AMOC Observing System Implementation and Evaluation

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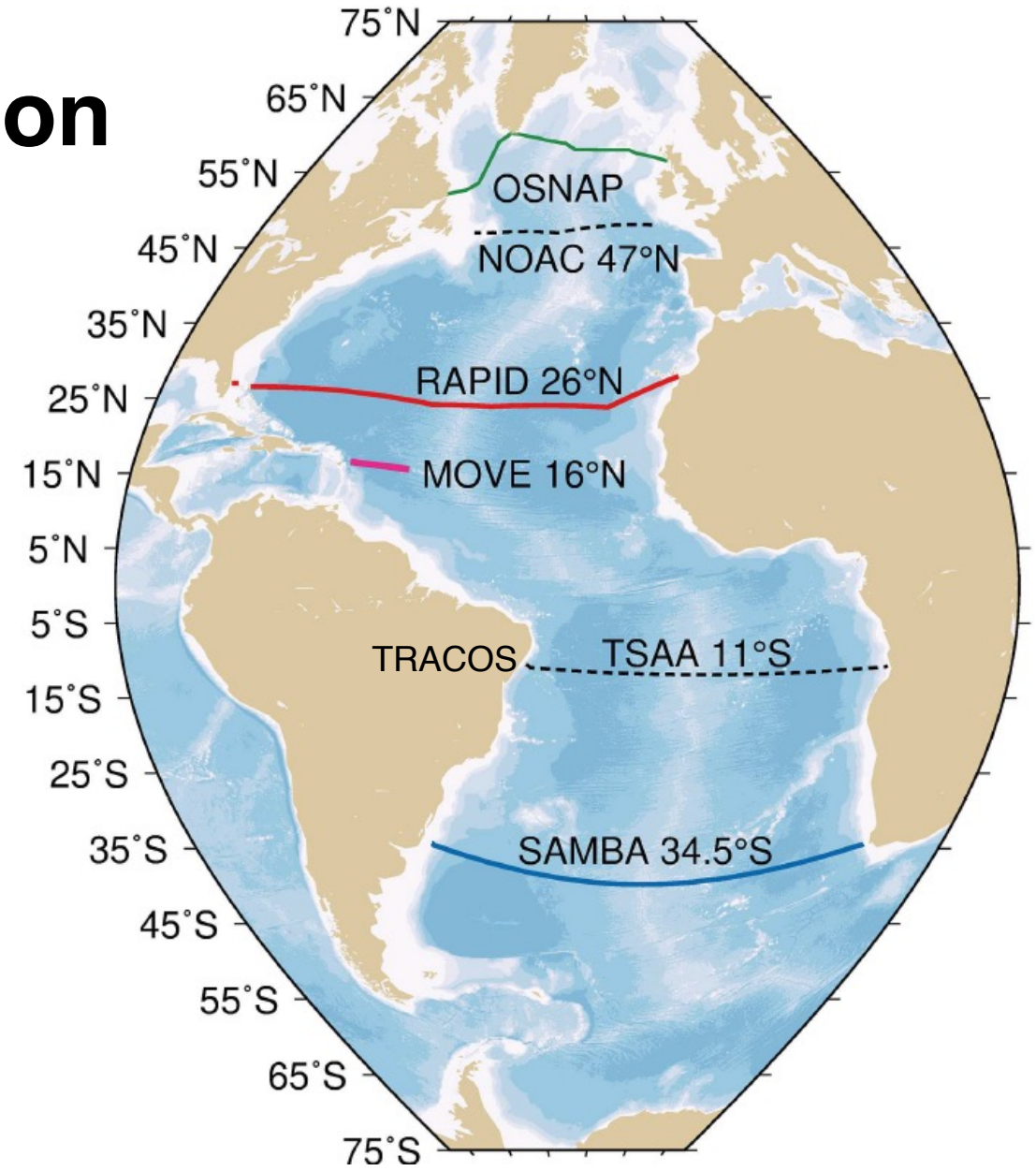


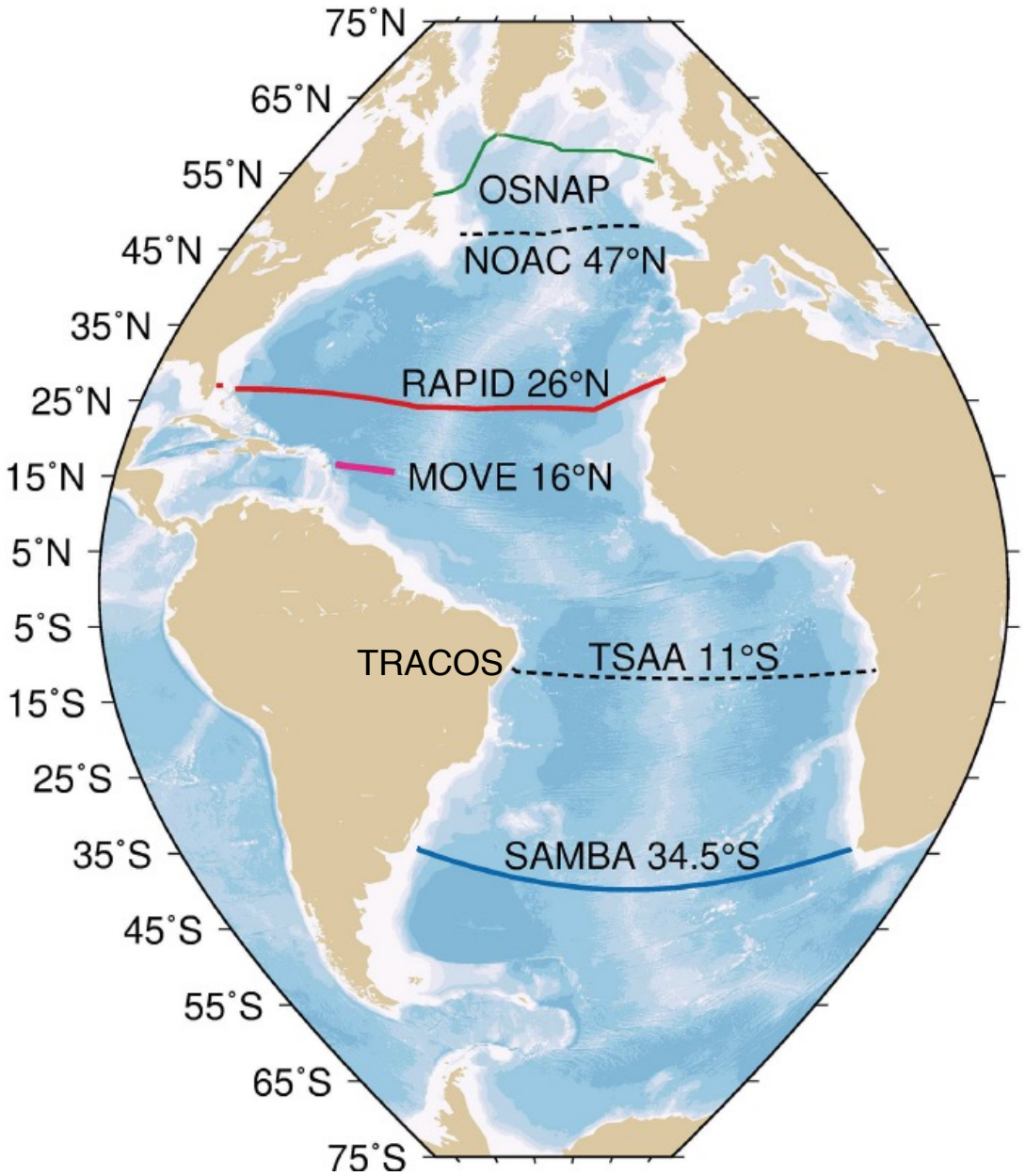
Frajka-Williams et al., 2019

Thank you to: Susan Lozier, Bill Johns, Renellys Perez, Eleanor Frajka-Williams, Renske Gelderloos, Ali Siddiqui, Greg Koman, Duo Chan, Arne Biastoch, Matthias Lankhorst

AMOC Observing System Implementation

Array	Configuration	Core variables
OSNAP	Trans-basin mooring array 53°N-60°N	MOC, MHT, MFT 30-day resolution 2014-present
NOAC	Trans-basin mooring + PIES array at 47°N	MOC Bi-monthly 2016-present
RAPID	Trans-basin mooring array at 26.5°N	MOC, MHT, MFT 10-day resolution 2004-present
MOVE	Western basin PIES array	MOC Daily resolution 2000-present
TRACOS	Trans-basin PIES array at 11°S	MOC 5-day resolution 2013-present
SAMBA	Trans-basin PIES array at 34.5°S	MOC, MHT Daily resolution 2009-2010; 2013-present

