A multi-decadal, eddying global simulation with HYCOM

Southern Atlantic Ocean & meridional coherence of the AMOC

Xiaobiao Xu

Center for Ocean-Atmospheric Prediction Studies

Florida State University

Thank Shengfu Dong, Molly Baringer (NOAA/AOML), Eric P. Chassignet,
Alan Wallcraft, and Alexandra Bozec (FSU/COAPS)

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Motivation

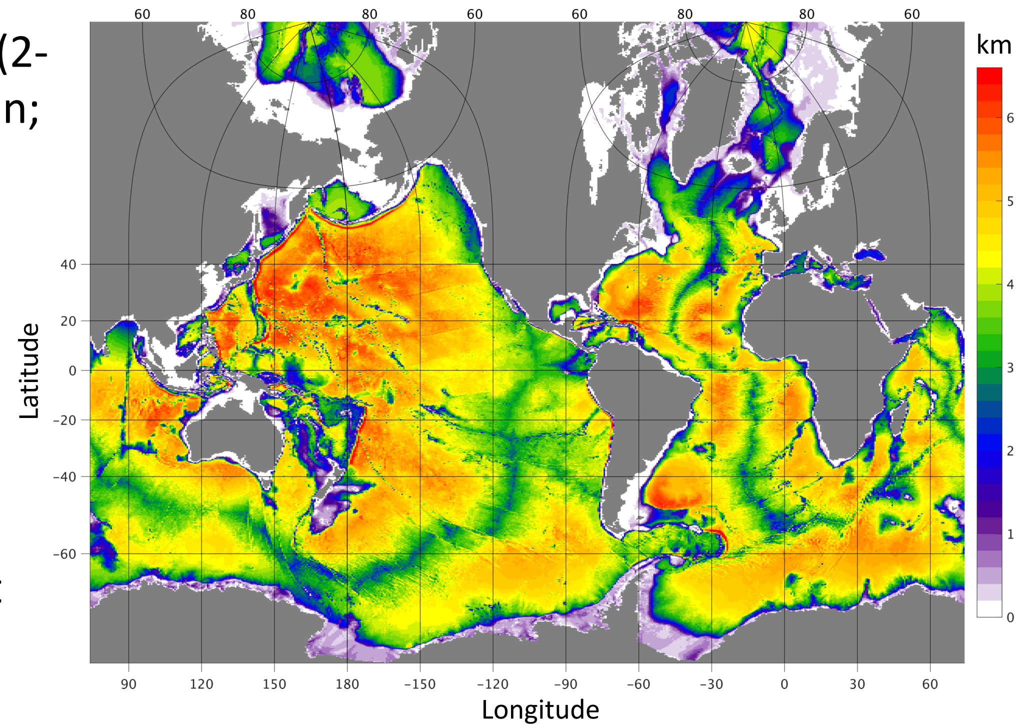
- Ocean simulations are complementary (to observations) to study the spatial structure and temporal variability of the ocean circulation.
- There are several long-term, eddying global simulations (e.g., OFES and NEMO), similar simulations using HYCOM are relatively short (10-20 years).

Model configuration

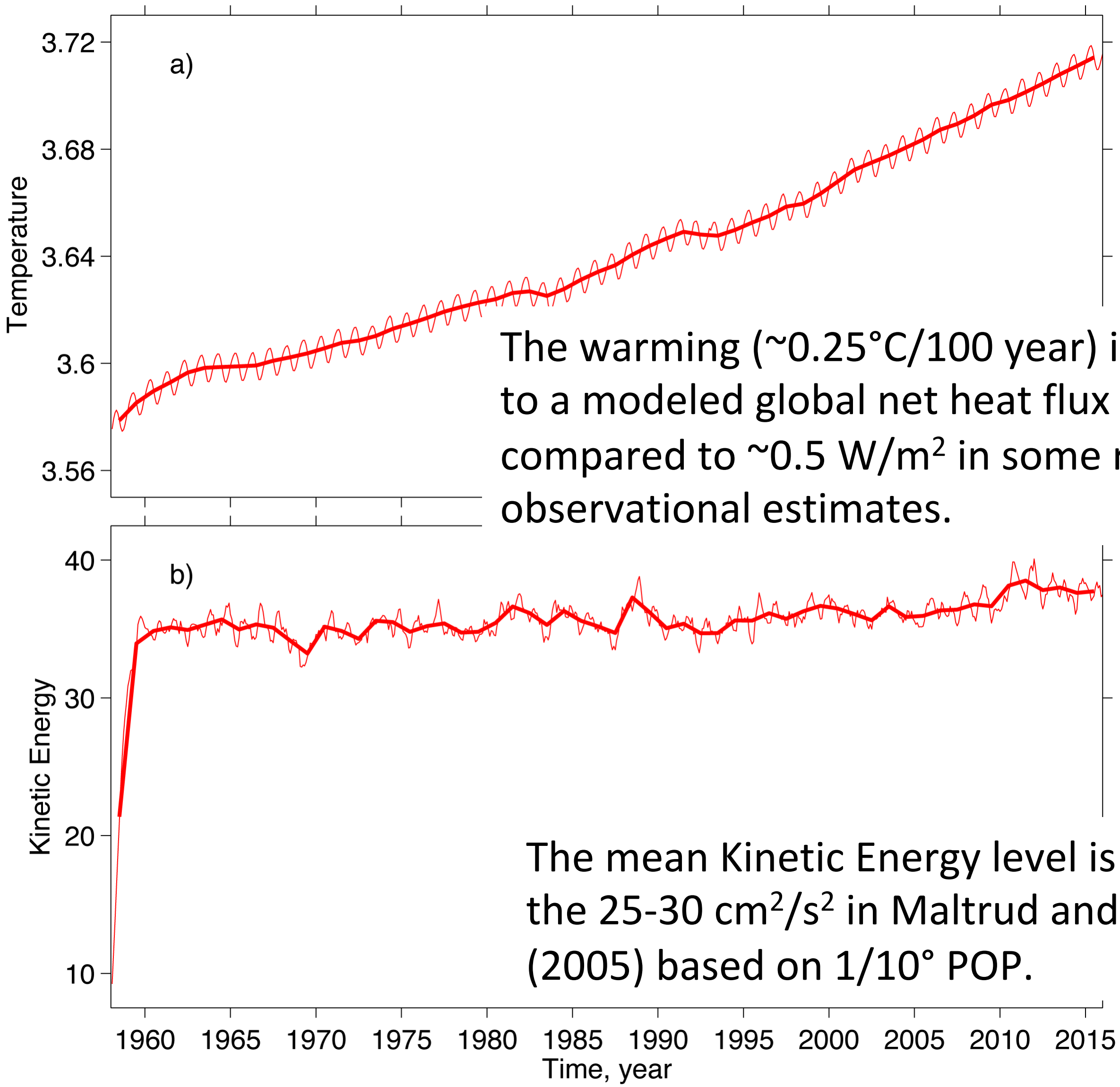
- Global ocean from 78.6°S to 90°N at 1/12° (8.9km at equator) resolution, total of 4500x3298 grid points; 36 (hybrid) layers in the vertical.
- Surface forcing uses the DRAKKAR forcing set (DFS5.2), which is based on ERA40 & ERA-interim for 1958-2015 (Dussin et al. 2016), and Large-Yeague bulk formula.
- The ocean circulation model (HYCOM, Bleck 2002; Chassignet et al. 2003; Halliwell 2004) is fully-coupled with the sea-ice module CICE (Hunke and Lipscomb, 2008).
- Strong surface salinity relaxation (2-month) plus zero net flux constrain; no SST relaxation.
- Horizontal diffusion/viscosity:

  visco2 = 0.05
  veldf2*dx = 20 m^2/s
  veldf4 = 2 cm/s
  thkdf4 = 2 cm/s;
  temdf2 = 0.5 cm/s;

- Vertical mixing uses KPP (Large et al., 1994)



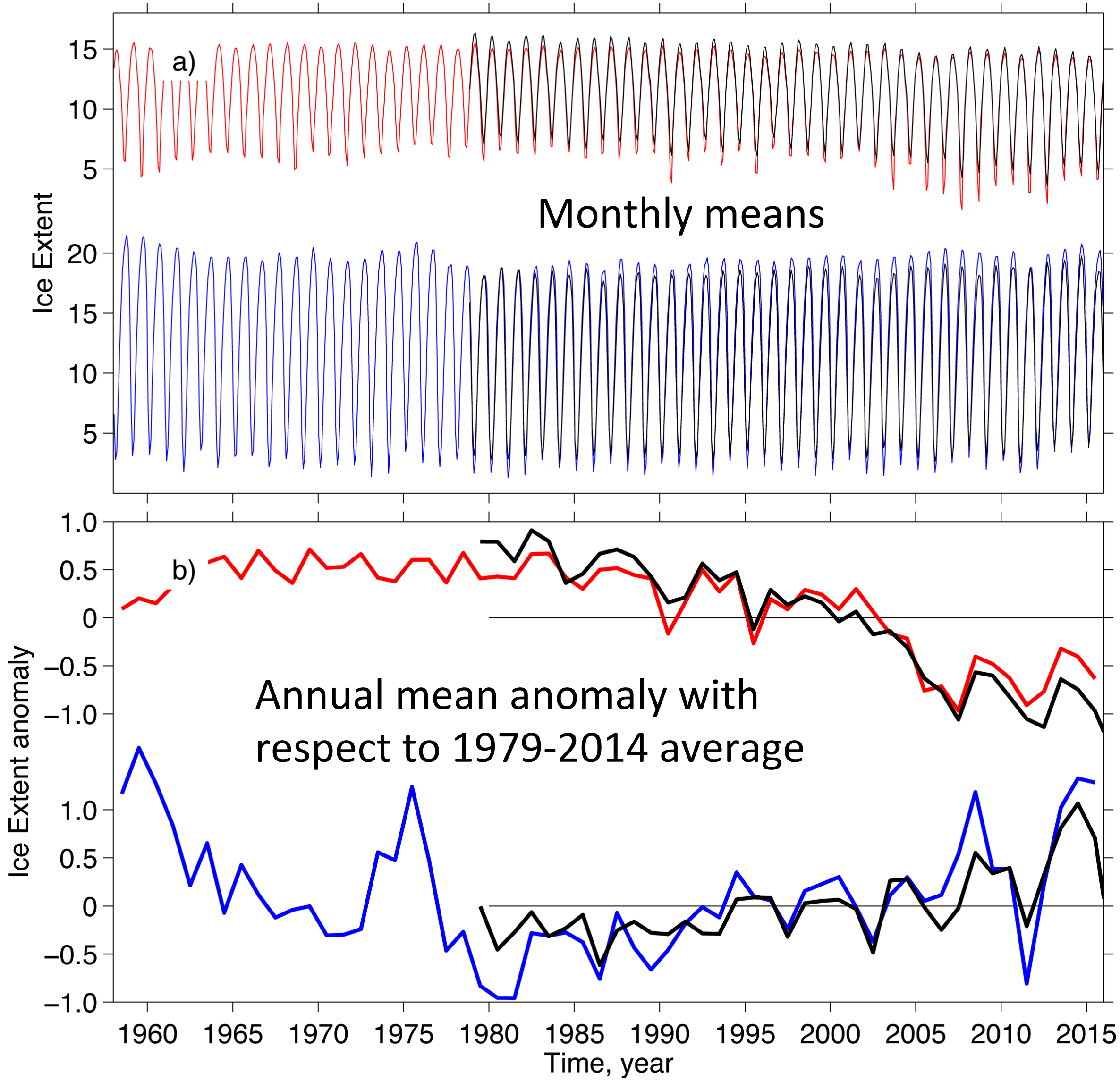
Some global aspects



The warming (~0.25°C/100 year) is corresponding to a modeled global net heat flux of ~1.2 W/m^2, compared to ~0.5 W/m^2 in some recent observational estimates.

The mean Kinetic Energy level is higher than the 25-30 cm^2/s^2 in Maltrud and McClean (2005) based on 1/10° POP.

Sea-ice extent

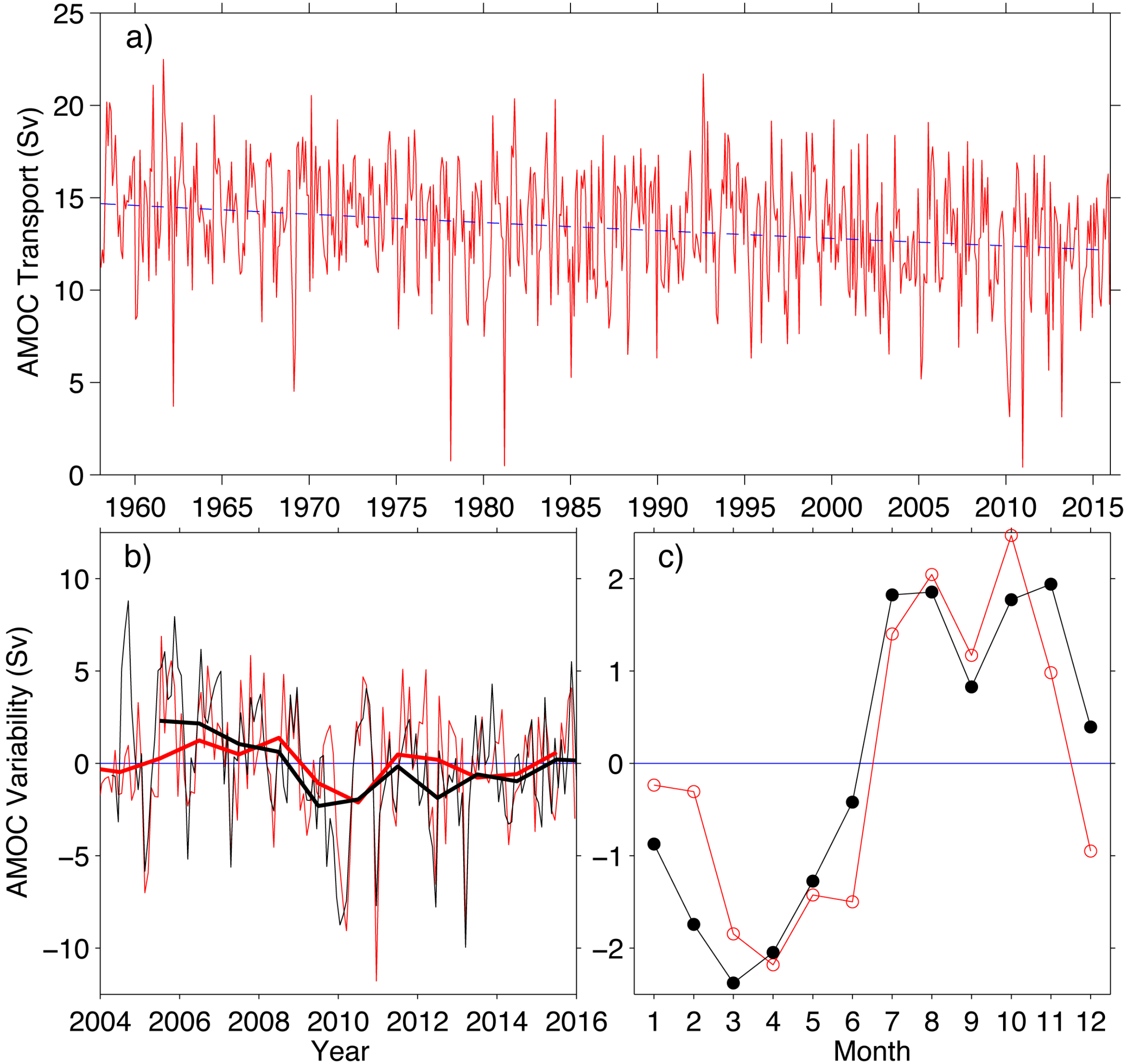


Northern H.
Southern H.
Data (NSIDC)

