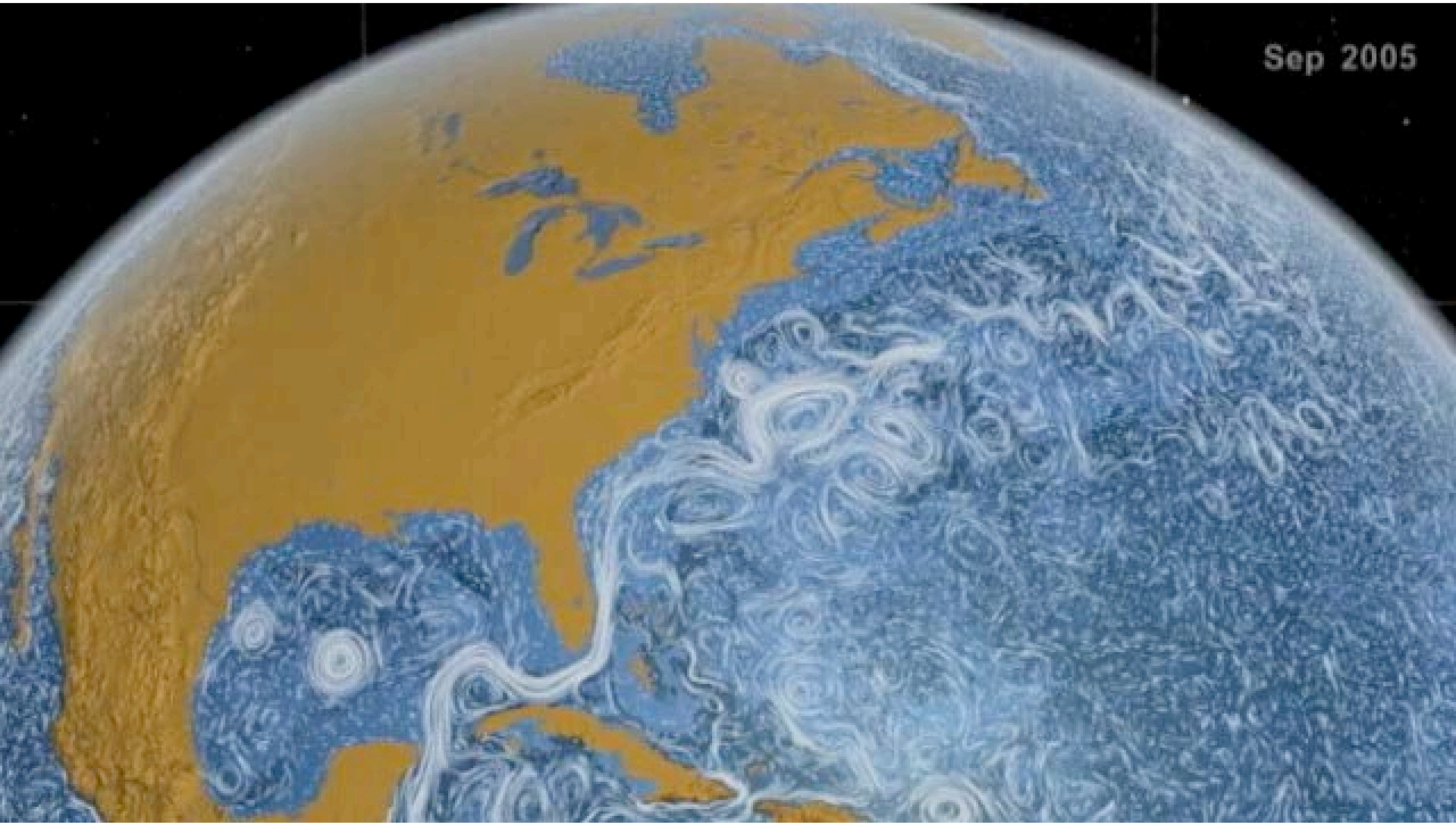
source: nasa.gov

Challenging the Conveyor Belt

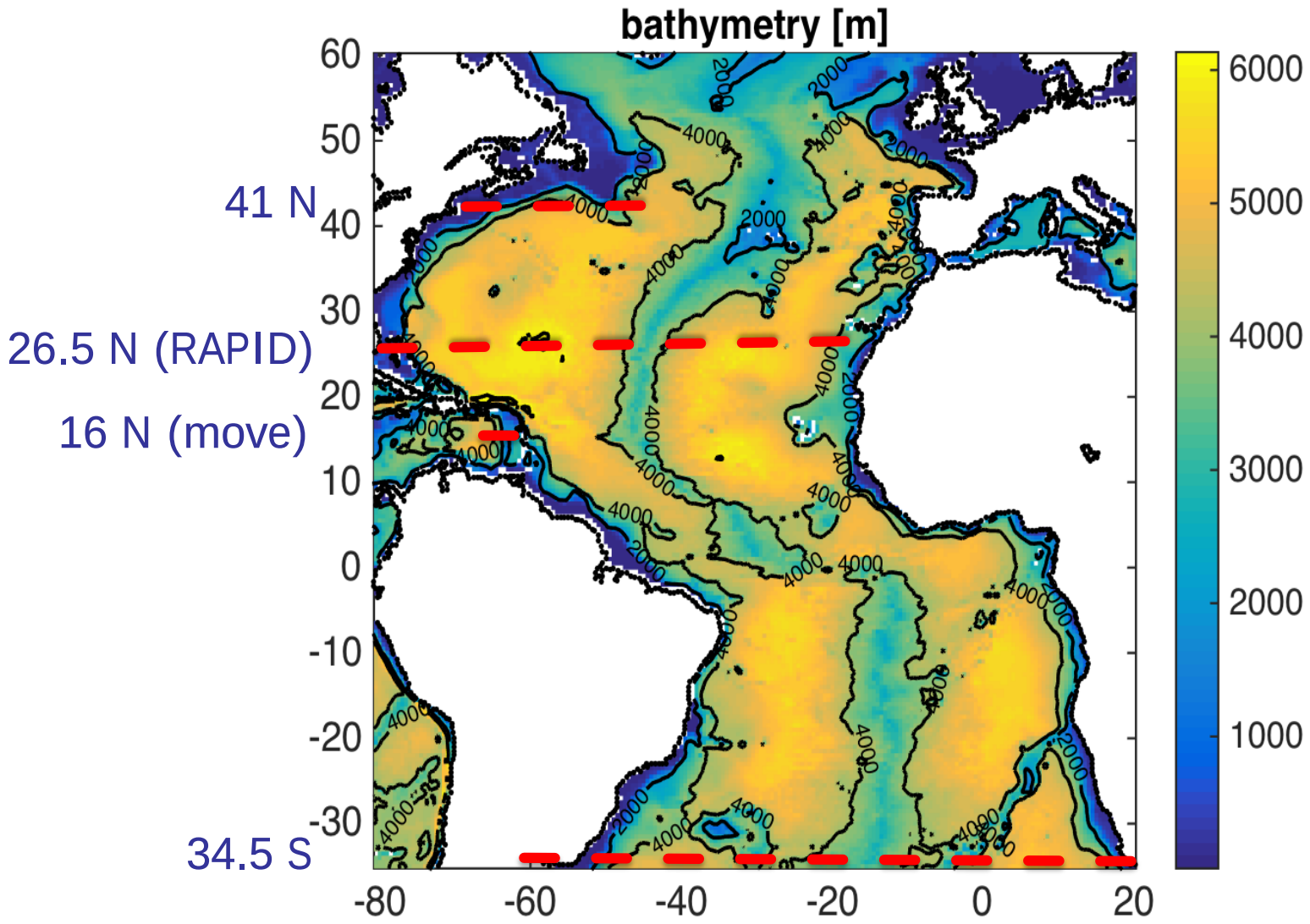


source: NOC

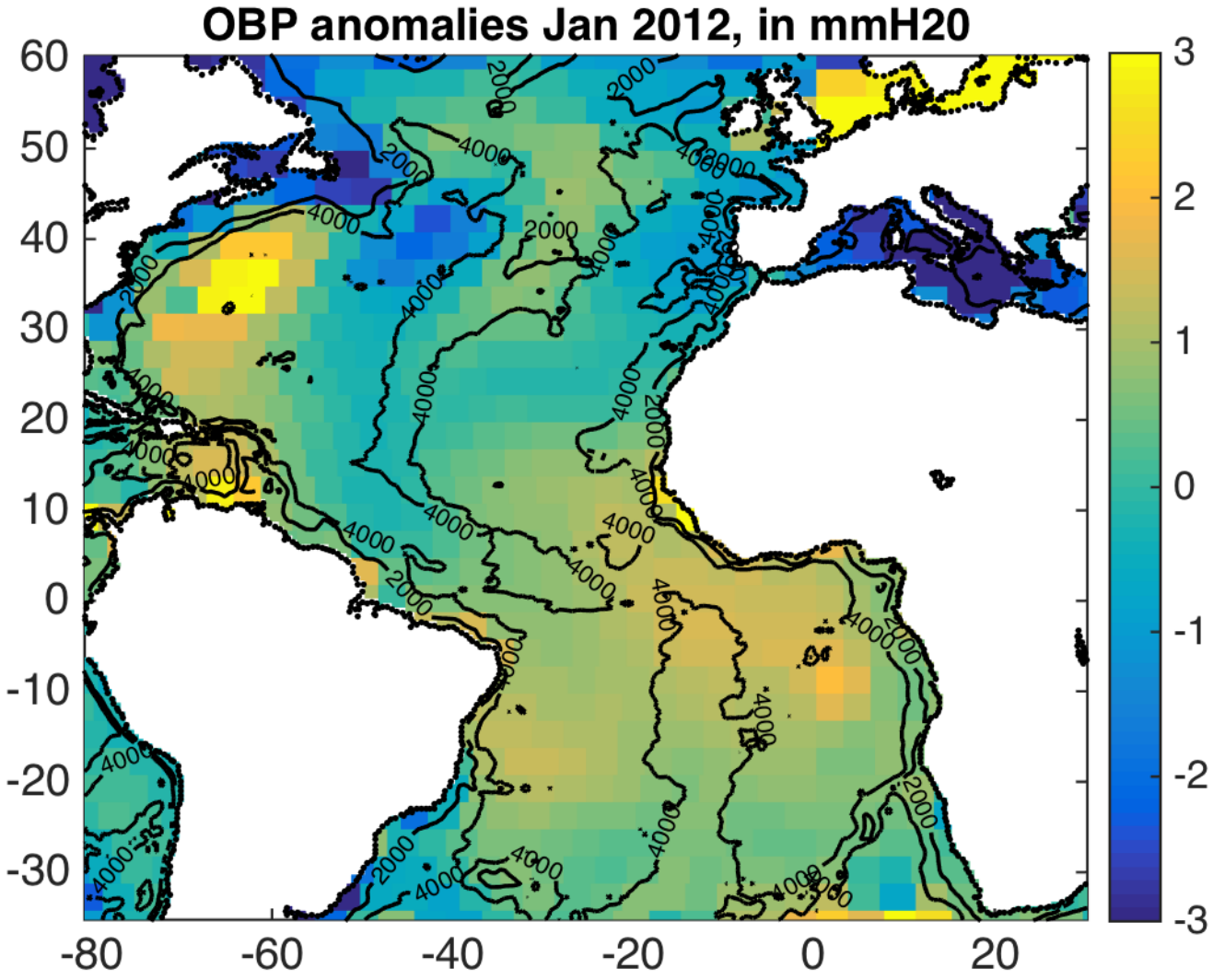
Challenging the Conveyor Belt



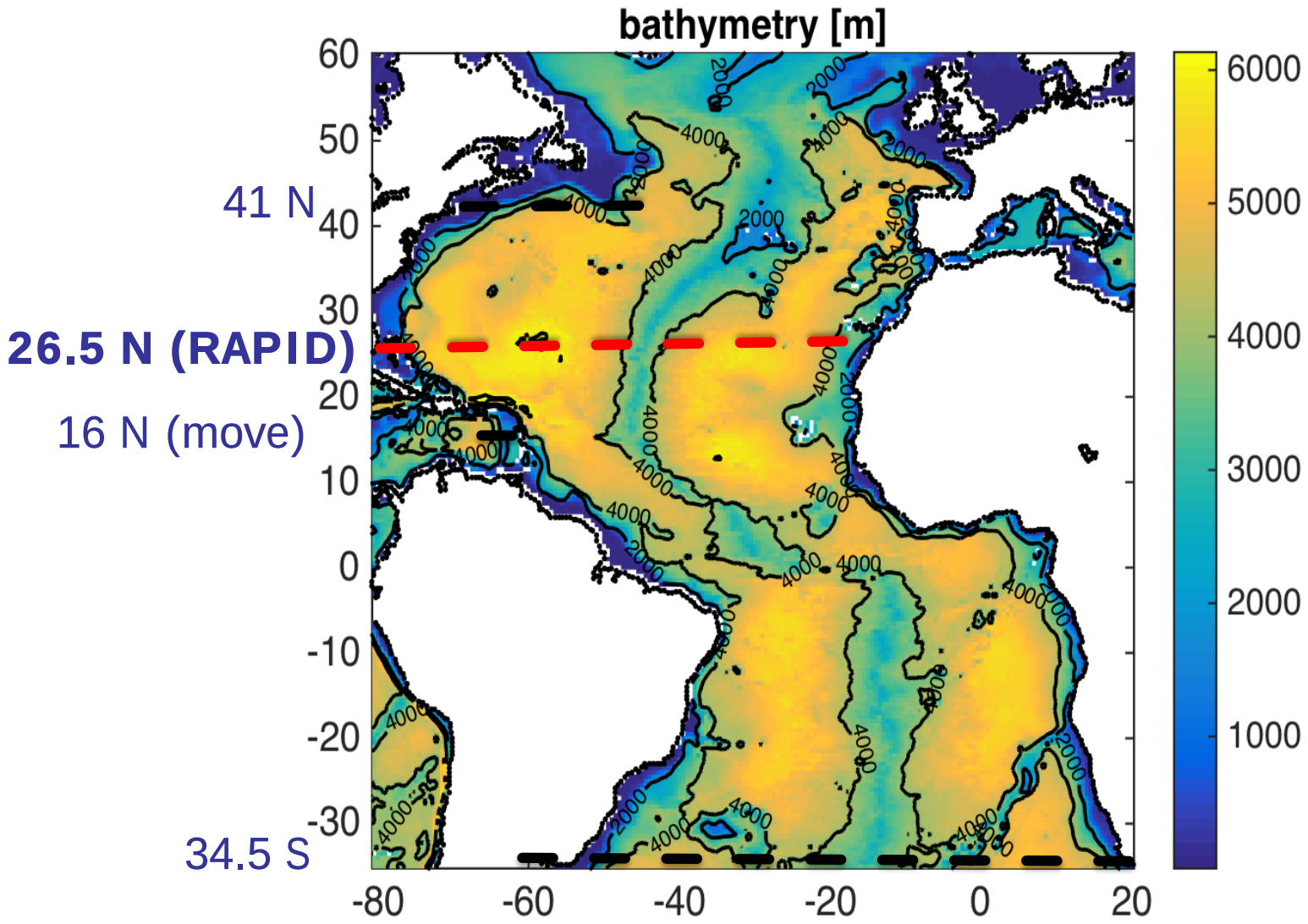
Available in-situ observations



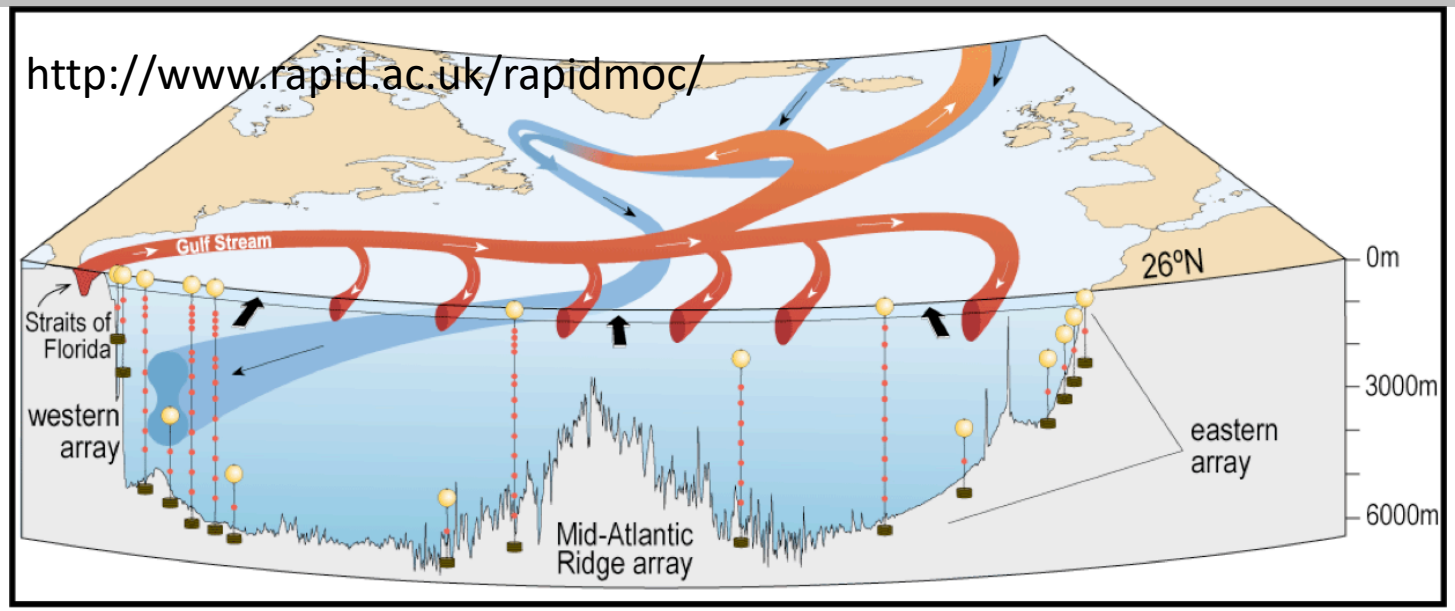
JPL-RL05 M mascon solution, inverted for OBP

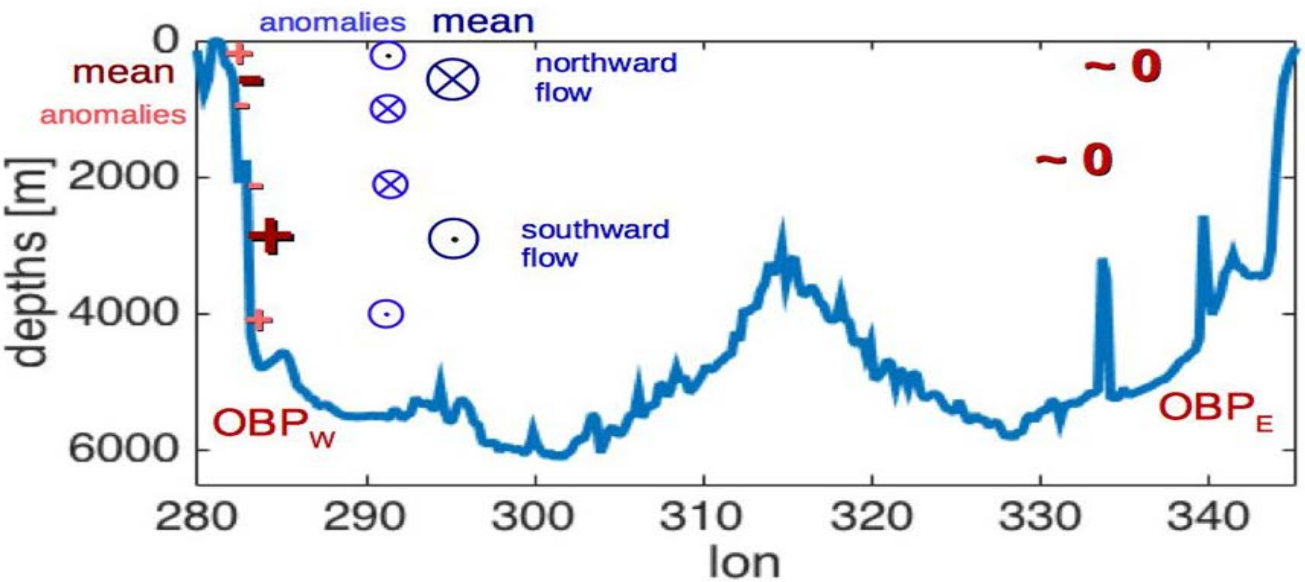


26.5 N, RAPID-MOCHA array (Kanzow et al 2007)