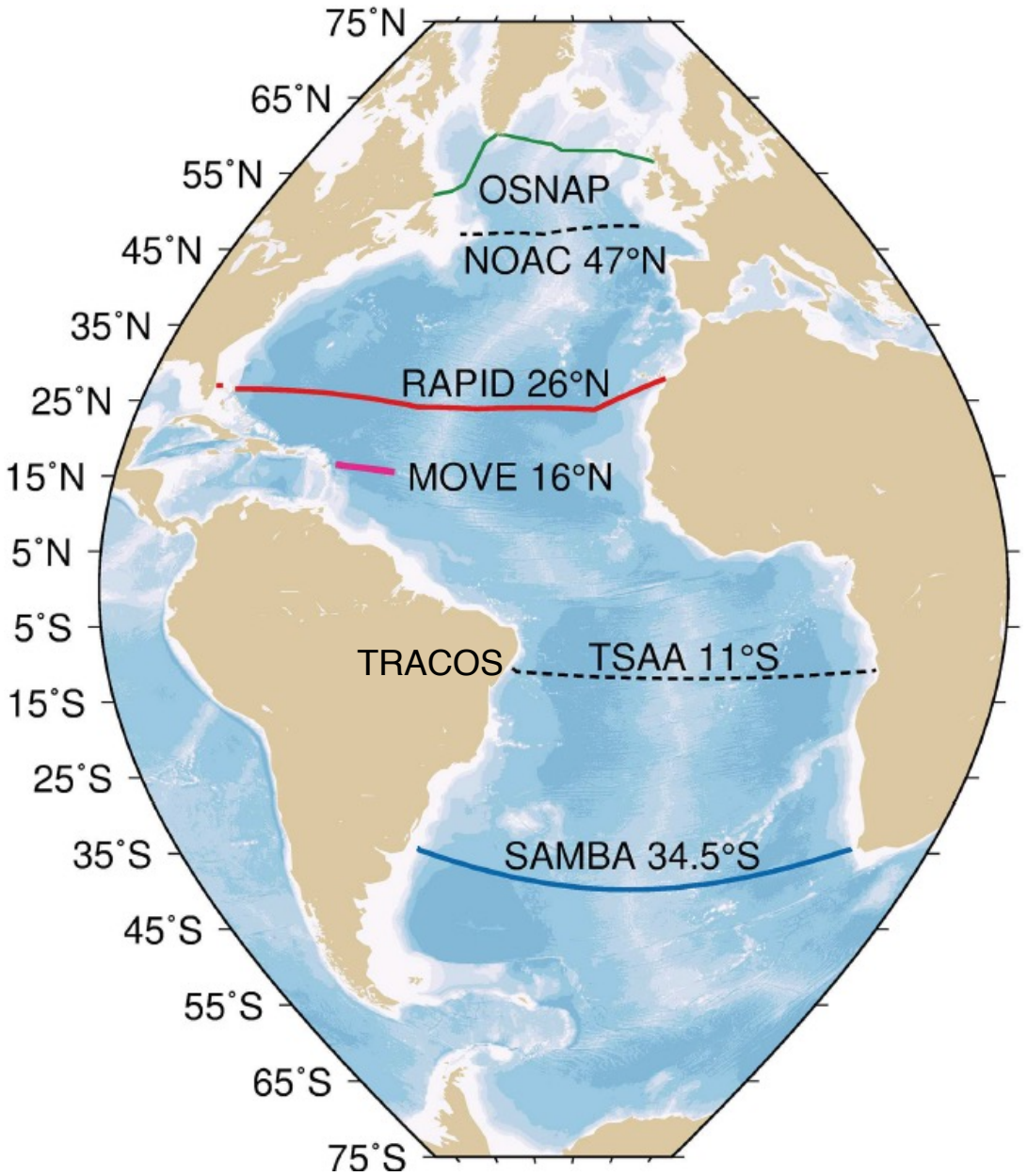
Argo/SSH lines at: 41°N, 20°S, 25°S, 30°S, 35°S
Commercial ships: Oleander, Nuka Arctica, Norröna
Hydrography: OVIDE, among others



Frajka-Williams et al., 2019

AMOC Observing System Implementation

Array	Reference velocity	Coordinate
OSNAP	Time-mean altimetry + barotropic velocity chosen to zero the net mass transport	Density
NOAC		Density
RAPID	Chosen to zero the net mass transport	Depth
MOVE	Level of no motion	Depth
TRACOS	Time-varying barotropic velocity from PIES + time-mean level of no motion at 1130 m	Depth
SAMBA	Time-varying barotropic velocity from PIES + time-mean from ECCO2	Depth



Frajka-Williams et al., 2019

AMOC Observing System Evaluation

Recommendations to facilitate evaluation

1. Adopt a common set of standards between mooring arrays:
    a. Report overturning in density space
    b. Reference velocity shear to satellite altimetry
    c. Publish time series of compensation transports

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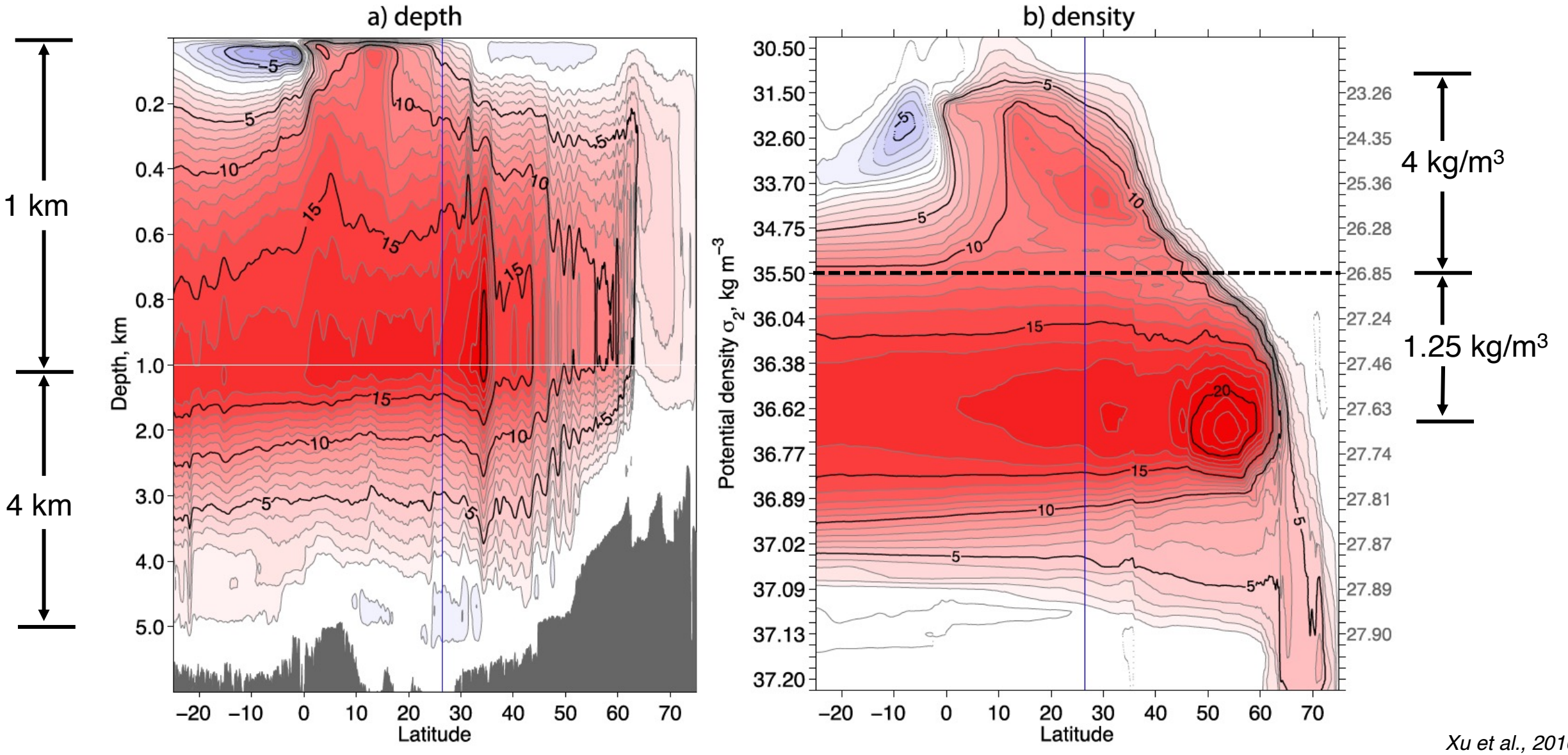
2. Conduct more Observing System Simulation Experiments (OSSEs):
    a. Use the entire AMOC observing system rather than individual arrays
    b. Evaluate MHT and MFT in addition to MOC
    c. Compare OSSE results across multiple models