The model results represent well the variability of the sea-ice extent* from seasonal to long-term timescales

**Sea ice extent is defined the area in million km^2 with 15% or more ice concentration*

AMOC at 26°N



The modeled AMOC decreases 2.5 Sv over the 58 years of integration (1958-2015)

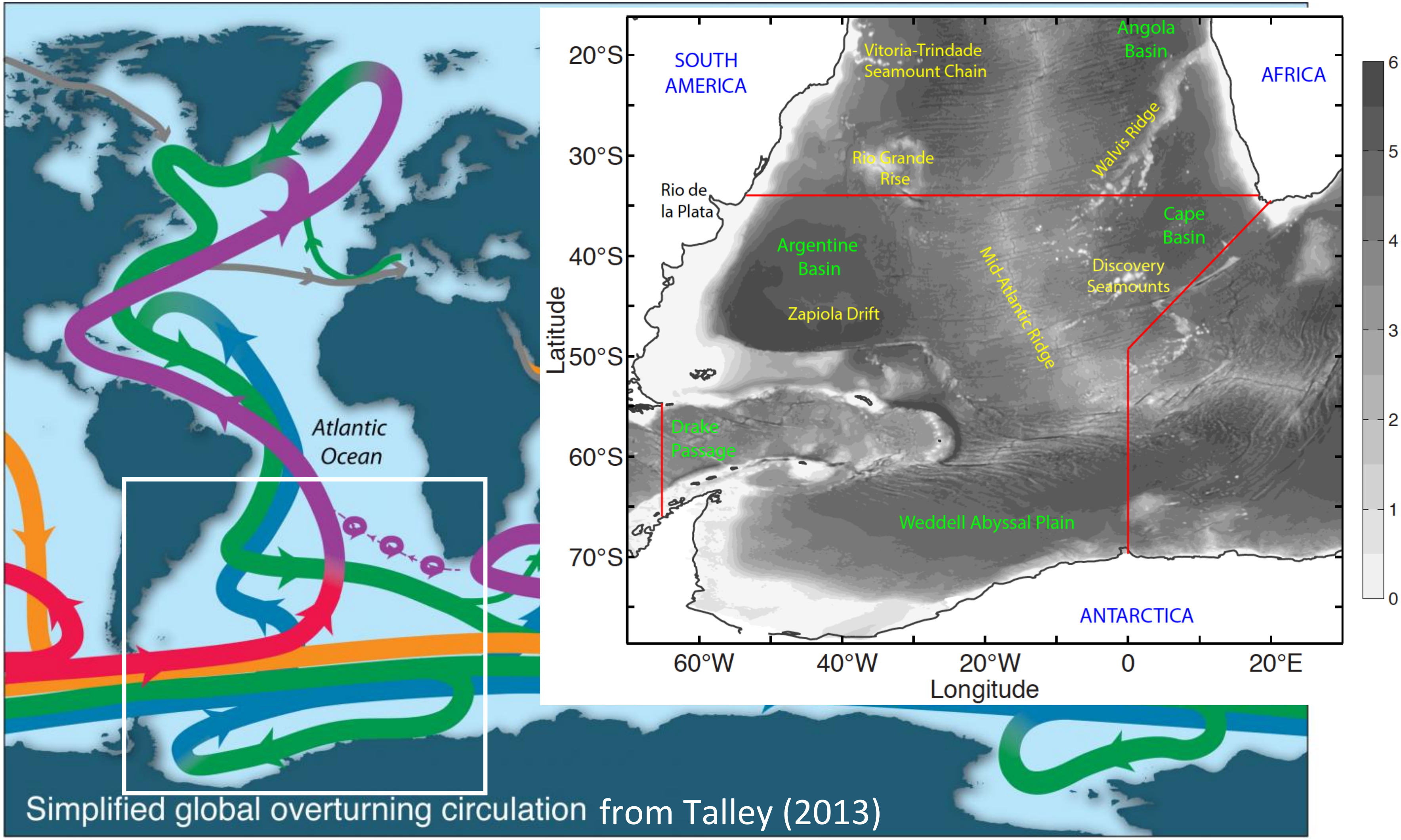
The time mean AMOC is 3.5 Sv lower than the RAPID results in 2004-2015; a similar AMOC transport is found in the NEMO simulation using similar DFS forcing.

Interannual and seasonal variability compared reasonably well with the RAPID results.

Circulation in the southern Atlantic Ocean

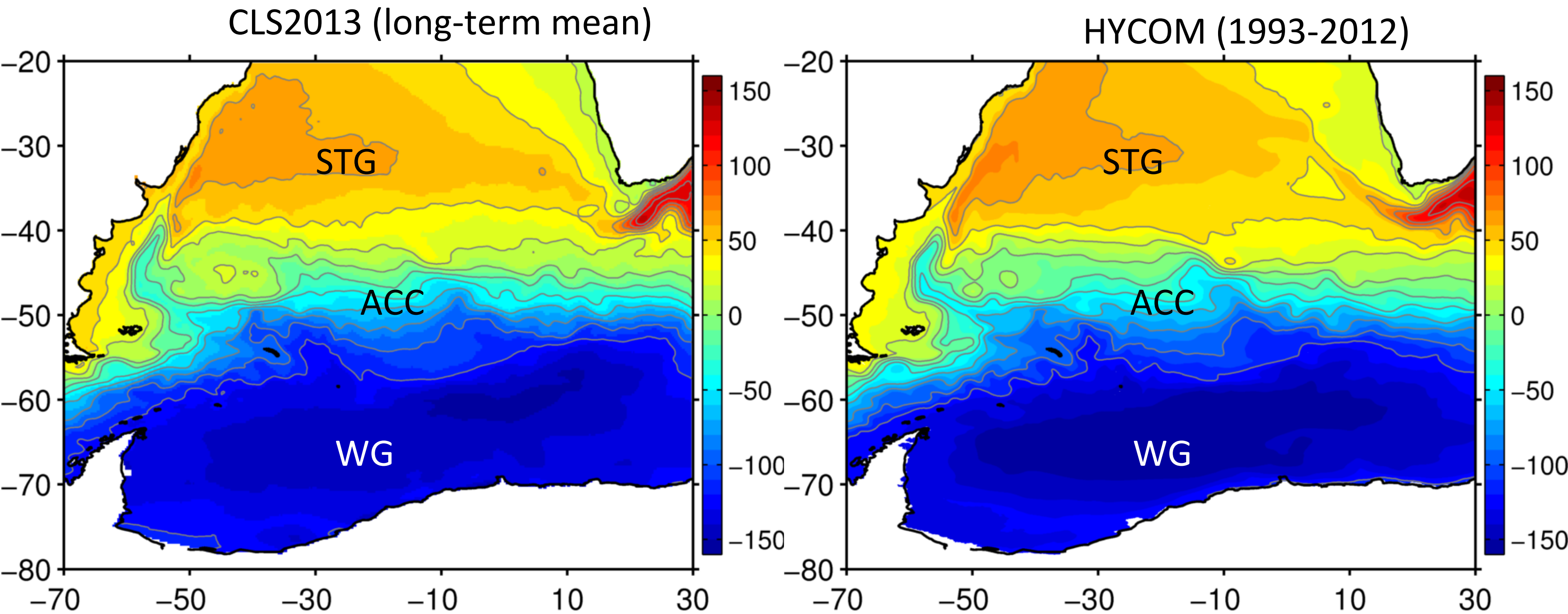
- Surface Circulation
- Trans-basin sections (zonal, meridional)
- Diapycnal transformation
- Horizontal circulation pattern

Southern Atlantic Ocean



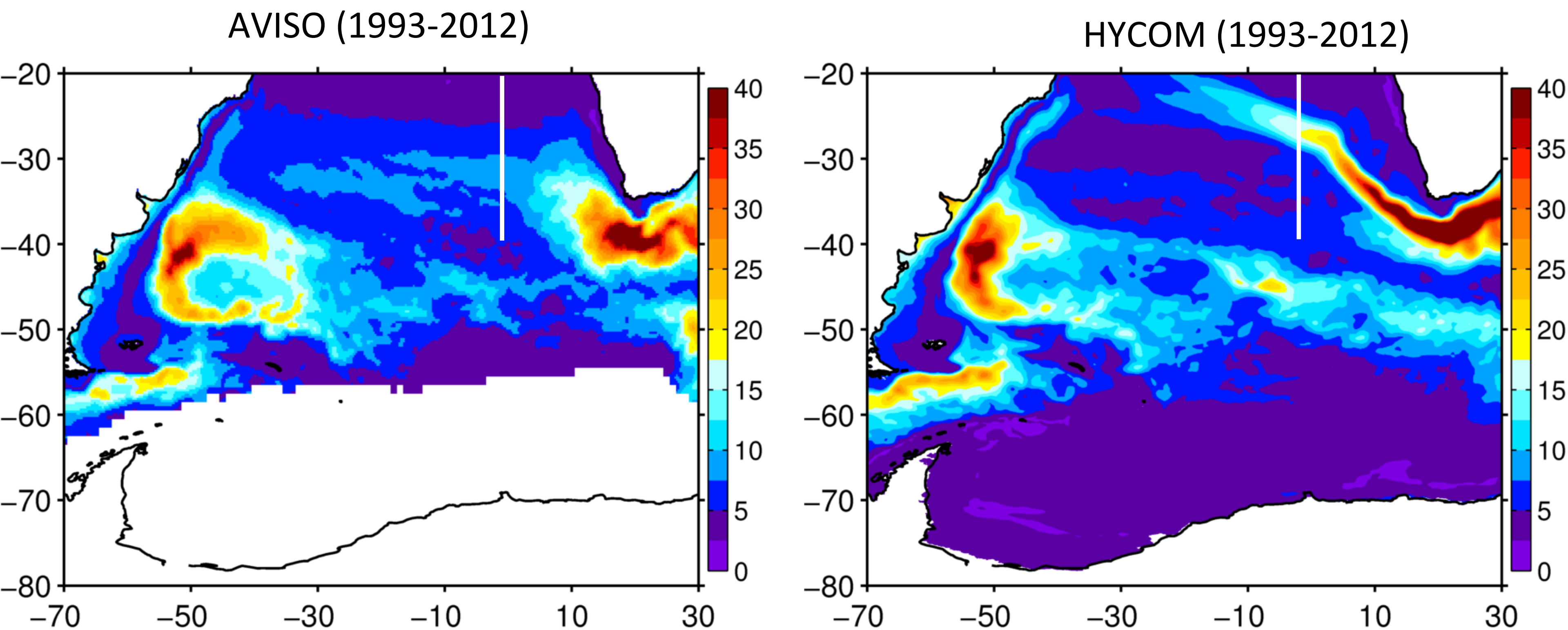
from Talley (2013)

Surface circulation (SSH mean)



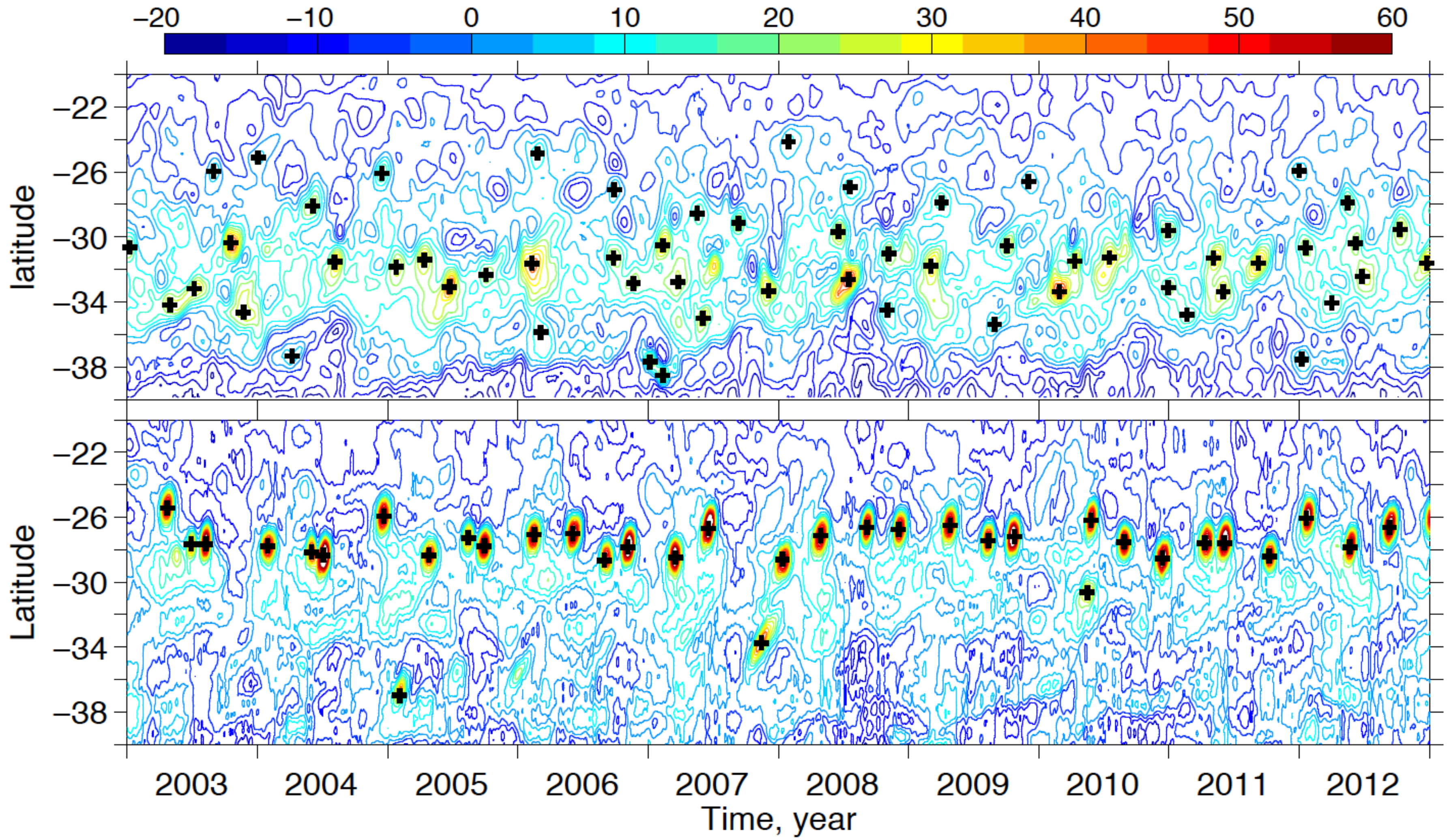
Long-term mean sea surface height (in cm) in observations (AVISO ¼) and global HYCOM simulations, showing the key circulation pattern of the region.