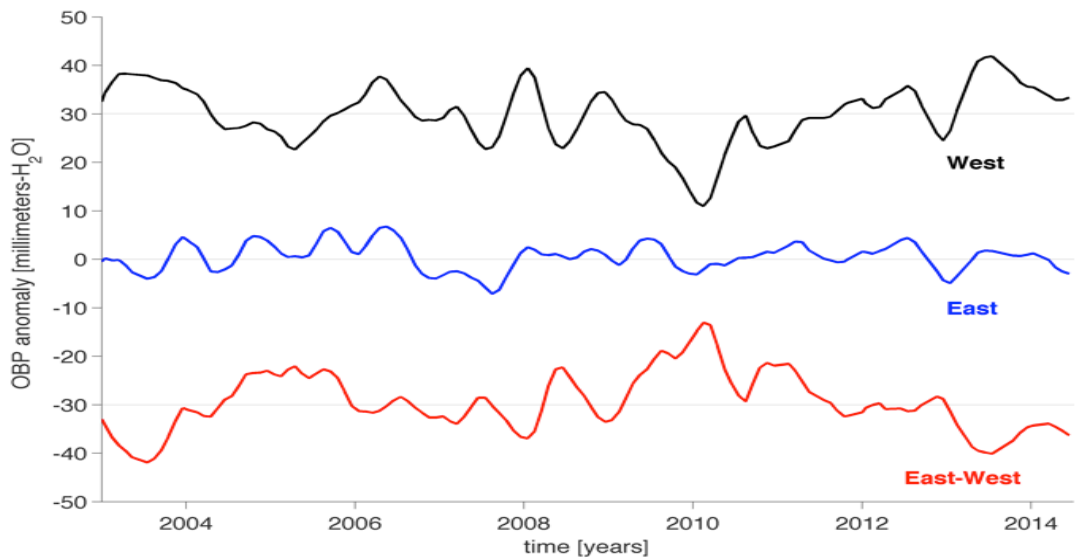
AMOC at 26.5N, RAPID-MOCHA array



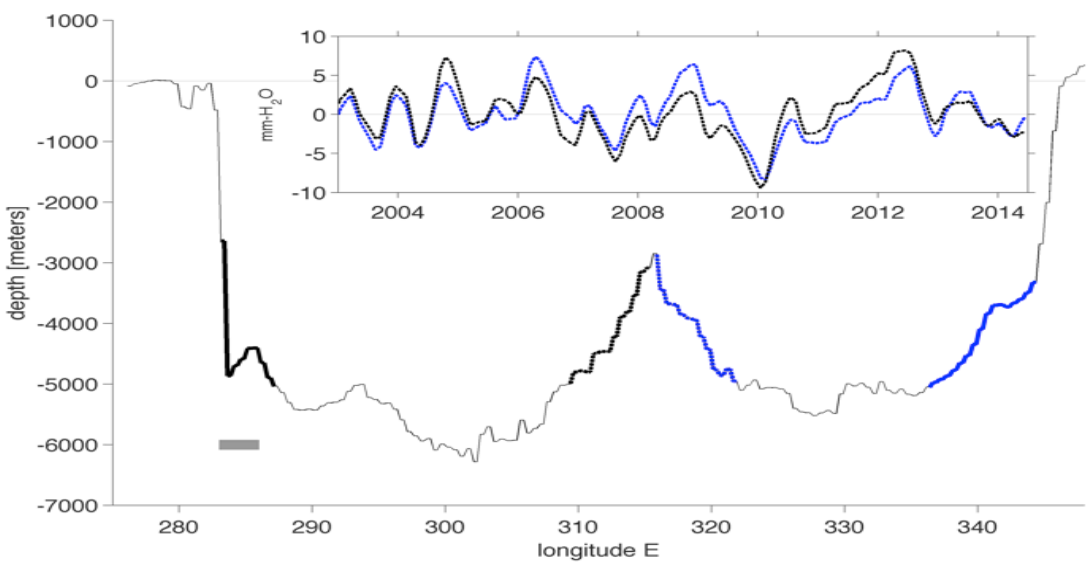


depth cross section at 26N, looking northward

AMOC at 26.5N, RAPID-MOCHA array



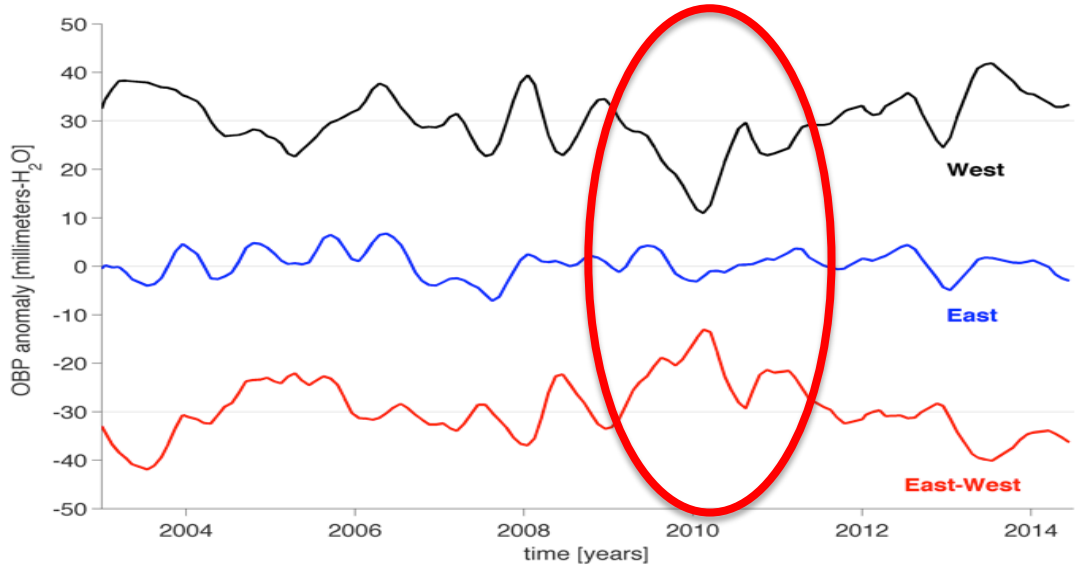
- 3000-5000m averaged pressures
- cross-basin pressure difference mostly driven by Western boundary (67%)



- fully intersecting mid-ocean ridge 'averages out'
- thus: it's sufficient to look at boundaries (but then there's land leakage …)