1a. Report overturning in density space

HYCOM 1/12° AMOC



Xu et al., 2016

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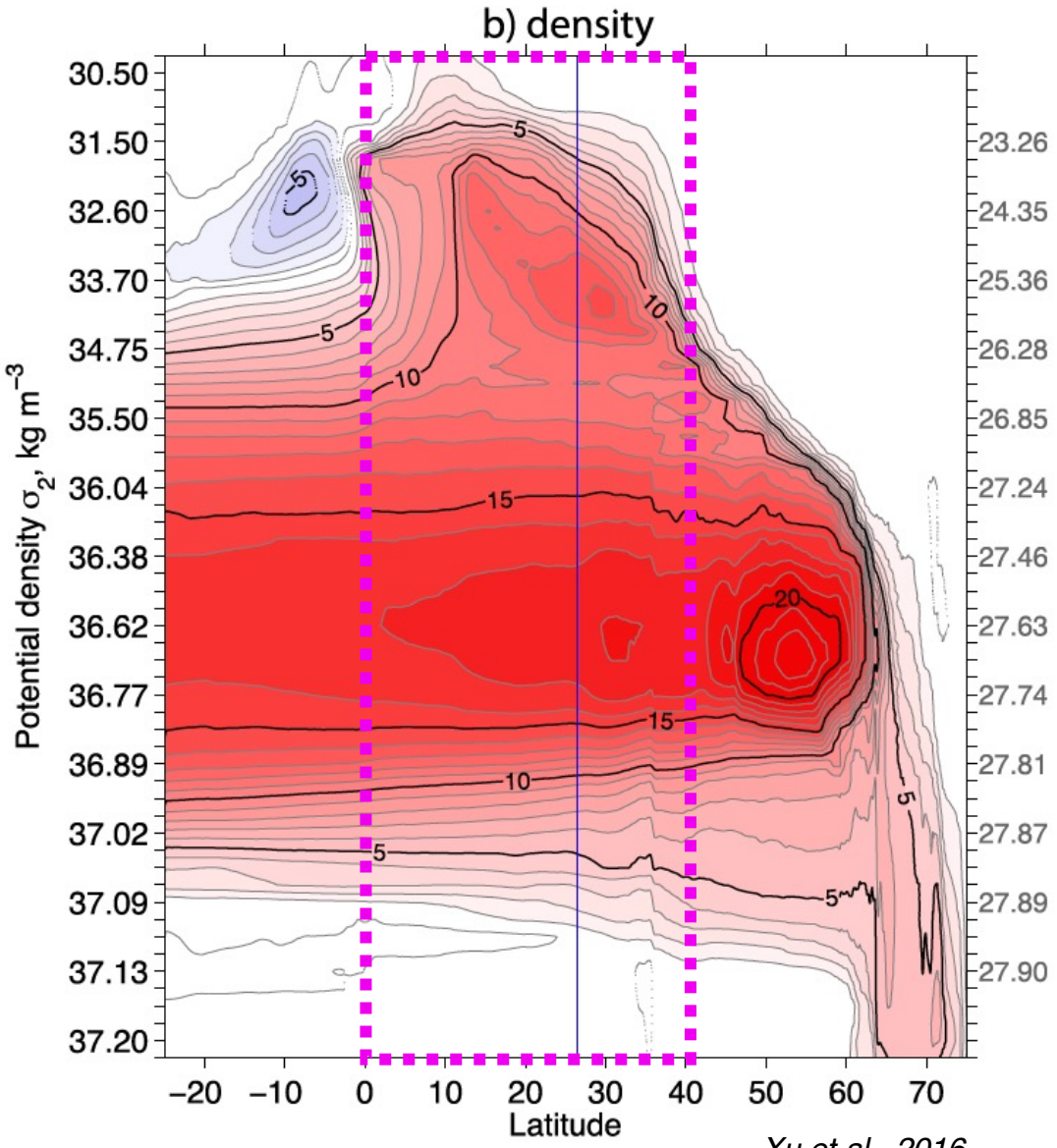
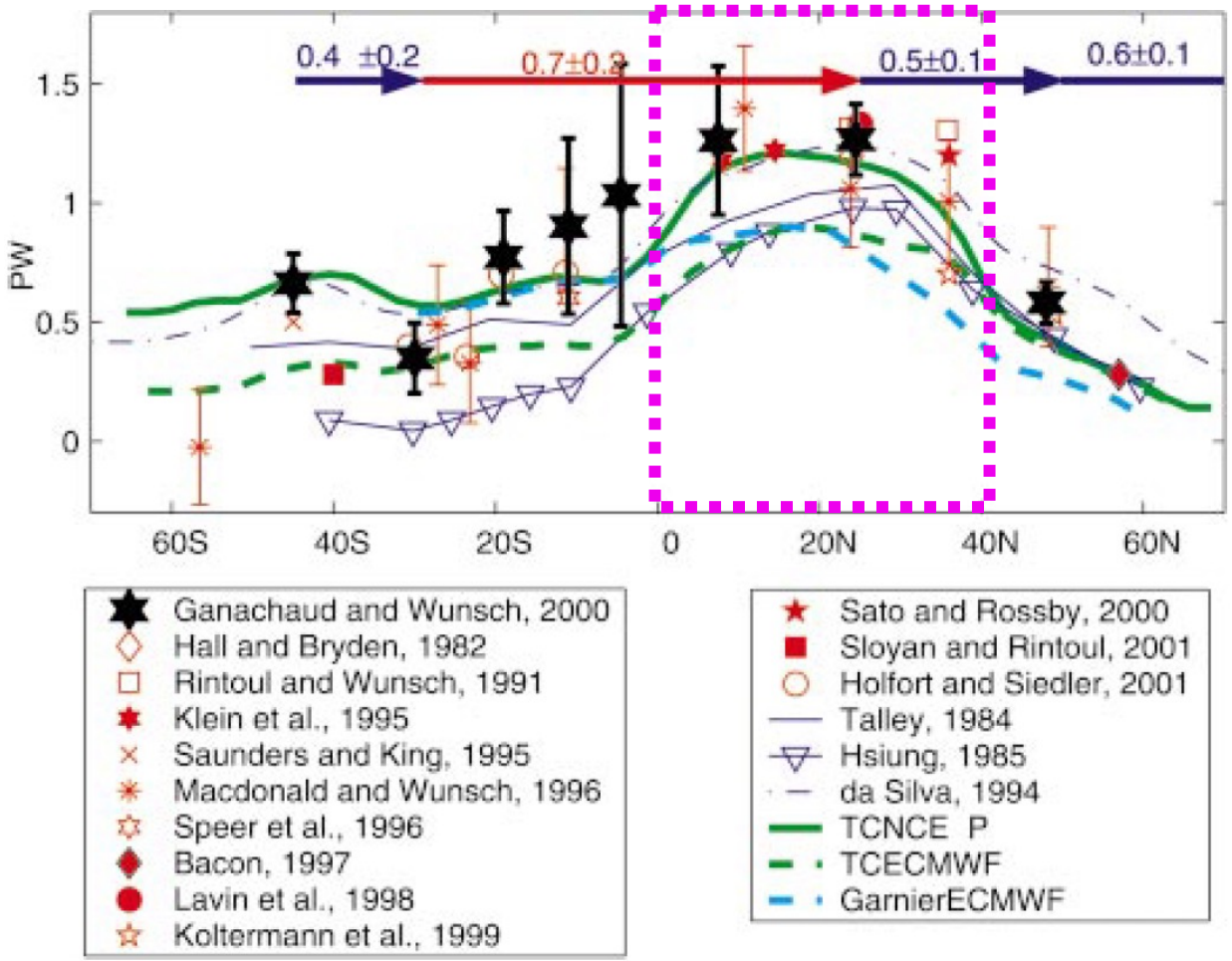
HYCOM 1/12° AMOC