Surface circulation (SSH rms)



RMS deviation of sea surface height (in cm) in observations (AVISO ¼) and global HYCOM simulations, showing the key circulation pattern of the region.

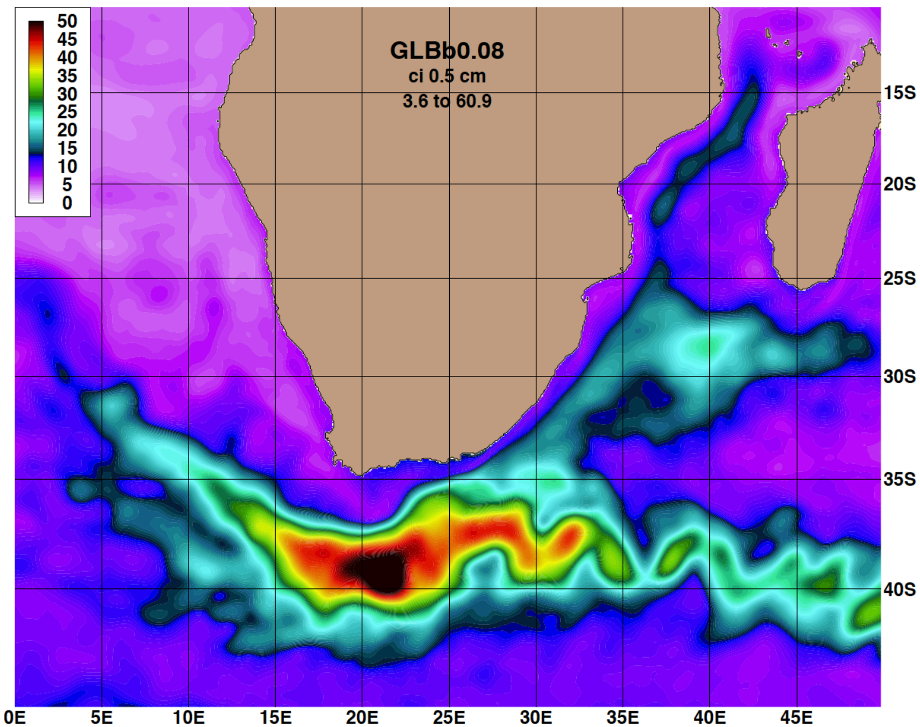
Agulhas Rings (eddies)



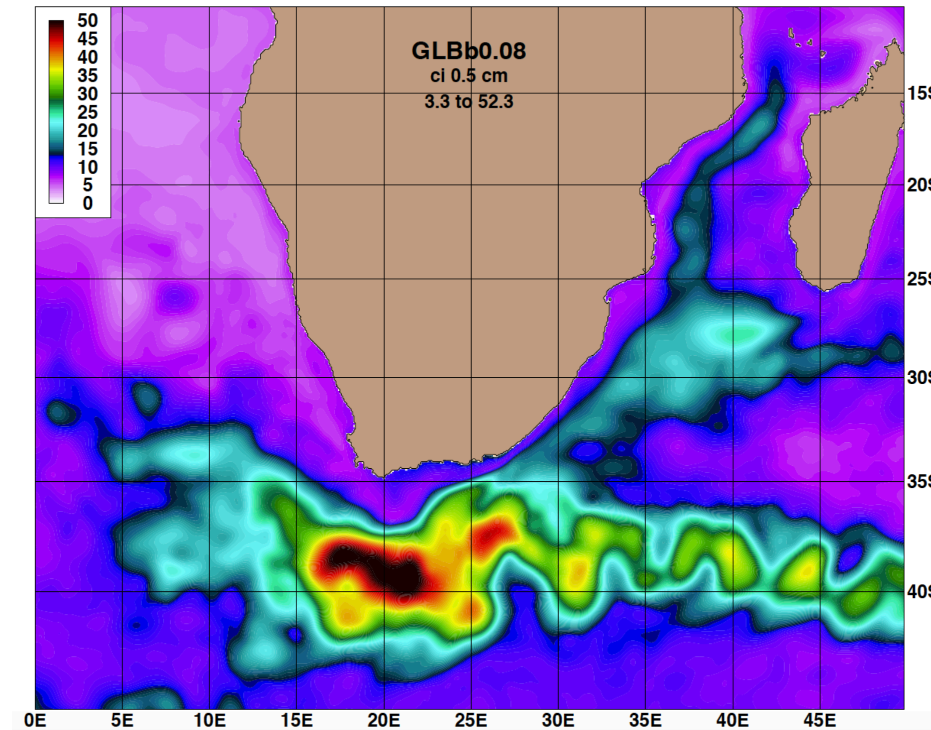
SSH anomaly along the Prime Meridian in latitude range 20-40°S (2003-2012): + denotes the location of high SSH associated with the Agulhas Rings that translate pass this longitude

Some recent improvement

Global HYCOM (2nd order)

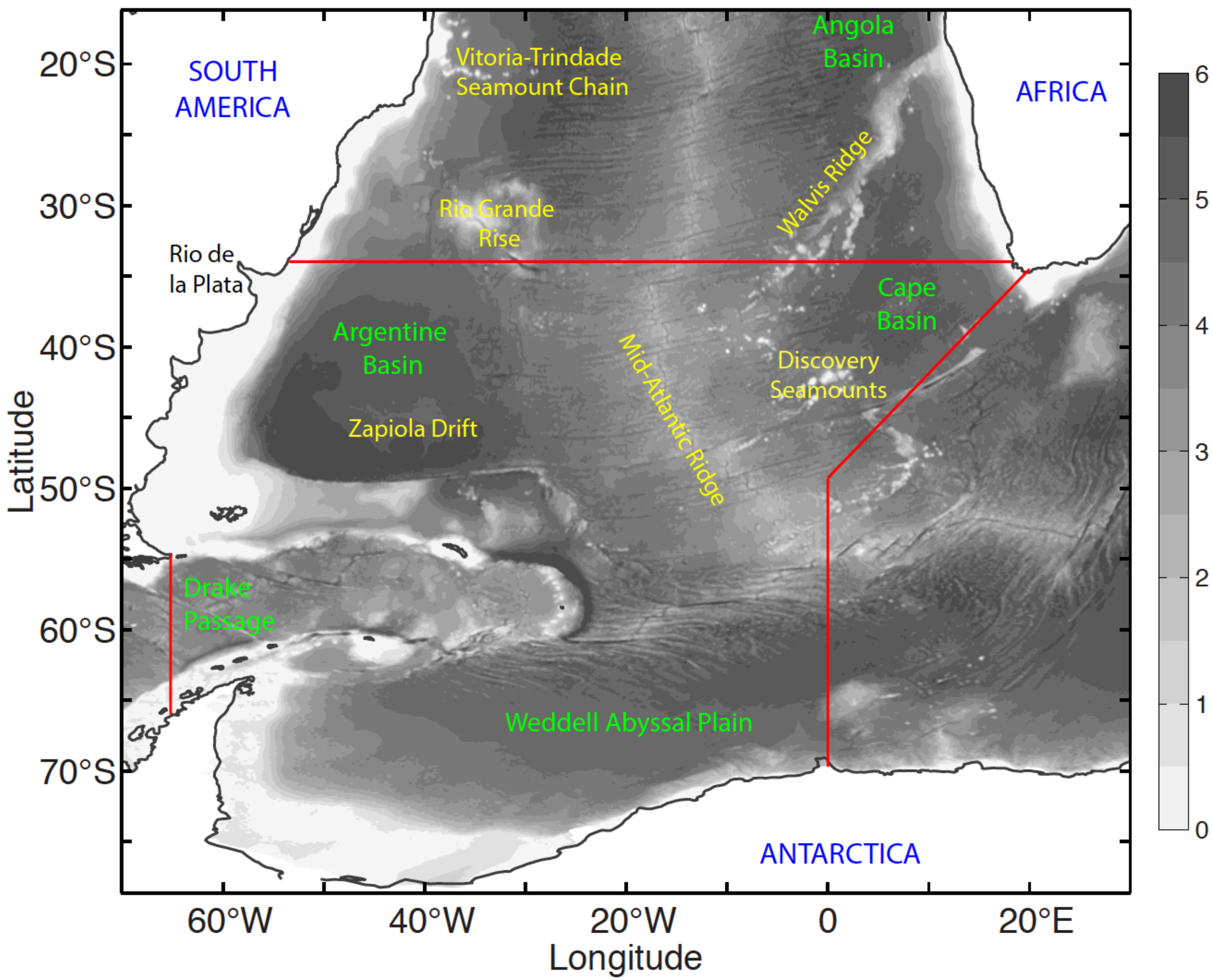


Global HYCOM (3nd order)

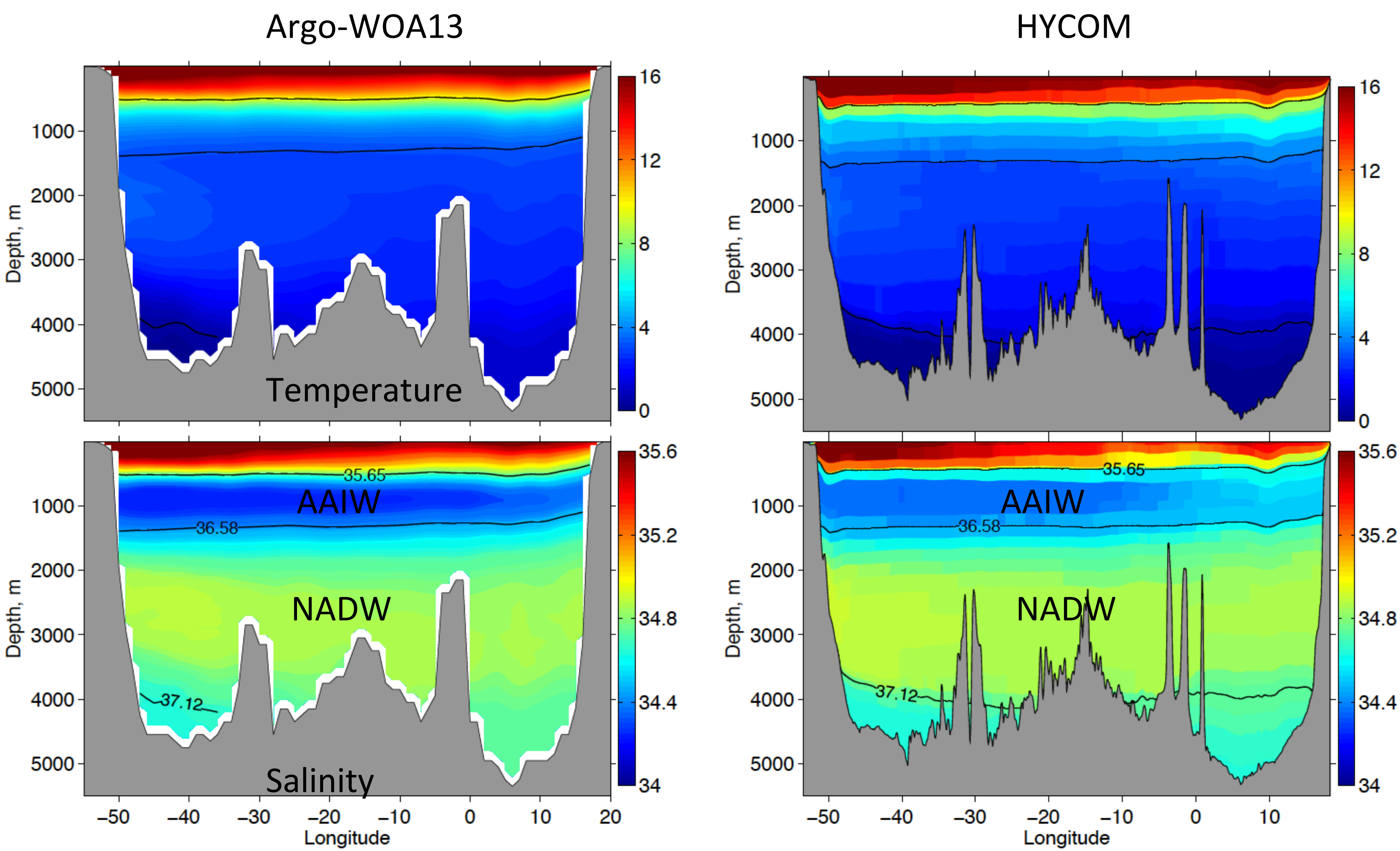


The SSH deviation based on 3-year (2012-2014) twin experiments using the current 2nd order and newly implemented 3rd order momentum scheme (the improvement is expected more significant on higher resolution)

