Simplifying the Dynamics of the Atlantic Meridional Overturning Circulation at 26°N

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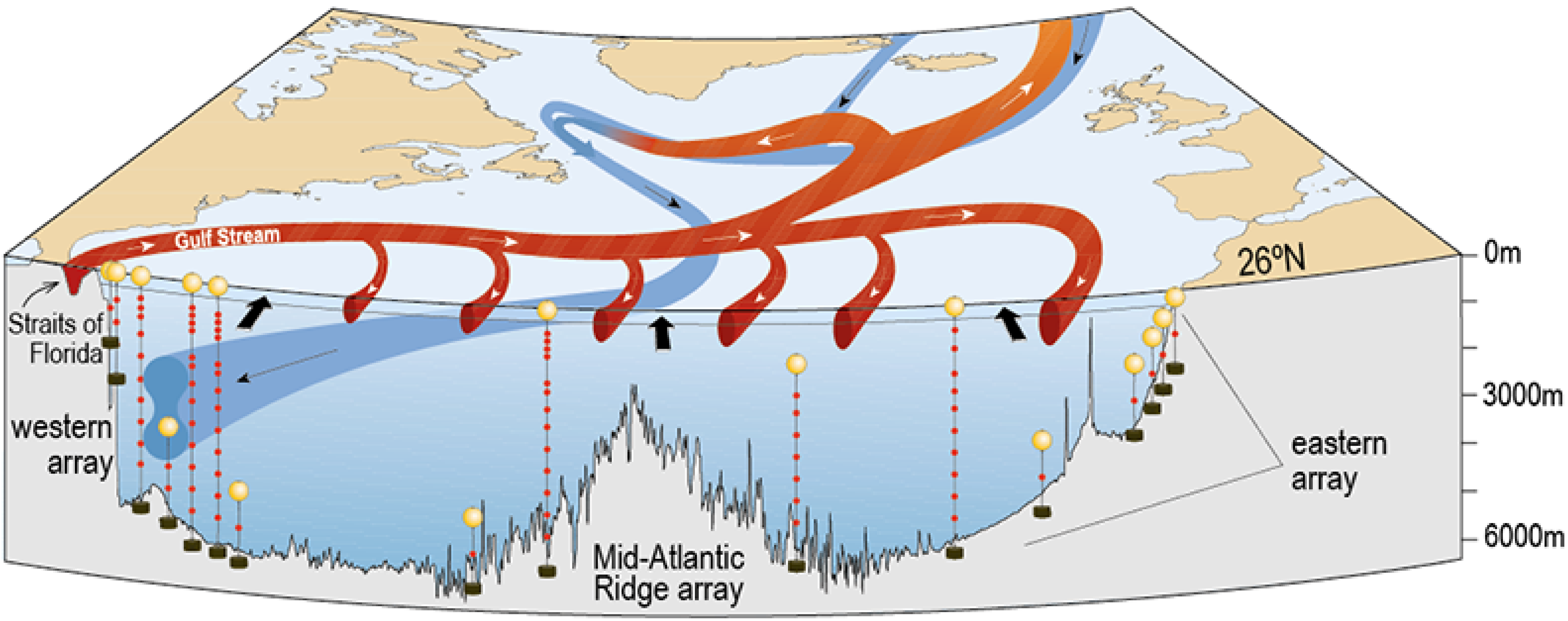
Overview

- Atlantic Meridional Overturning Circulation
- Why do we want to simplify its dynamics?
- A simple linear regression model
- More complex regression models
- Conclusions

Atlantic Meridional Overturning Circulation

(AMOC)

AMOC observed by RAPID array at 26°N



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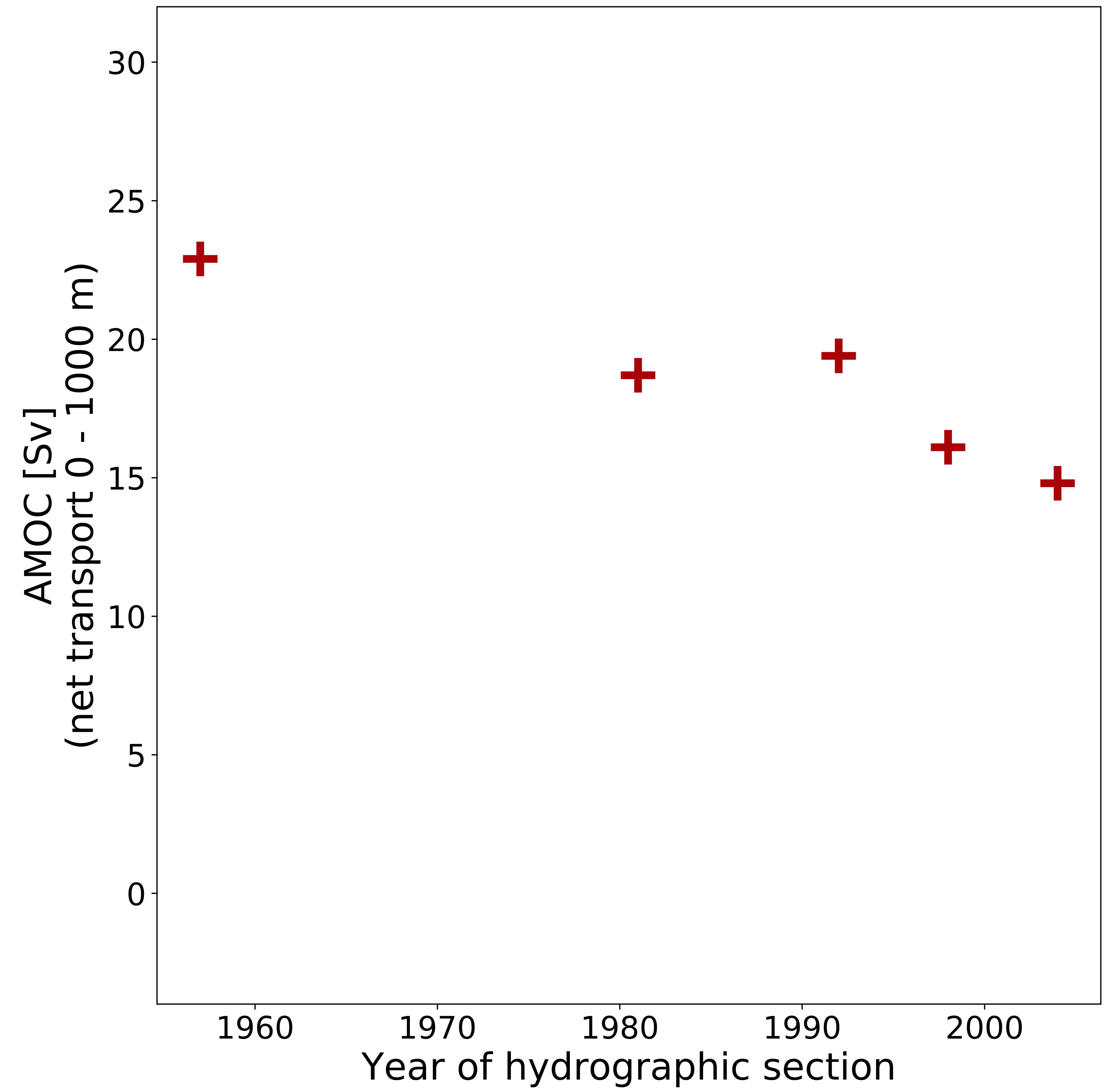
Observations of the AMOC

Hydrographic sections

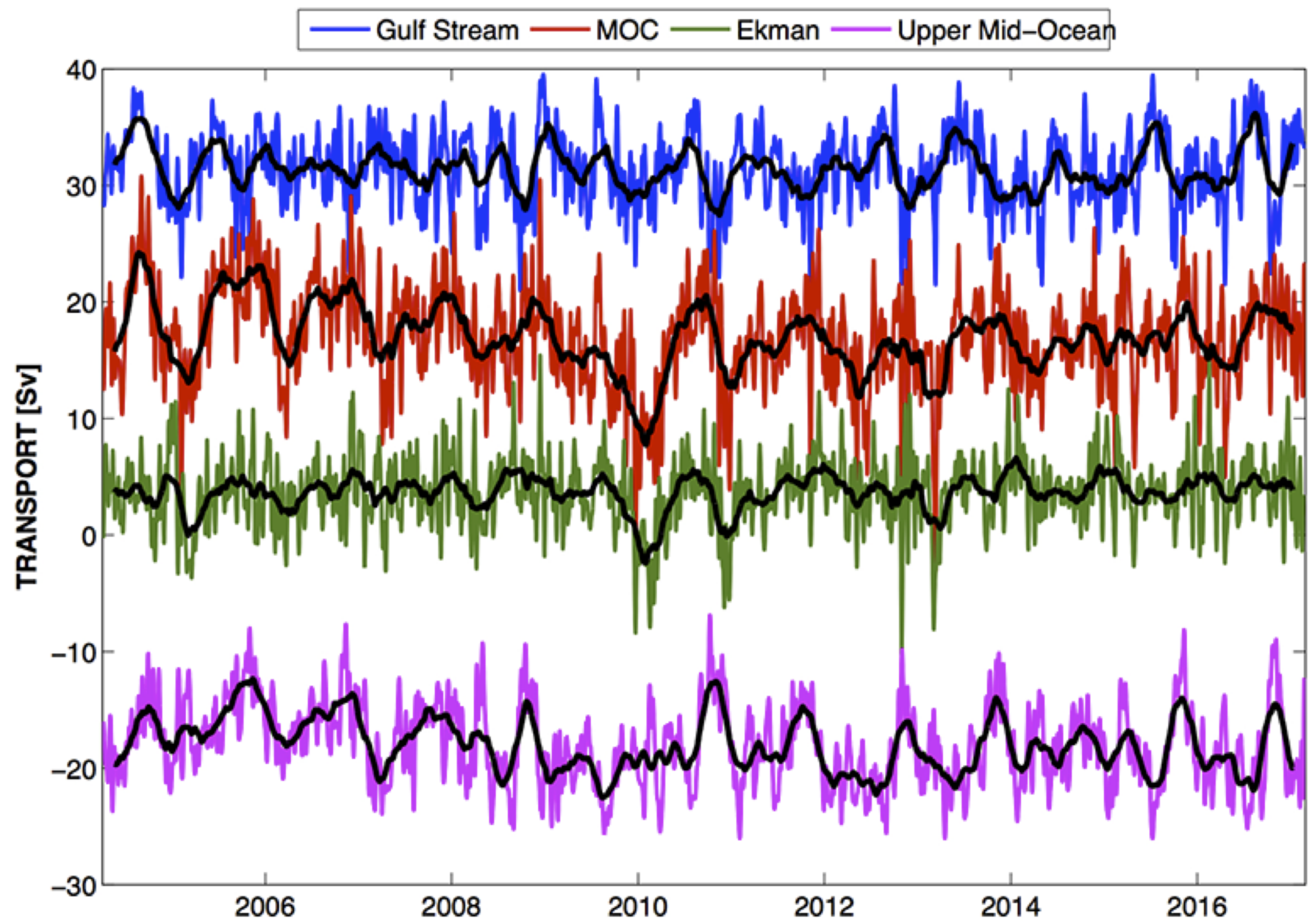
1957 to 2004



[Data from Bryden et al., 2005]

RAPID timeseries

2004 to present



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Can we learn more about the AMOC before 2004?