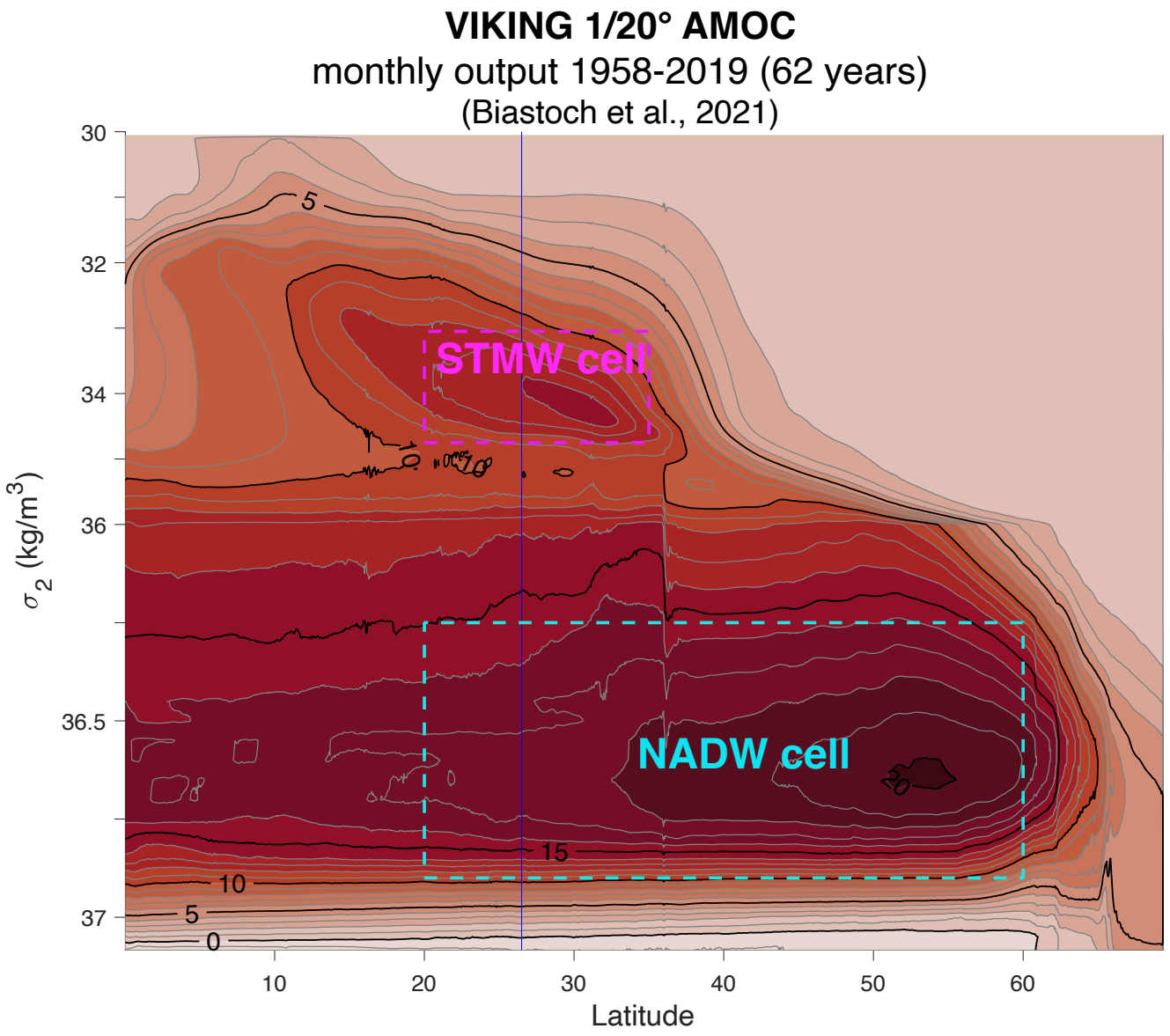
Xu et al., 2016

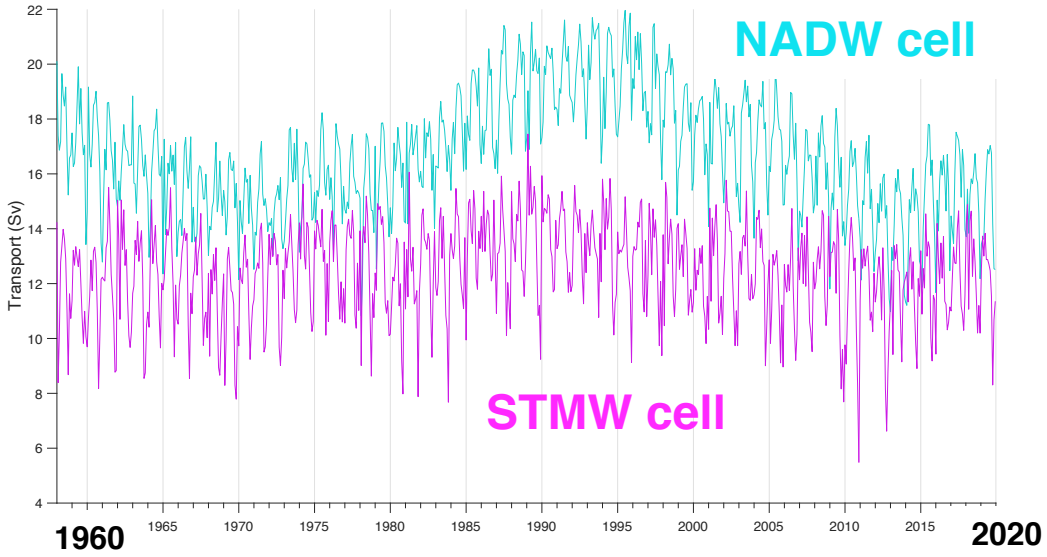
Compilation of oceanic MHT observations



Ganachaud and Wunsch, 2003

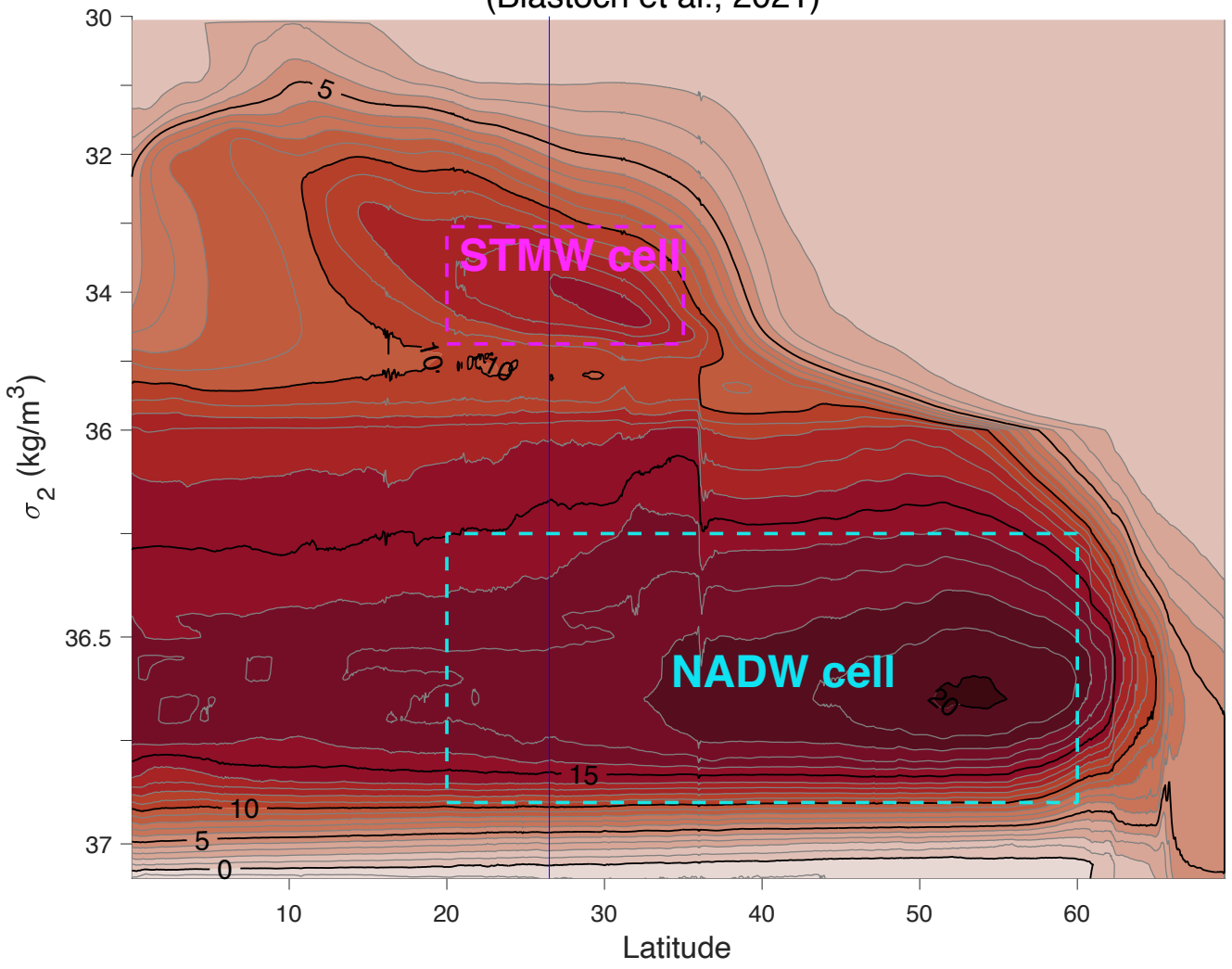
1a. Report overturning in density space

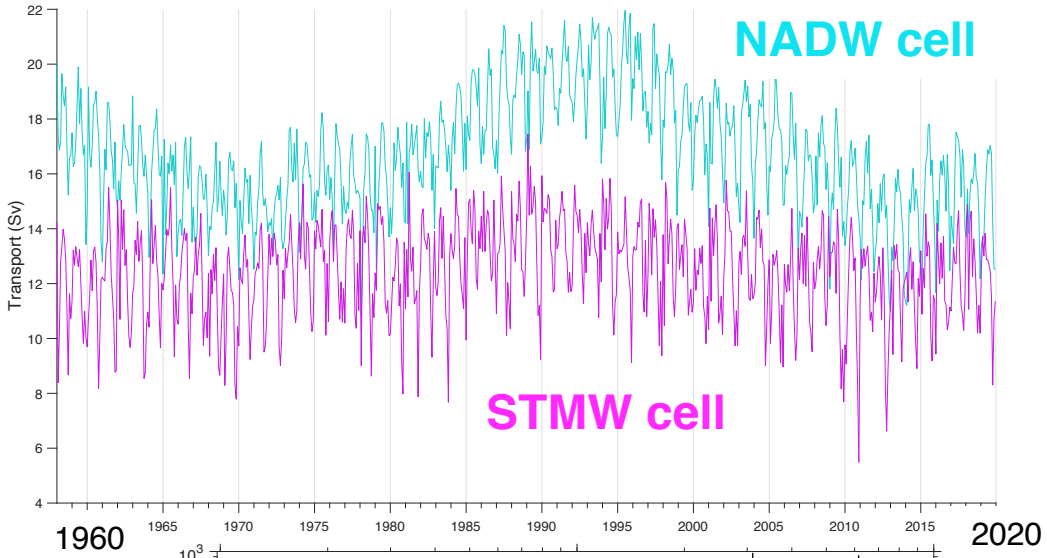


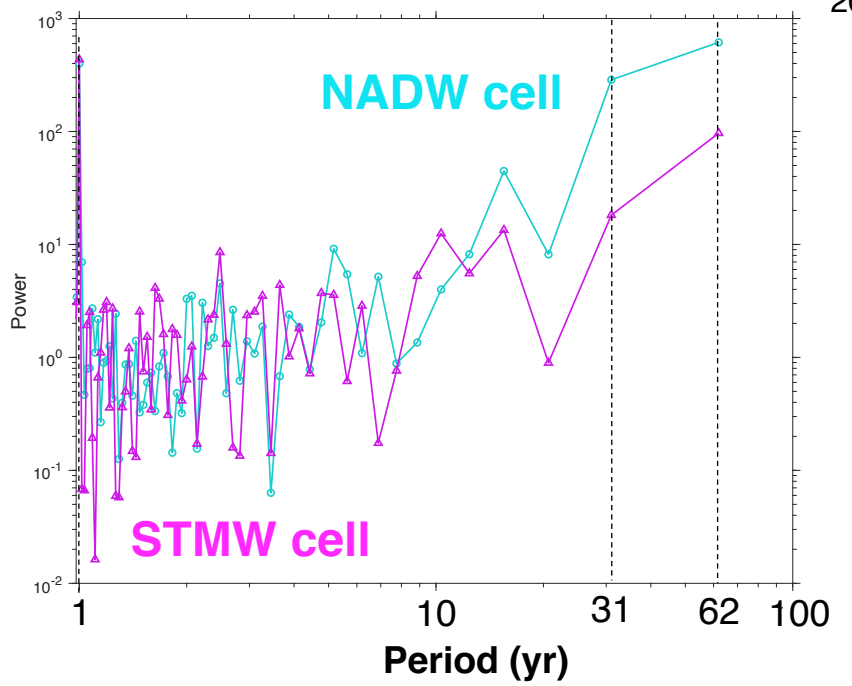


1a. Report overturning in density space

VIKING 1/20° AMOC
monthly output 1958-2019 (62 years)
(Biastoch et al., 2021)







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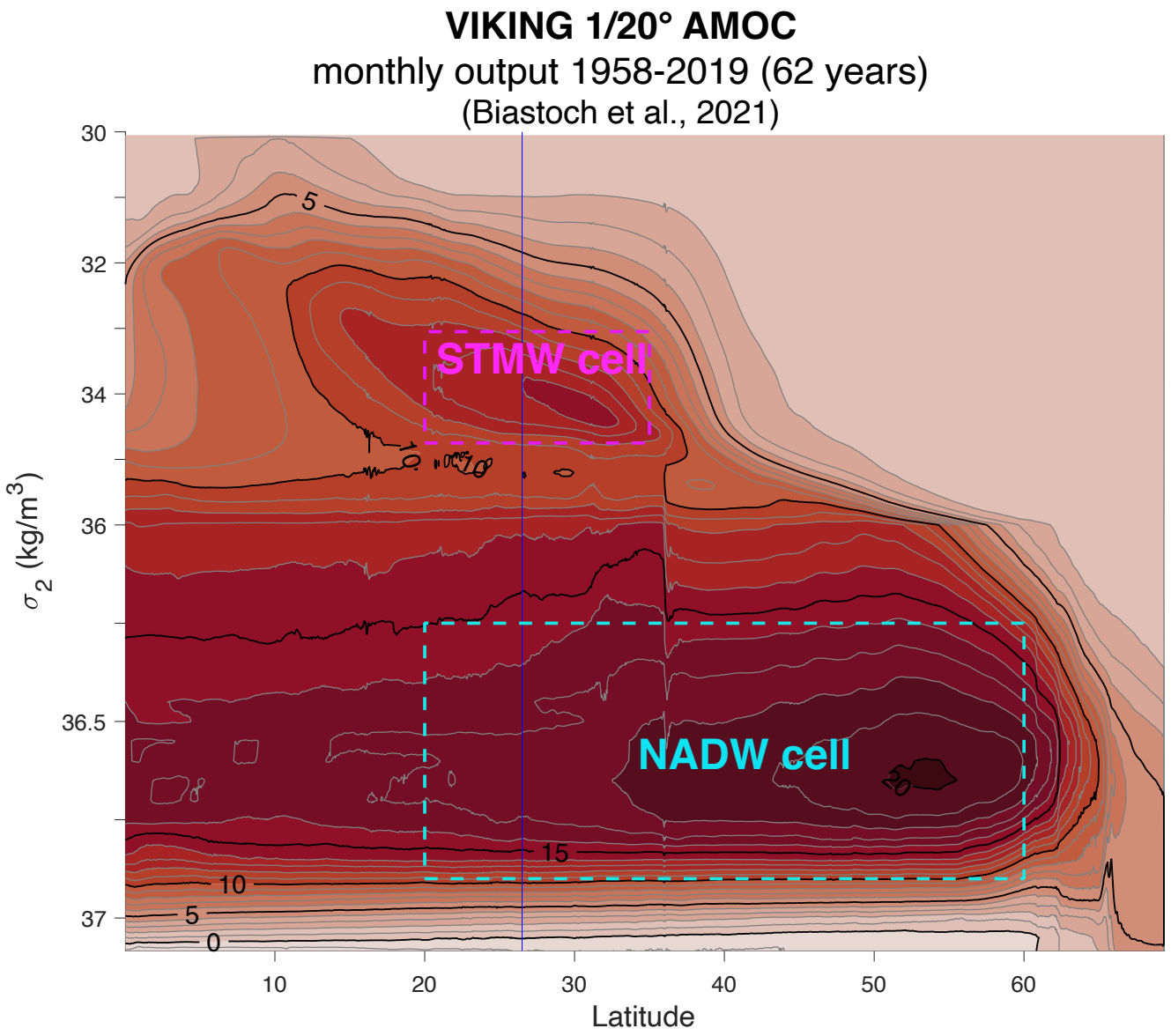