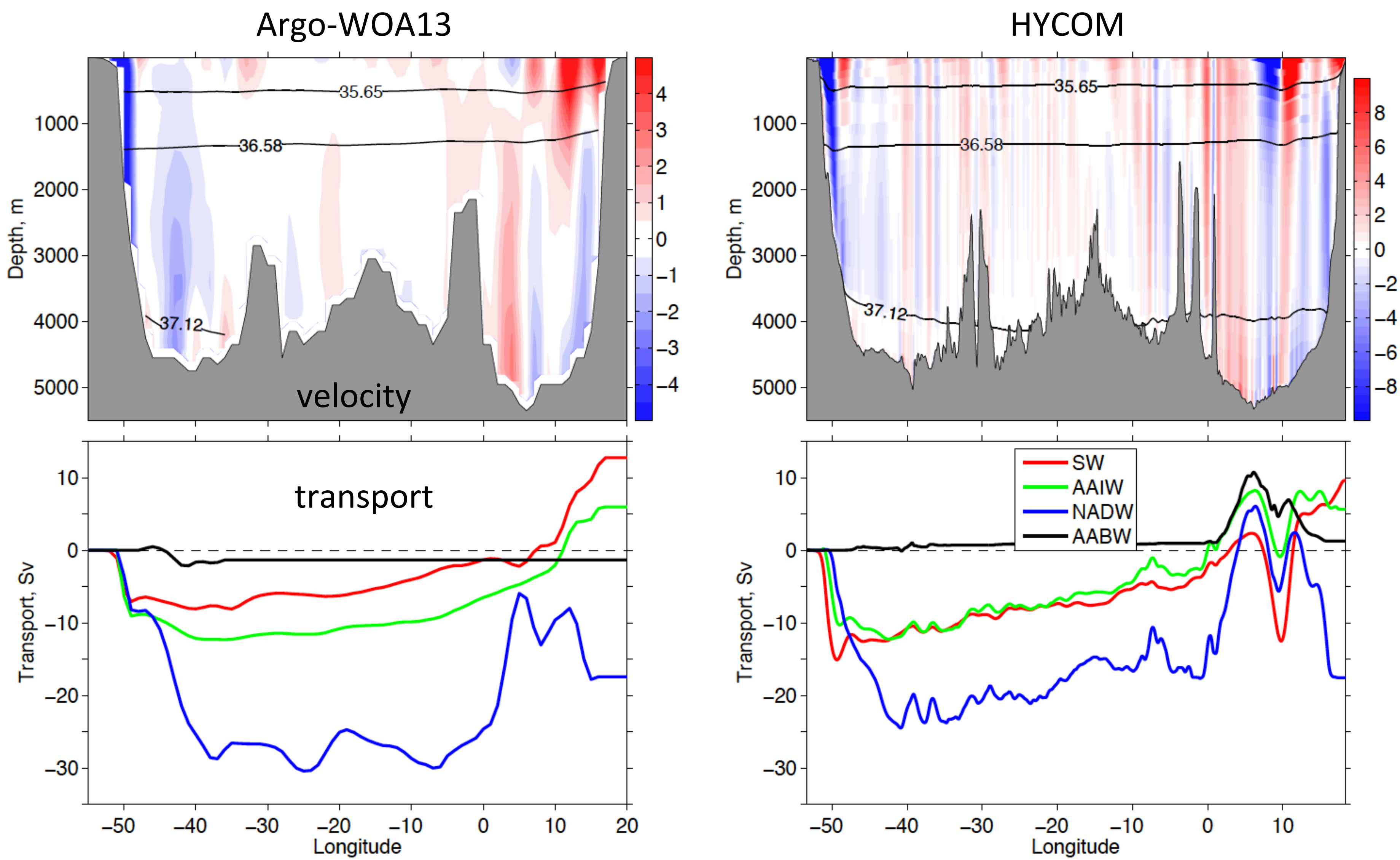
Zonal section at 34°S



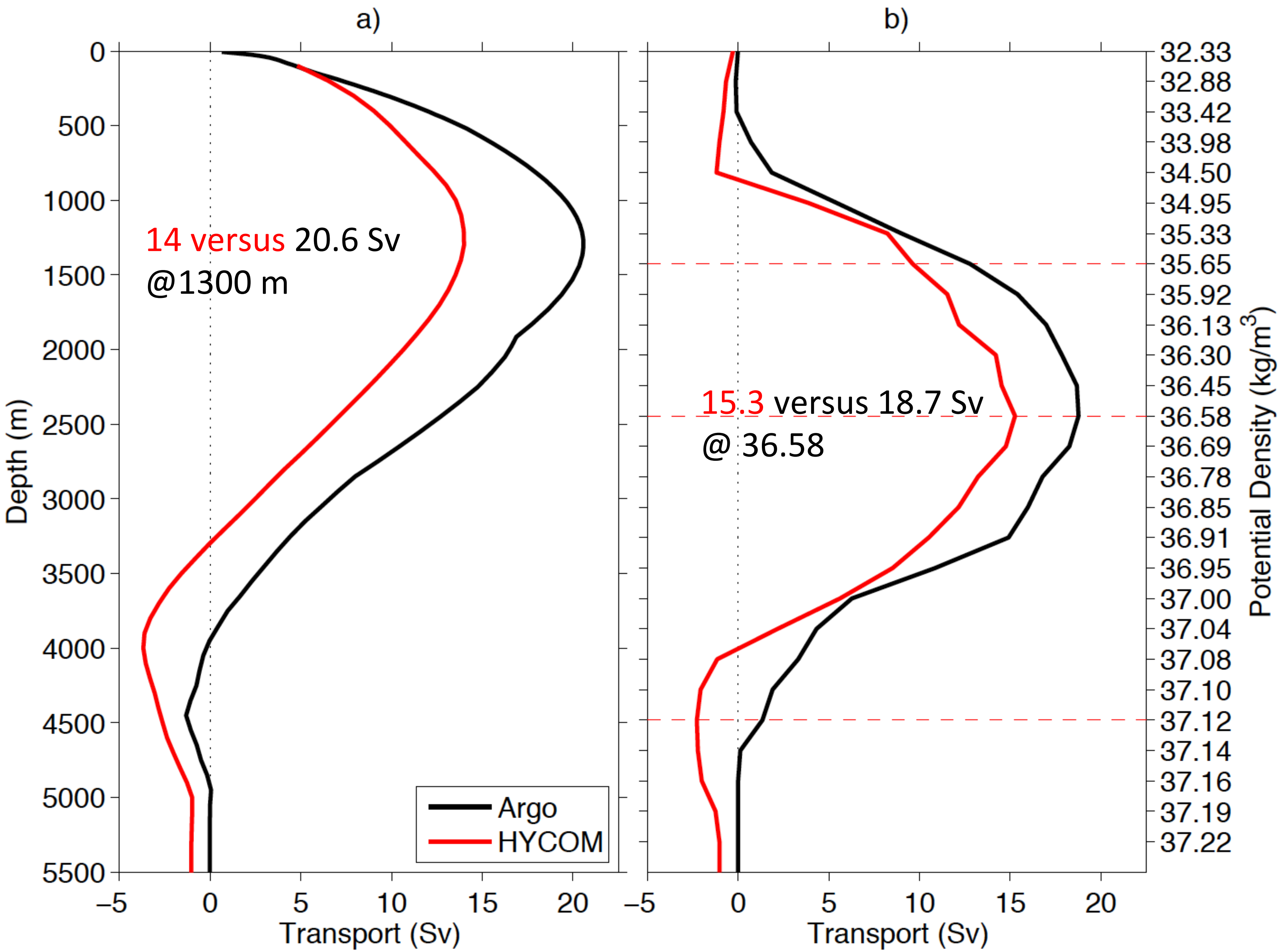
T/S properties along 34°S



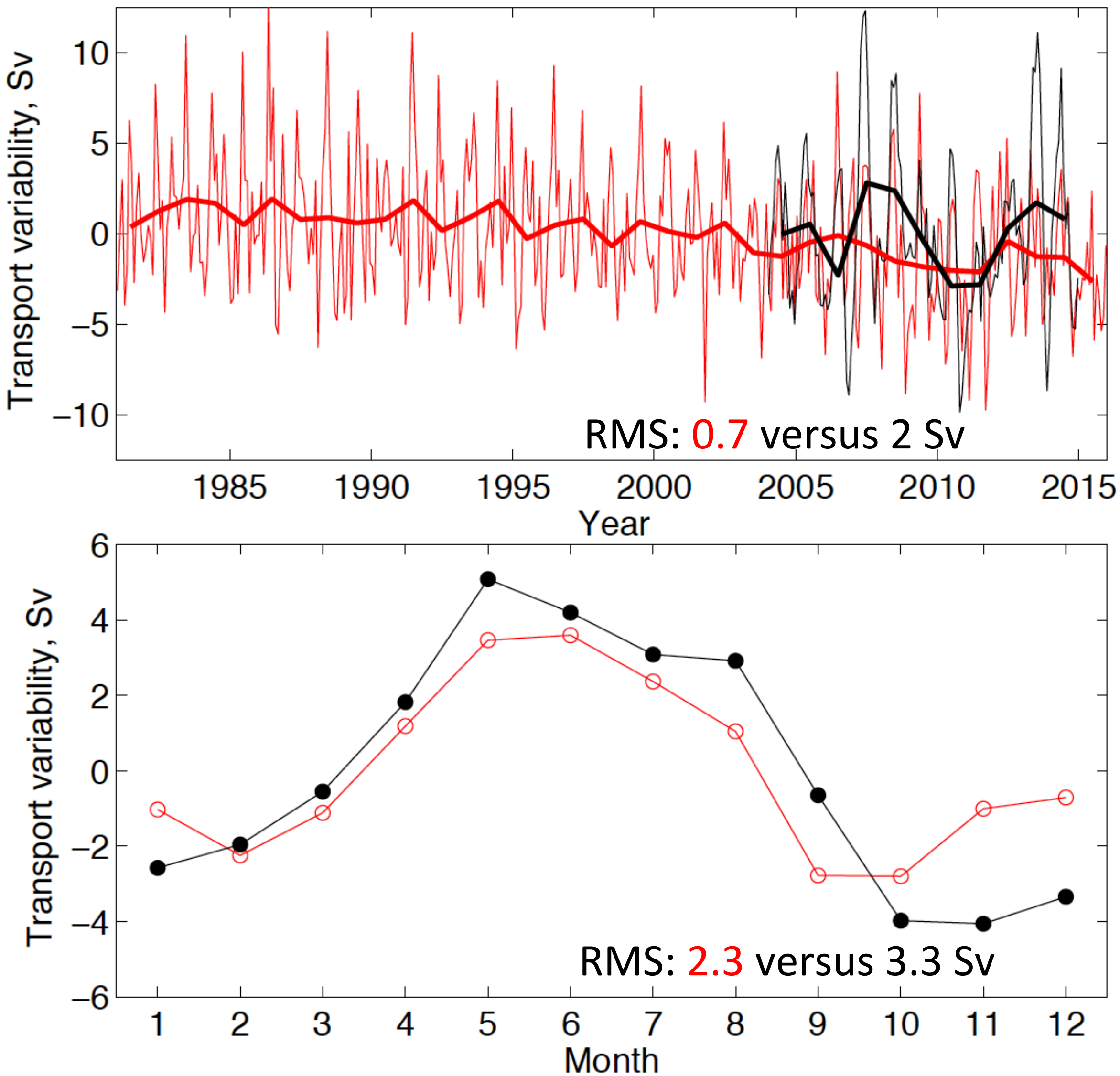
Velocity/transport across 34°S



Mean trans-basin AMOC across 34°S

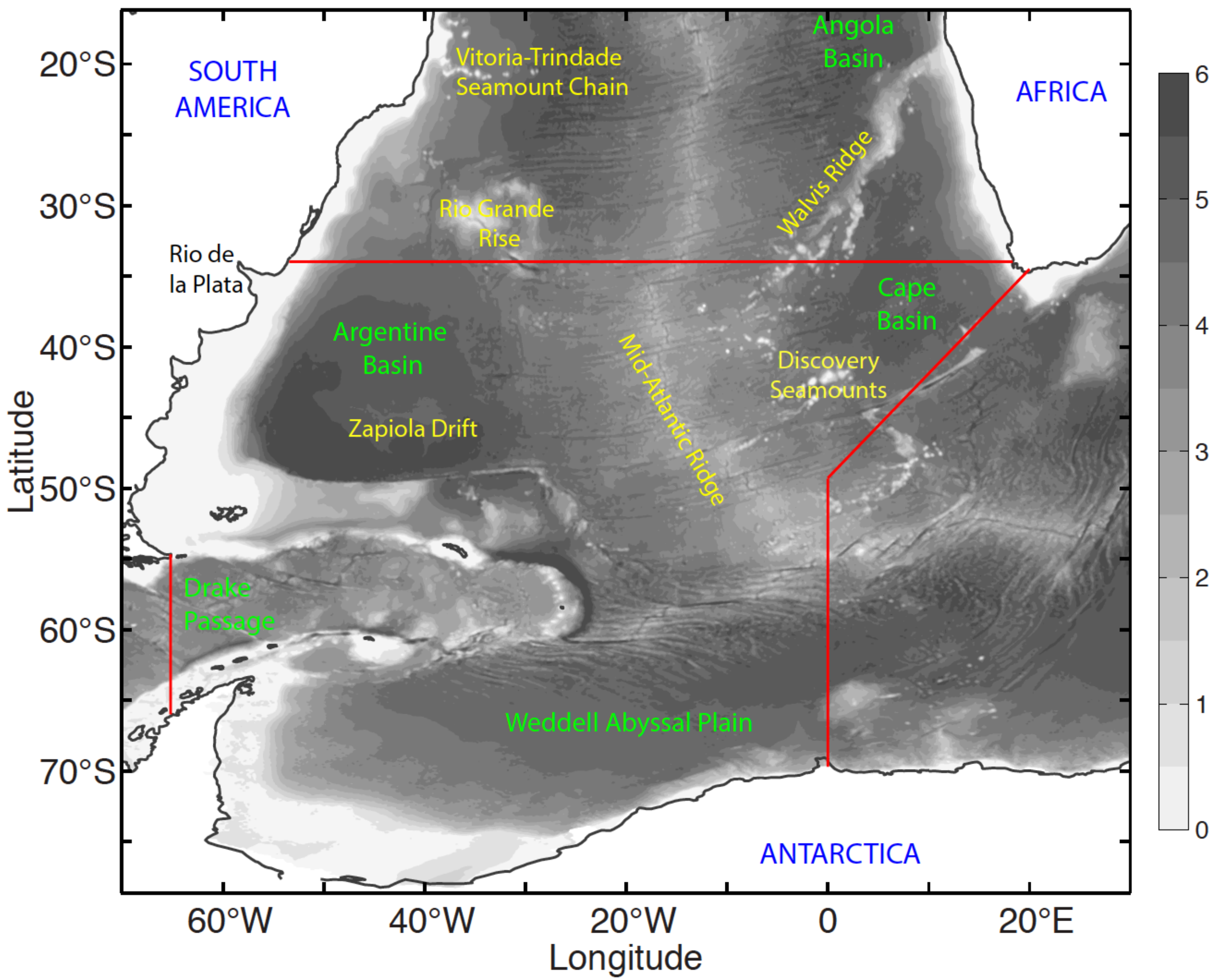


AMOC variability at 34°S

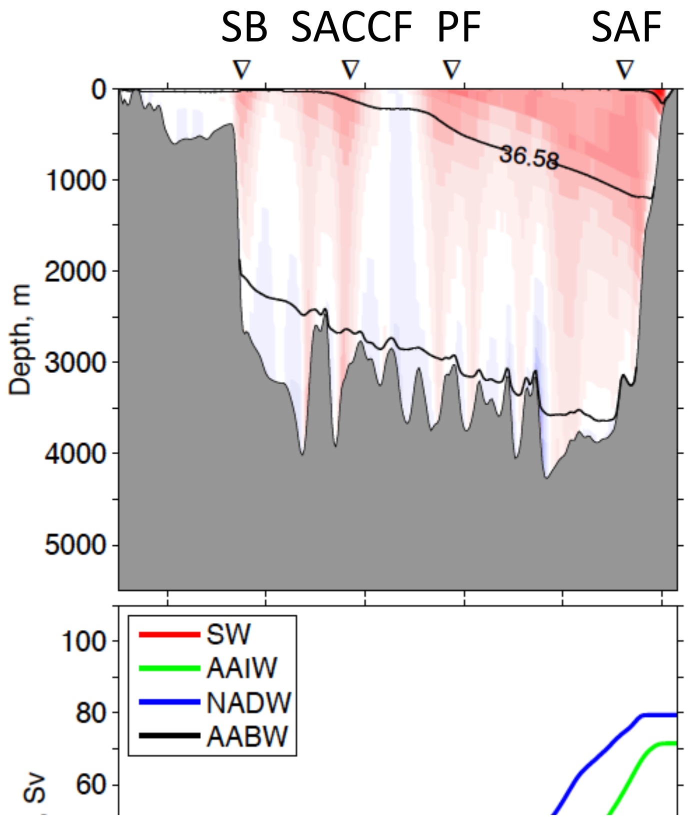


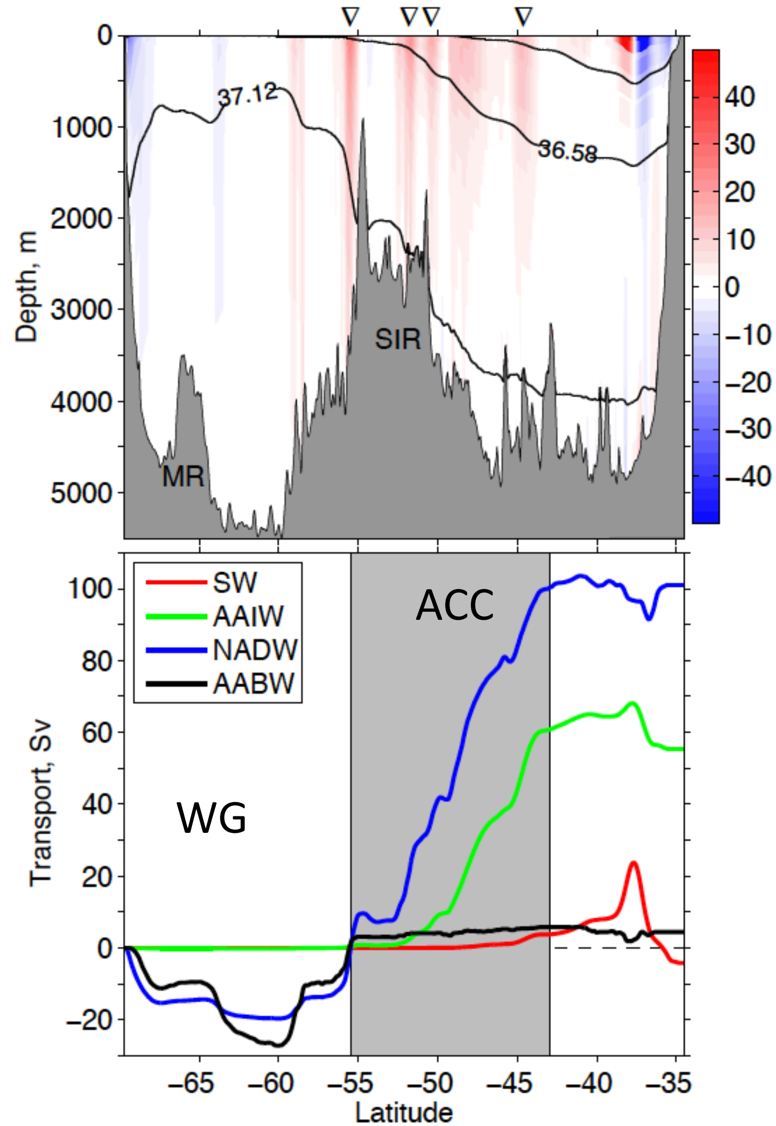
Model results show a weaker variability on both interannual and seasonal timescales (compared to the Argo-WOA13 based observations).

Drake Passage (65°W) & PM-GH



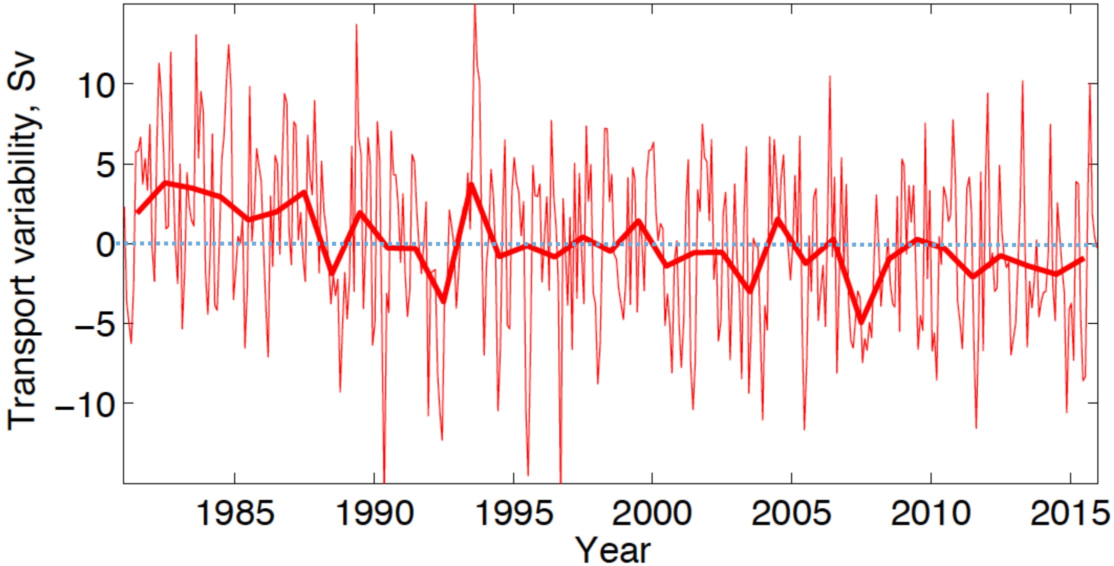
65°W & PM-GH

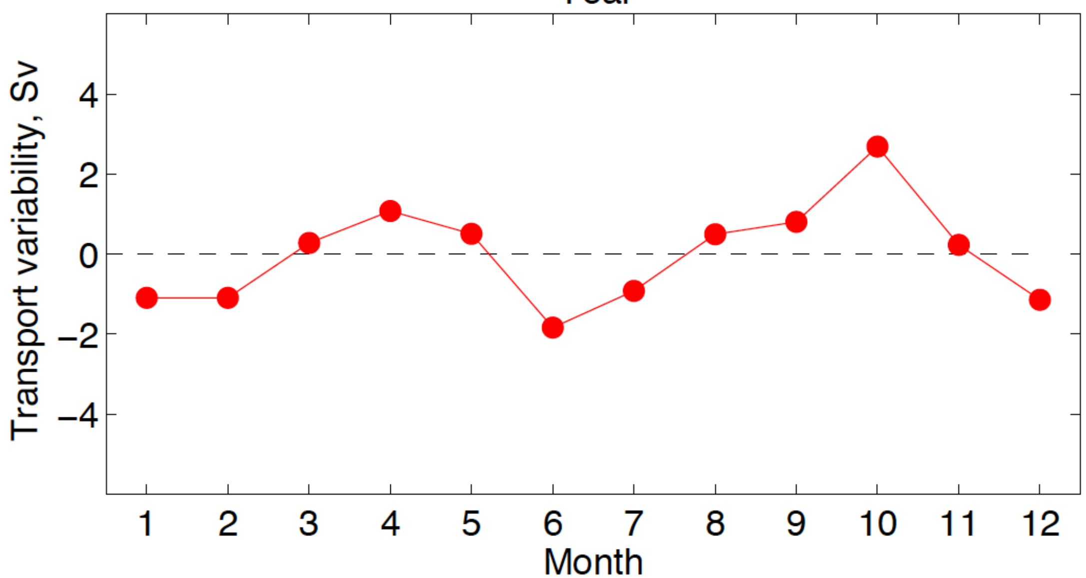