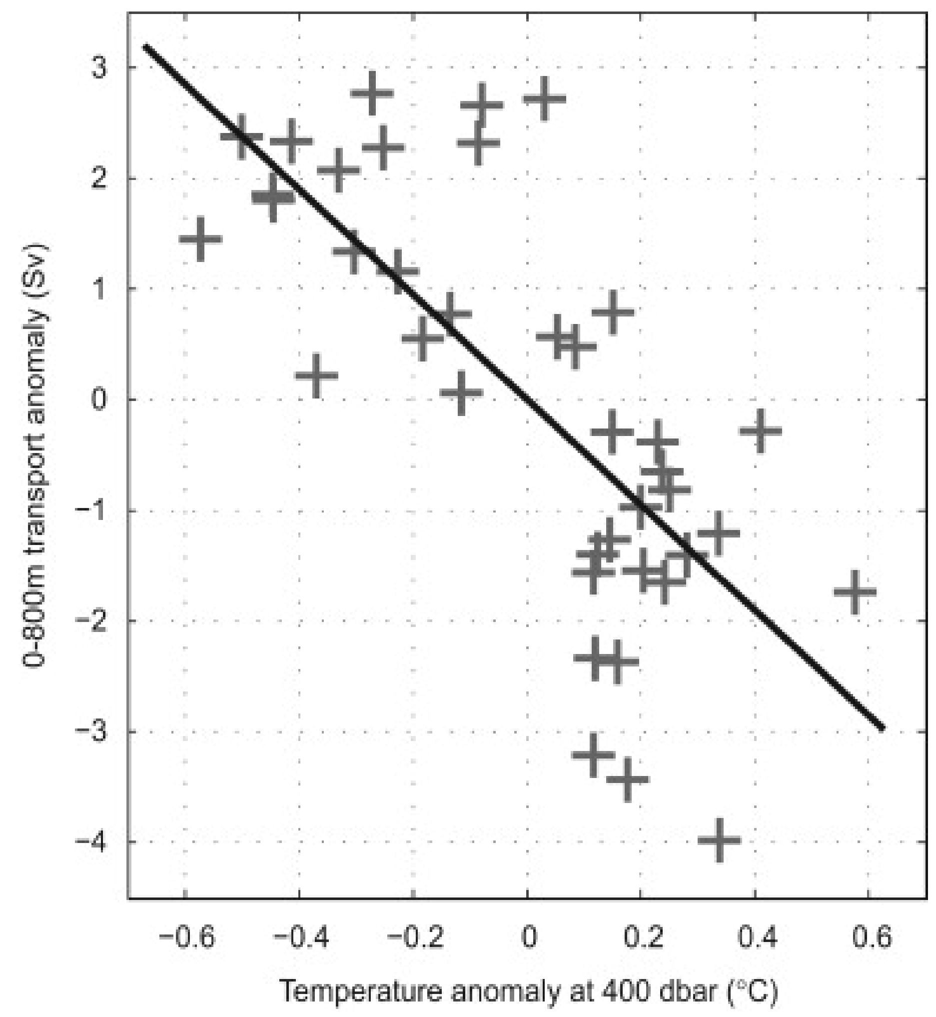
Other hydrographic data is available prior to 2004 e.g. repeat CTDs, short mooring arrays, but it is not sufficient to estimate AMOC as RAPID does.

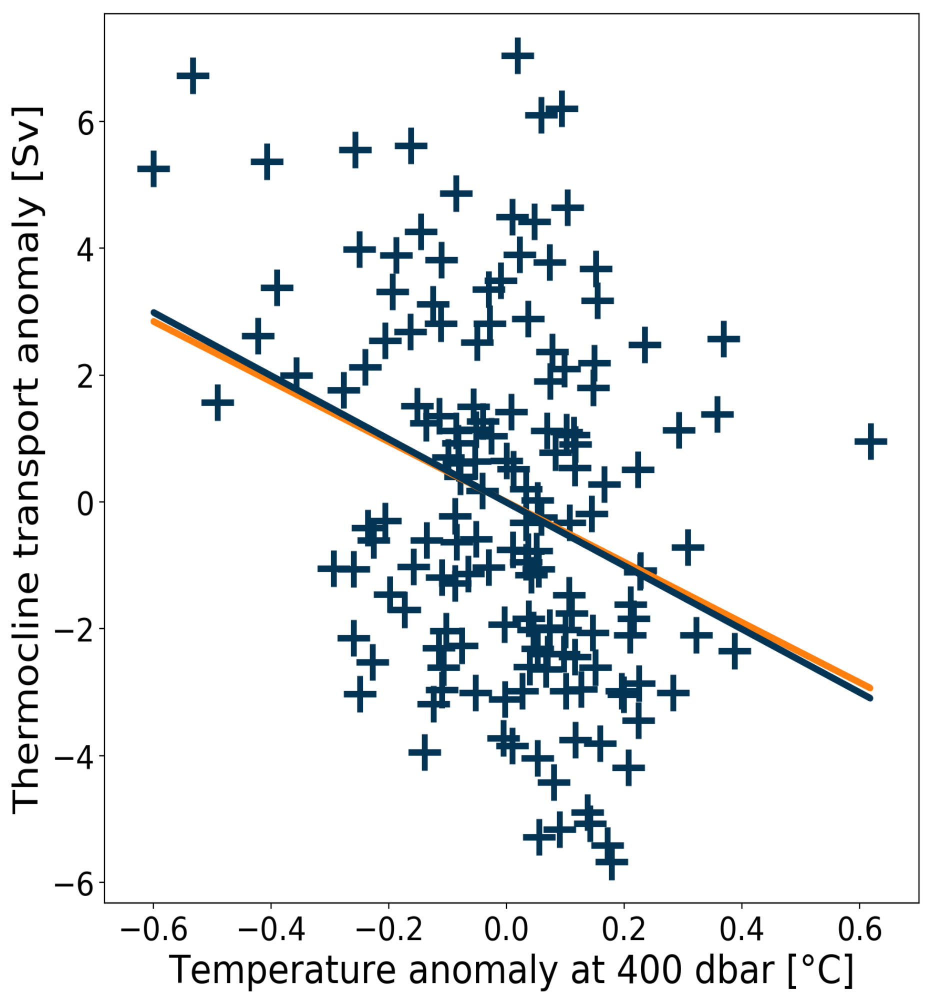
Can we simplify the dynamics of the overturning circulation using a linear regression model?

Longworth et al. (2011) used temperature at a depth of 400 dbar at the western boundary as a proxy for thermocline transport.

39 values between 1986 and 1998

Repeat WB CTD stations



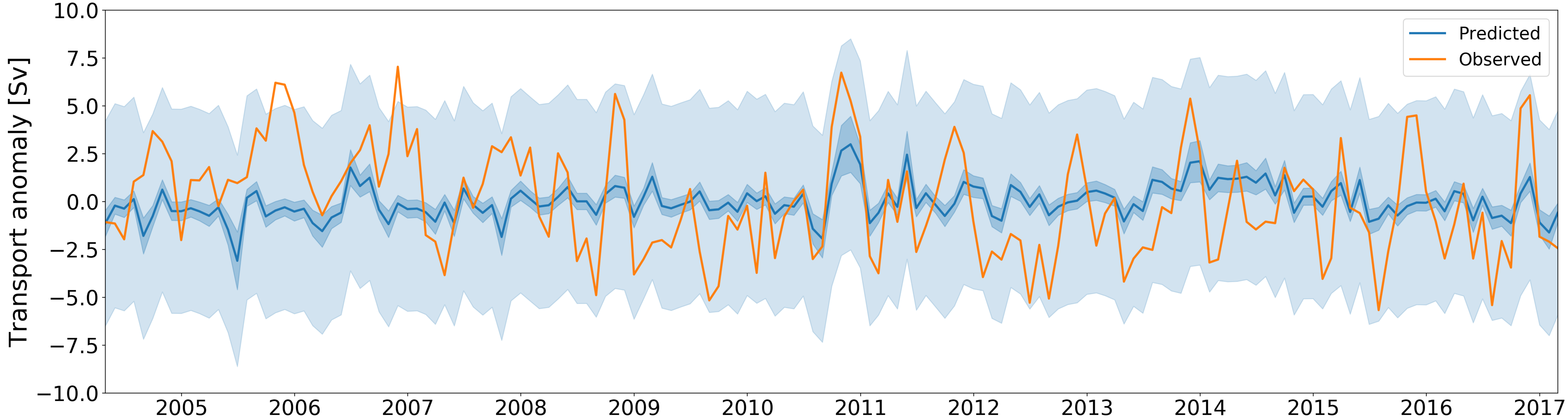


155 **monthly mean** values between 2004 and 2017

RAPID WB profile

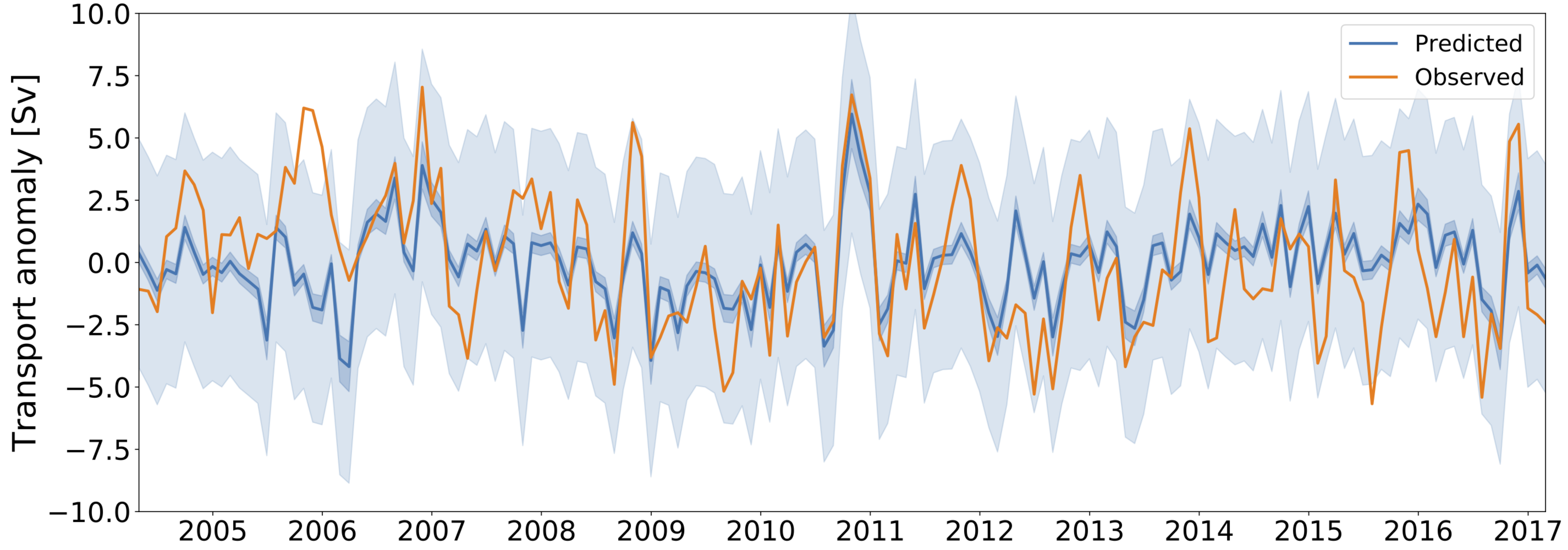
Longworth regression model explained 53% of the observed thermocline transport variance

RAPID data regression model explains only 10%



How can it be improved?