AMOC metrics should be reported in density space because:

- STMW cell is neglected in depth-space but likely important to processes with structure in the upper ocean (MHT, biogeochemistry, etc.)
- Density-space AMOC streamfunction contains more information on water mass transformation than depth-space streamfunction

1b. Reference velocity shear to satellite altimetry

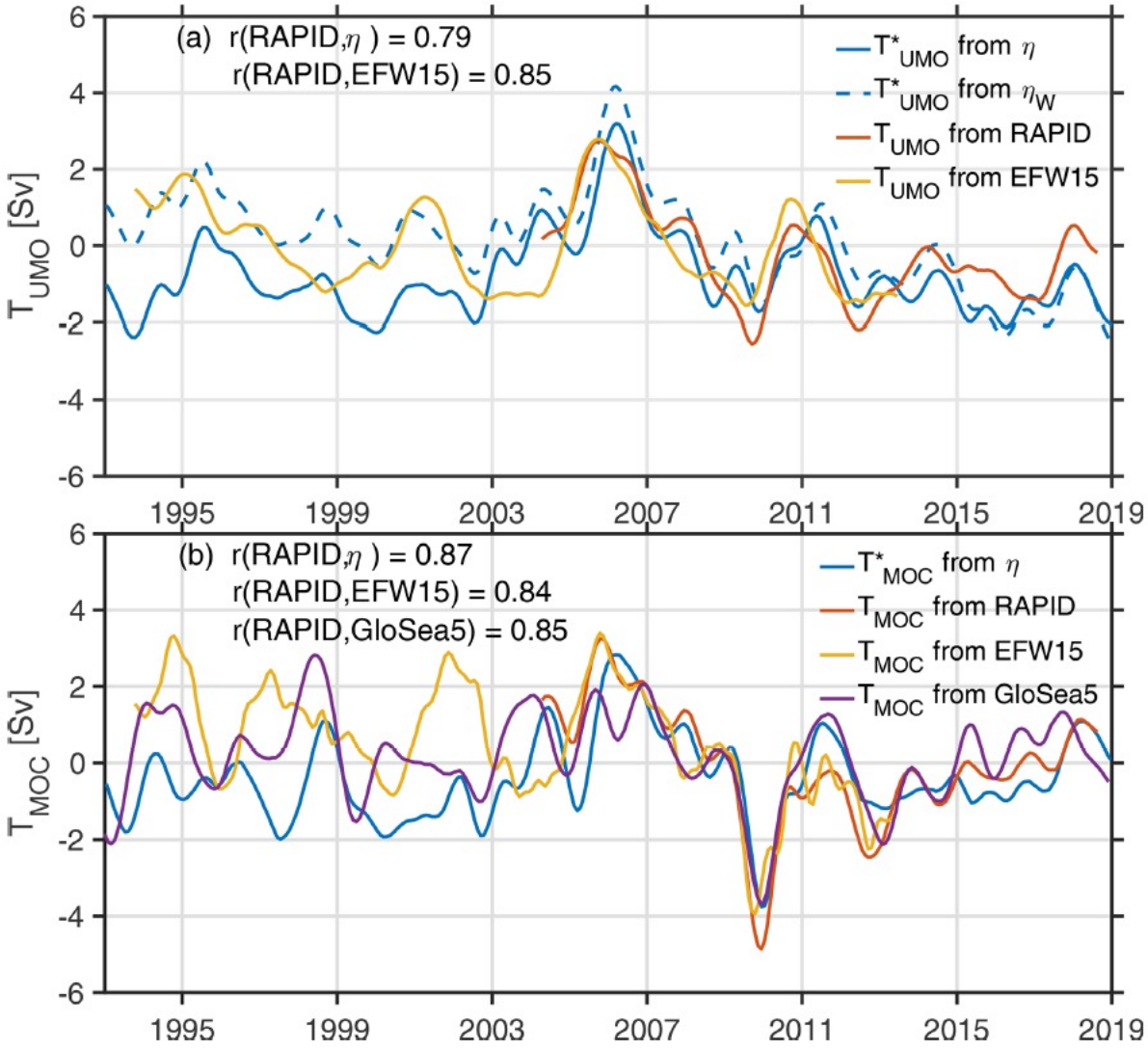
'Highlights' of altimetry as a reference velocity:

1. Altimetry provides a directly-measured "level of known motion" to reference geostrophic shear

2. At RAPID: Altimetry-referenced UMO transport closely tracks zero net mass-referenced UMO (Sanchez-Franks et al., 2021).

3. At NOAC: altimetry is well-correlated to ship-board and moored data (*e.g.*, Mertens et al., 2014; Breckenfelder et al., 2017)

4. Altimetry + Argo could sustain a cost-efficient AMOC monitoring array



Sanchez-Franks et al., 2021

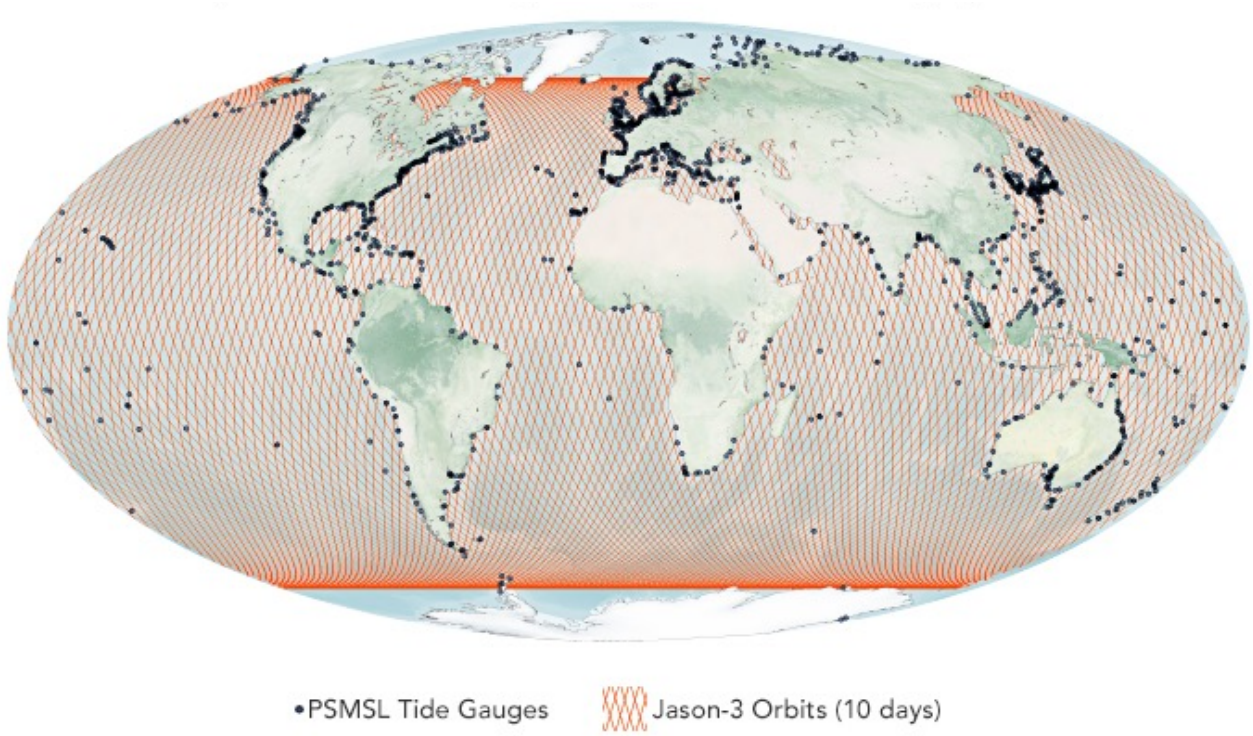
1b. Reference velocity shear to satellite altimetry

'Lowlights' of altimetry as a reference velocity:

1. Referencing to altimetry is difficult because SSH contains both baroclinic and barotropic components
   (McCarthy et al., 2020; Sanchez-Franks et al., 2021)

2. At OSNAP: time-varying altimetry is too noisy compared to ADCPs: issues w/ geoid?

3. Most OSSEs at RAPID have not tested SSH to reference velocities
   (Roberts et al., 2013; McCarthy et al., 2015; Danabasoglu et al., 2021)