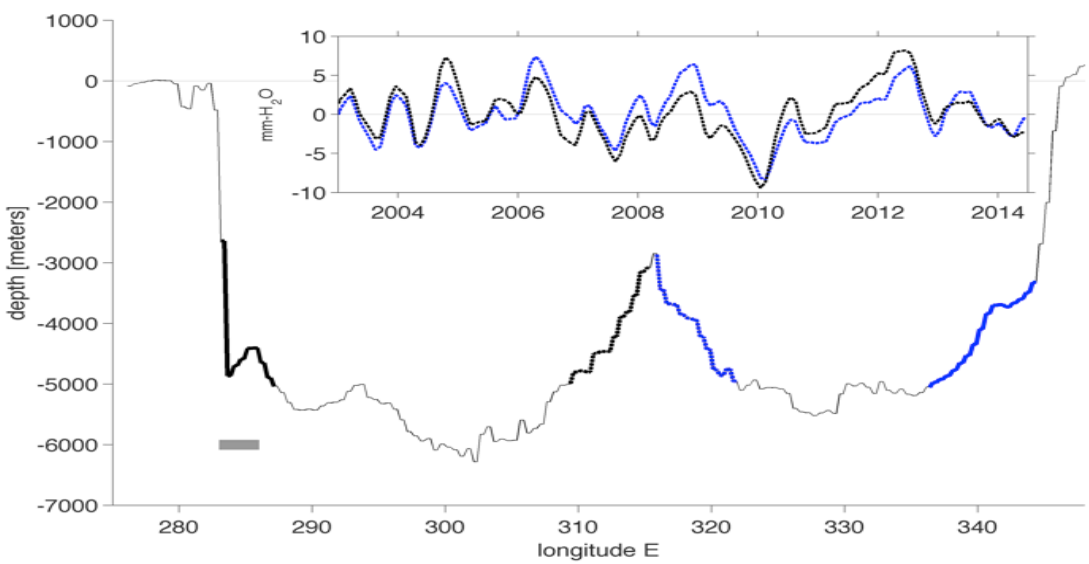
figures from Felix W. Landerer, JPL

AMOC at 26.5N, RAPID-MOCHA array



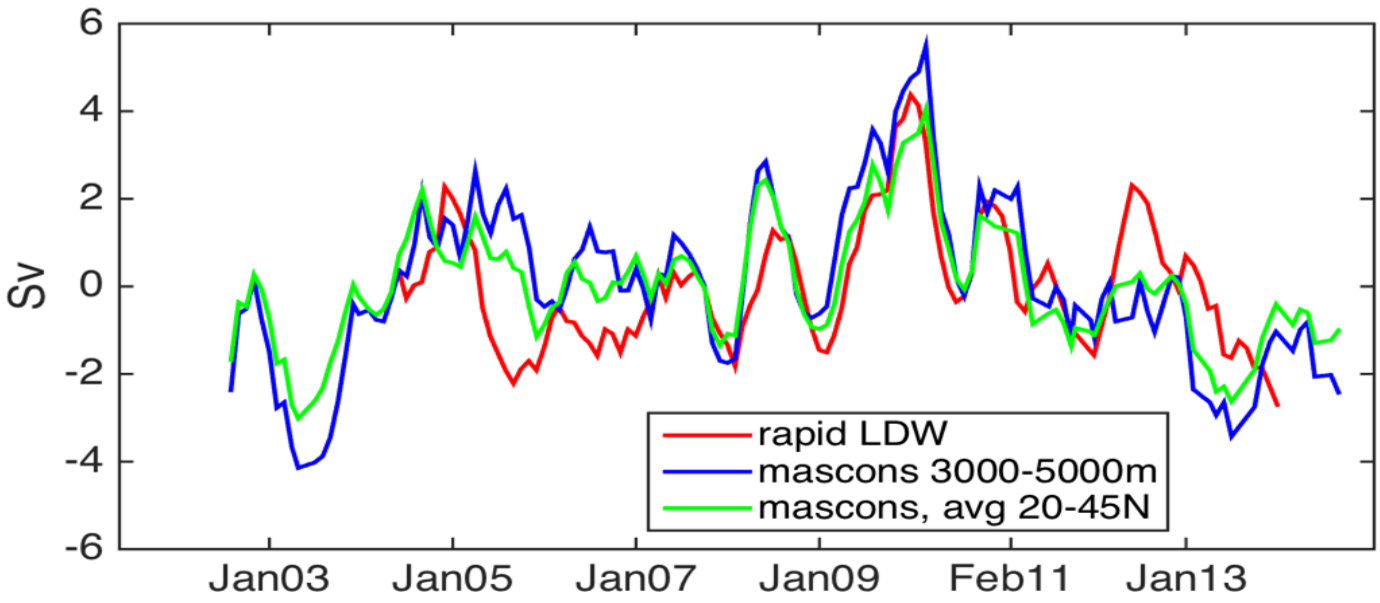
2009/2010 AMOC anomaly:

- ~5 Sv slowdown
- 20 mm OBP anomaly averaged over 3000-5000m

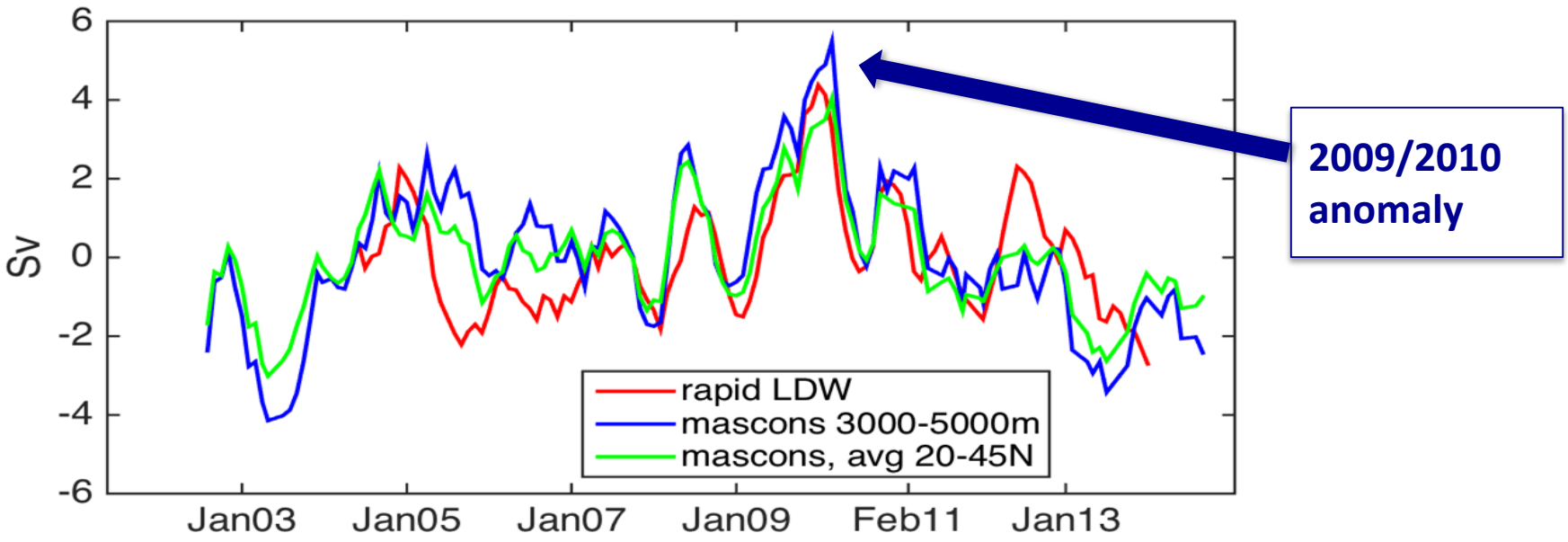


figures from Felix W. Landerer, JPL

AMOC at 26.5N, RAPID-MOCHA array



AMOC at 26.5N, RAPID-MOCHA array



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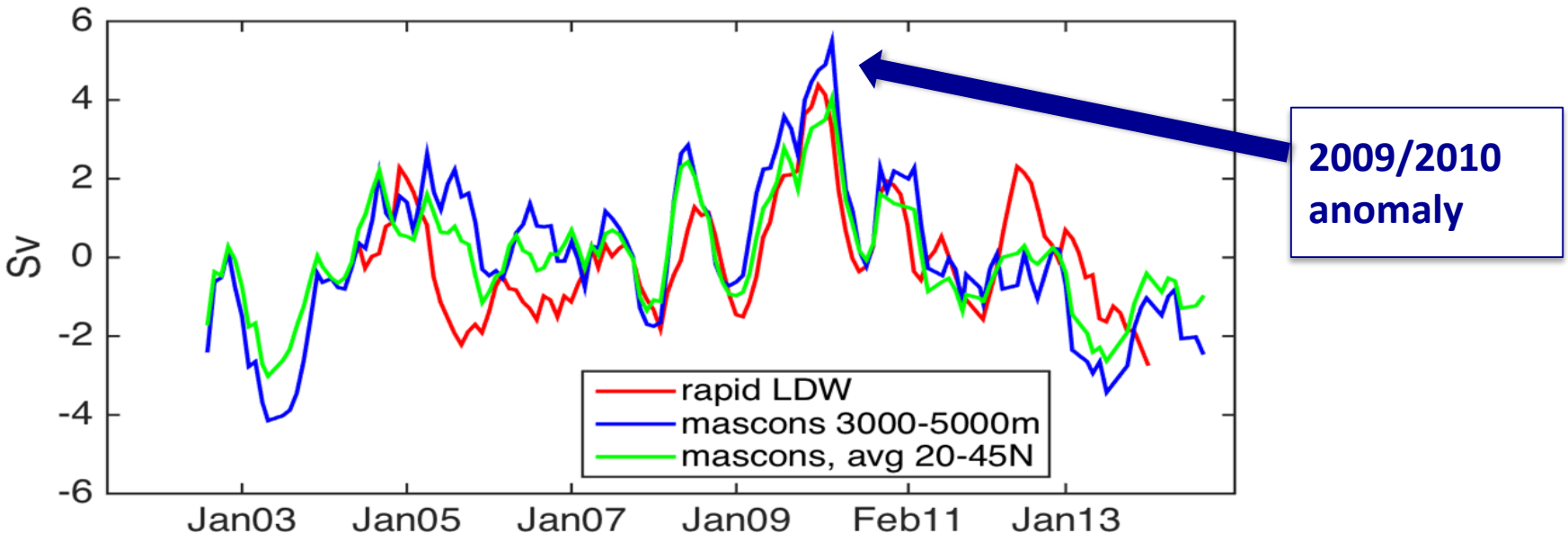
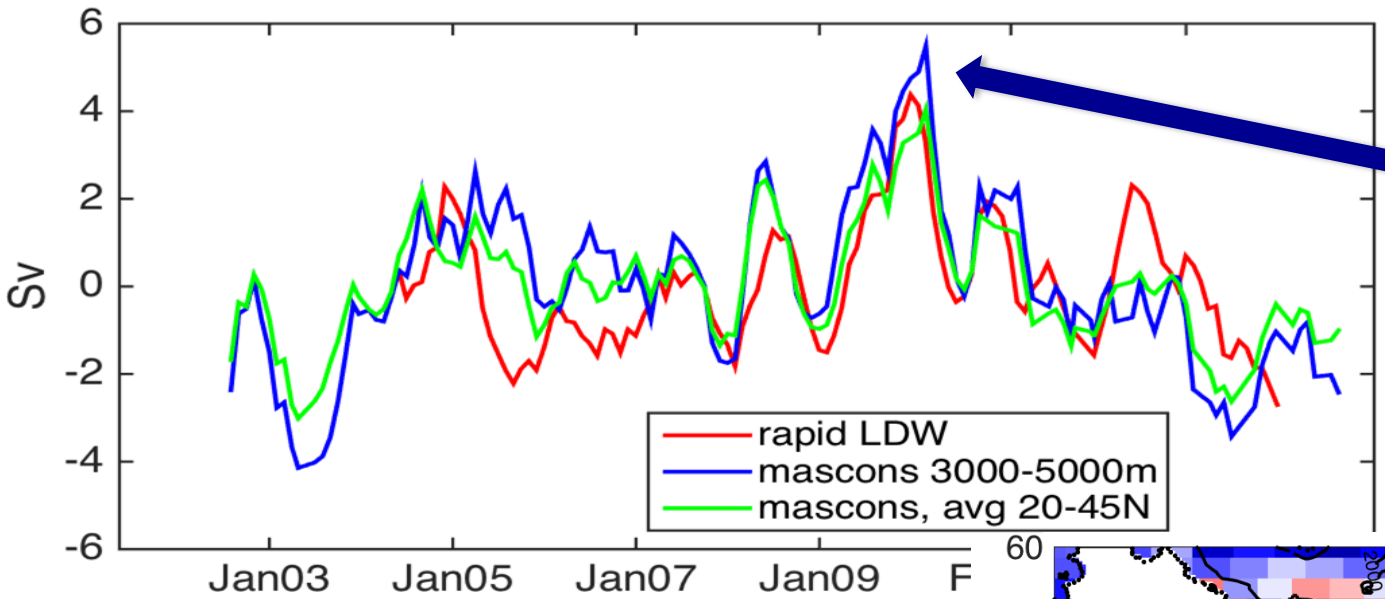


in-situ 26.5N &	corr coeff	error RMS
mascons	0.75	1.1 Sv
mascon avg	0.82	0.8 Sv

AMOC at 26.5N, RAPID-MOCHA array



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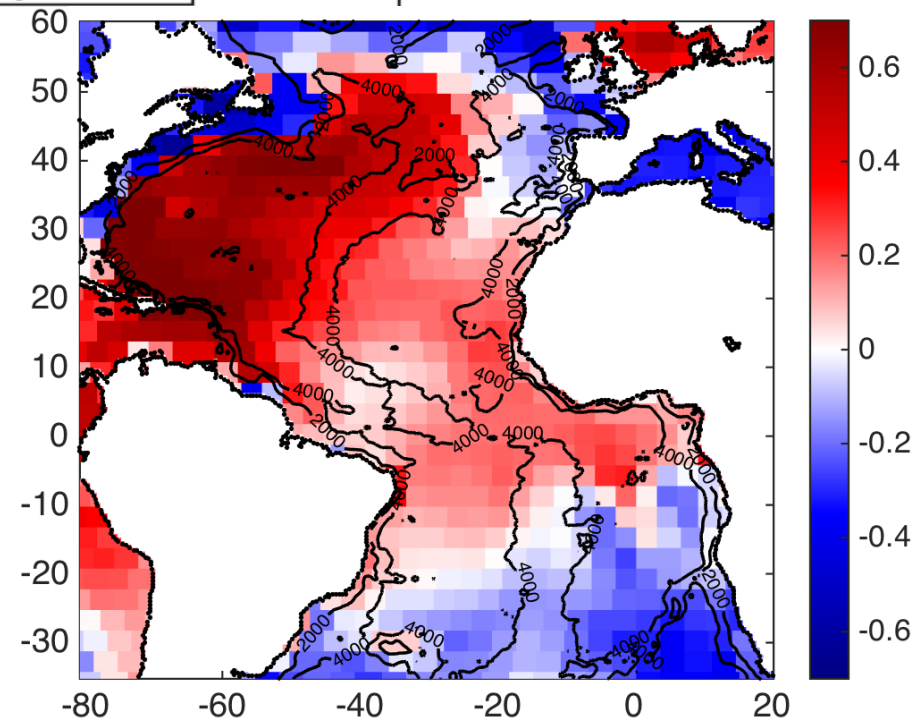