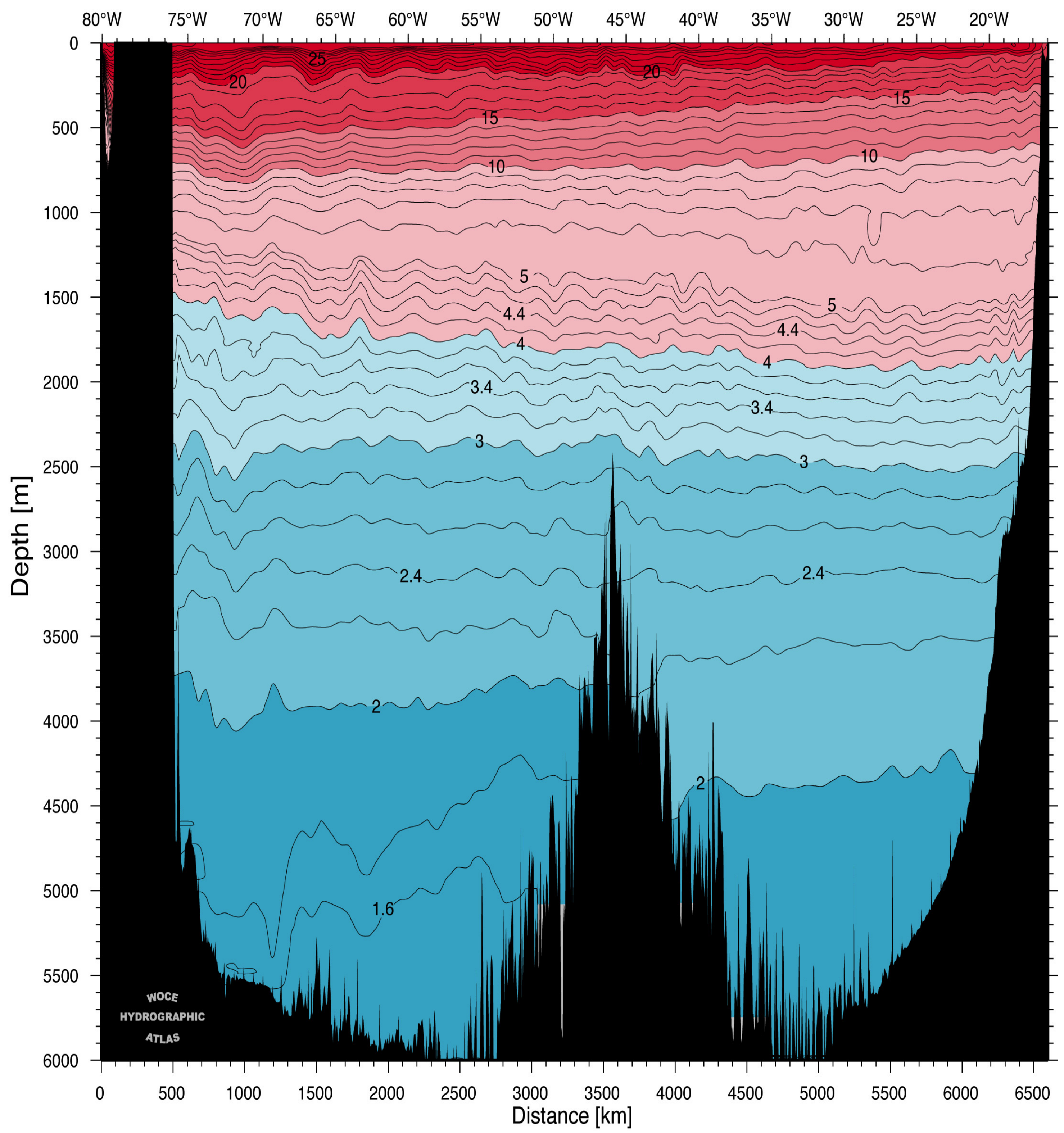
Using the temperature anomaly at 780 dbar depth improves explained variance to 33%



A single layer regression model cannot capture the dynamics of the overturning circulation

What does the mid-ocean transport look like at 26°N?

Temperature



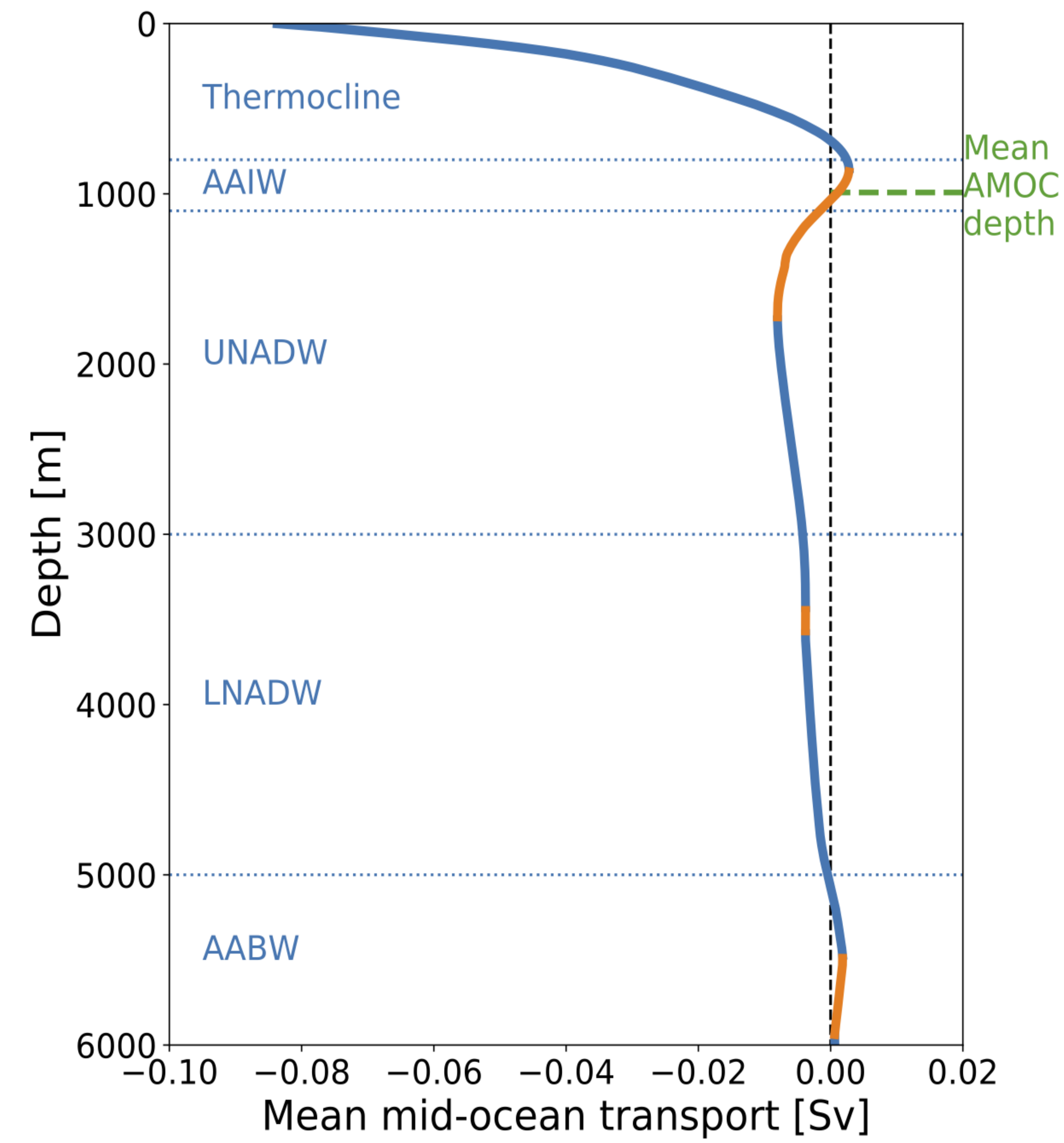
Isotherms (and isopycnals) slope up to the east above 1000 m, down to the east below

$$\frac{\partial \rho}{\partial x} = -\frac{f\rho_0}{g}\frac{\partial v}{\partial z}$$

EB > WB = negative shear

WB > EB = positive shear

Mid-ocean transport



Southwards above ~800 m and below ~1100 m, with an intermediate northwards layer

Variability in the mid-ocean (geostrophic) AMOC component is defined by partition between two southwards transports:

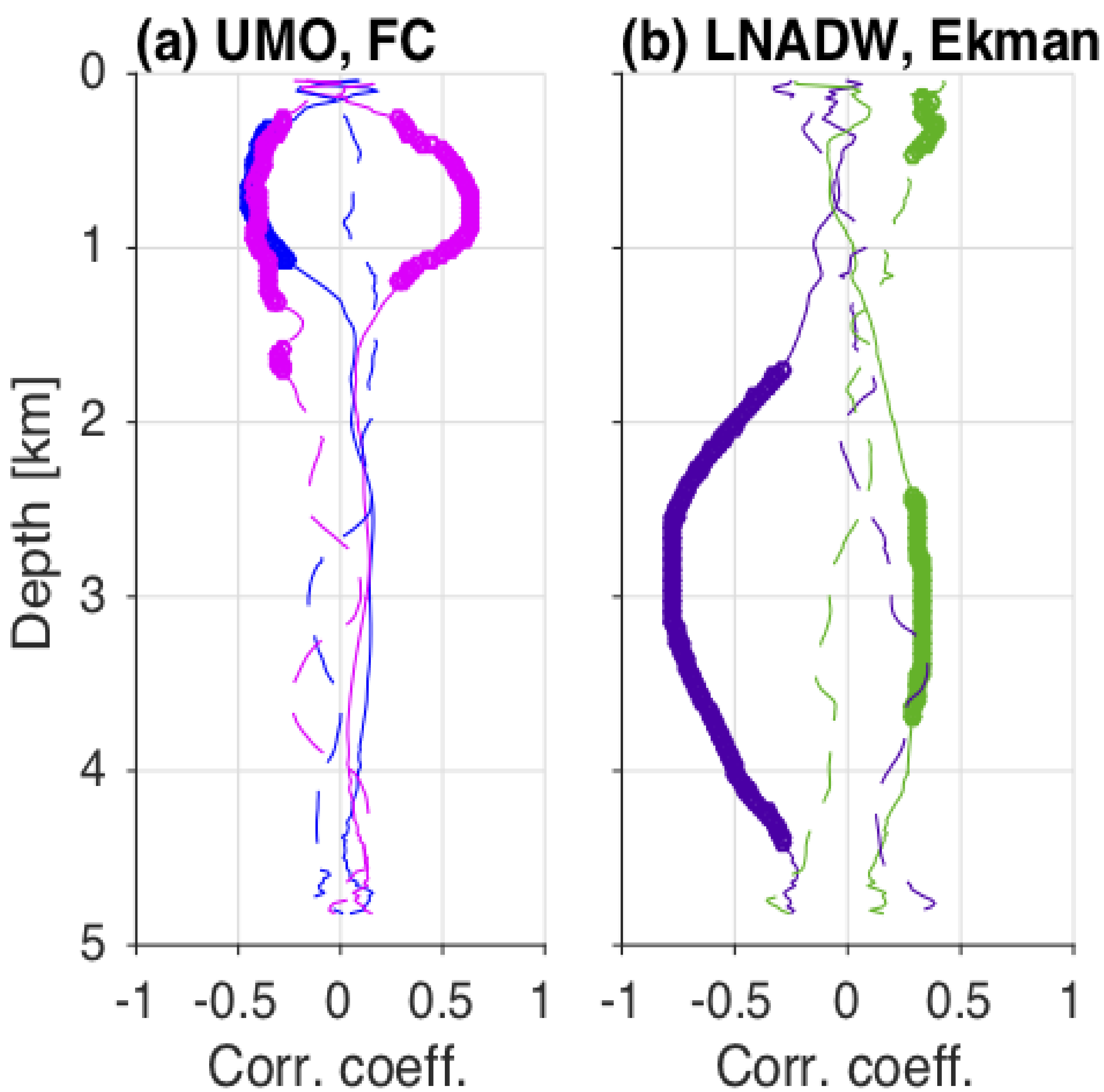
Recirculation in the upper layer	vs.	Deep overturning return flow (NADW)

To capture this variability, at least 3 layers need to be represented by the regression model