Modeled mean ACC transport 155.5 Sv, compared to 134 Sv (Whitworth, 1983, Whitworth and Peterson, 1985)
141 Sv (Koenig et al. 2014)
173 Sv due to a much higher BT contribution (Donohue et al. 2016)

ACC transport variability at 65°W

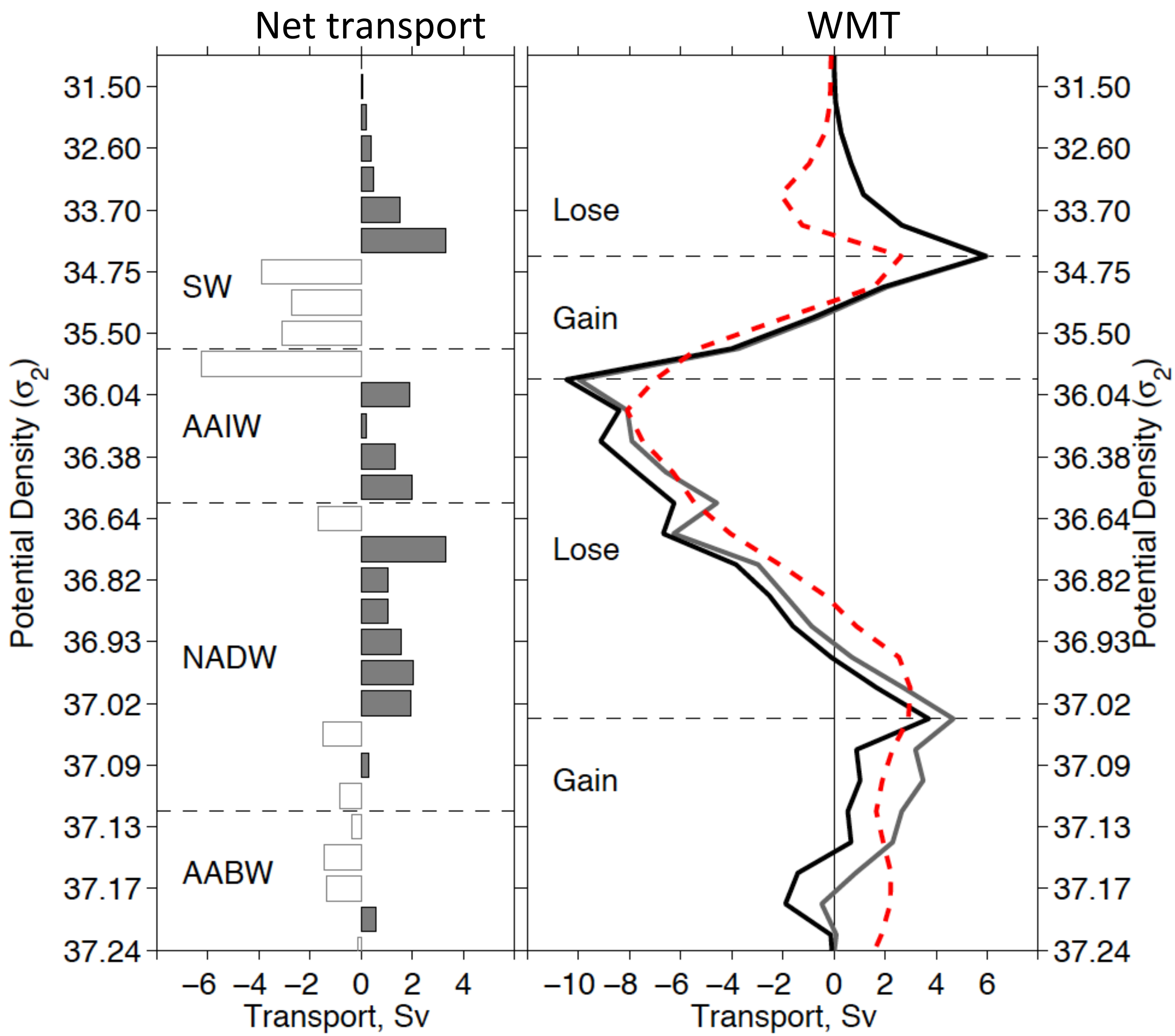




Modeled ACC transport variability has a rms value of 5.2 Sv based on monthly means (2.1 Sv based on annual means). The seasonal variability shows a bi-annual cycle.

Koenig et al (2016) show that ACC transport variability is mostly on intraseasonal timescales, and the low-frequency variability is much weaker, with significant variance to annual and bi-annual timescales.