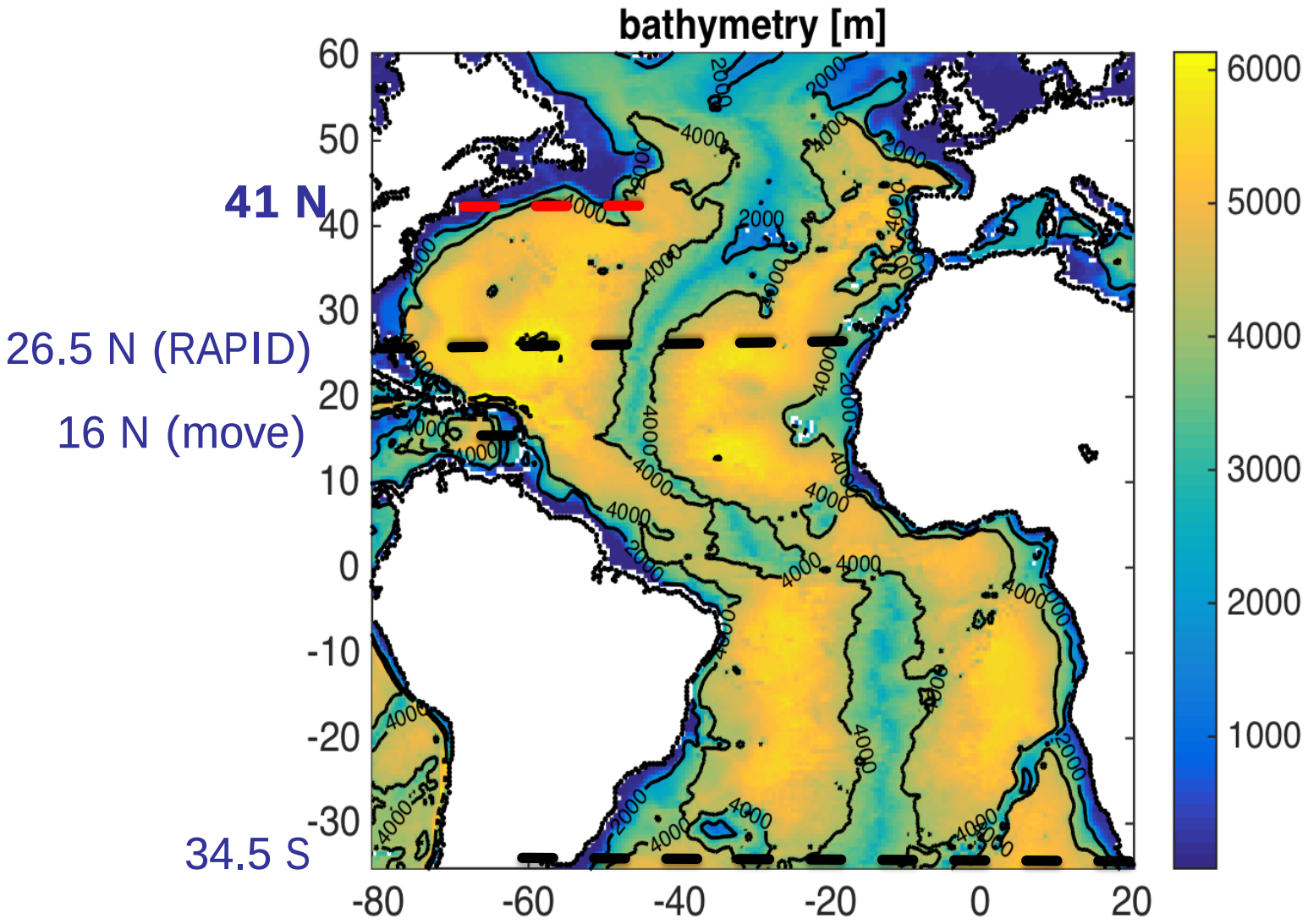
AMOC at 26.5N, RAPID-MOCHA array

Lower North Atlantic Deep Water time series:

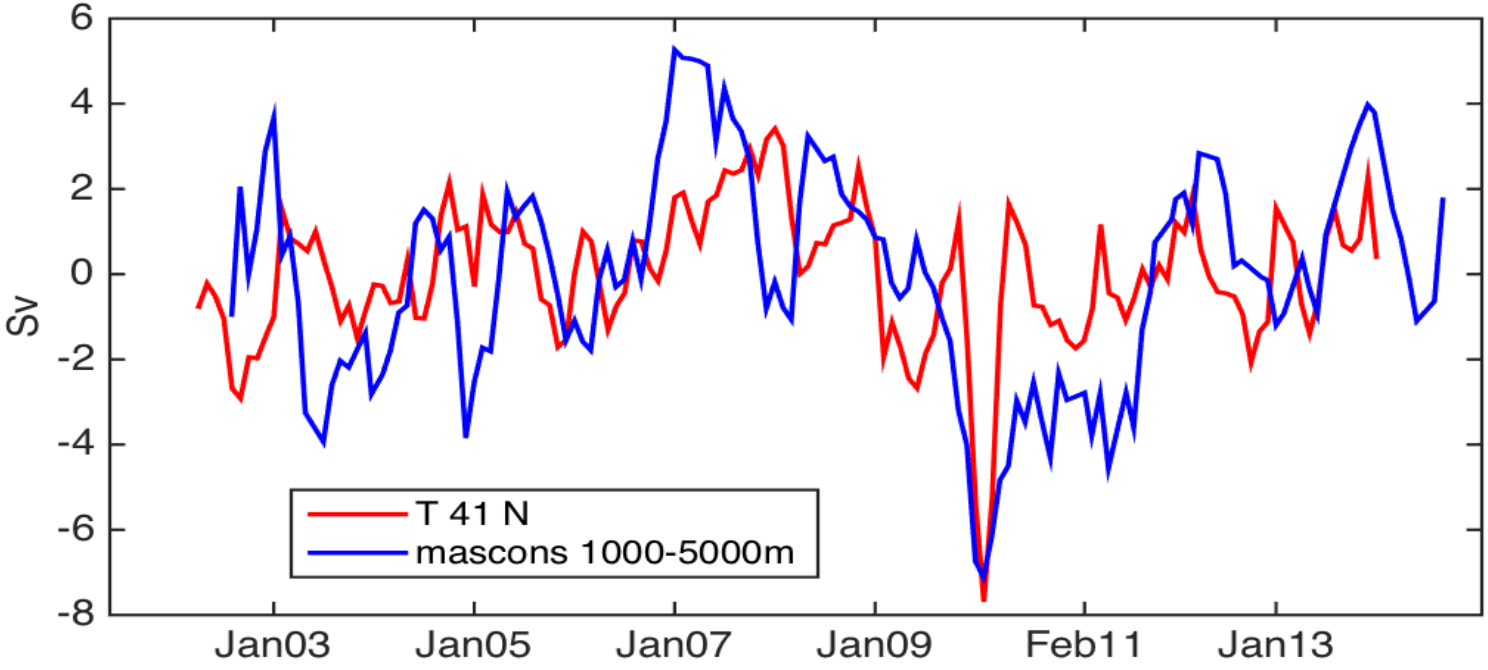
- 1st estimate from GRACE
- correlation with RAPID: R=0.75
- RMSD: 1.1 Sv

Landerer, Wiese, Bentel, Boening, Watkins (2015), North Atlantic meridional overturning circulation variations from GRACE ocean bottom pressure anomalies, *Geophys. Res. Lett*

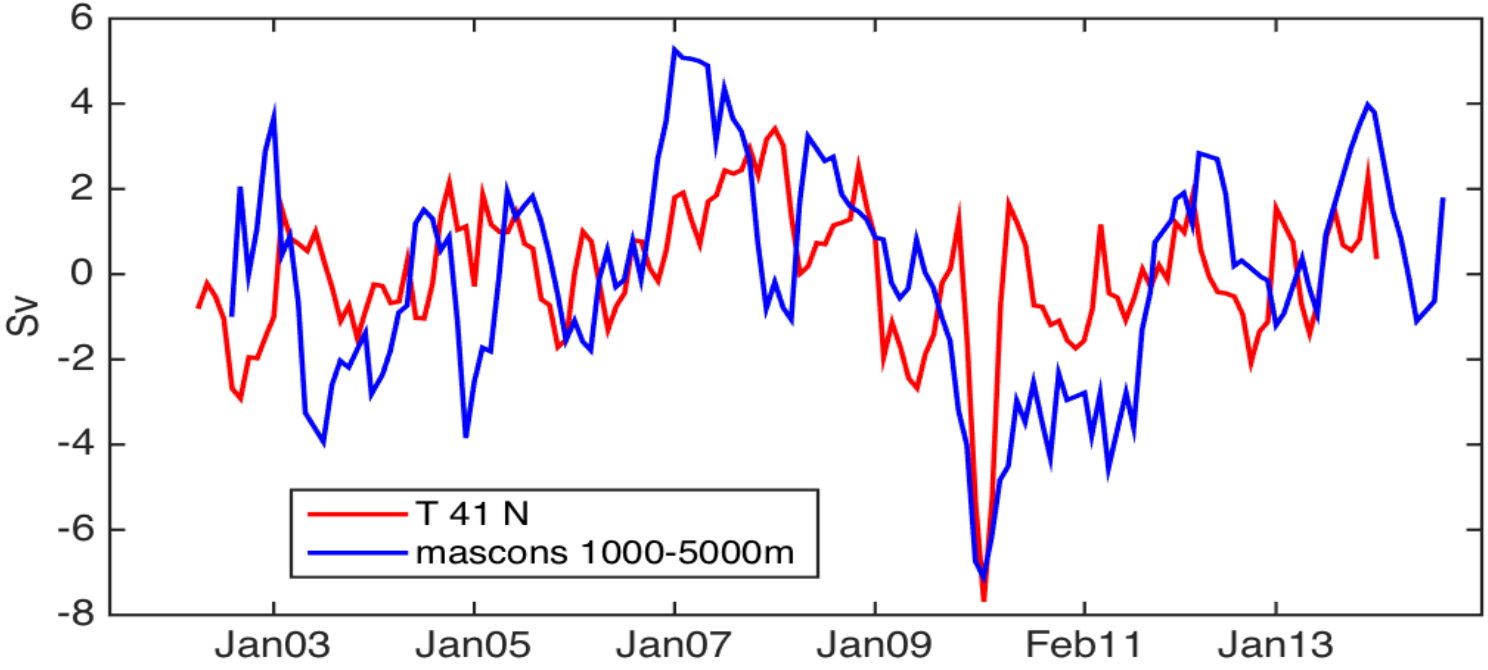
41 N (Willis 2010)



AMOC at 41N

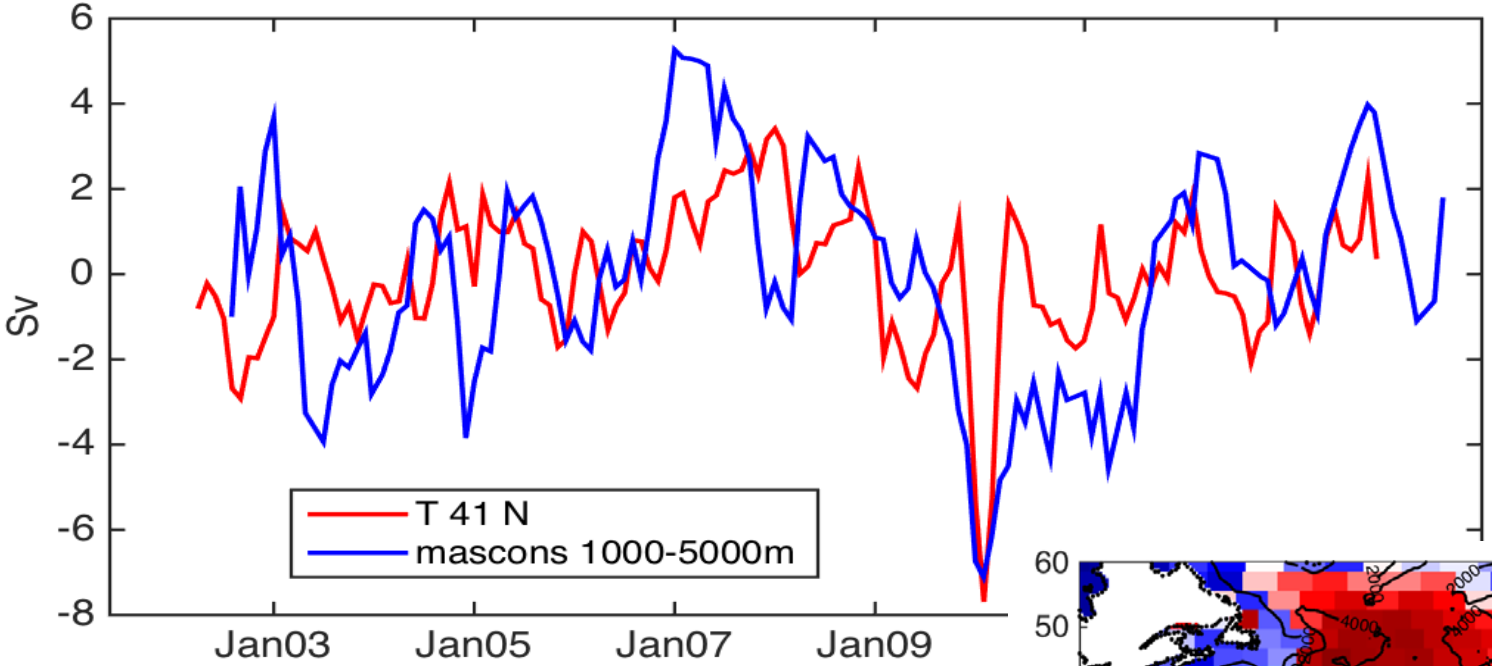

6
4
2
0
-2
-4
-6
-8
Sv
Jan03
Jan05
Jan07
Jan09
Feb11
Jan13
T 41 N
mascons 1000-5000m