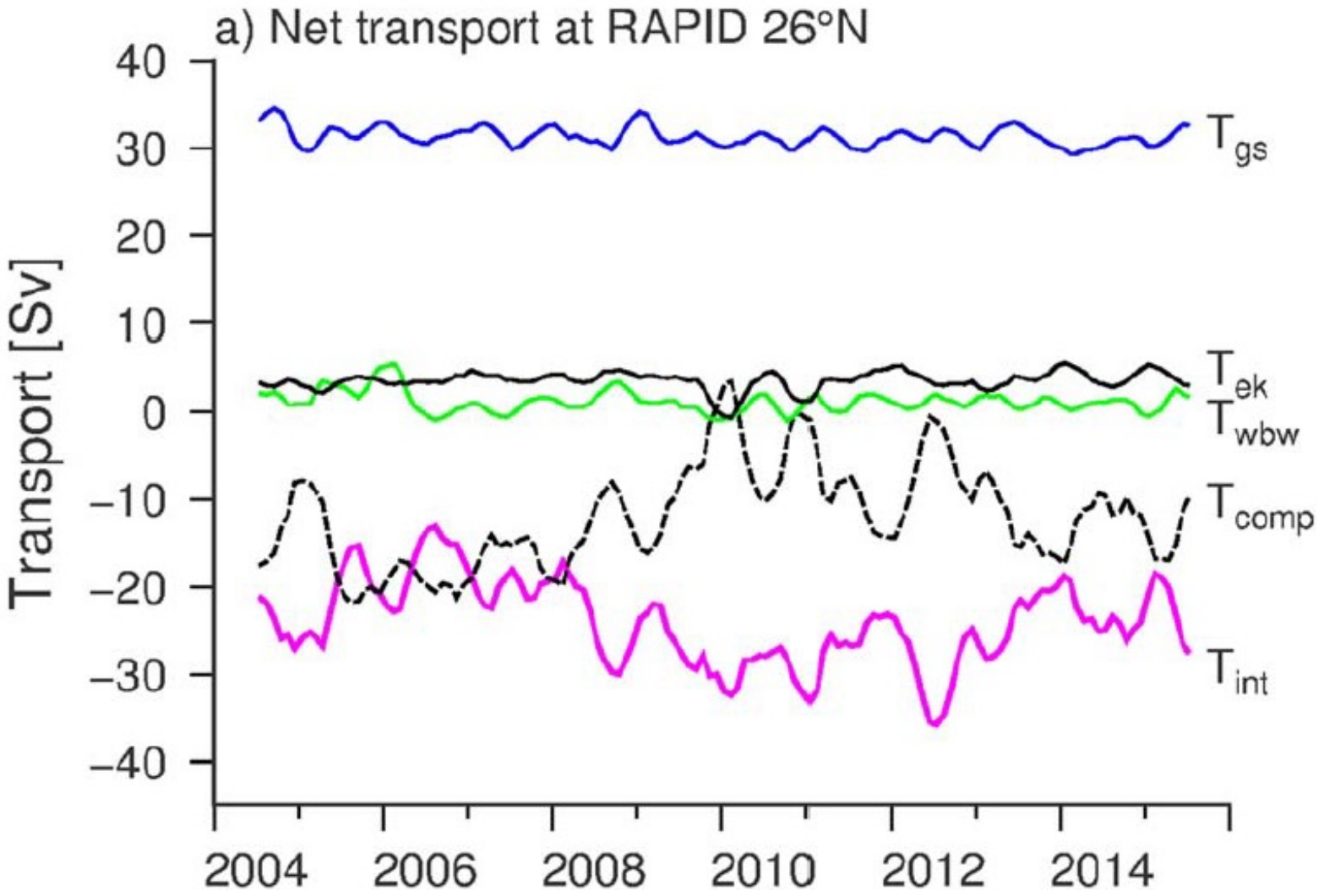
1c. Publish the compensation tranports

RAPID: 12 +/- ?? Sv
(McCarthy et al., 2015)

OSNAP: 0.7 +/- 3.3 Sv
(Lozier et al., 2019)

SAMBA: 6.6 +/- 0 Sv
(Kersalé et al., 2021)

NOAC: 5-10 Sv
(Wett et al., in prep.)



Frajka-Williams et al., 2018

2. Conduct more OSSEs

$$\frac{MOC_{observed}}{MOC_{truth}} = 1?$$

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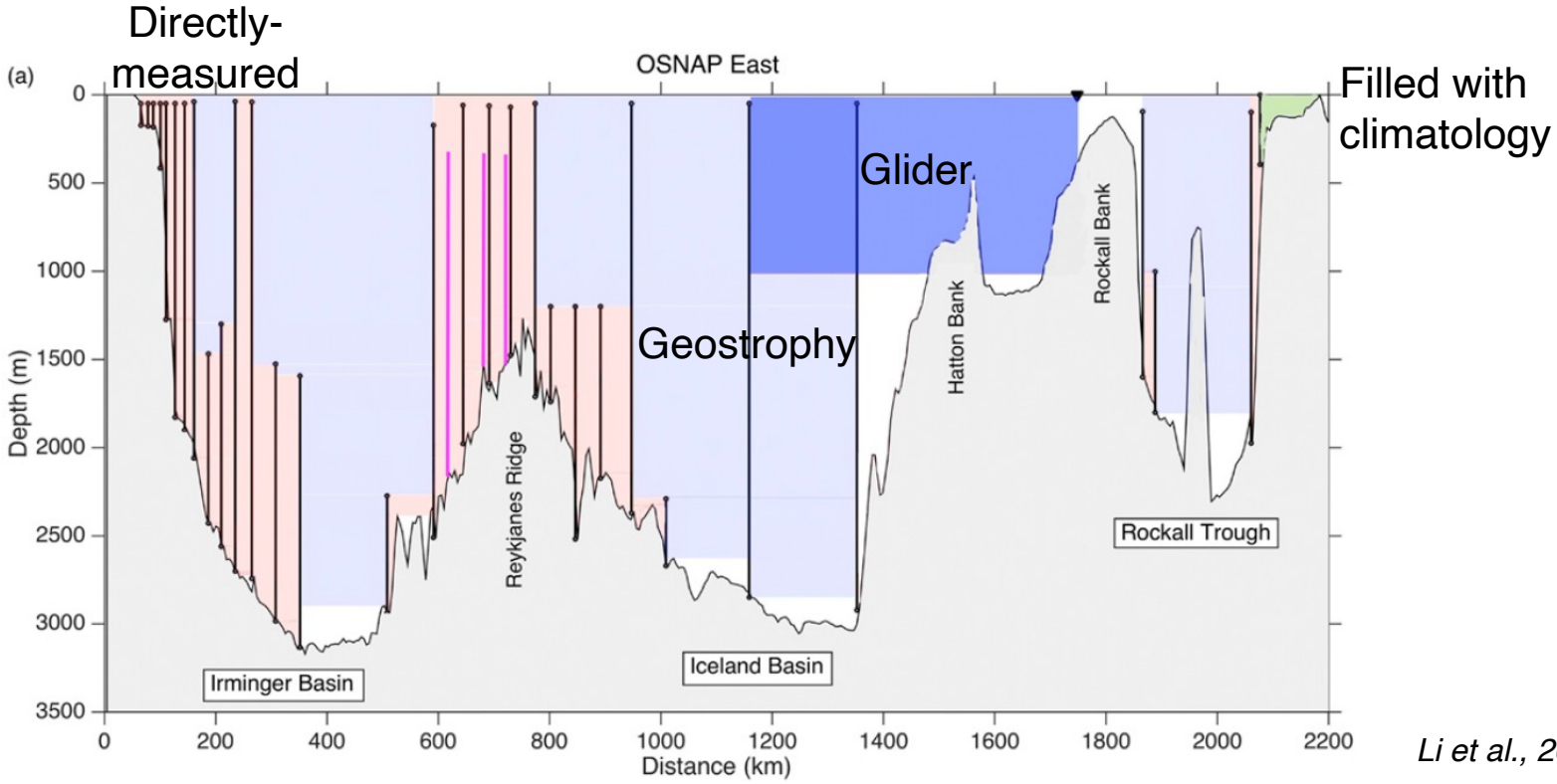
$$\frac{MOC_{observed}}{MOC_{truth}} = \frac{MOC_{observed}}{MOC_{truth}}\Bigg|_{model}$$



- ORCA025 model (1/4°)

Li et al., 2017

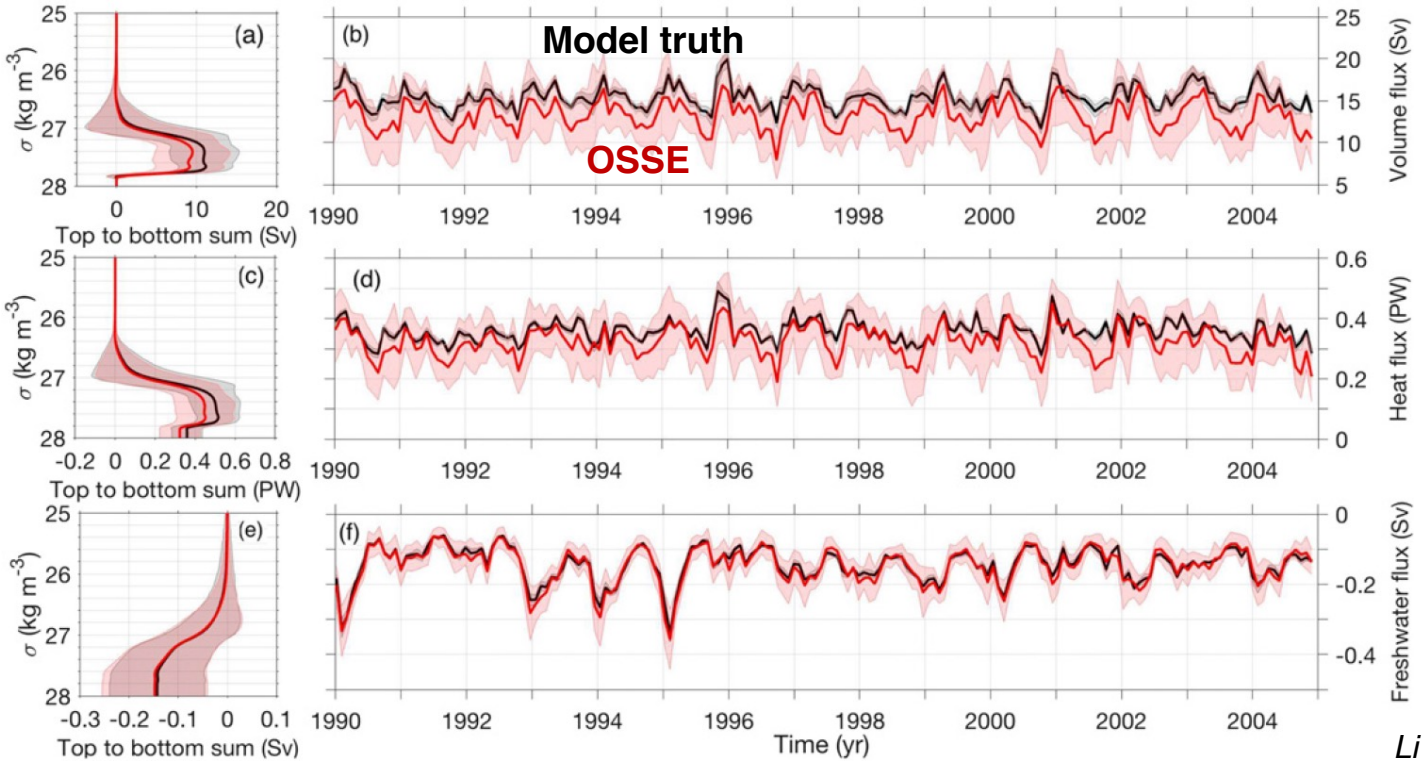
2. Conduct more OSSEs

$$\frac{MOC_{observed}}{MOC_{truth}} = \frac{MOC_{observed}}{MOC_{truth}}\Bigg|_{model}$$

Volume

MHT

MFT



- ORCA025 model (1/4°)
- MOC: OSSE underestimated model truth by ~1.5 Sv (~10%)
- MHT: OSSE underestimated model truth by 0.04 PW (~10%)

Li et al., 2017

2. Conduct more OSSEs

The accuracy of estimates of the overturning circulation from basin-wide mooring arrays