Multiple layer regression model

Selecting explanatory variables

Strong correlation between isopycnal displacements and UMO transport on both western (solid) and eastern boundaries (dashed) above 1400 m



Strong correlation between deep western boundary isopycnal displacements and LNADW transport

Fig. 8, Frajka-Williams et al., 2016

Selecting explanatory variables

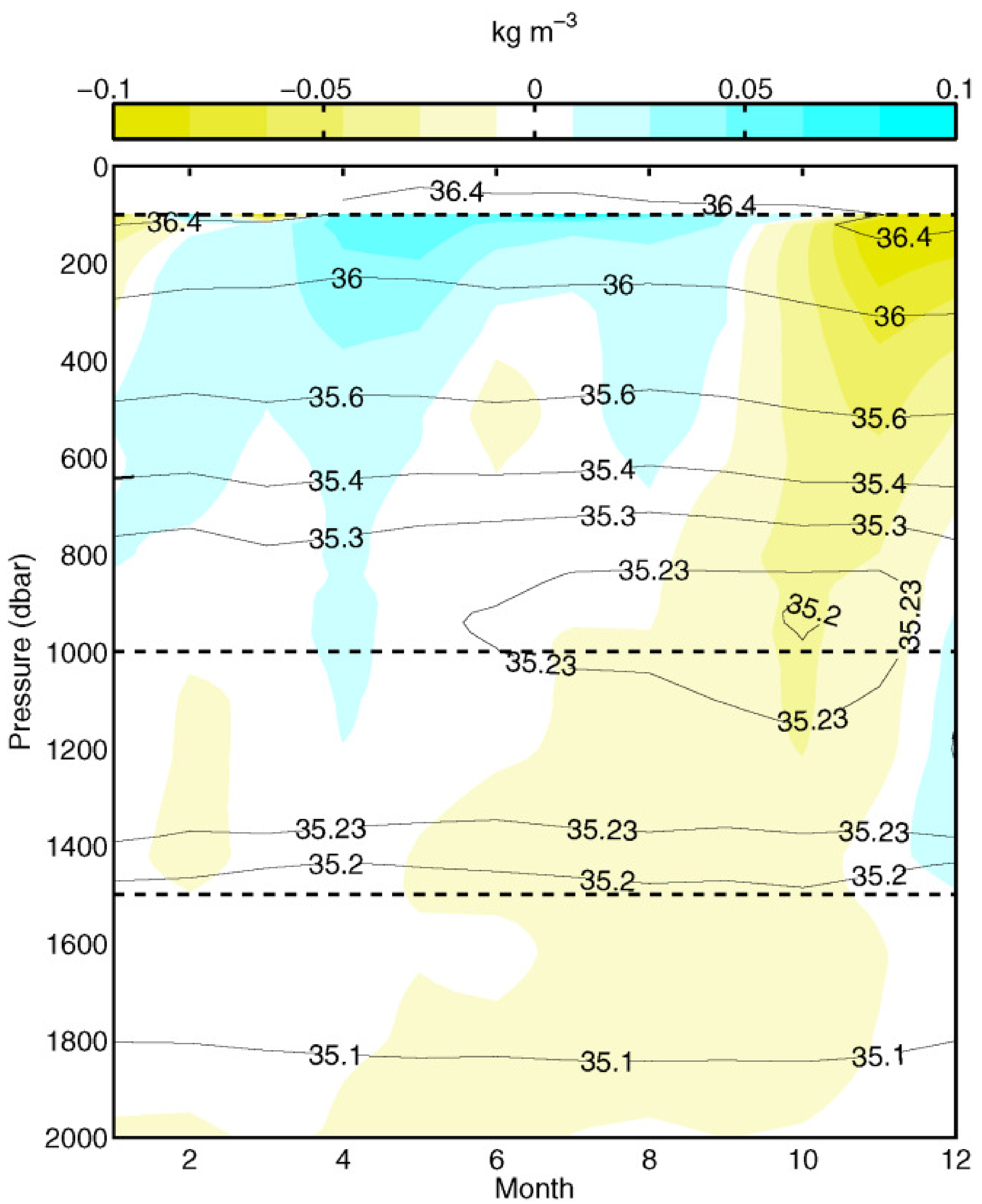


Fig. 11, Péréz-Hernández et al., 2015. EB seasonal salinity anomaly (black contours) and density anomaly (coloured contours).

UMO seasonality is driven by eastern boundary density anomalies

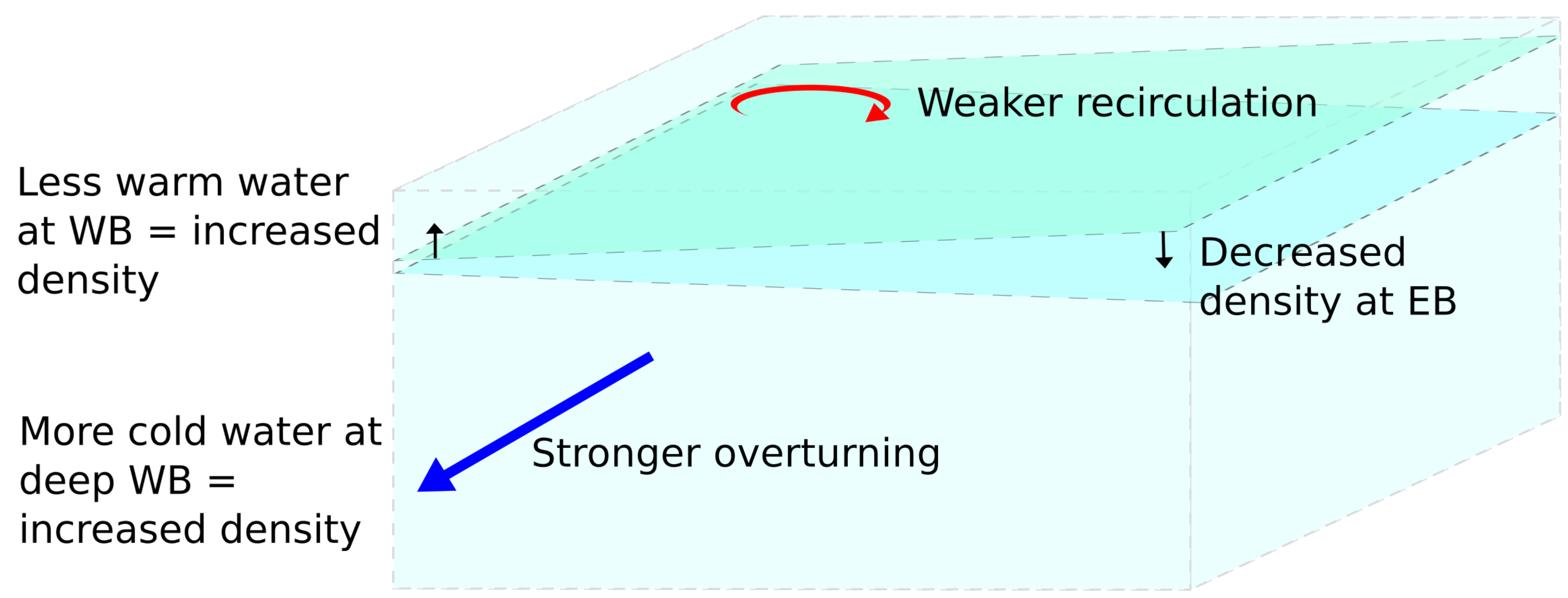
Salinity minimum near 1000 m in September associated with stretching of the intermediate layer and increased northwards transport

UMO weakest from Jul-Dec, with peak northwards anomaly Sep-Oct

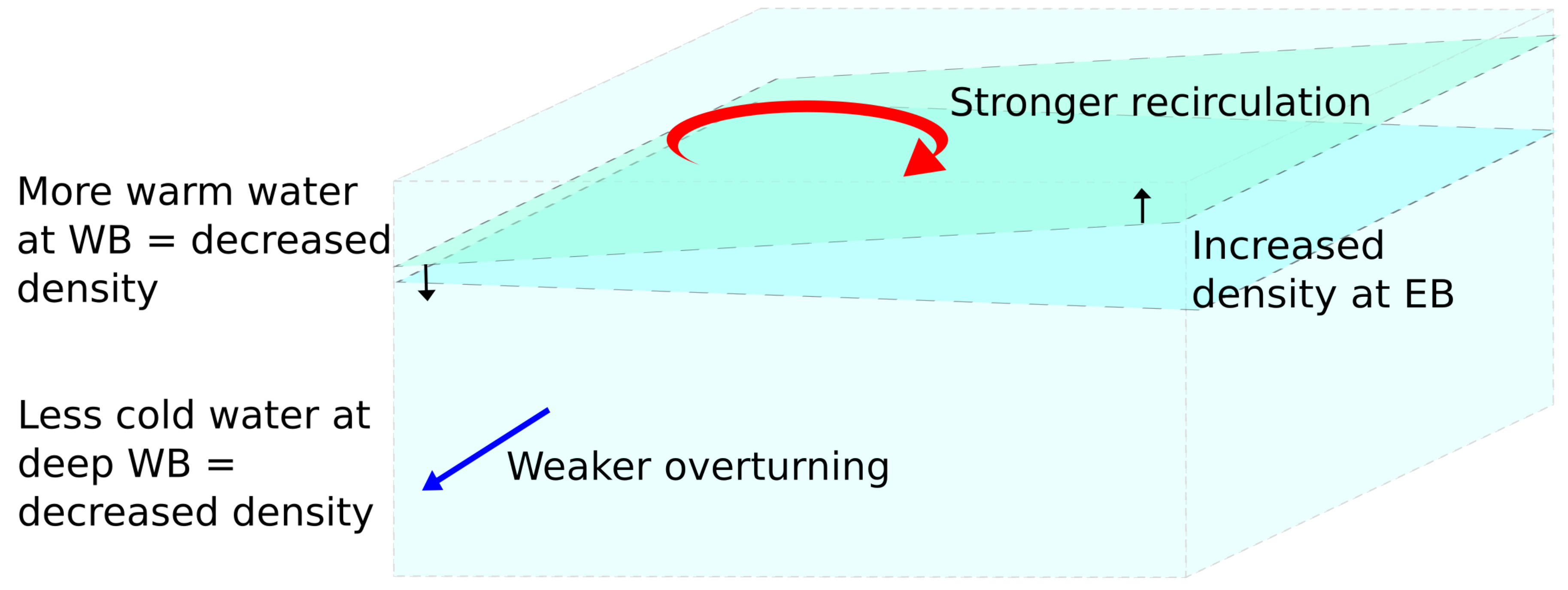
Chidichimo et al., 2010; Péréz-Hernández et al., 2015