AMOC at 41N



in-situ 41N &	corr coeff	error RMS
mascons	0.61	2.0 Sv

AMOC at 41N



in-situ 41N &	corr coeff	error RMS
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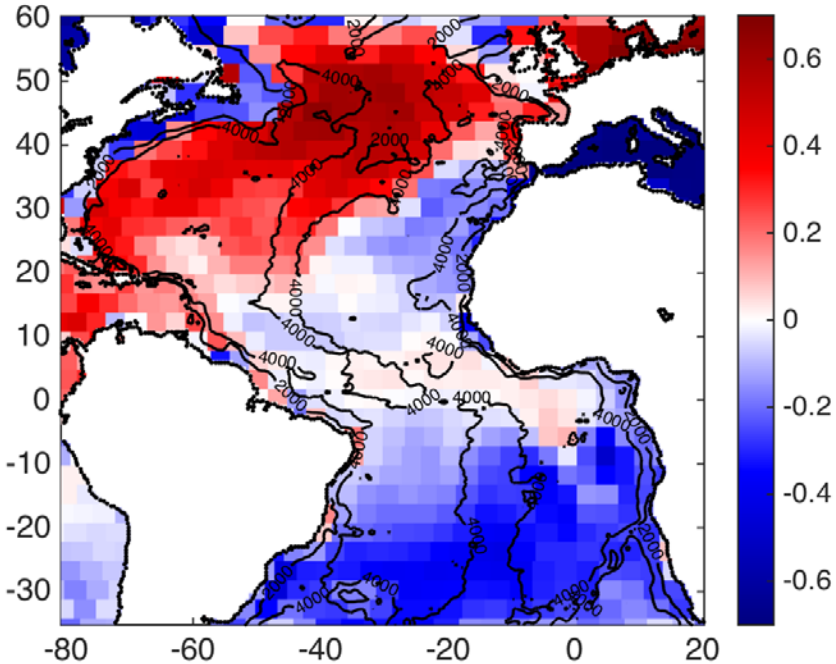
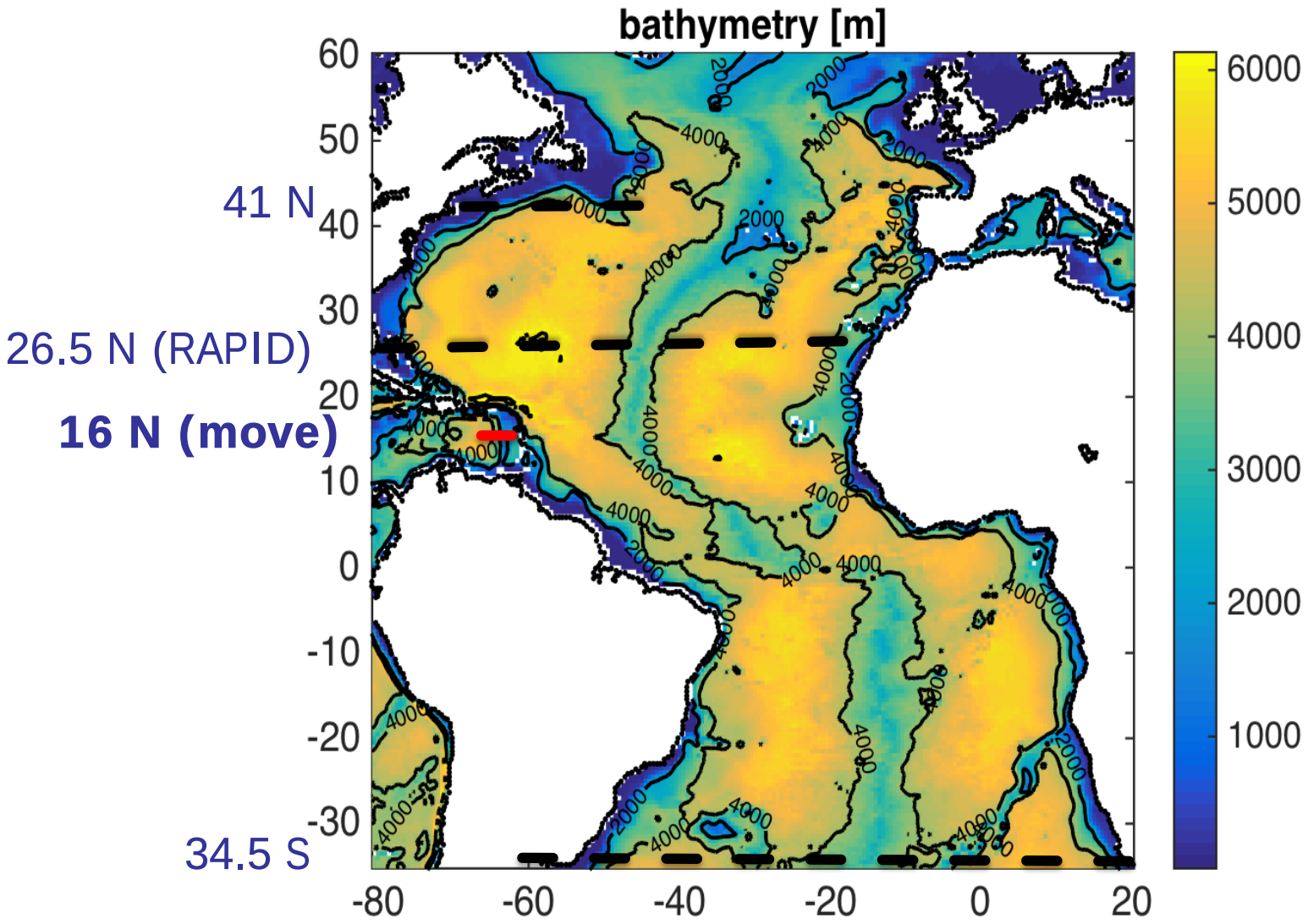
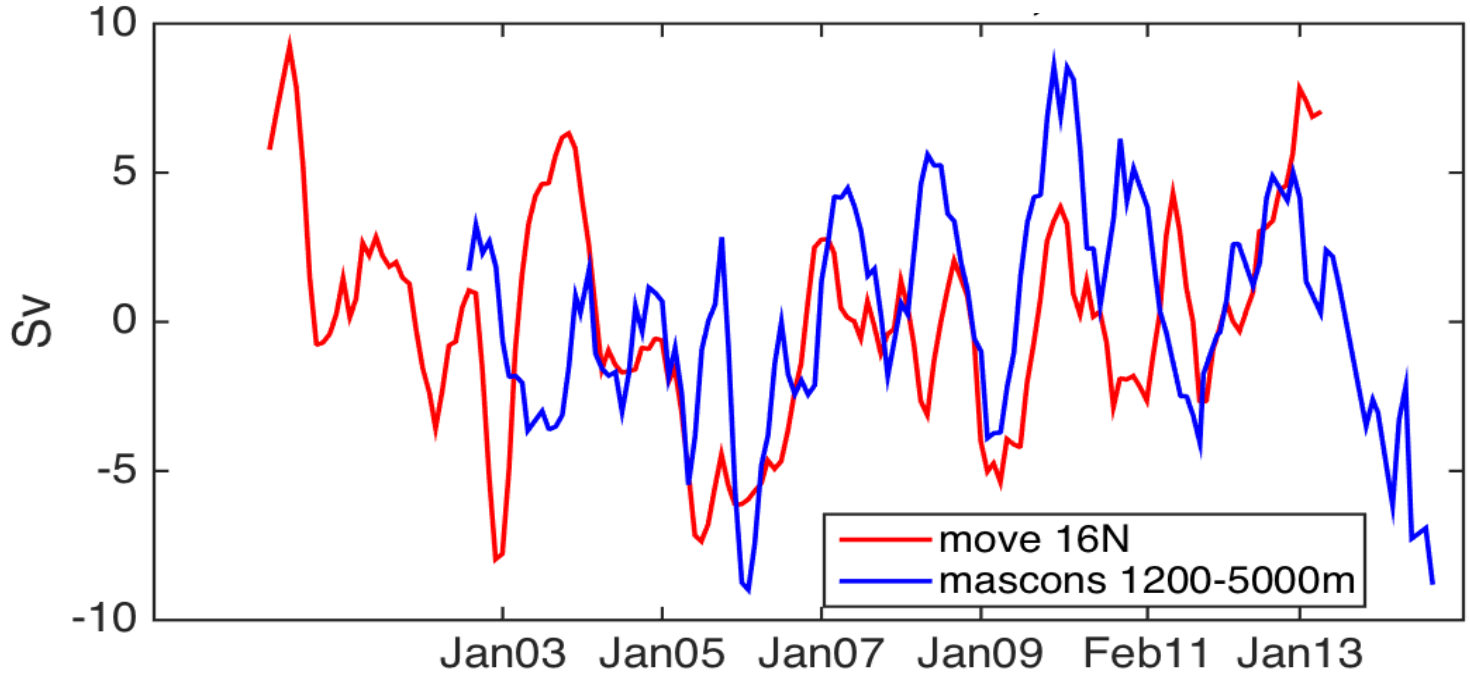


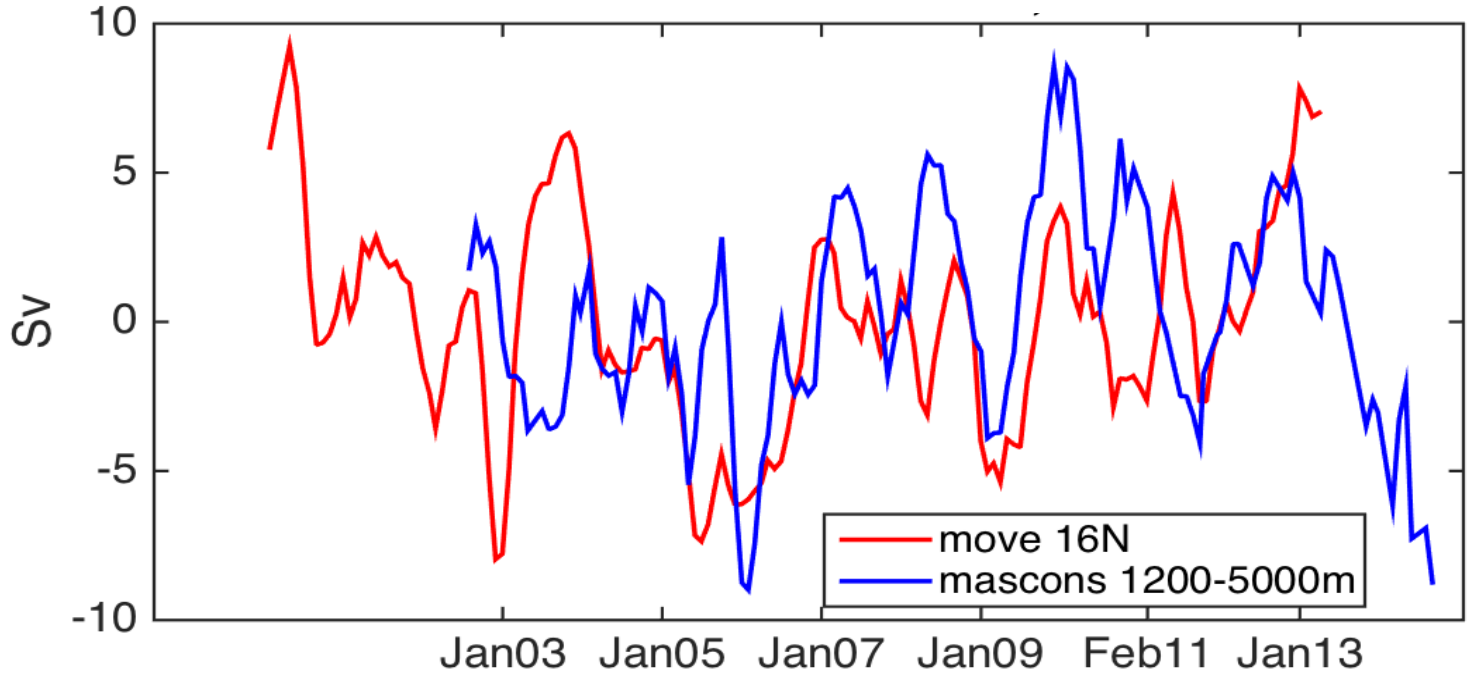
16 N, MOVE project (Kanzow et al 2006)