B. Sinha[a,*], D.A. Smeed[a], G. McCarthy[d], B.I. Moat[a], S.A. Josey[a], J.J.-M. Hirschi[a], E. Frajka-Williams[b], A.T. Blaker[a], D. Rayner[a], G. Madec[c]

- ORCA12 model (1/12°)
- MOC: OSSE underestimated model truth by ~1.5 Sv
- OSSE captured variability in MOC
- MHT: OSSE underestimated model truth by 0.16 PW

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- ORCA12 model (1/12°)
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- OSSE captured variability in MOC
- MHT: OSSE underestimated model truth by 0.16 PW

Revisiting AMOC Transport Estimates From Observations and Models

Gokhan Danabasoglu[1,2], Frederic S. Castruccio[1,2], R. Justin Small[1,2], Robert Tomas[1], Eleanor Frajka-Williams[3], and Matthias Lankhorst[4]

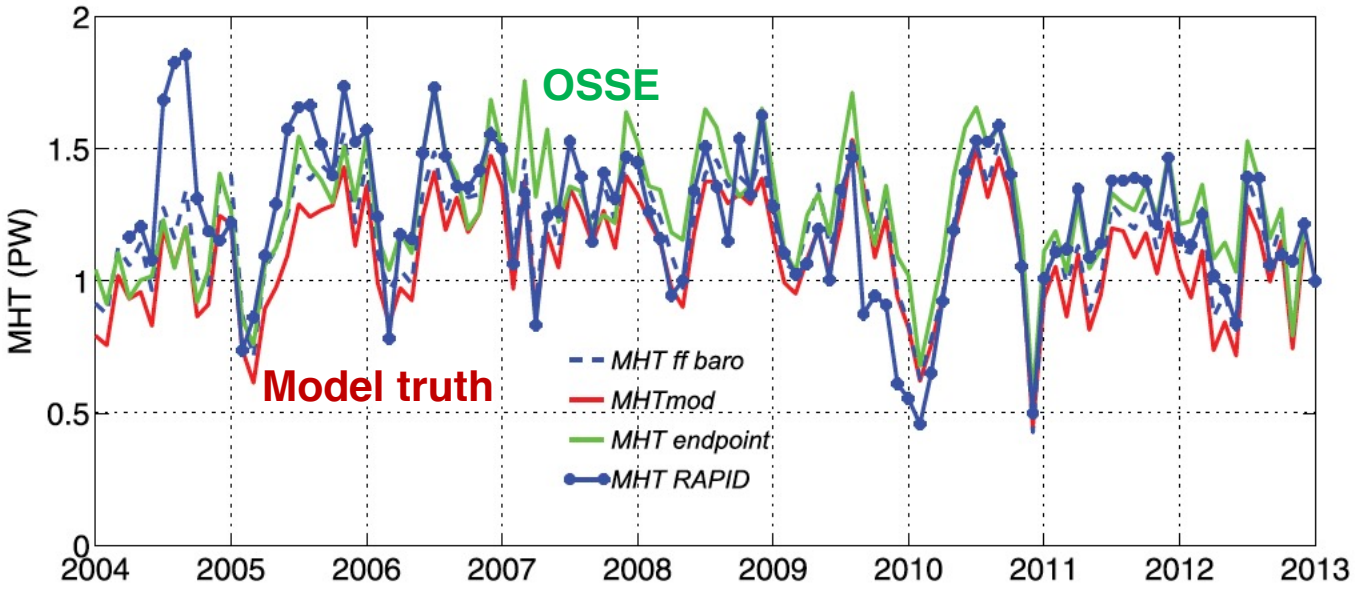
- FOSI POP model (1/10°)
- MOC: OSSE slightly overestimated model truth
- RapidMOC and METRIC python packages

2. Conduct more OSSEs

- GLOB4 (¼°) and GLOB16 (1/16°) models
- MOC: OSSE in 1/16° model similar to model truth
- MHT: OSSE in 1/16° model overestimated model truth (1.27 PW vs 1.10 PW)
- Model truth MHT in ¼° model 0.65 PW

Methods of calculation of the Atlantic meridional heat and volume transports from ocean models at 26.5°N

Vladimir N. Stepanov[1], Doroteaciro Iovino[1], Simona Masina[1,2], Andrea Storto[1], and Andrea Cipollone[1]



2. Conduct more OSSEs

Array	Methodology	MOC	MHT	MFT
RAPID	McCarthy et al., 2015; McDonagh et al., 2015	**Hirschi et al., 2003; Baehr et al., 2004;** Roberts et al., 2013; **Stepanov et al., 2016; Sinha et al., 2018; Danabasoglu et al., 2021**	**Stepanov et al., 2016**; Sinha et al., 2018	
OSNAP	Lozier et al., 2017; Li et al., 2017; Li et al., 2021	**Li et al., 2017**	**Li et al., 2017**	**Li et al., 2017**
NOAC	Rhein et al., 2019; Nowitzki et al., 2021; Wett et al., in prep.	Breckenfelder et al., 2017	N/A	N/A
SAMBA	Meinen et al., 2018; Kersalé et al., 2021	*ongoing work*		
TRACOS	Herrford et al., 2021	Herrford et al., 2021	N/A	N/A
MOVE	Kanzow et al., 2006; Send et al., 2011	Kanzow et al., 2008; **Danabasoglu et al., 2021**	N/A	N/A

Total system

2. Conduct more OSSEs

More OSSEs needed

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RAPID	McCarthy et al., 2015; McDonagh et al., 2015	**Hirschi et al., 2003; Baehr et al., 2004;** Roberts et al., 2013; **Stepanov et al., 2016; Sinha et al., 2018; Danabasoglu et al., 2021**	**Stepanov et al., 2016**; Sinha et al., 2018	
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Capitalize on this incredible period of intense AMOC sampling

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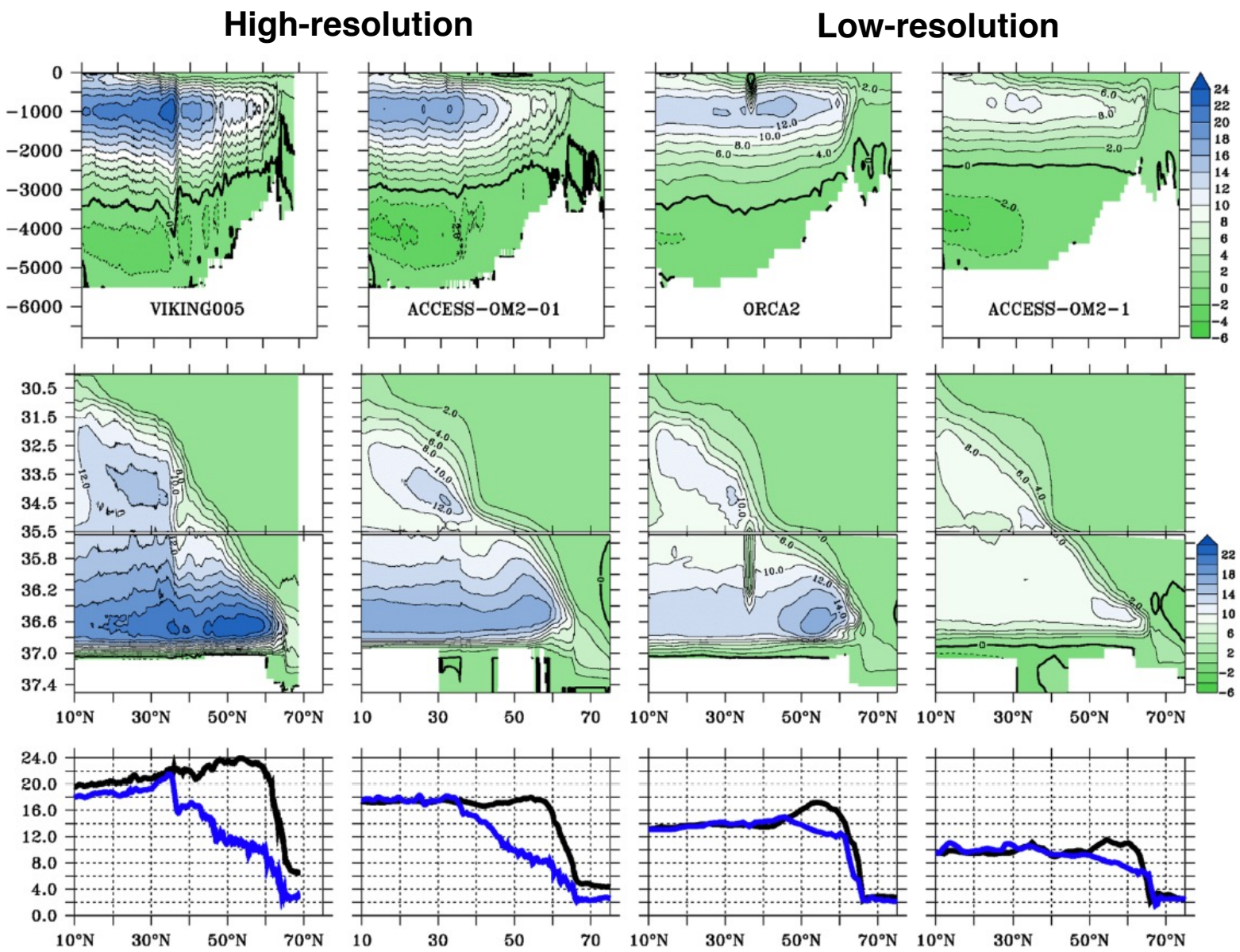