Density anomalies and circulation changes

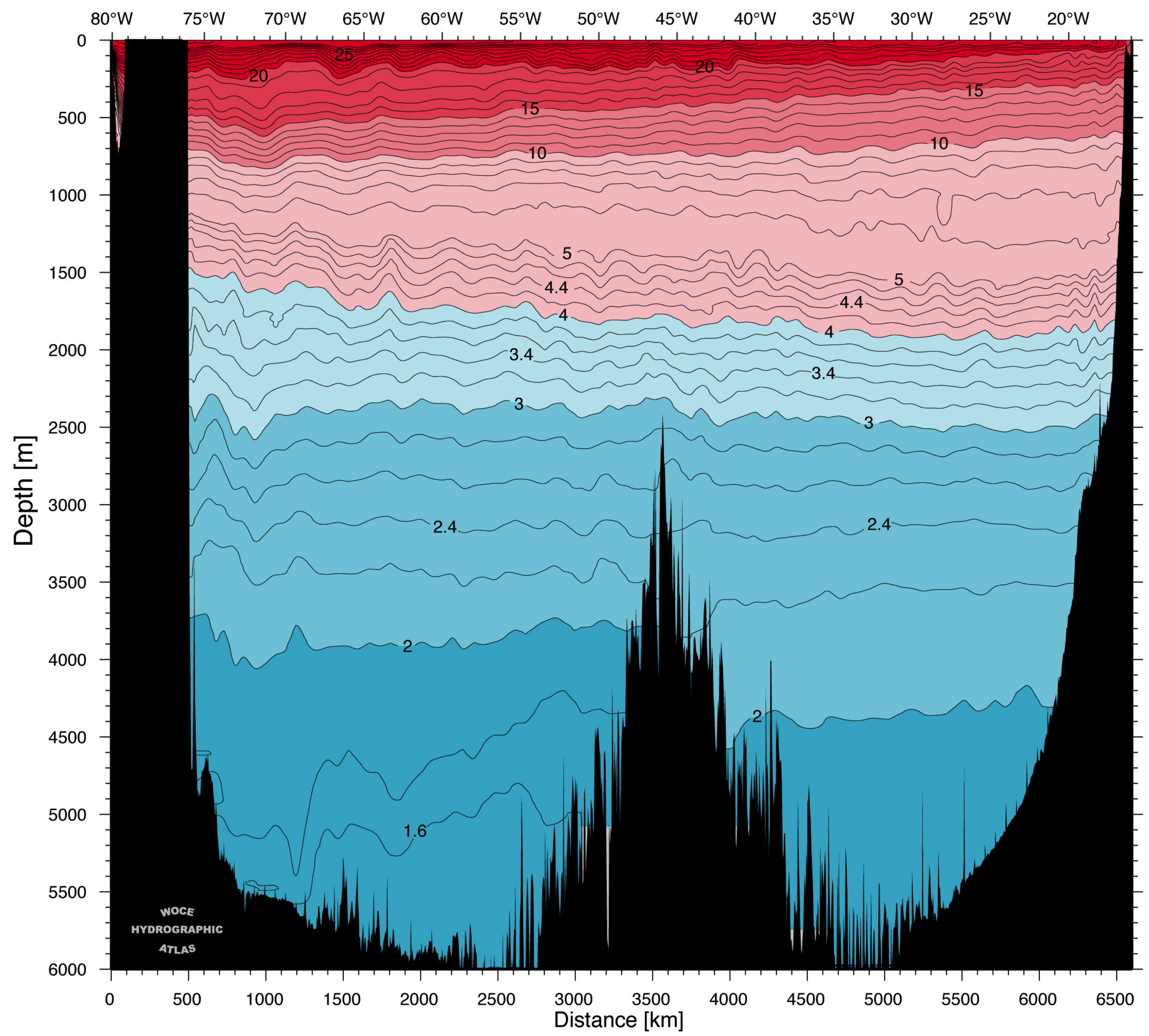
Positive UMO anomaly: weaker southwards recirculation



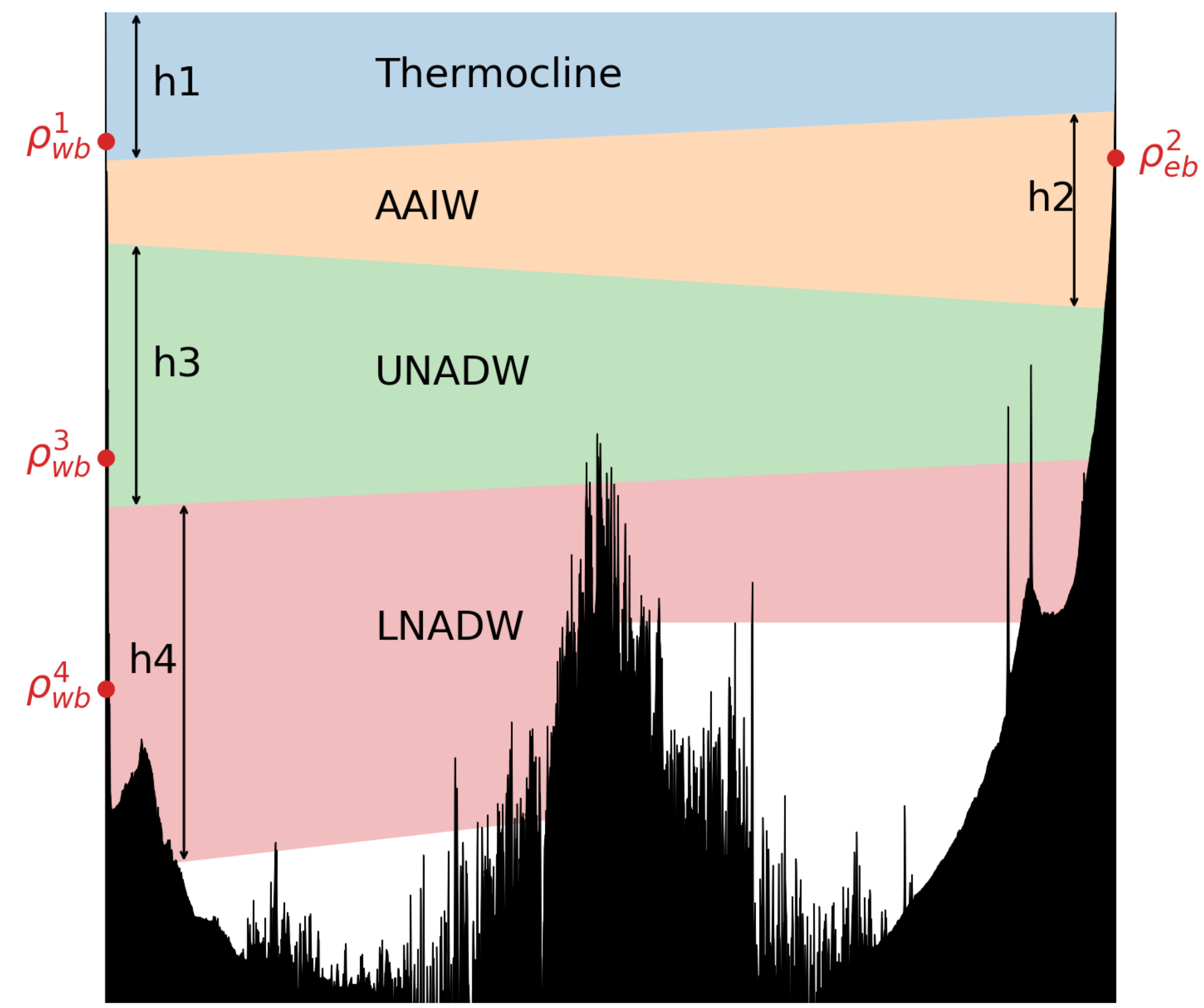
Negative UMO anomaly: stronger southwards recirculation



Temperature



Layer model

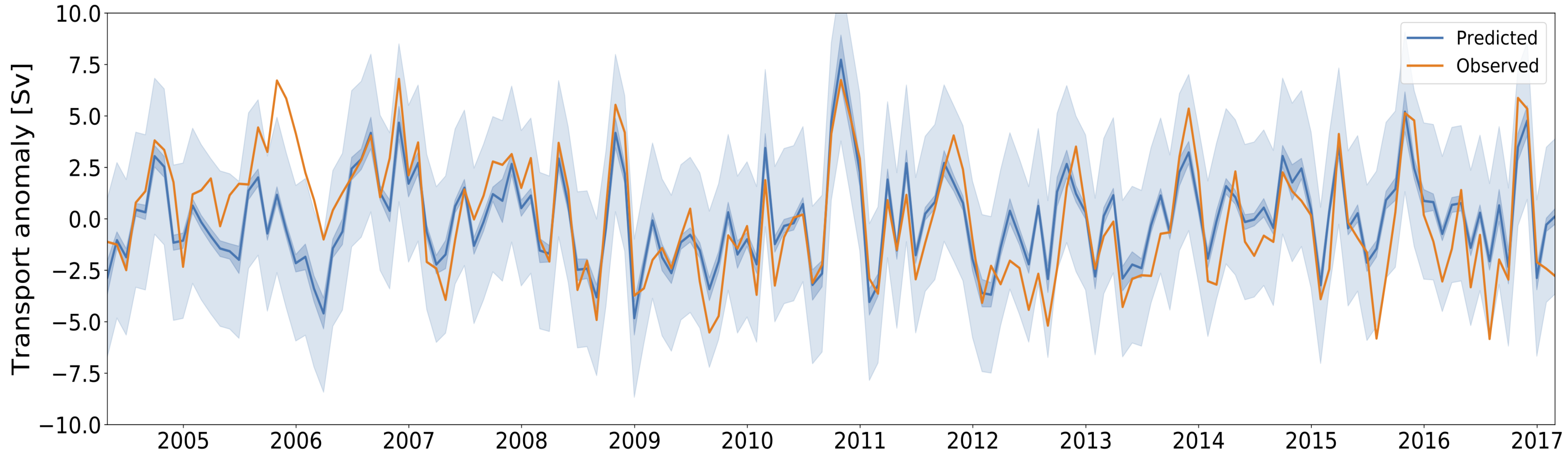


At which combination of depths 1–4 do the boundary density anomalies give the highest variance of UMO transport explained by the regression:

$$UMO = \alpha \cdot \rho^1_{wb} + \beta \cdot \rho^2_{eb} + \gamma \cdot \rho^3_{wb} + \zeta \cdot \rho^4_{wb}$$