AMOC at 16N, MOVE project

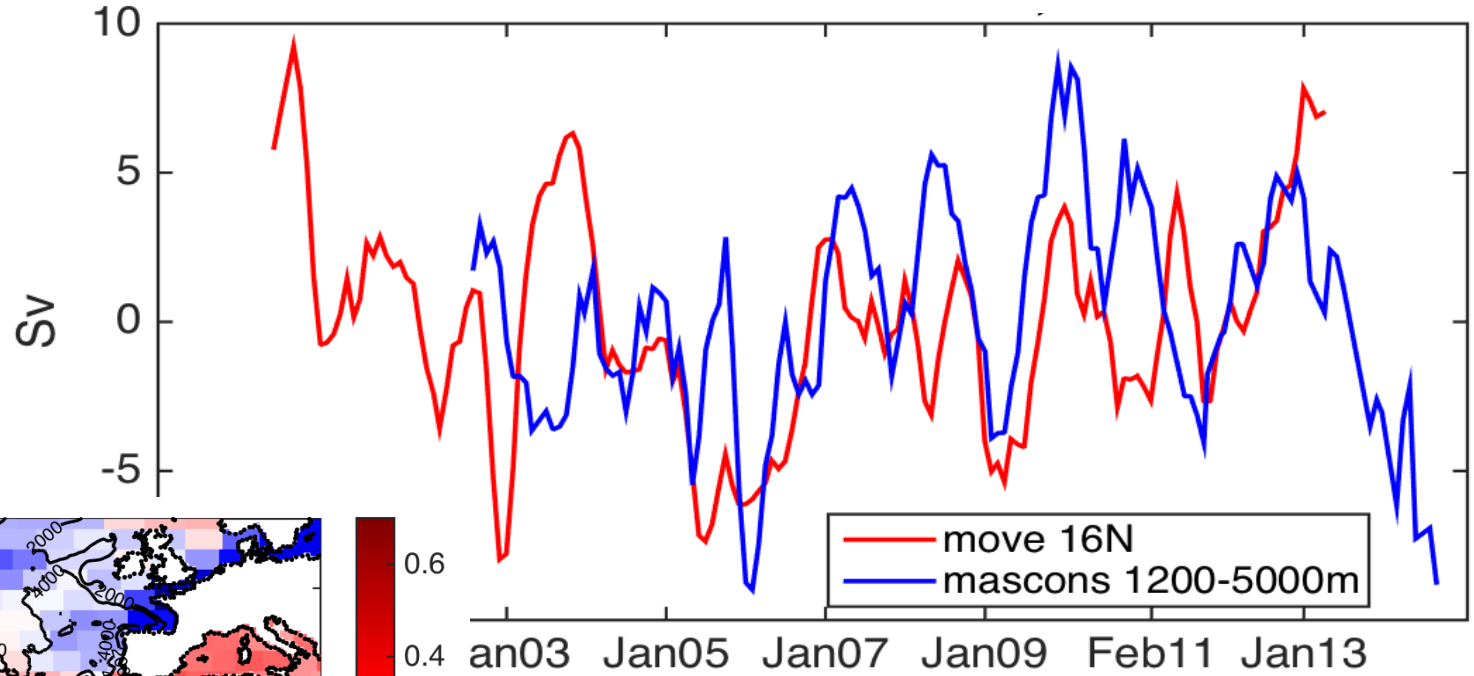


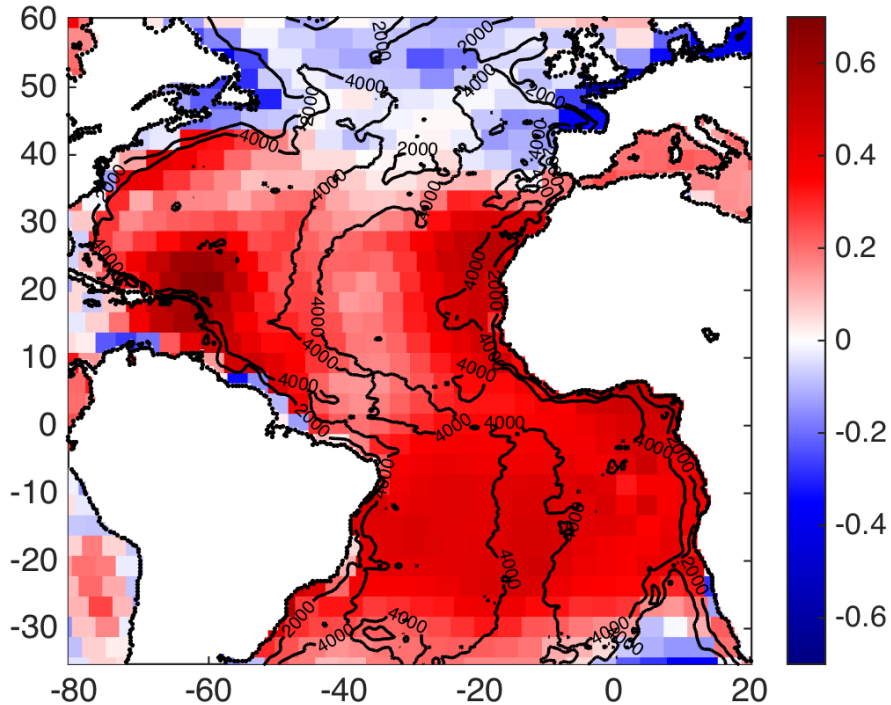
AMOC at 16N, MOVE project



in-situ 16N &	corr coeff	error RMS
mascons	0.53	2.8 Sv

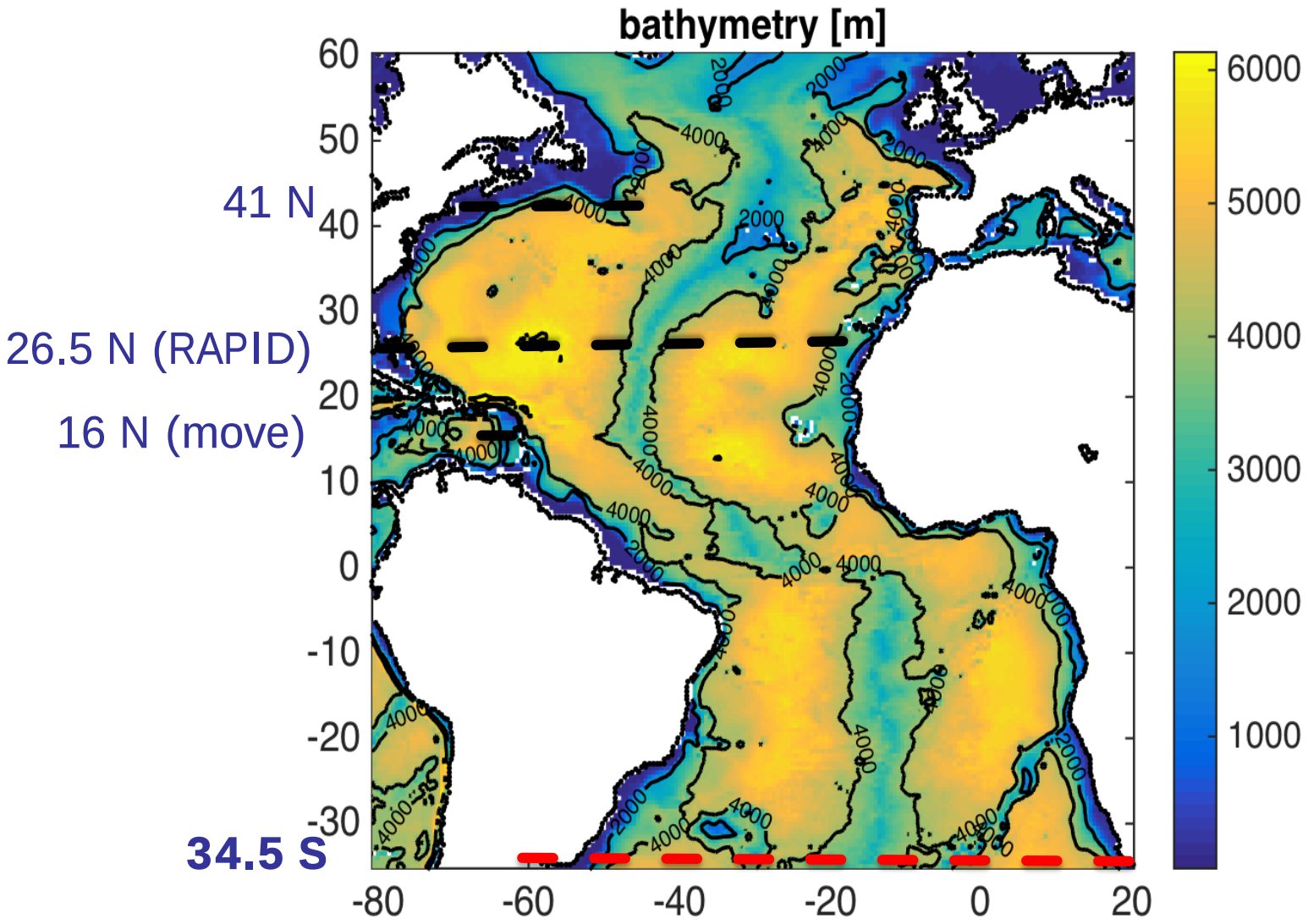
AMOC at 16N, MOVE project



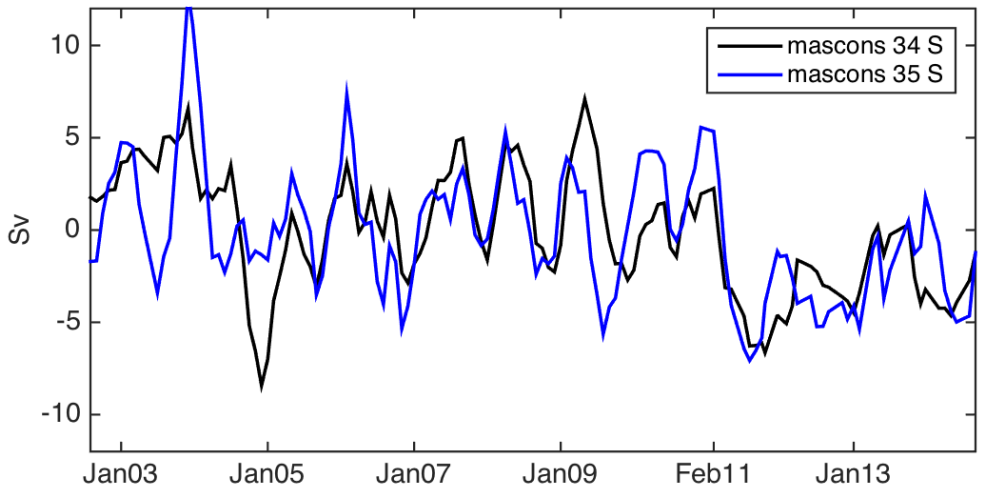


in-situ 16N &	corr coeff	error RMS
mascons	0.53	2.8 Sv

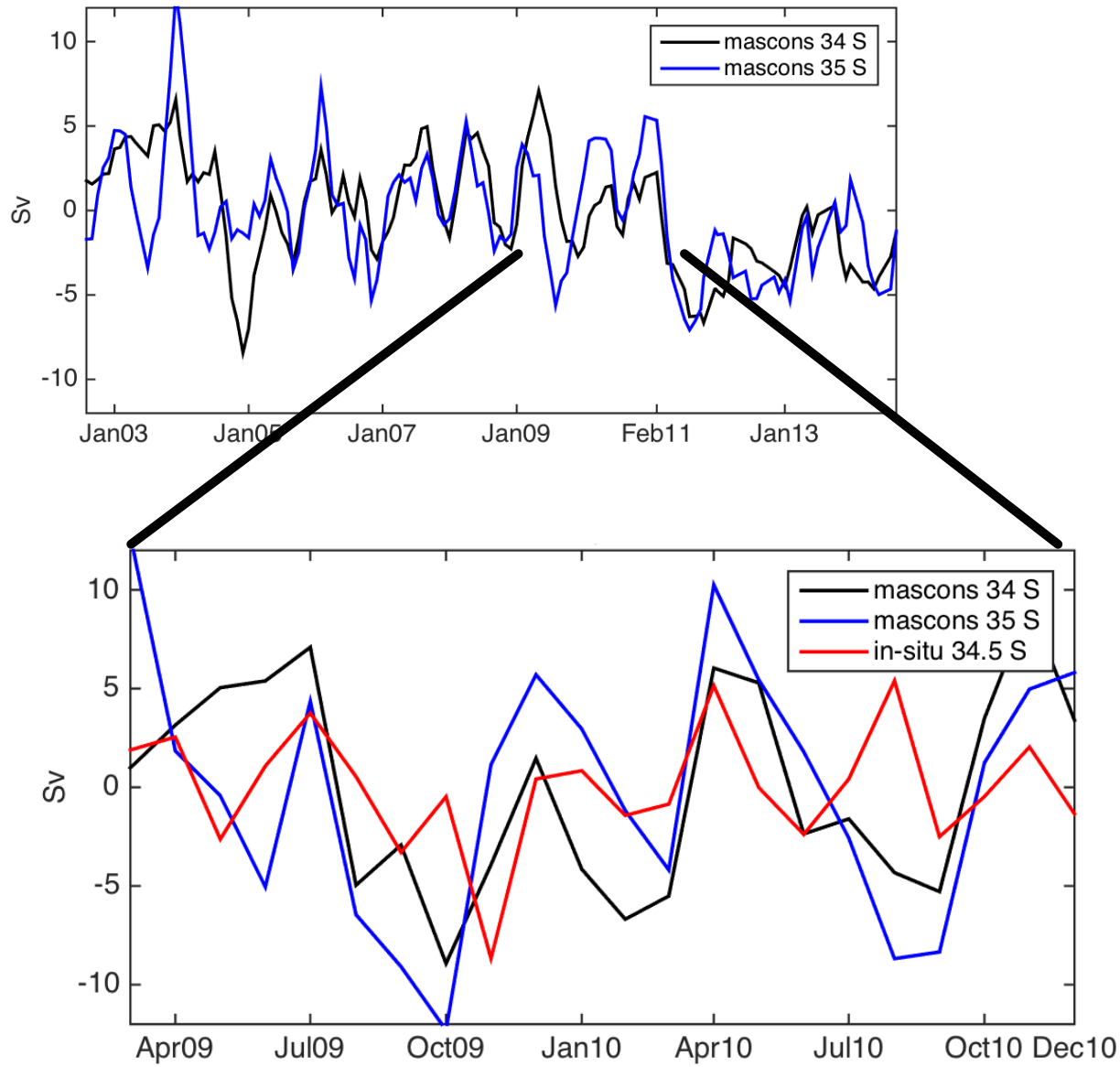
34.5 S (Meinen et al 2013)