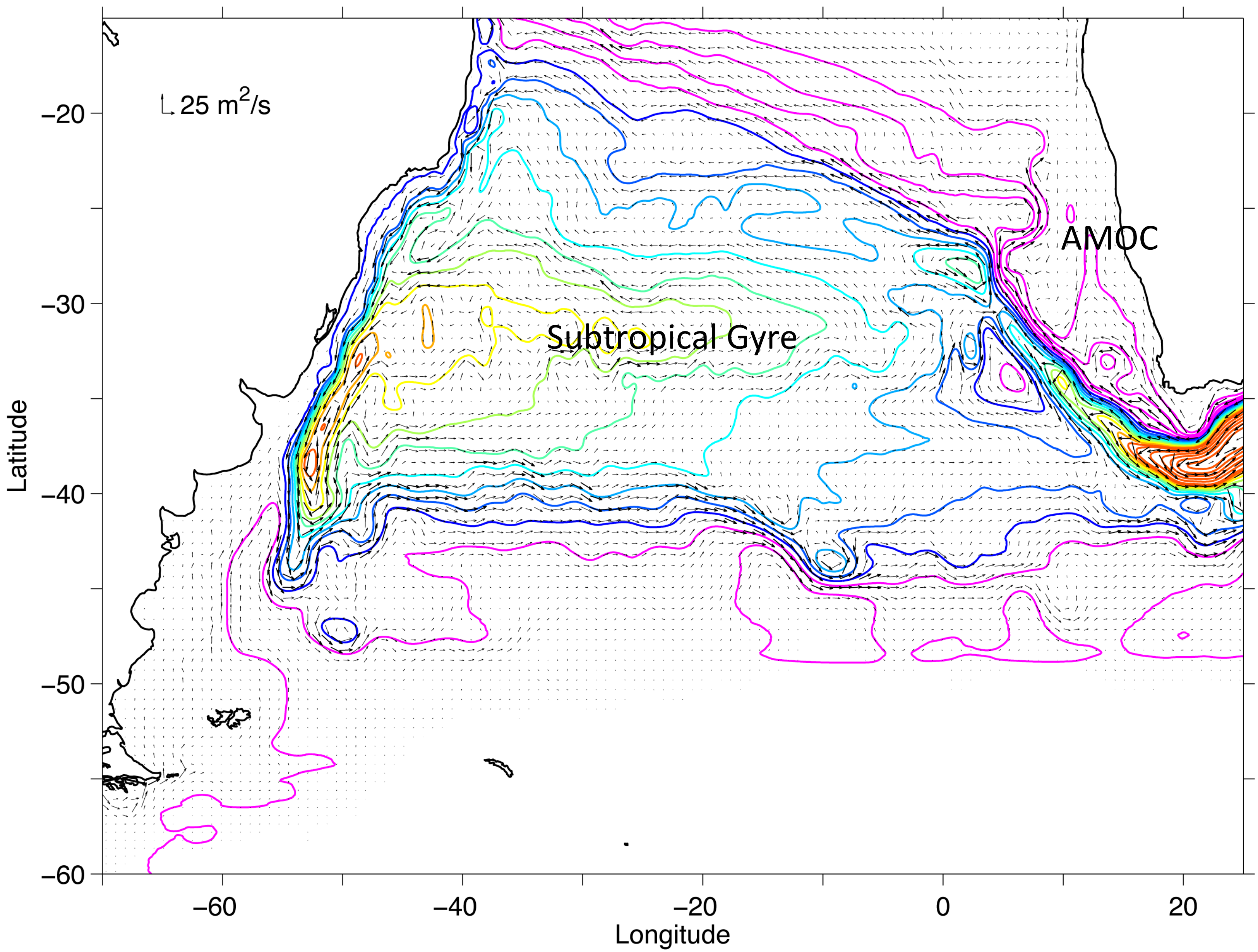
Transformation in Southern Atlantic



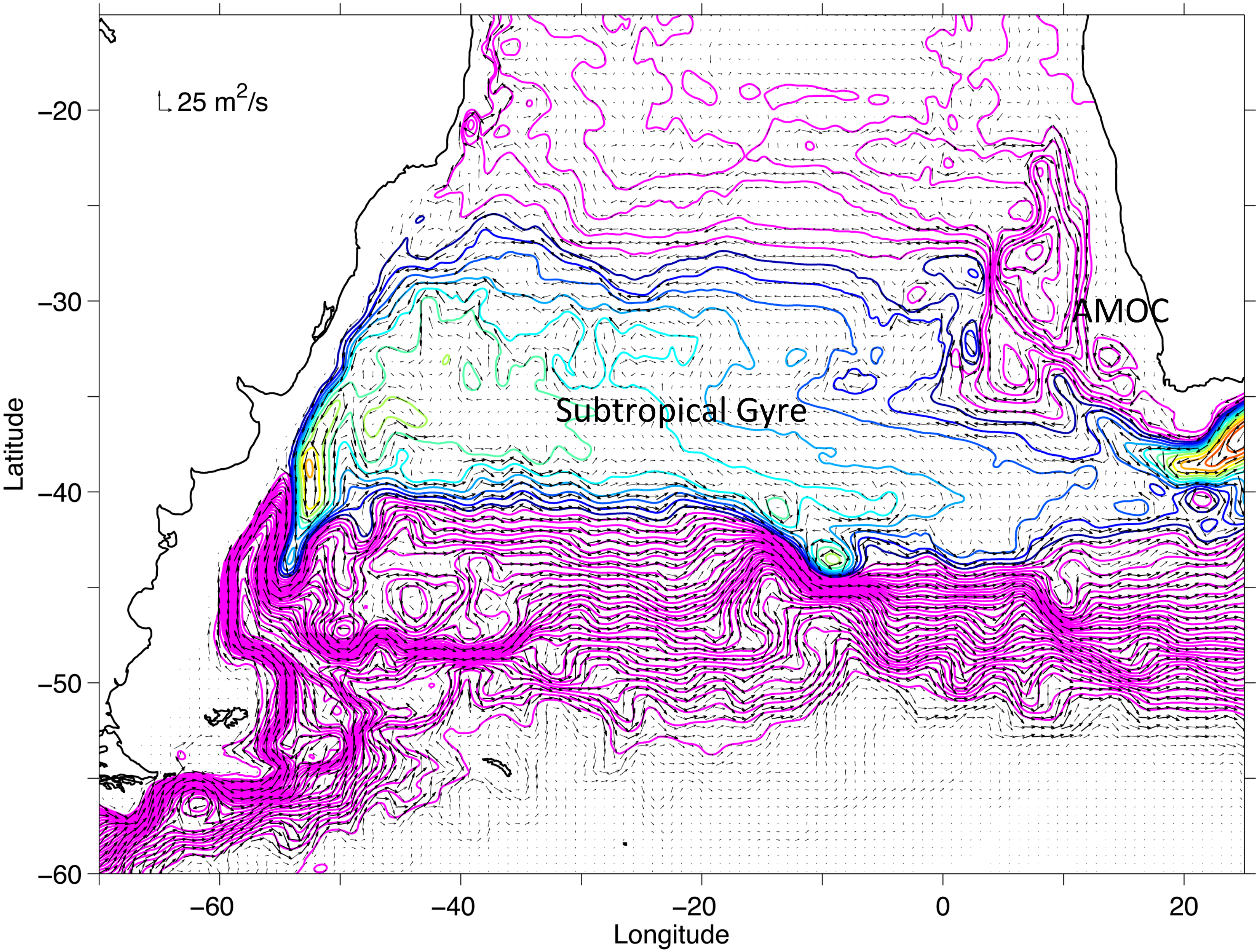
34.50

35.92

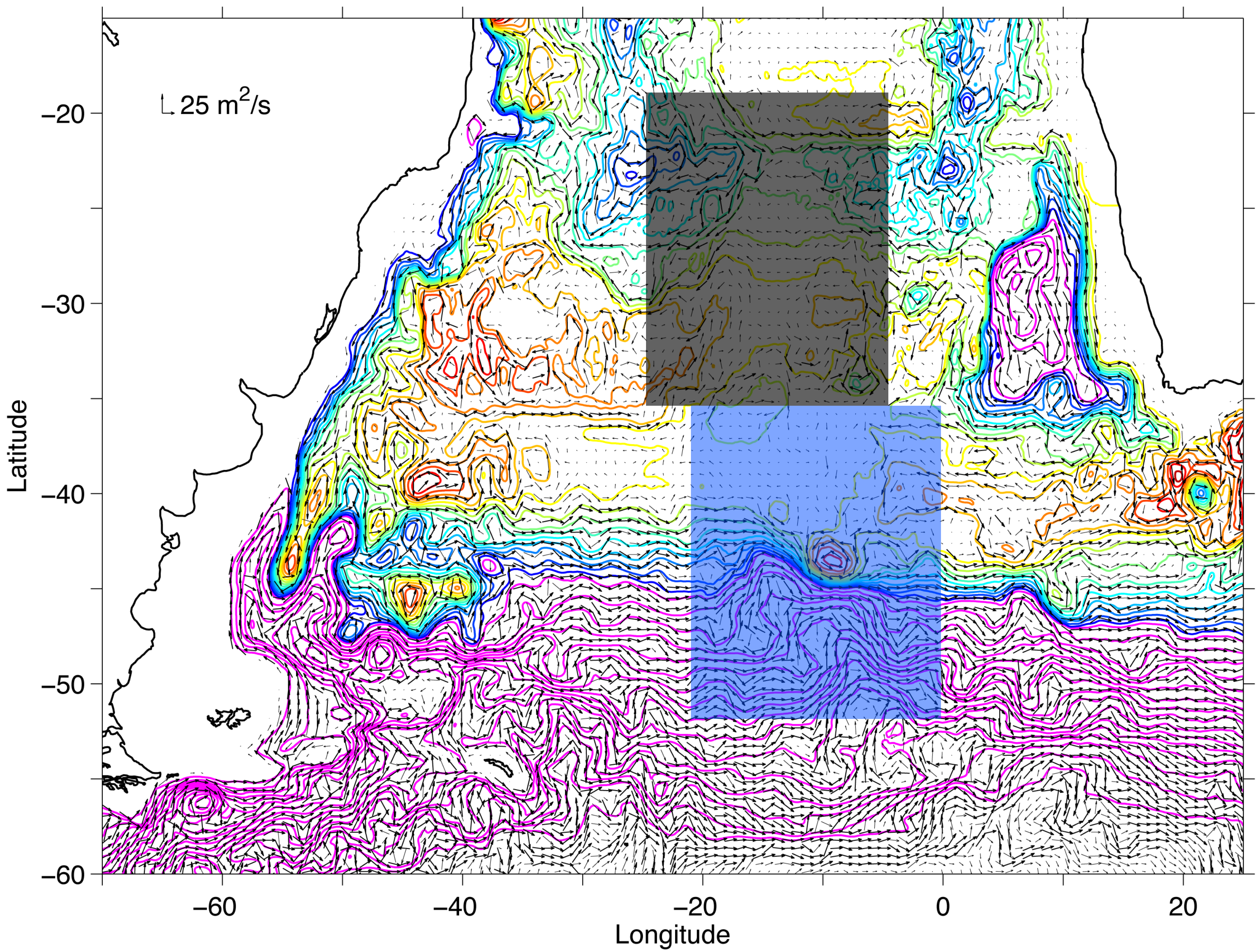
Horizontal circulation (SW)

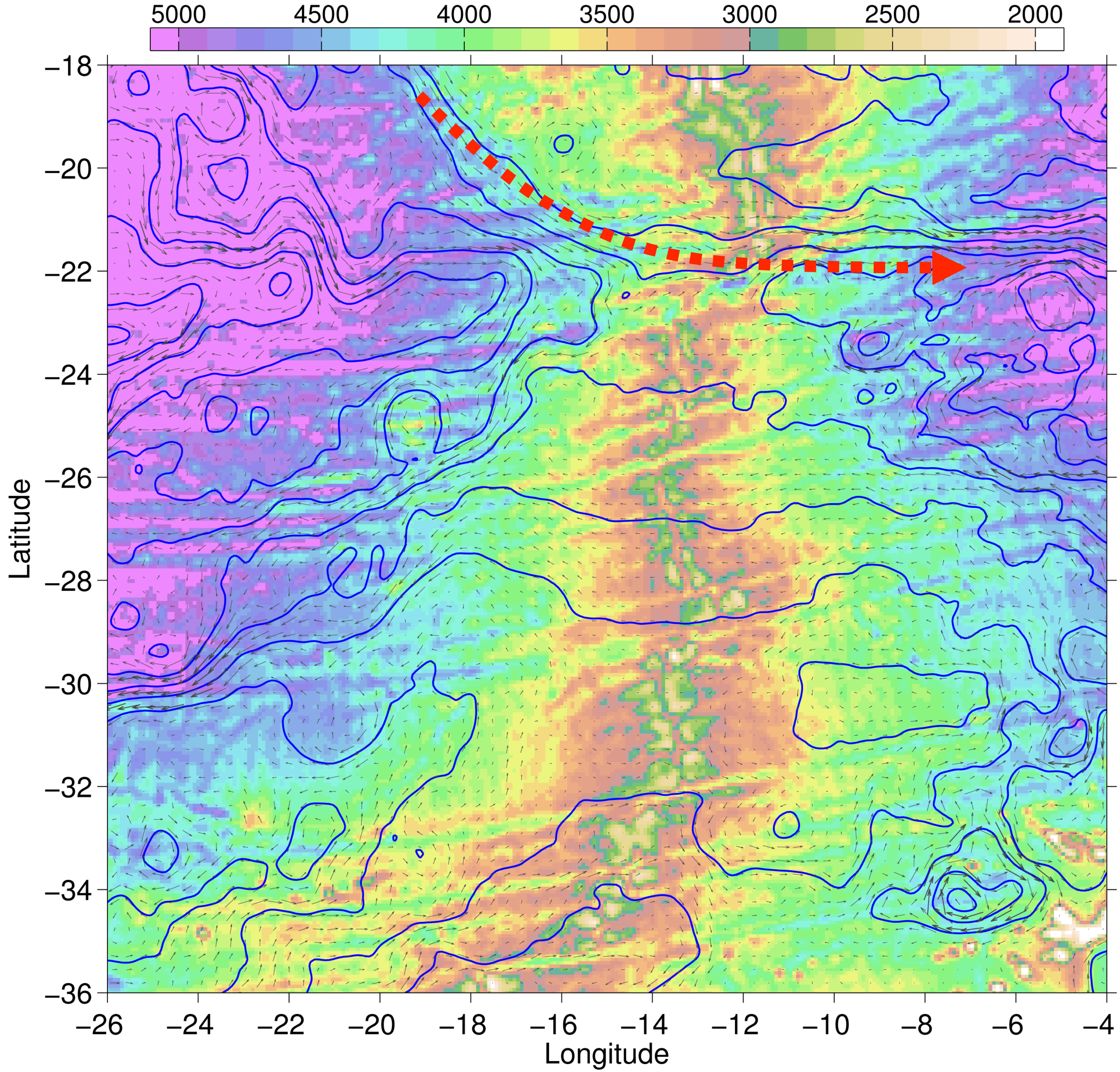


Horizontal circulation (AAIW)



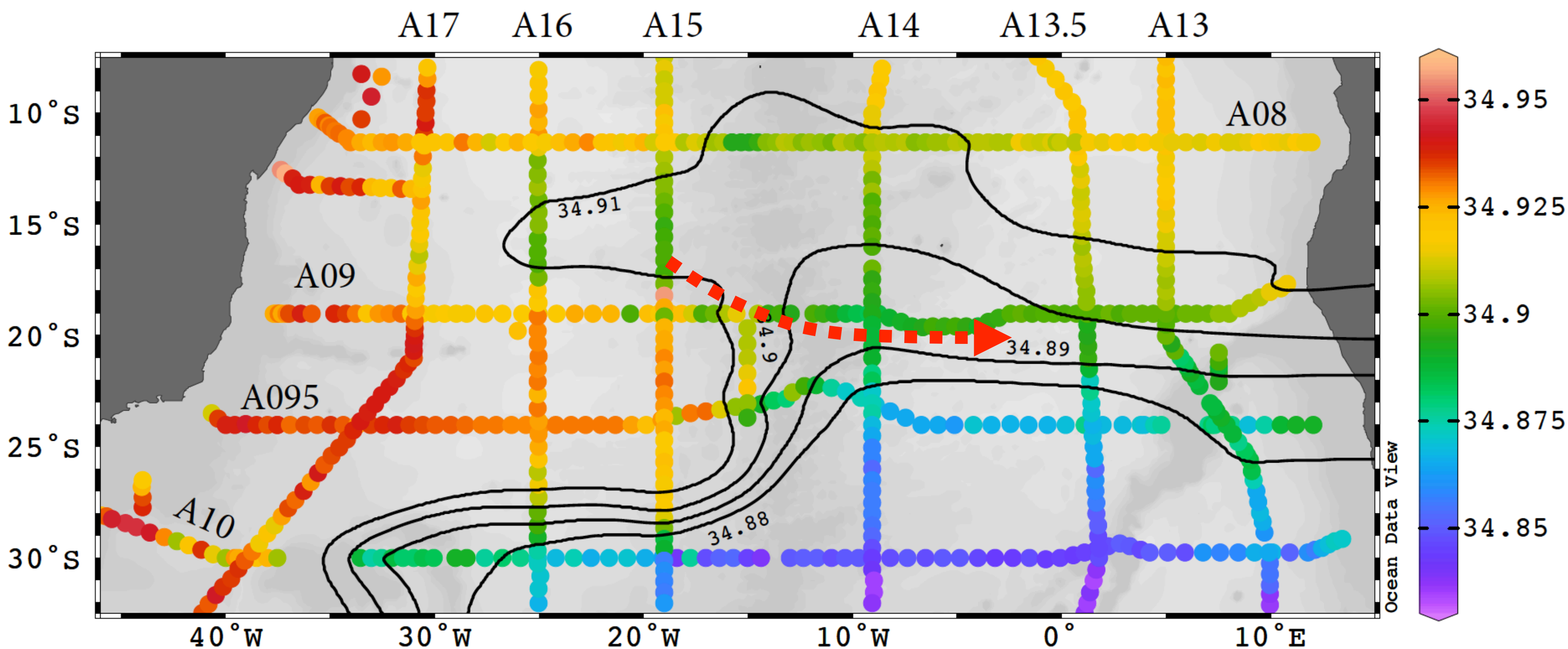
Horizontal circulation (NADW)