Hirschi et al., 2020

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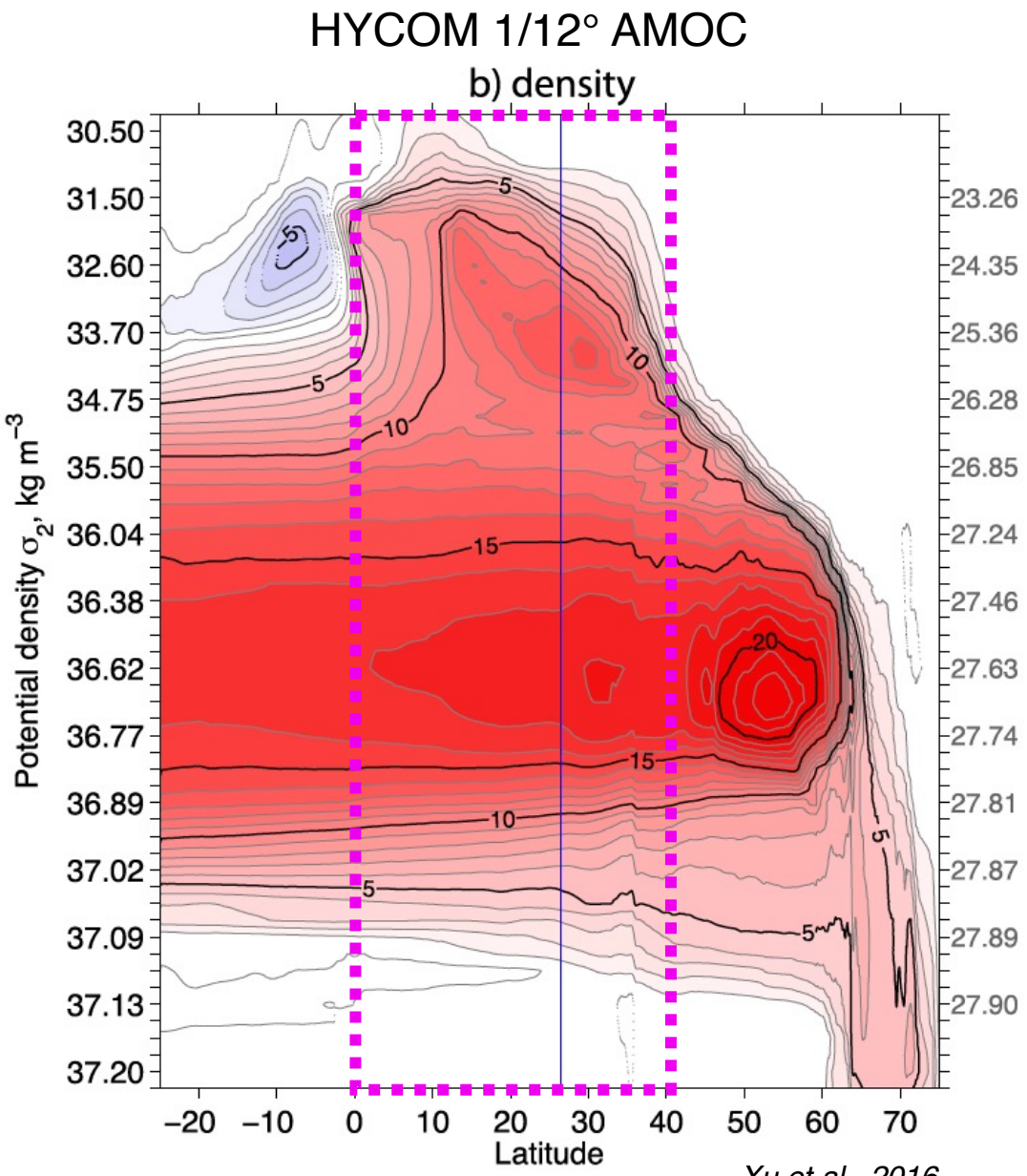
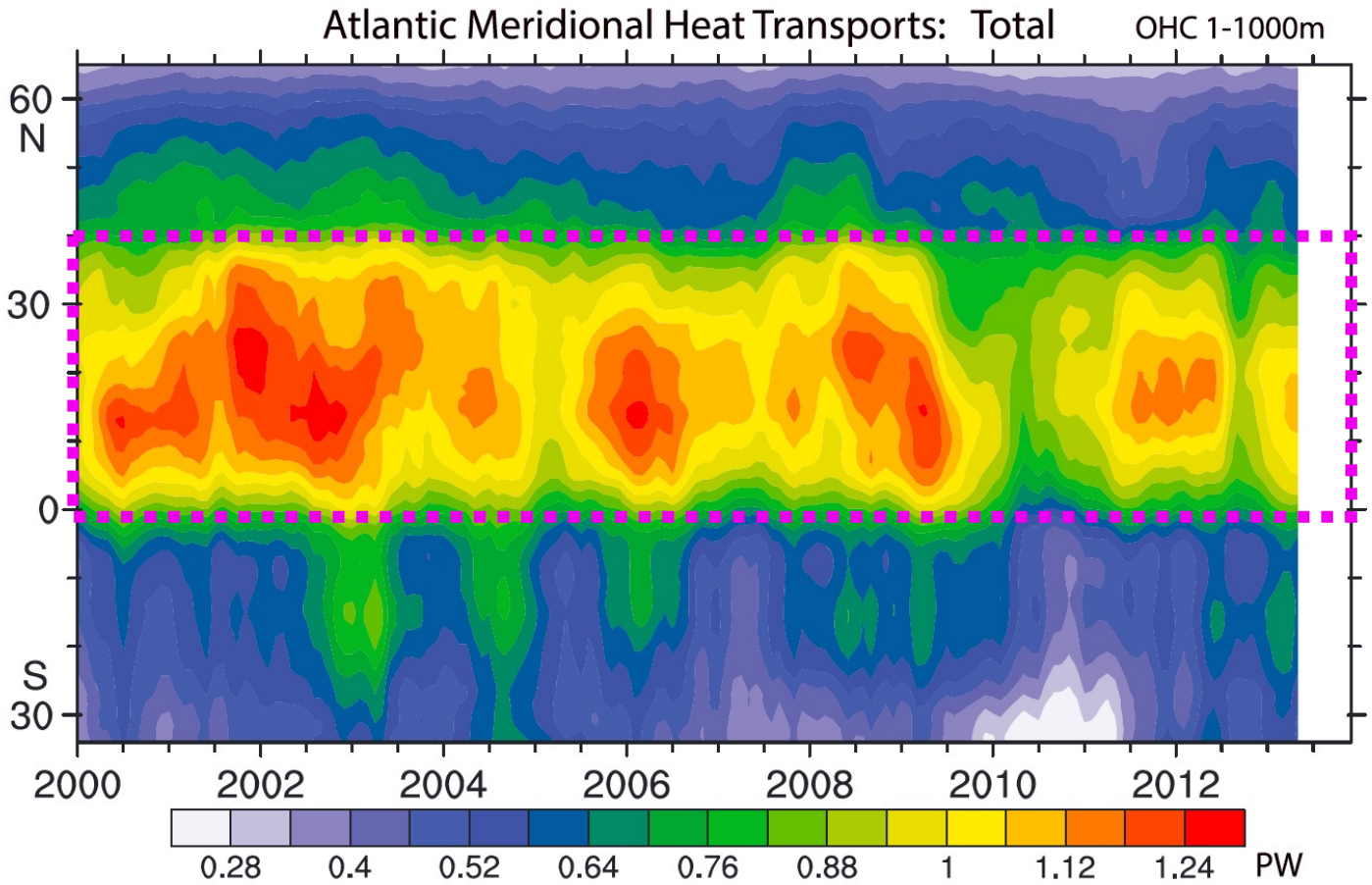


Xu et al., 2016



Trenberth and Caron, 2017

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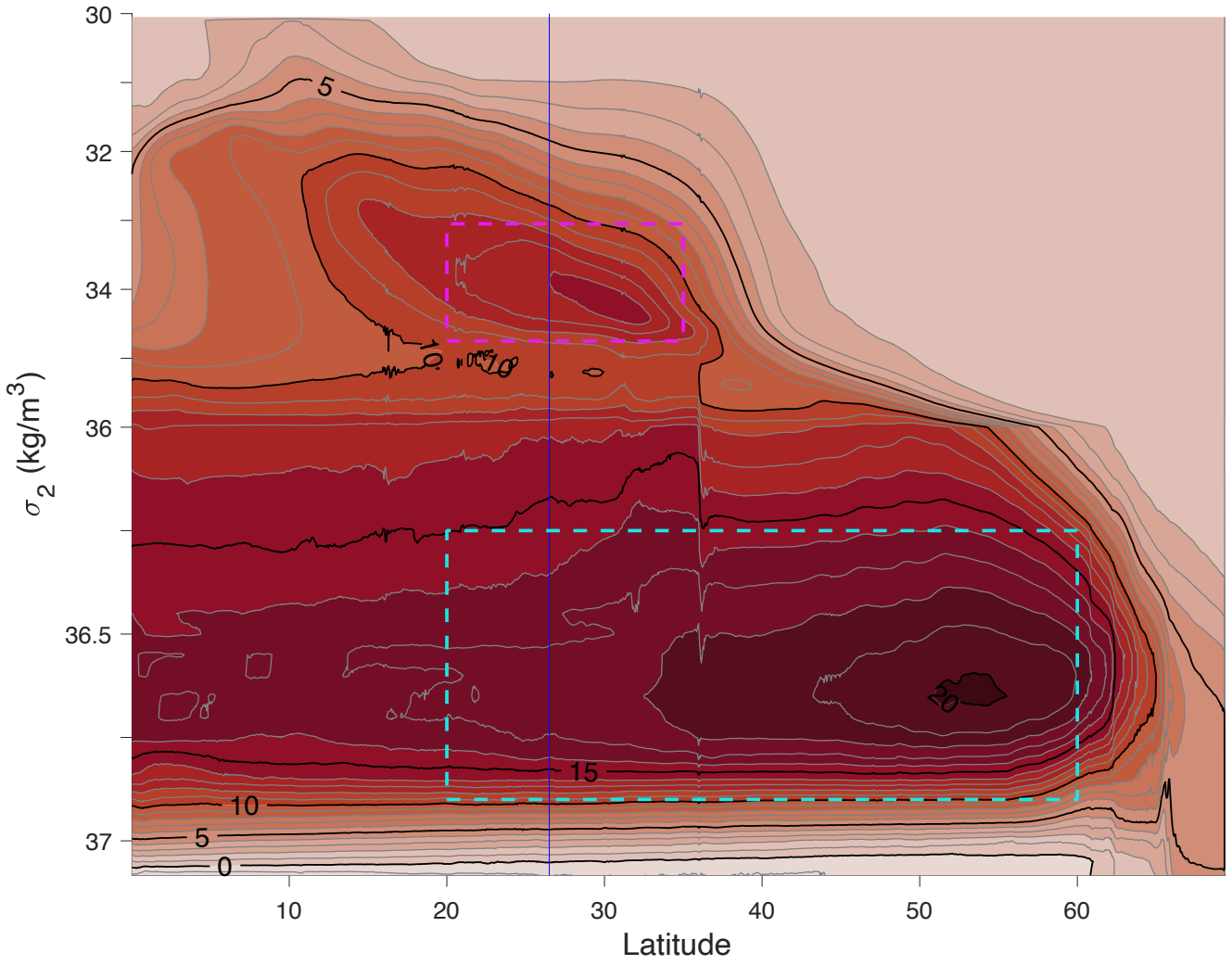

Does $AMOC_{max}$ at 26.5°N ever occur in the light cell?