SAMOC at 34.5 S (South Atlantic)

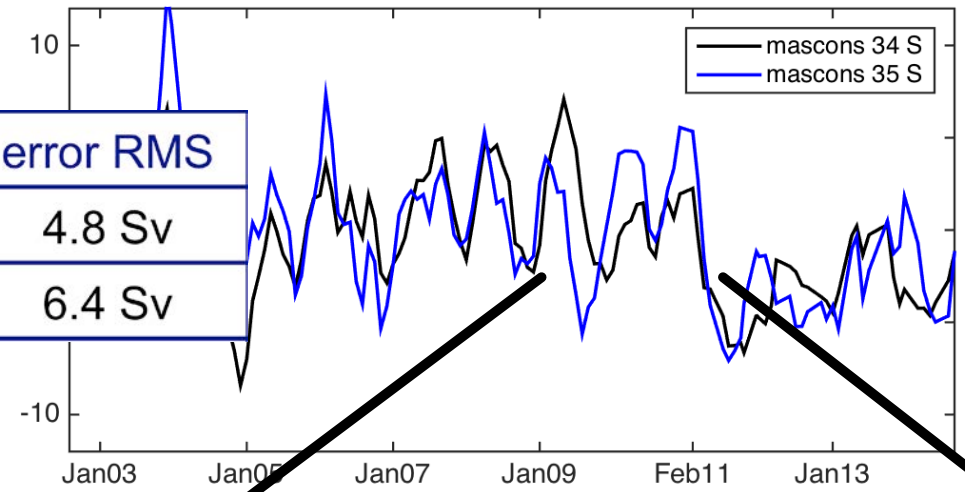


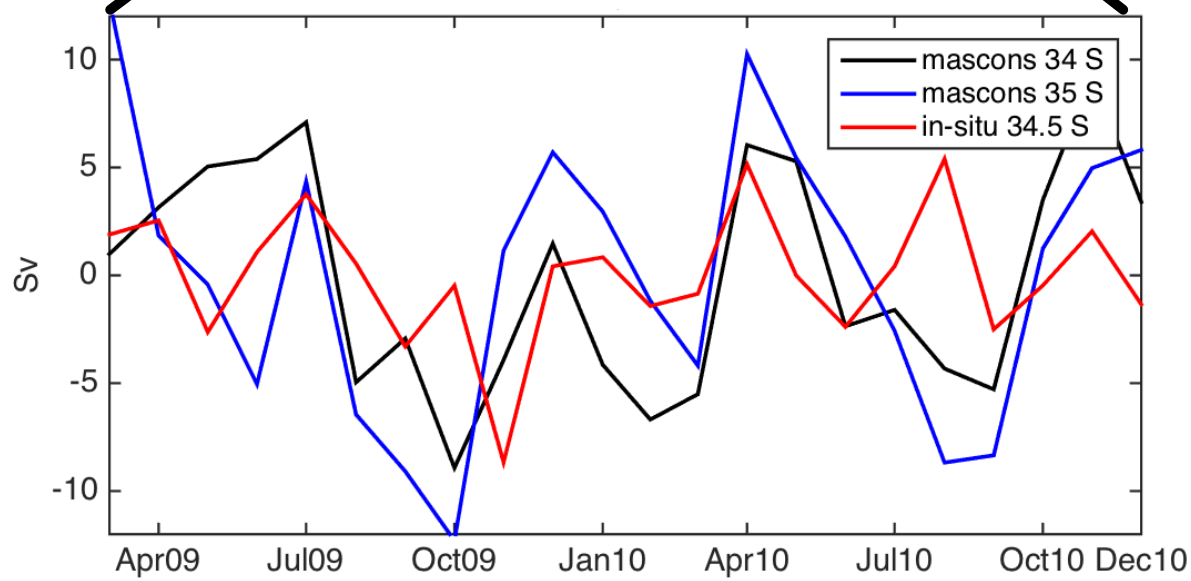
SAMOC at 34.5 S (South Atlantic)



SAMOC at 34.5 S (South Atlantic)

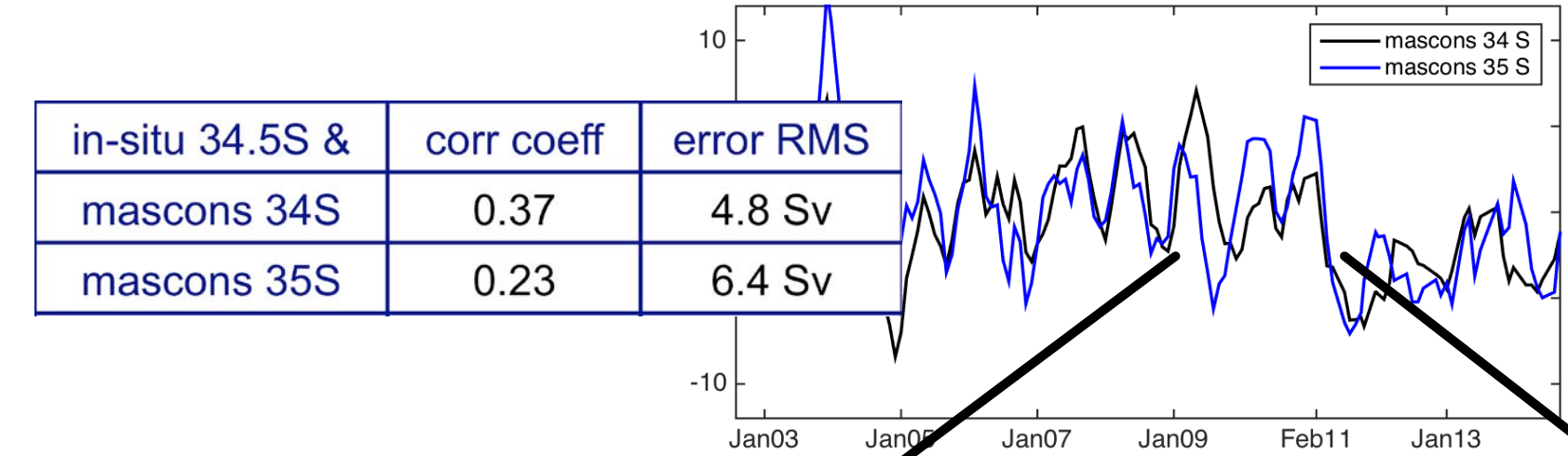
in-situ 34.5S &	corr coeff	error RMS
mascons 34S	0.37	4.8 Sv
mascons 35S	0.23	6.4 Sv

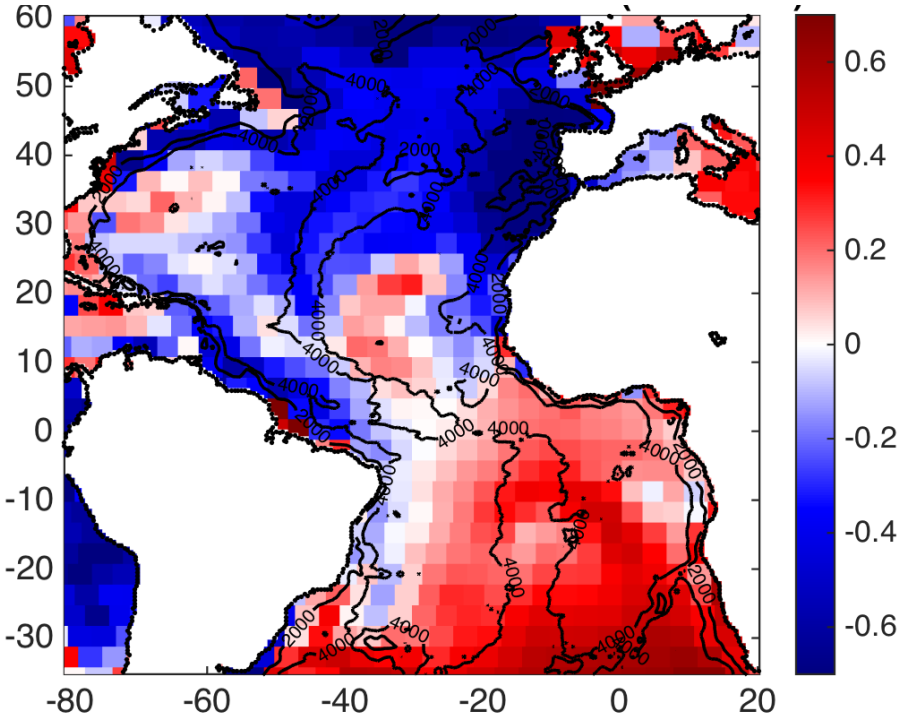


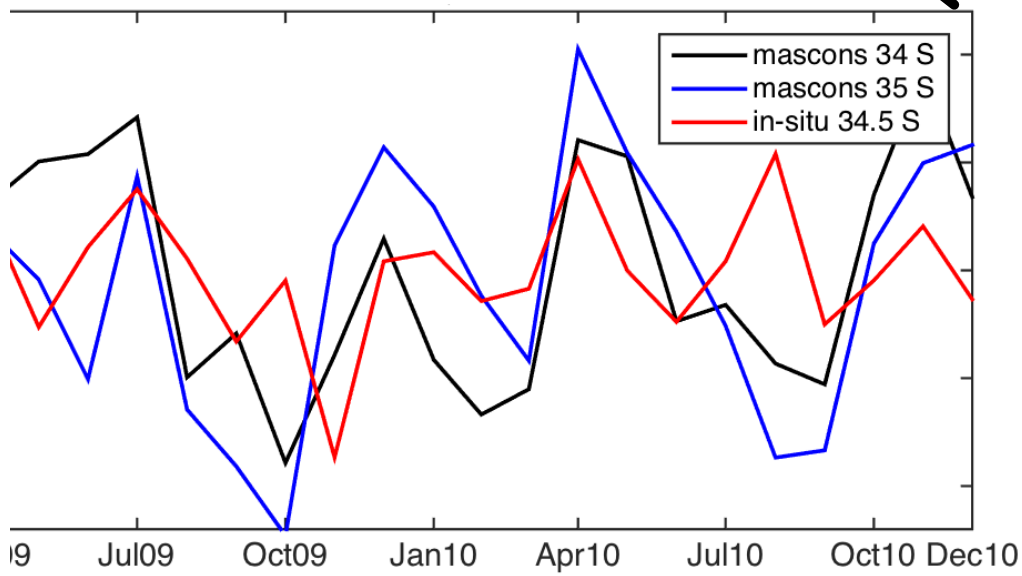


SAMOC at 34.5 S (South Atlantic)

in-situ 34.5S &	corr coeff	error RMS
mascons 34S	0.37	4.8 Sv
mascons 35S	0.23	6.4 Sv







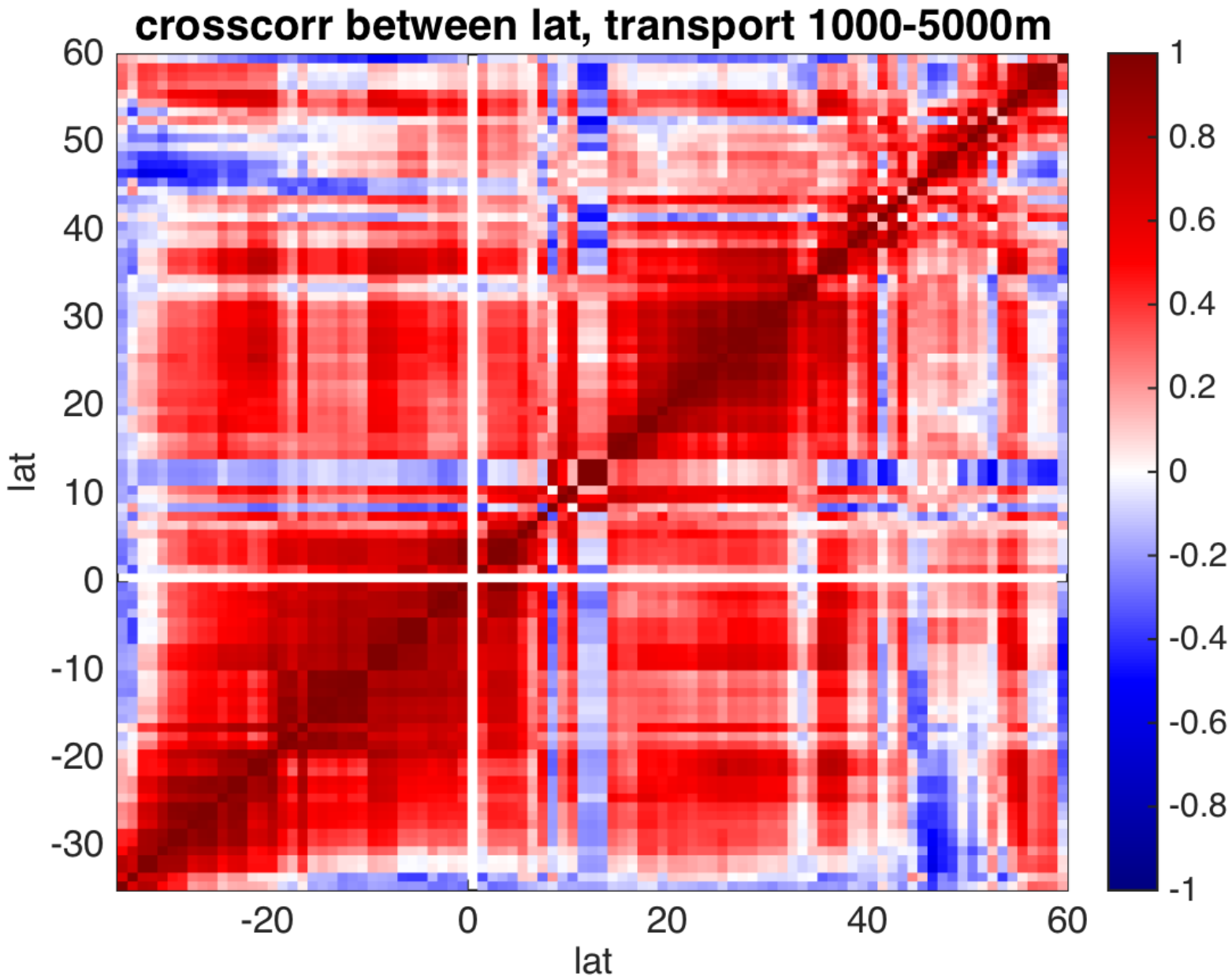
Summary of time series comparison

- limited in-situ observations at different time scales
  - e.g., only 22 months at 34.5 S