Model Results

2-layer model: thermocline + AAIW

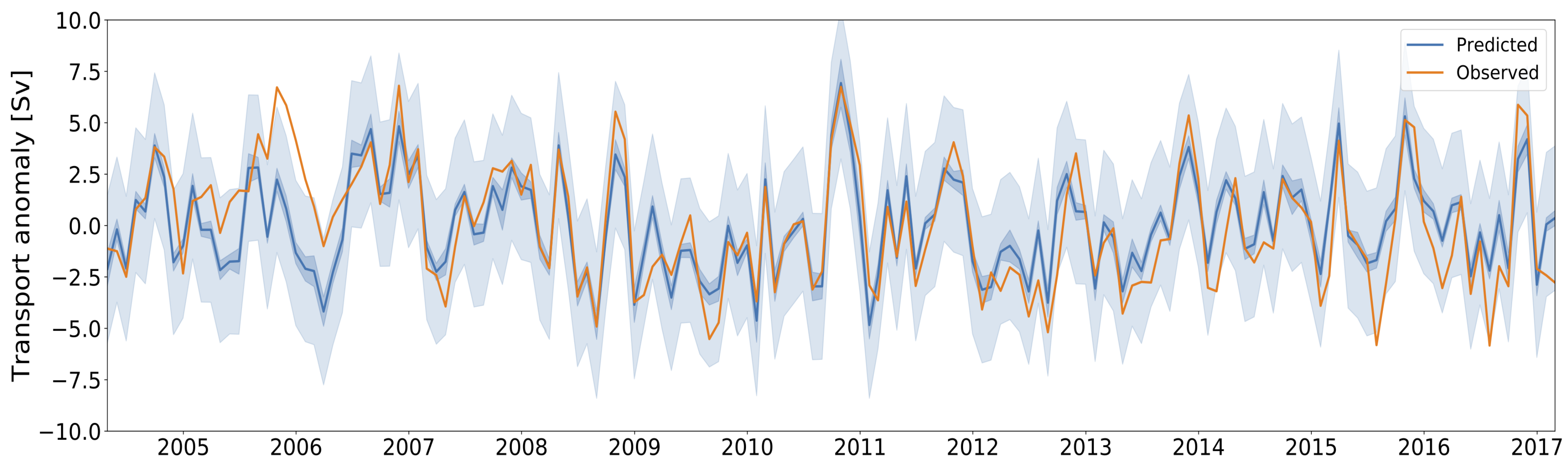


$$UMO = \alpha \cdot \rho_{wb}^{740} + \beta \cdot \rho_{eb}^{1020}$$

58% variance explained

SE of regression: 1.90 Sv

3-layer model: thermocline + AAIW + UNADW

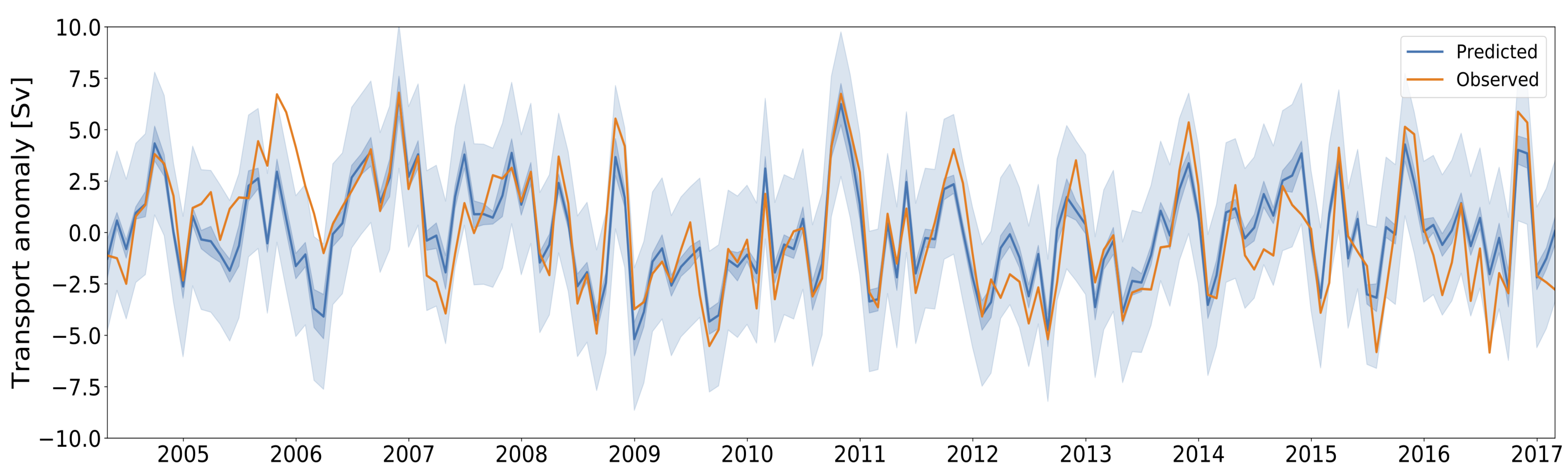


$$UMO = \alpha \cdot \rho_{wb}^{740} + \beta \cdot \rho_{eb}^{1020} + \gamma \cdot \rho_{wb}^{2840}$$

63% variance explained

SE of regression: 1.77 Sv

4-layer model: thermocline + AAIW + UNADW + LNADW



$$UMO = \alpha \cdot \rho_{wb}^{680} + \beta \cdot \rho_{eb}^{900} + \gamma \cdot \rho_{wb}^{1200} + \zeta \cdot \rho_{wb}^{4100}$$

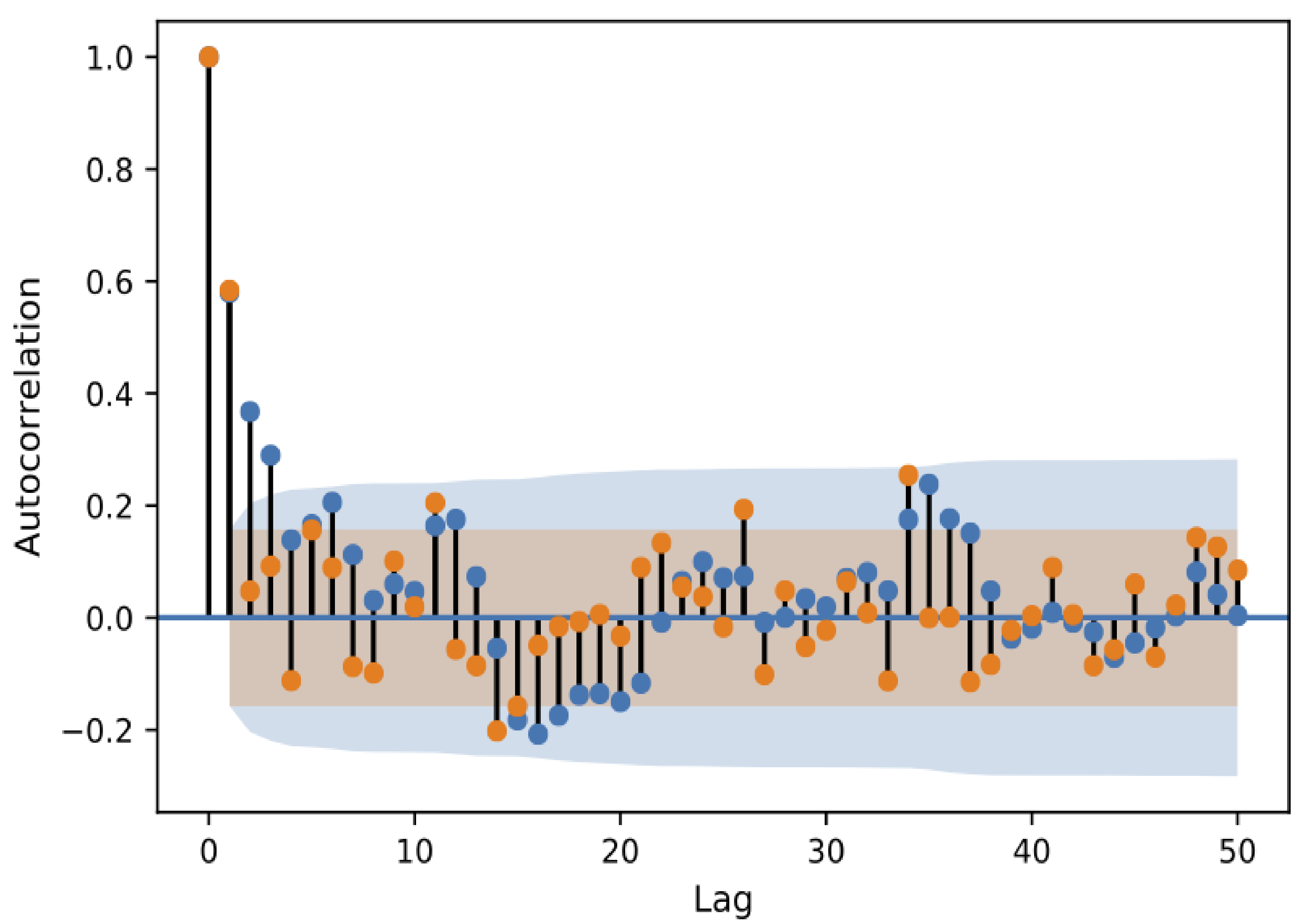
70% variance explained

SE of regression: 1.70 Sv

All linear regressions so far have been ordinary least-squares (OLS) models

As they are based on a time series, OLS models fail the following assumptions:

- Autocorrelation of residuals
- Homoscedasticity (equal variance of residuals)
- Normal distribution of residuals



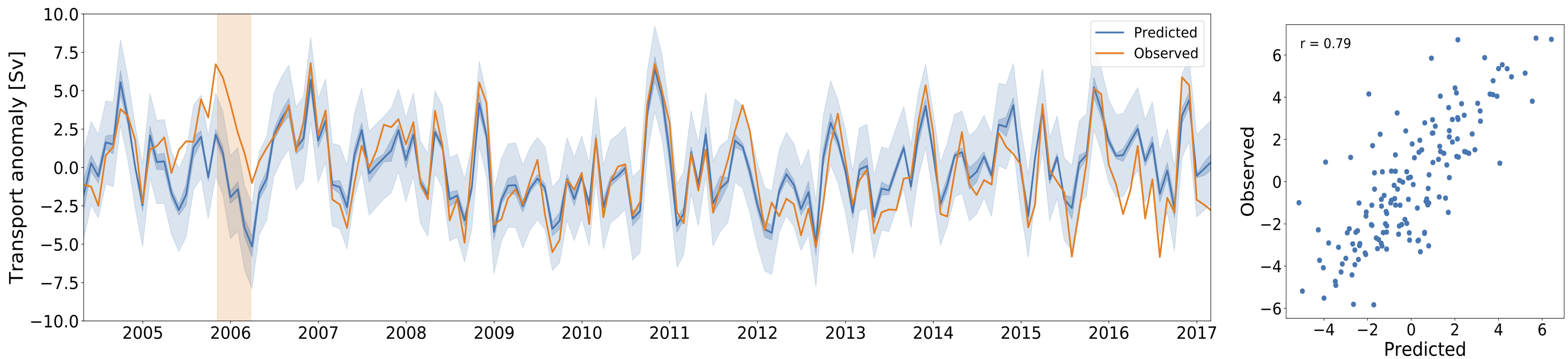
Autocorrelation and partial autocorrelation of residuals with 95% significance shaded

An alternative model is a generalized least-squares with autocorrelated errors (GLSAR) *McKinney et al., 2019*

The significant partial autocorrelation gives the number of lags

GLSAR(1) model

$$UMO = 38.04\,\rho_{wb}^{720} - 100.53\,\rho_{eb}^{880} + 54.83\,\rho_{wb}^{1300} + 129.05\,\rho_{wb}^{4100}$$



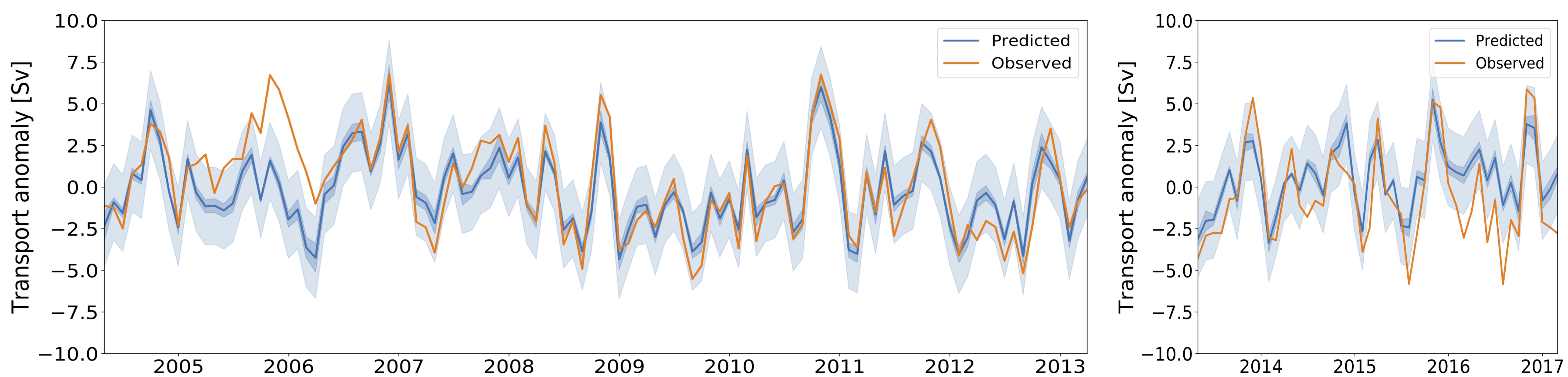
Observed monthly mean UMO transport compared to GLSAR(1) model results. Orange shaded area shows duration of WB2 moooring collapse.