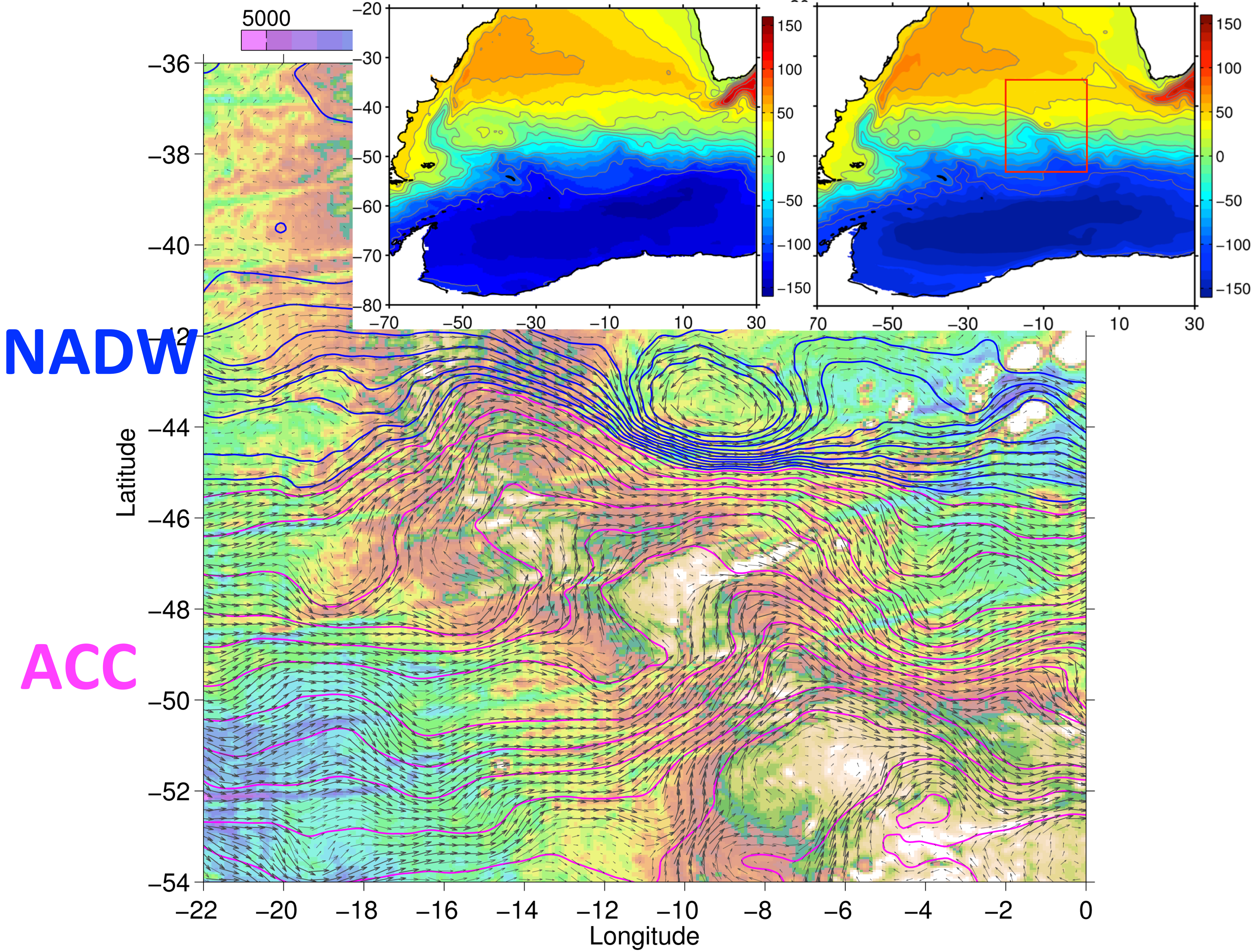




5000
4500
4000
3500
3000
2500
2000
−18
−20
−22
−24
−26
−28
−30
−32
−34
−36
Latitude
−26
−24
−22
−20
−18
−16
−14
−12
−10
−8
−6
−4
Longitude

Salinity distribution at 2500 m





NADW
ACC
5000
Latitude
Longitude

Summary

- The model results represent reasonable well the vertical-horizontal structure of the AMOC, ACC, and Weddell gyre in the southern Atlantic Ocean. The magnitude of the modeled mean transports differs from observations by 10-30%.

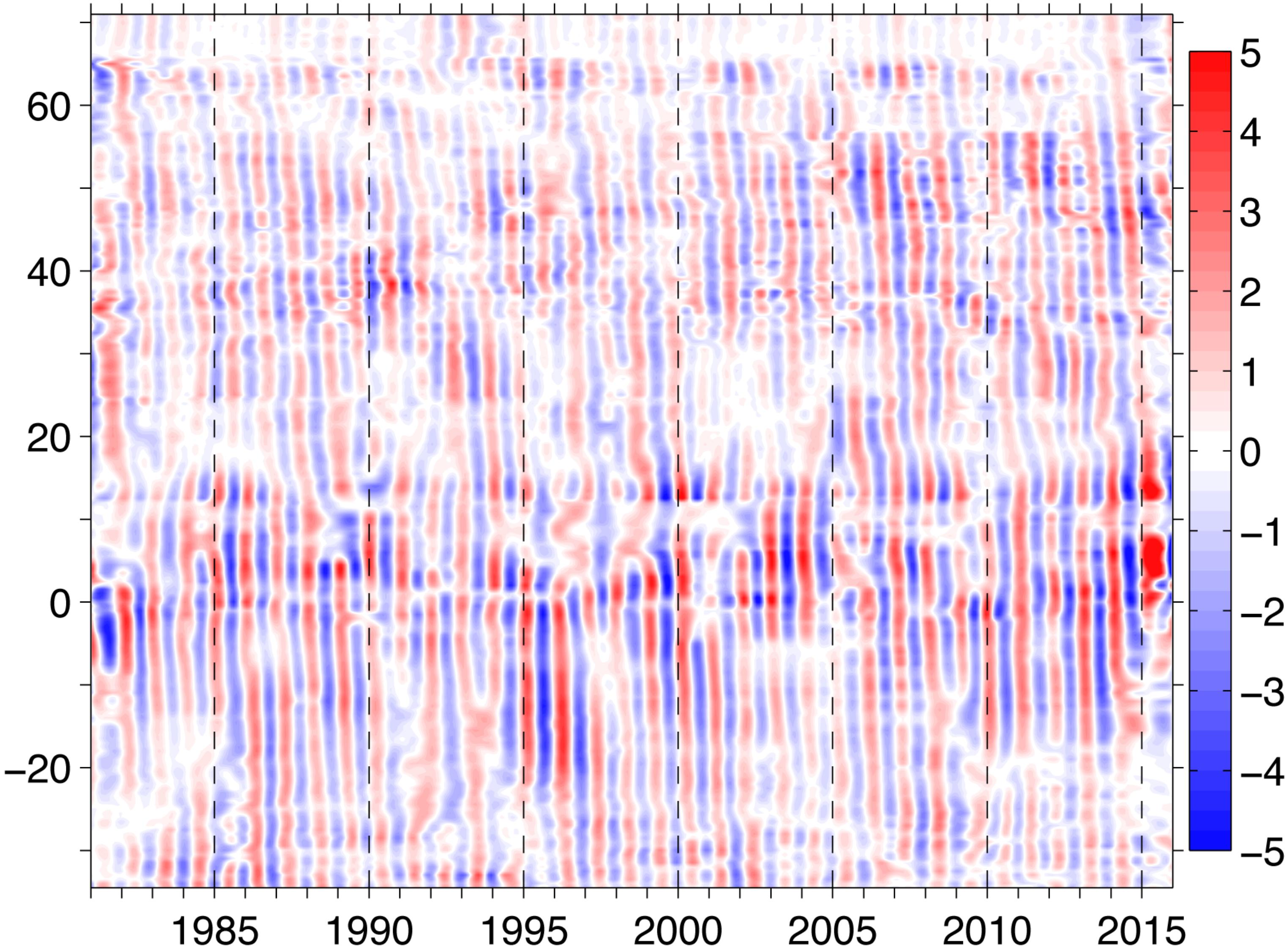
- Upper limb of the AMOC is from Agulhas leakage and the super gyre (which connects the subtropic of the Indian/Atlantic oceans) prevents a direct feeding of the cold Pacific water to the AMOC (the cold water does modify the water property of the southern Atlantic Ocean-heat/freshwater transport).

- The lower limb of the AMOC (NADW) flows southward along western boundary to near 45S and turns eastward to flow across the Mid-Atlantic Ridge.

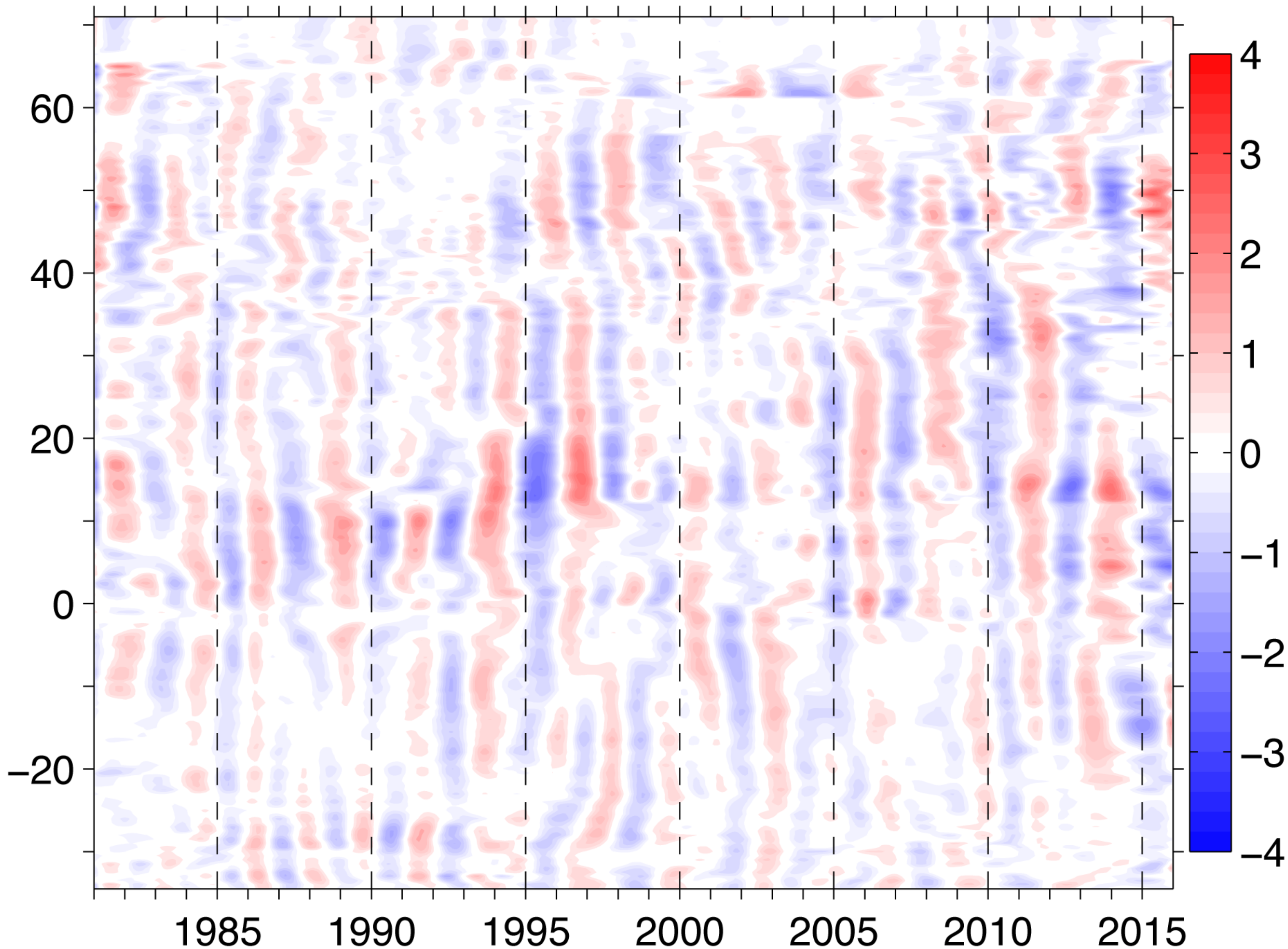
Is the AMOC coherent in latitude?

To examine the coherence on different timescales, we decompose the AMOC transport at each latitude (1980-2015) into a series of “intrinsic mode functions” or IMFs using the ensemble mode decomposition (EEMD, Wu and Huang, 2009). Then piece together the same IMF to construct the variability over the whole Atlantic domain.