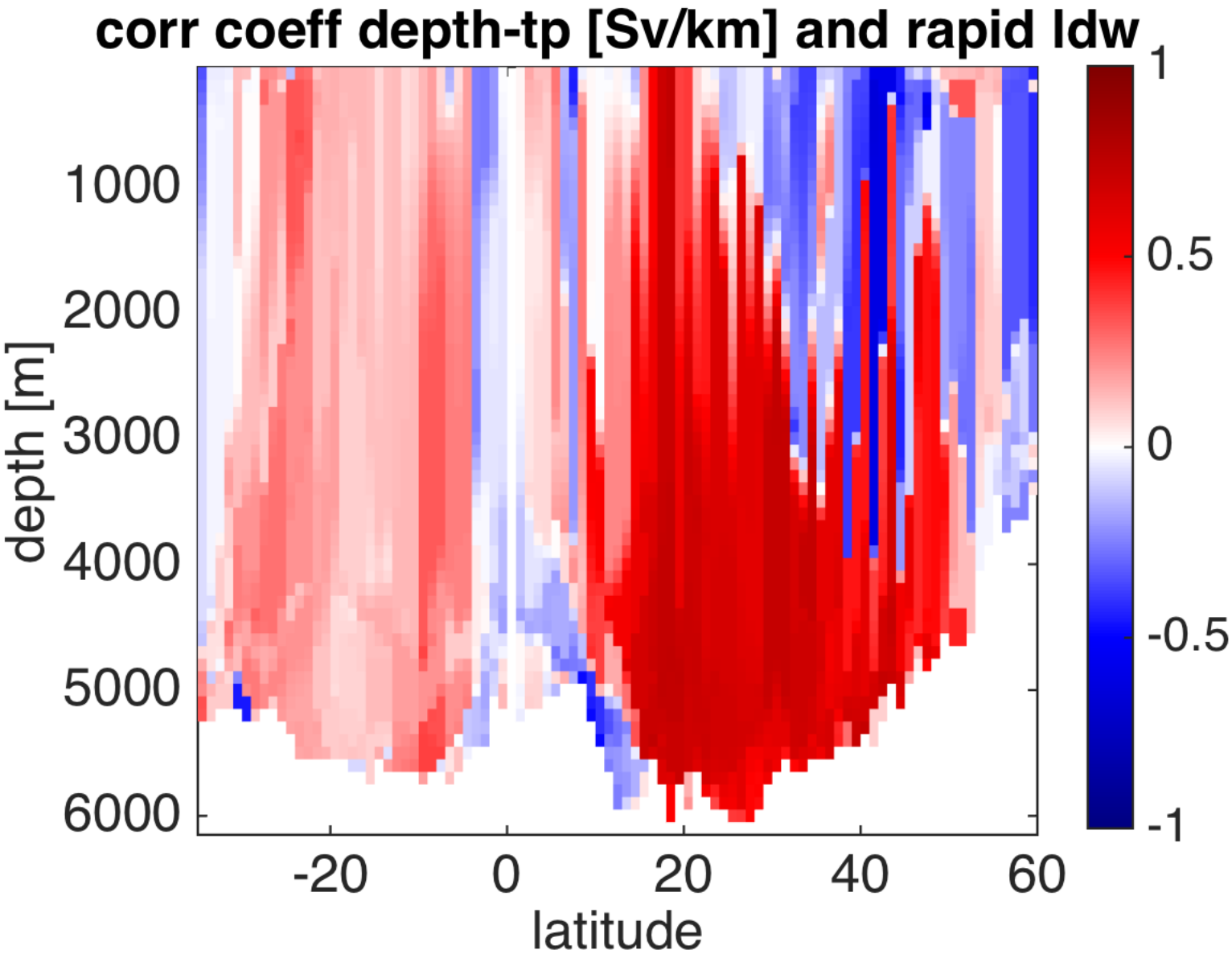
- 26.5 N (rapid) in-situ observations spanning the whole Atlantic cross section, 9 yr time series
  - correlation with mascons ~0.8, less than 1 Sv RMSD

➔ **use mascon-OBP to evaluate AMOC at all latitudes!**

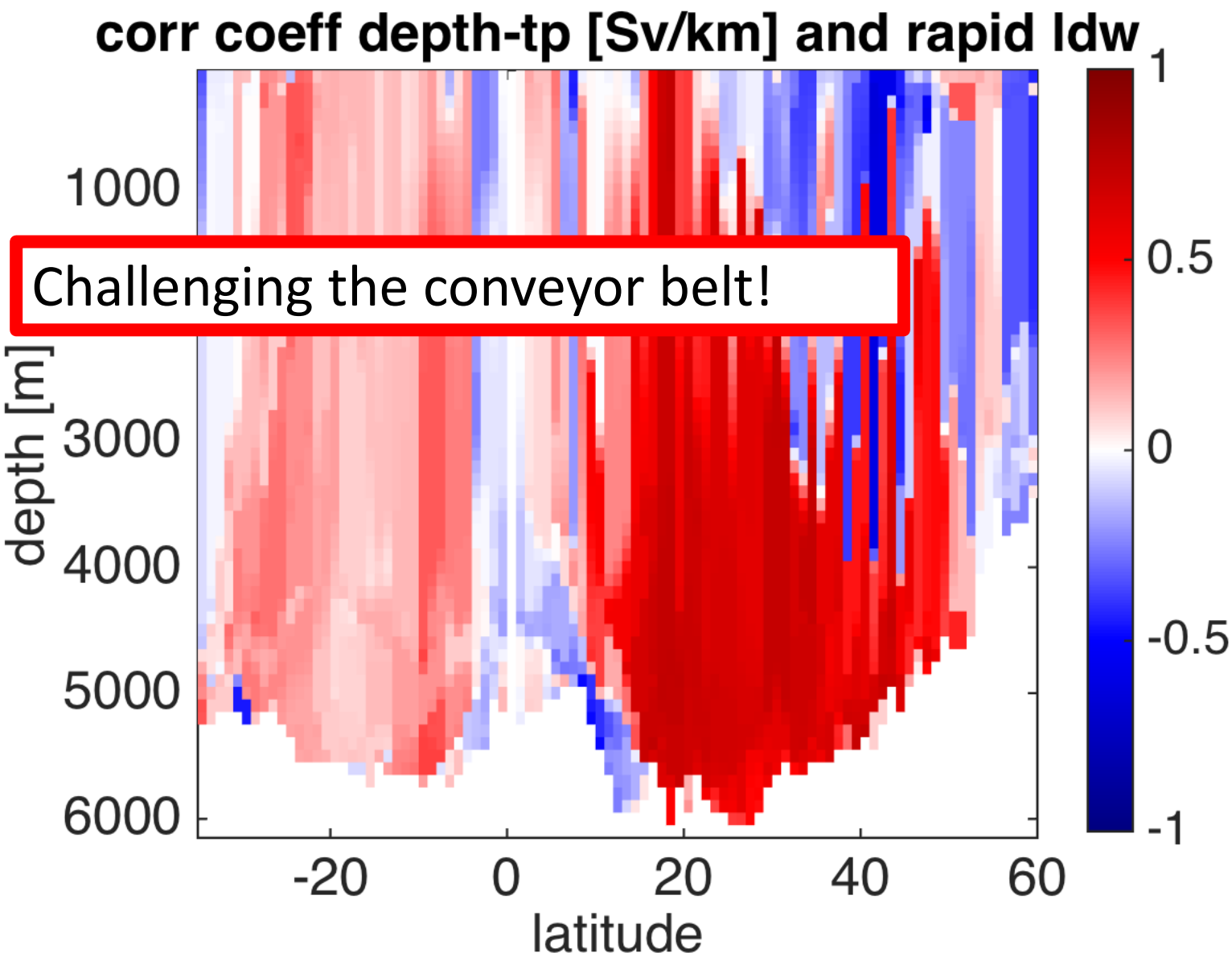
North and South Atlantic: cross-correlation



Correlation of LNADW with depth-dependent transport



Correlation of LNADW with depth-dependent transport

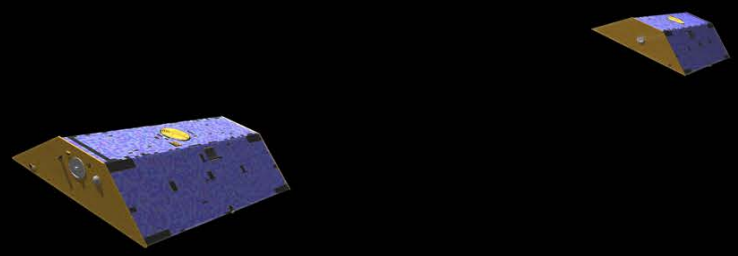


Challenging the conveyor belt!

Summary & take-home message

- 1st measurements of LNADW from GRACE satellites from 2003 until now!
- Good agreement of GRACE JPL mascon-derived LNADW transport with RAPID array, reasonable agreement with all other available in-situ data
- At 26N, LNADW variations strongly correlate with AMOC transport (upper limb); not clear how unique this is compared to other latitudes
- GRACE-OBP noise floor maps into ~2Sv AMOC sensitivity
- AMOC resolution capability dependent on bathymetry slopes

Can the Atlantic overturning variability be observed with GRACE?



YES, GRACE-mascons can be used to monitor AMOC variability!

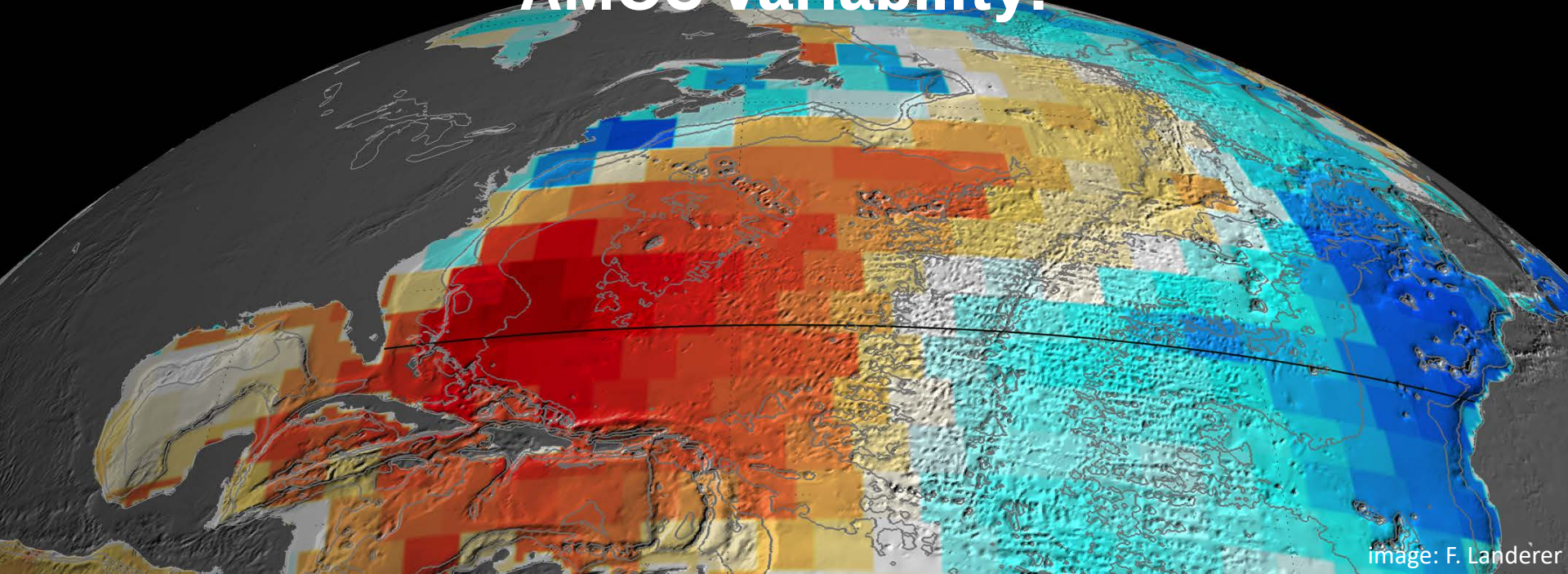


image: F. Landerer