Explained variance = 73%, SE of regression = 1.35 Sv

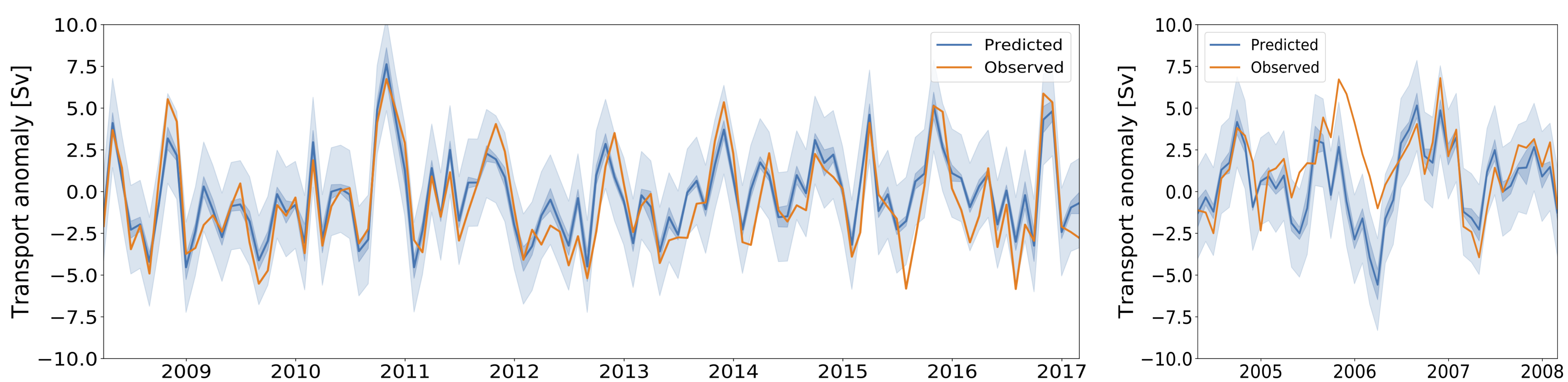
Cross-validation

Regression model created using first and last 60%, 70%, 80% and 90% of data

Model predicts UMO transport using remaining 40%, 30%, 20% and 10%



Model created with first 70% predicting last 30% - RMSE = 2.1 Sv



Model created with last 70% predicting first 30% - RMSE = 2.4 Sv

Cross-validation model results

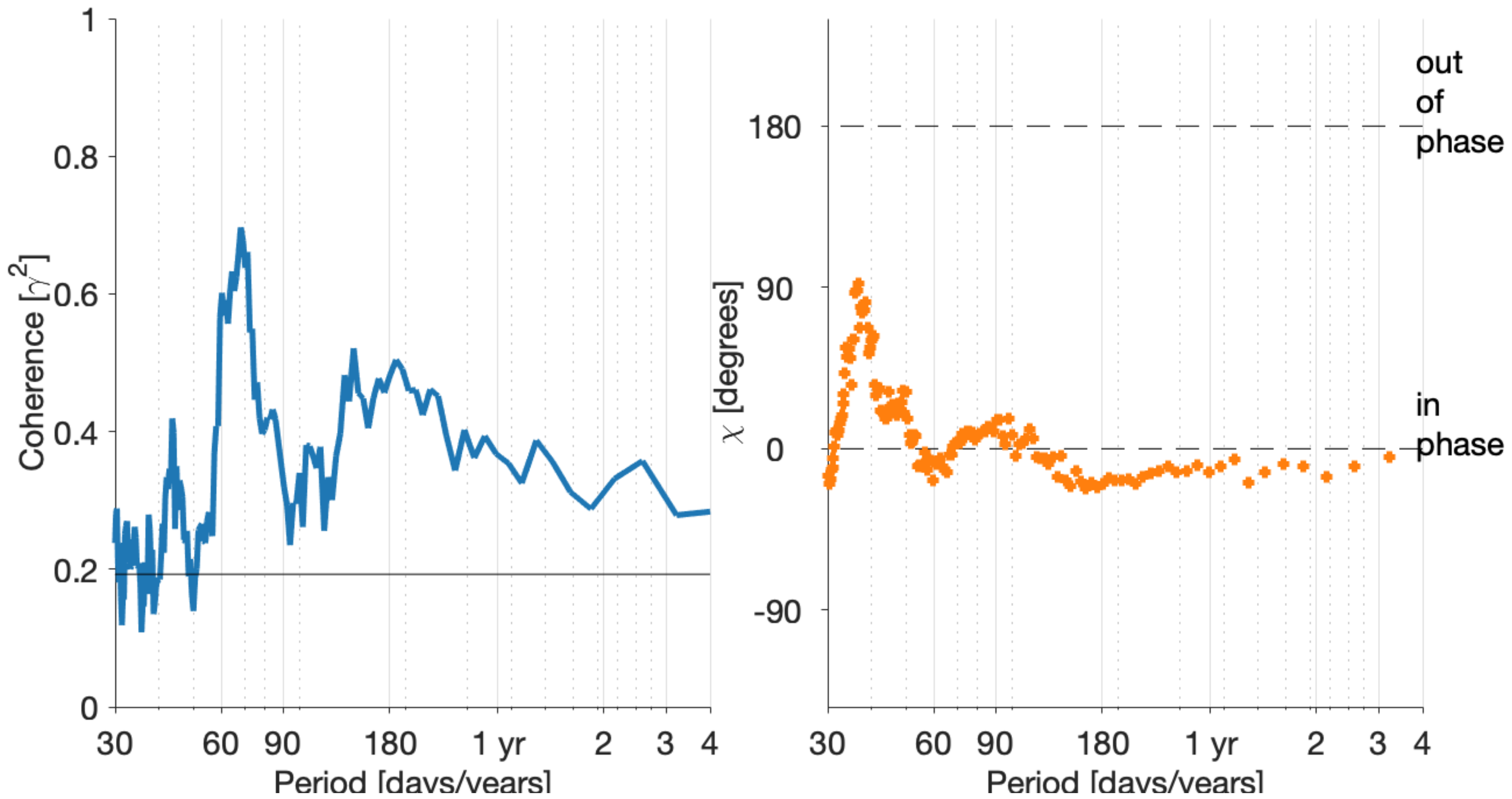
	Min	**Max**	**Mean**
Explained variance	74%	81%	77%
SE [Sv]	1.1	1.3	1.2

Cross-validation prediction results

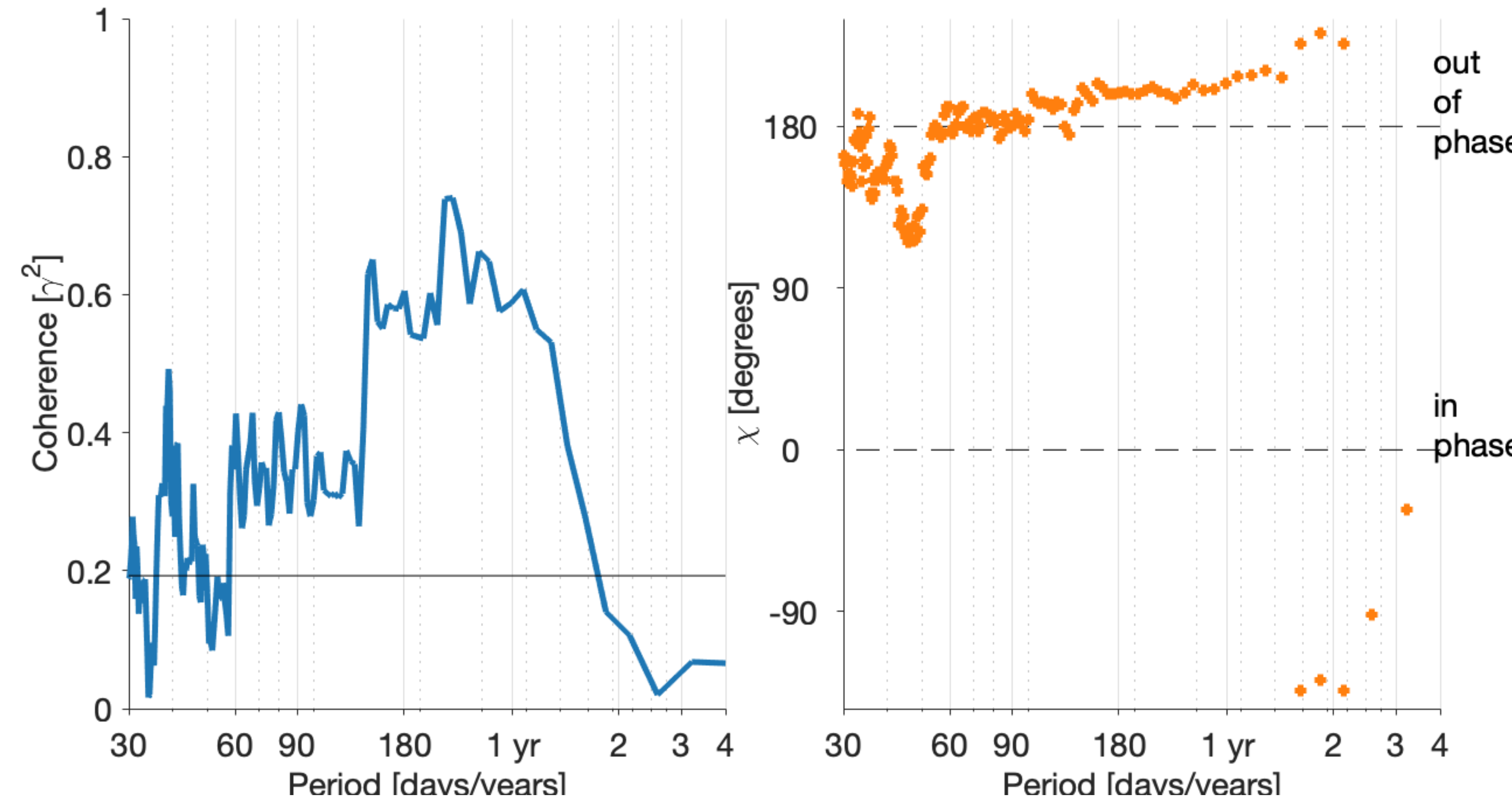
	Min	**Max**	**Mean**
RMSE [Sv]	2.1	2.8	2.3
Percent in PI	58%	87%	73%