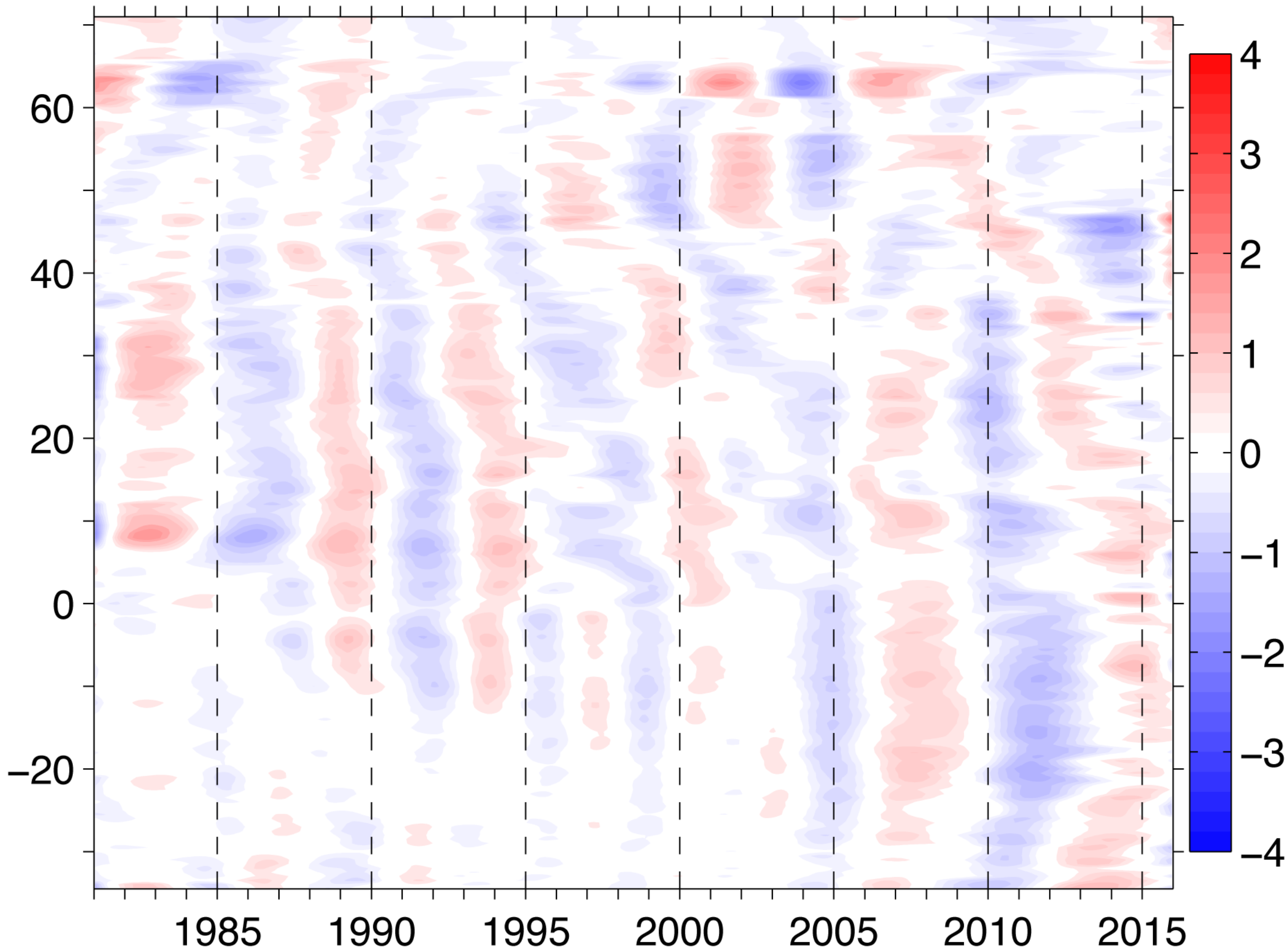
IMF3 (Seasonal scale)



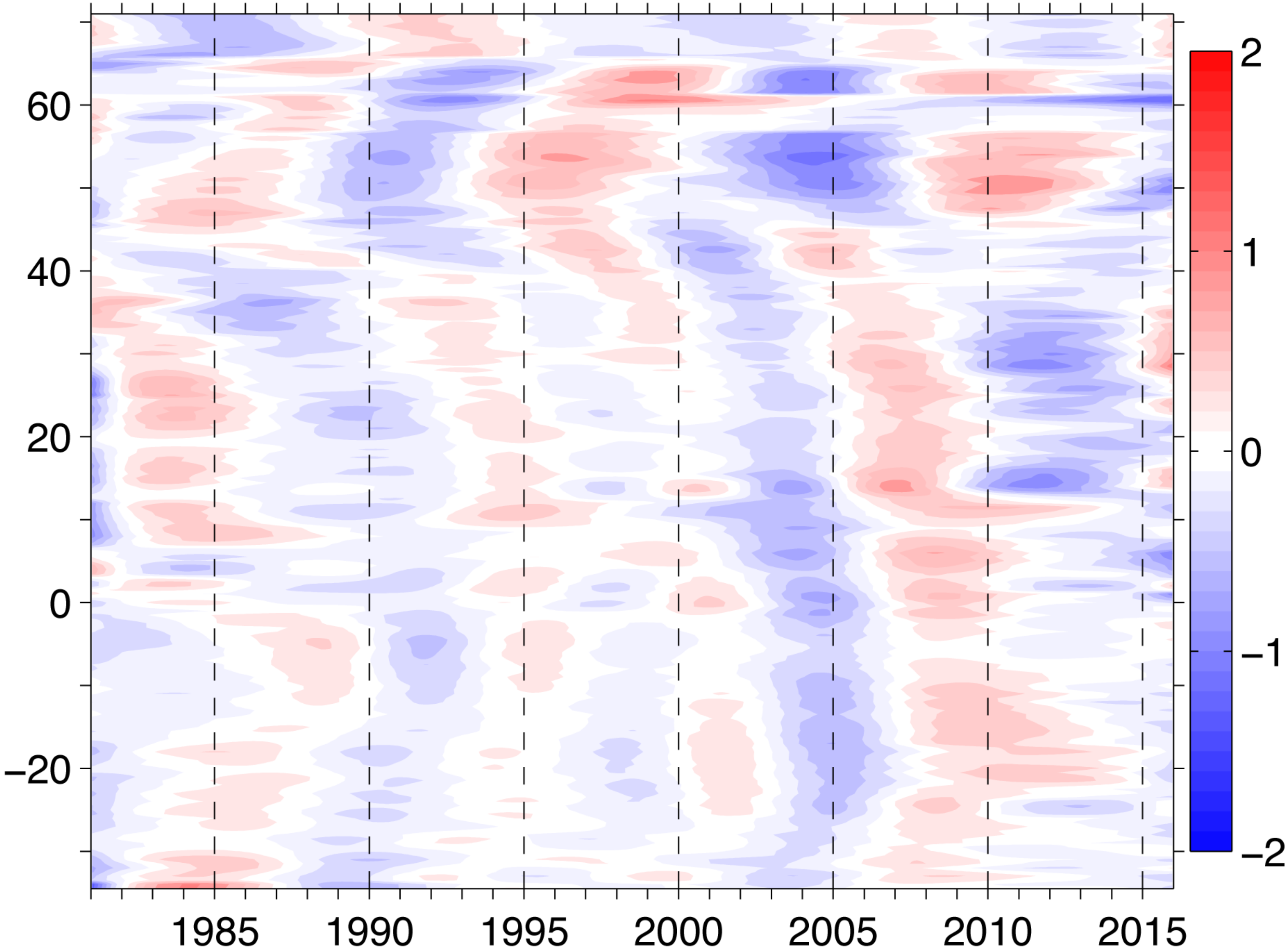
IMF4 (Interannual scale)



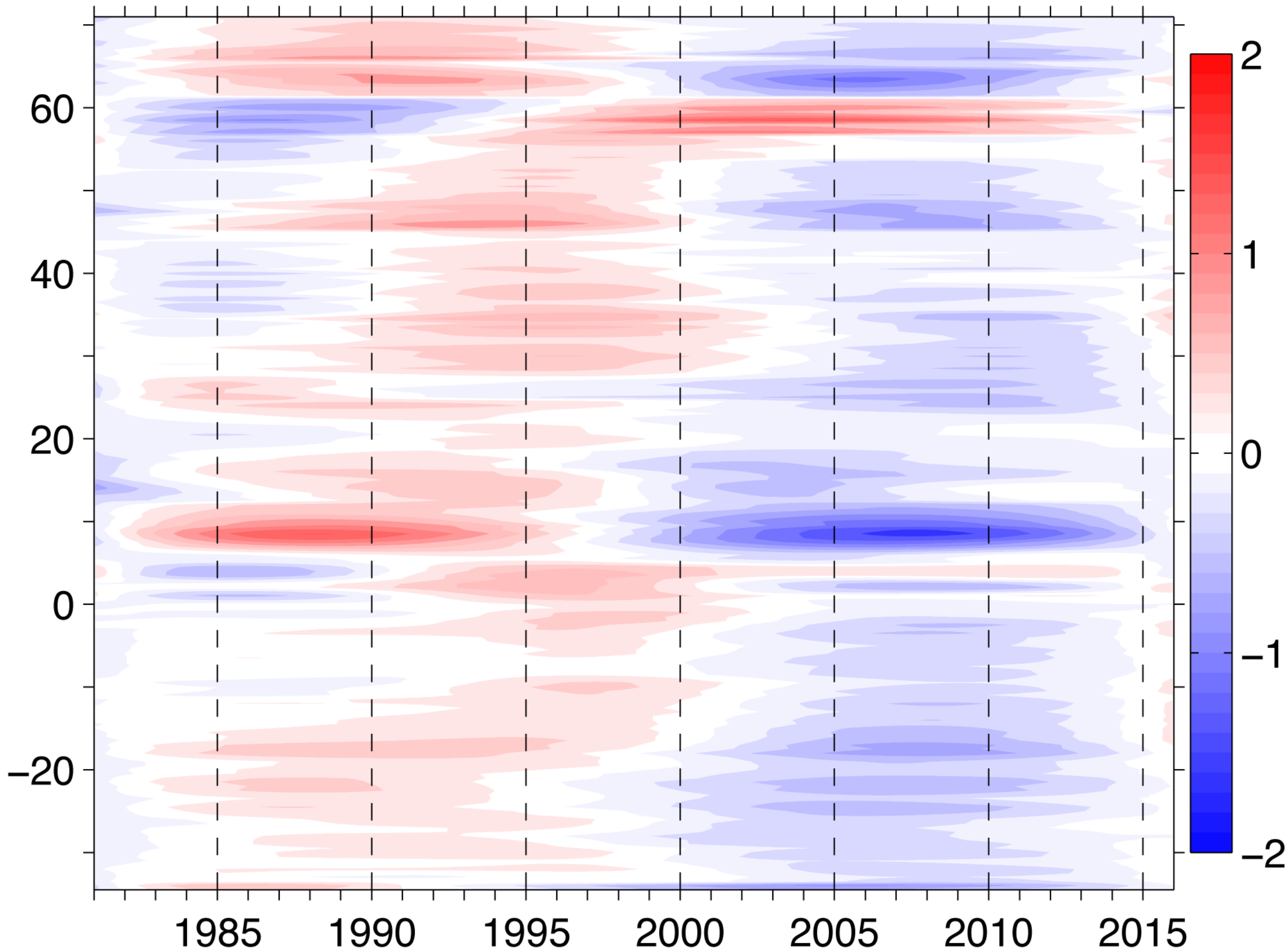
IMF5 (Interannual scale)



IMF6 (decadal scale)

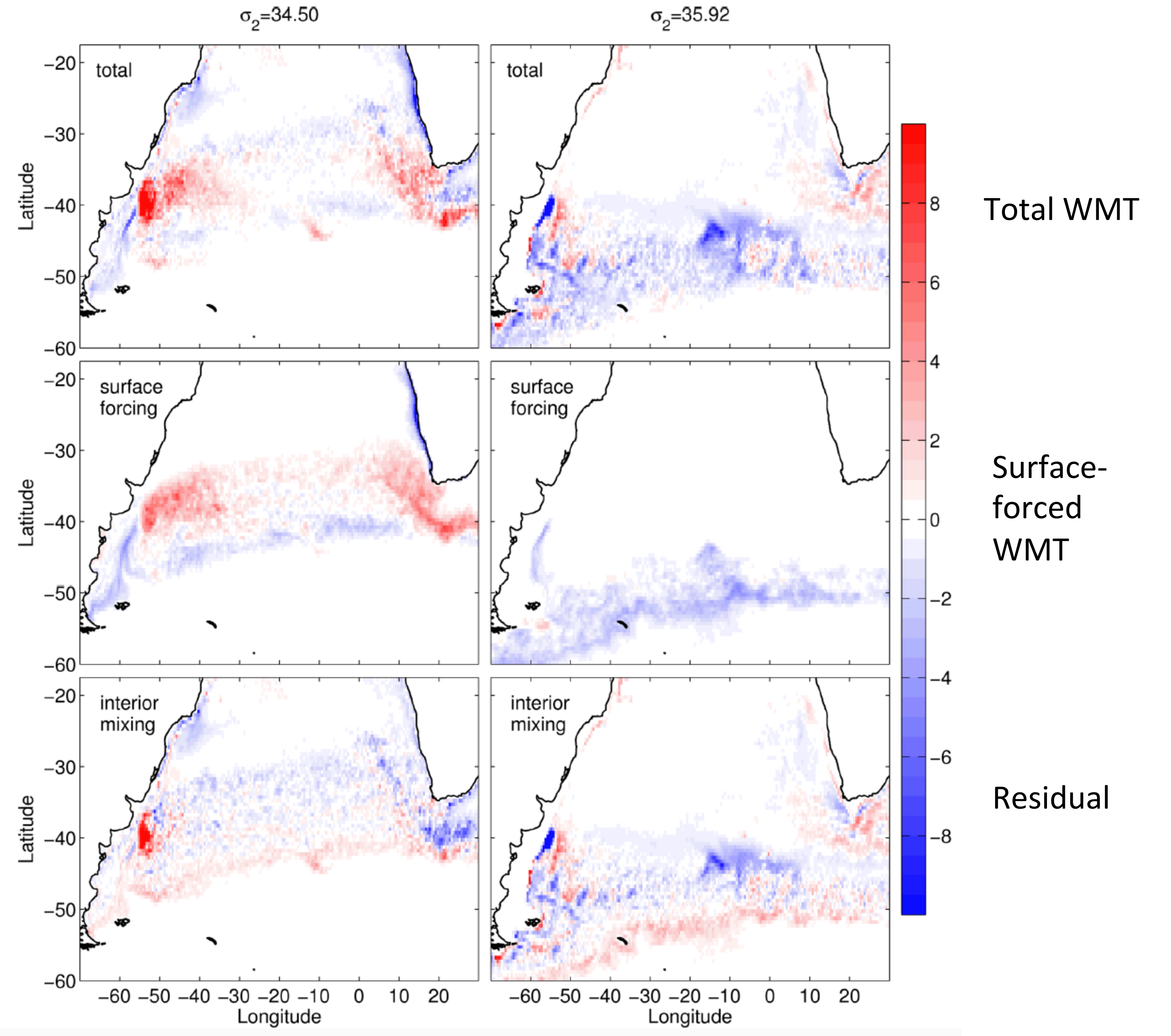


IMF7 (decadal scale)



Summary

- The AMOC variability exhibits significant coherence from seasonal to decadal timescales.



σ2=34.50
σ2=35.92
total
surface forcing
interior mixing
Latitude
Longitude
Total WMT
Surface-forced WMT
Residual