Coherence between UMO and density anomalies

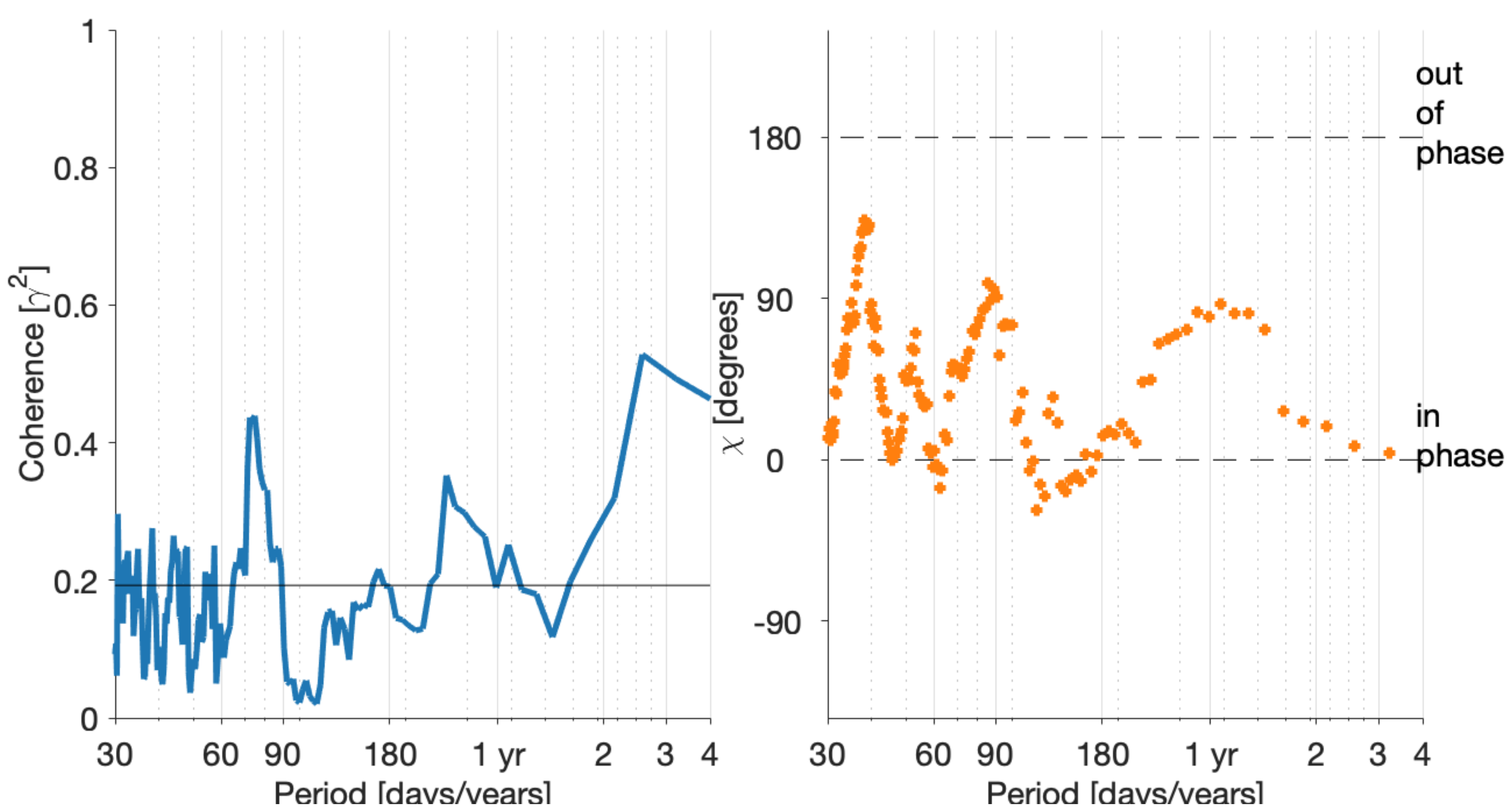
Thermocline [720 dbar]



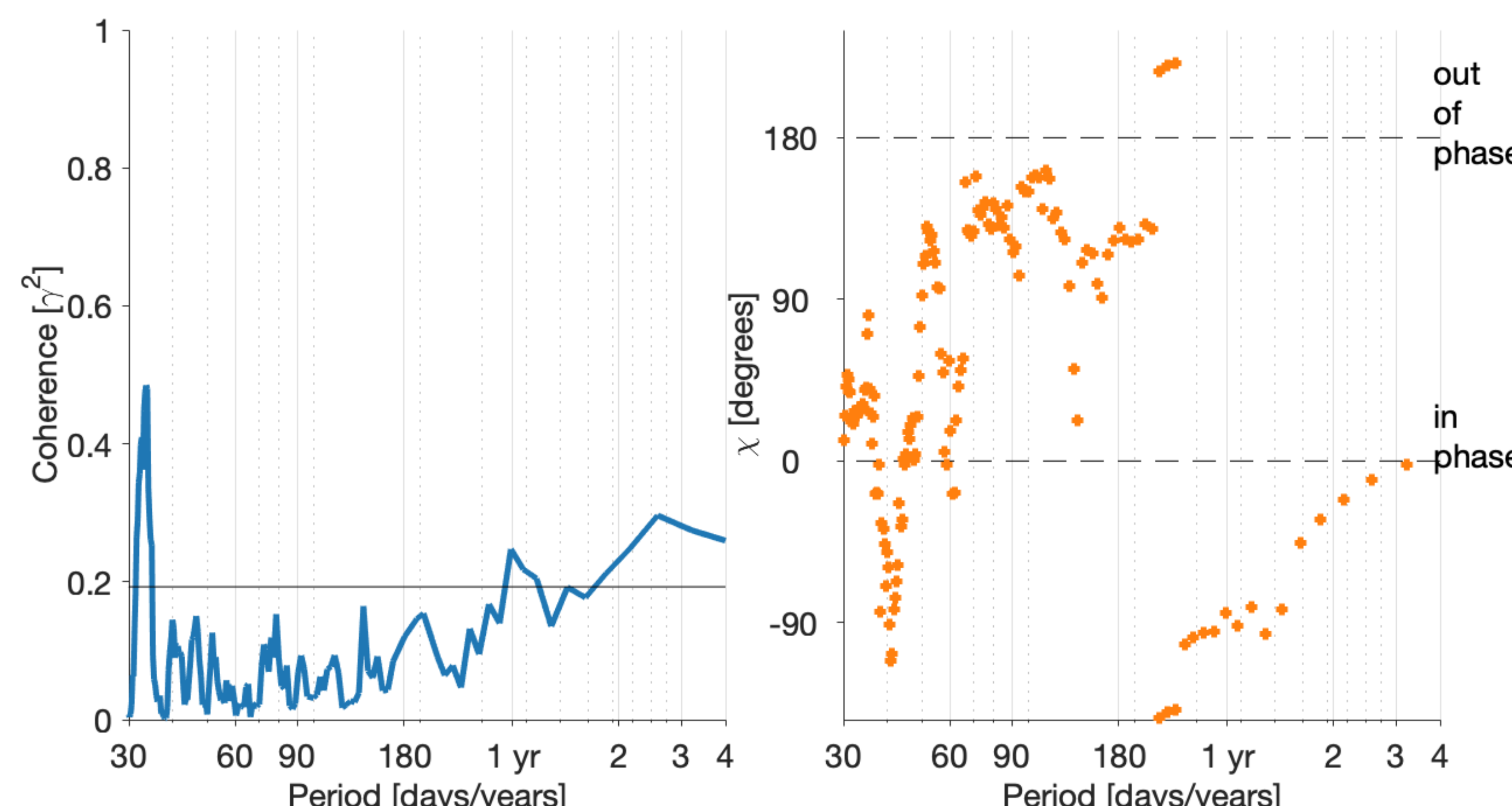
AAIW [880 dbar]



UNADW [1300 dbar]



LNADW [4100 dbar]



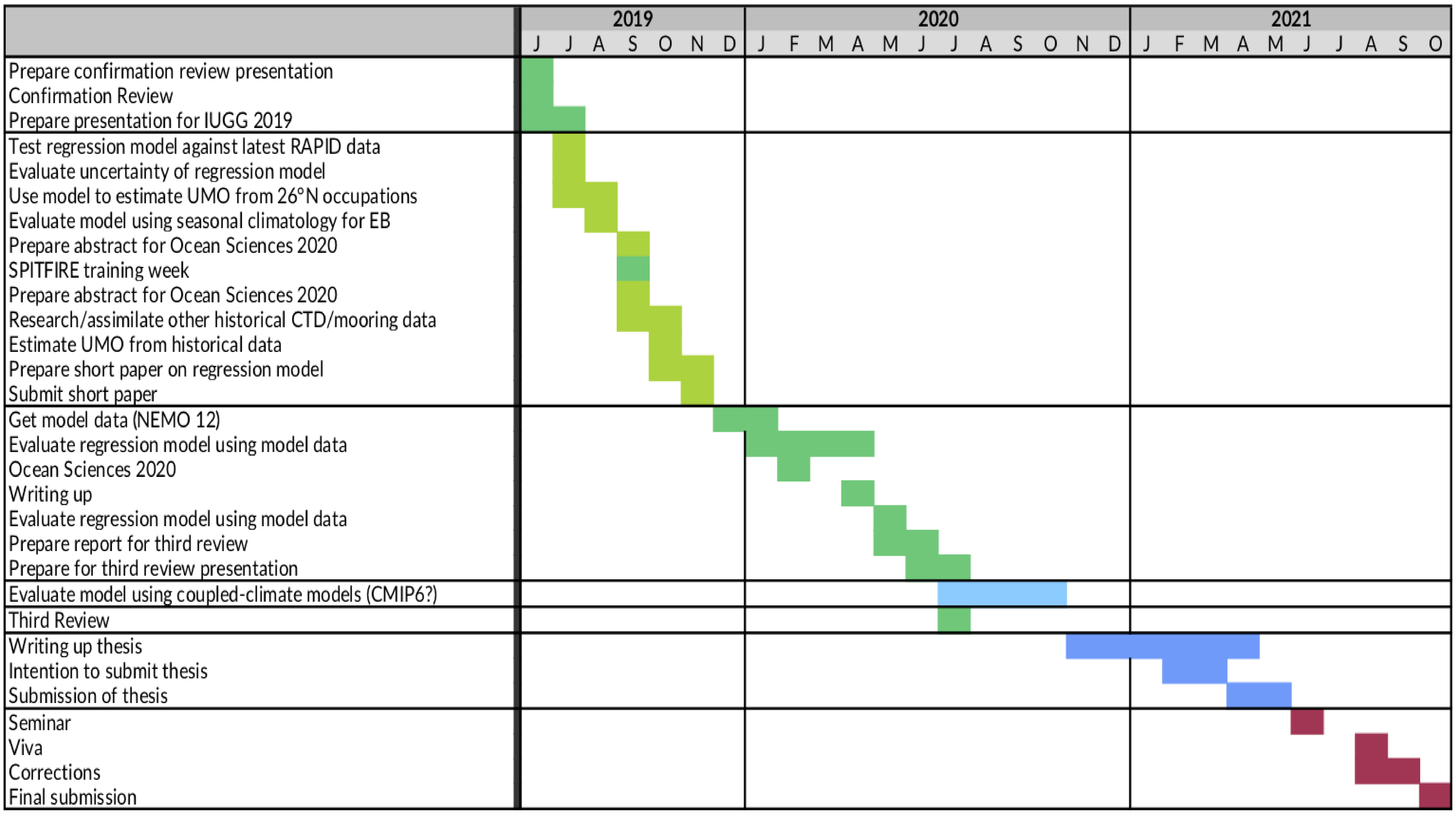
Conclusions

- Shown that single-layer models (e.g., *Longworth et al., 2011*) cannot capture the dynamics of the overturning circulation
  - At least 3 layers are required to explain more than 60% variance of UMO transport
- 4-layer GLSAR model explains 73% of the variance in the observed UMO transport
  - Uncertainty: cross-validation shows mean RMSE of 2.3 Sv
- Regression model captures variability on all timescales:
  - Seasonal variability dominated by AAIW layer
  - Longer timescale variability found in thermocline and deeper layers
- Changes in RAPID data (e.g., WB2 mooring collapse) increase error between model and observations
- Model is sensitive to depth of density anomalies, which may be an issue with sparsely-deployed instruments

Future work

- Test model against new RAPID results and hydrographic section data - is level of uncertainty reasonable?
- Assess whether seasonal climatology can replace eastern boundary variable
- Apply model to historical CTD and mooring data
- Investigate model further using NEMO ocean model with 1/12° resolution

Gantt chart


2019
2020
2021
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O
Prepare confirmation review presentation
Confirmation Review
Prepare presentation for IUGG 2019
Test regression model against latest RAPID data
Evaluate uncertainty of regression model
Use model to estimate UMO from 26°N occupations
Evaluate model using seasonal climatology for EB
Prepare abstract for Ocean Sciences 2020
SPITFIRE training week
Prepare abstract for Ocean Sciences 2020
Research/assimilate other historical CTD/mooring data
Estimate UMO from historical data
Prepare short paper on regression model
Submit short paper
Get model data (NEMO 12)
Evaluate regression model using model data
Ocean Sciences 2020
Writing up
Evaluate regression model using model data
Prepare report for third review
Prepare for third review presentation
Evaluate model using coupled-climate models (CMIP6?)
Third Review
Writing up thesis
Intention to submit thesis
Submission of thesis
Seminar
Viva
Corrections
Final submission

References

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Thank you

Any questions?