What drives upper ocean heat content variability?

Erik Tesdal, Ryan Abernathey
LDEO

Erik Tesdal

- Columbia Ph.D. student
- **Salinity Trends within the Upper Layers of the Subpolar North Atlantic**

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(Manuscript received 9 August 2017, in final form 21 November 2017)

- Really good at working with ECCO!

Hiatuses and Blobs

Earth's Future

RESEARCH ARTICLE
10.1002/2013EF000165

Key Points:
- There is a hiatus in the rise in global mean surface temperatures over the

An apparent hiatus in global warming?

Kevin E. Trenberth[1] and John T. Fasullo[1]

[1]National Center for Atmospheric Research, Boulder, Colorado, USA

nature Vol 465|20 May 2010|doi:10.1038/nature09043

LETTERS

Robust warming of the global upper ocean

John M. Lyman[1,2], Simon A. Good[3], Viktor V. Gouretski[4], Masayoshi Ishii[5,6], Gregory C. Johnson[2], Matthew D. Palmer[3], Doug M. Smith[3] & Josh K. Willis[7]

LETTERS
PUBLISHED ONLINE: 18 SEPTEMBER 2011 | DOI: 10.1038/NCLIMATE1229
nature climate change

Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods

Gerald A. Meehl[1]*, Julie M. Arblaster[1,2], John T. Fasullo[1], Aixue Hu[1] and Kevin E. Trenberth[1]

LETTER
doi:10.1038/nature12534

Recent global-warming hiatus tied to equatorial Pacific surface cooling

Yu Kosaka[1] & Shang-Ping Xie[1,2,3]

ARTICLES | FOCUS
PUBLISHED ONLINE: 9 FEBRUARY 2014 | DOI: 10.1038/NCLIMATE2106
nature climate change

Recent intensification of wind-driven circulation in the Pacific and the ongoing warming hiatus

Matthew H. England[1,2]*, Shayne McGregor[1,2], Paul Spence[1,2], Gerald A. Meehl[3], Axel Timmermann[4], Wenju Cai[5], Alex Sen Gupta[1,2], Michael J. McPhaden[6], Ariaan Purich[5] and Agus Santoso[1,2]

GLOBAL WARMING

Recent hiatus caused by decadal shift in Indo-Pacific heating

Veronica Nieves,[1,2]* Josh K. Willis,[2] William C. Patzert[2]

Geophysical Research Letters

RESEARCH LETTER
10.1002/2014GL061456

Key Points:
- Heat uptake increased in the Southern, Atlantic, and Indian Oceans
- The increase of 0.5–1 W/m^2 in ocean heat uptake is enough to explain the hiatus

Surface warming hiatus caused by increased heat uptake across multiple ocean basins

S. S. Drijfhout[1], A. T. Blaker[2], S. A. Josey[2], A. J. G. Nurser[2], B. Sinha[2], and M. A. Balmaseda[3]

[1]NOCS, University of Southampton, Southampton, UK, [2]National Oceanography Centre, Southampton, Southampton, UK, [3]European Centre for Medium range Weather Forecasts, Reading, UK

nature geoscience
LETTERS
PUBLISHED ONLINE: 18 MAY 2015 | DOI: 10.1038/NGEO2438

Pacific origin of the abrupt increase in Indian Ocean heat content during the warming hiatus

Sang-Ki Lee[1,2]*, Wonsun Park[3], Molly O. Baringer[2], Arnold L. Gordon[4], Bruce Huber[4] and Yanyun Liu[1,2]

nature COMMUNICATIONS

ARTICLE
Received 17 Jun 2015 | Accepted 2 Feb 2016 | Published 30 Mar 2016 DOI: 10.1038/ncomms10926 OPEN

Tracking ocean heat uptake during the surface warming hiatus

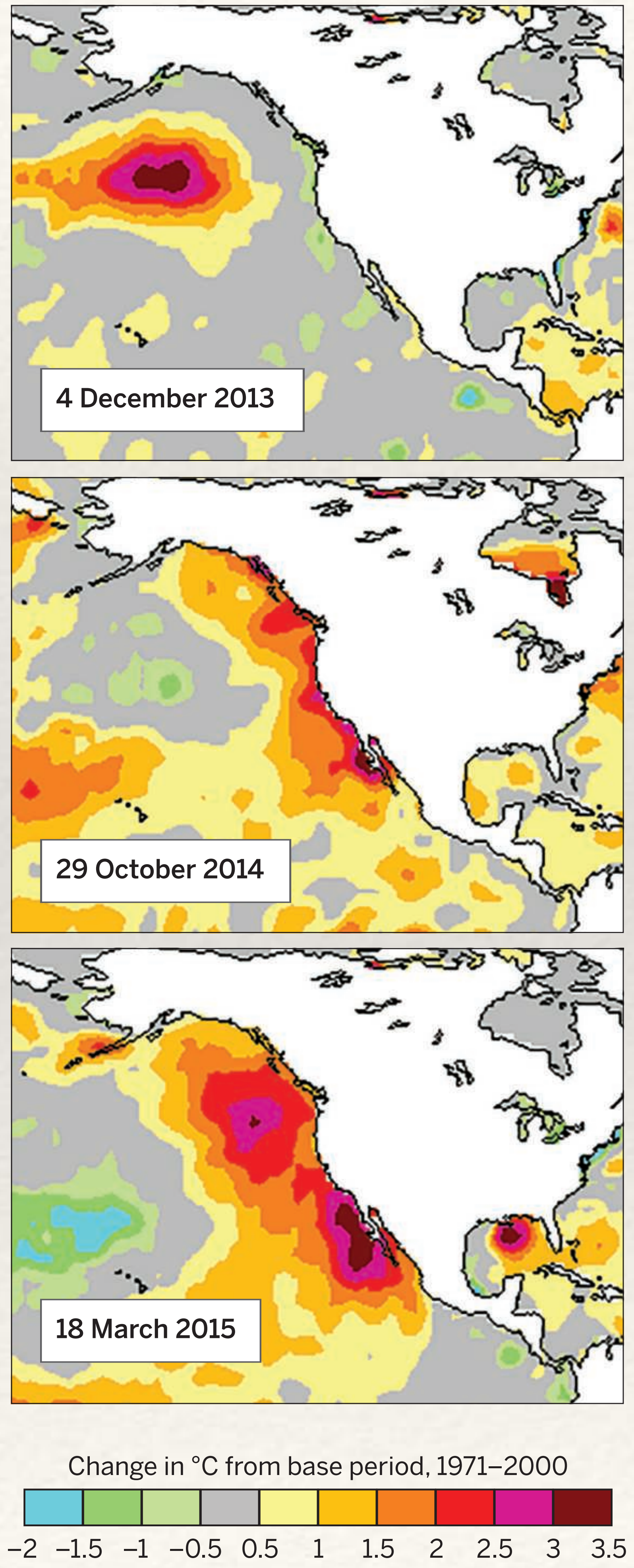
Wei Liu[1], Shang-Ping Xie[1] & Jian Lu[2]

Hiatuses and Blobs

MARINE SCIENCE

'The Blob' invades Pacific, flummoxing climate experts

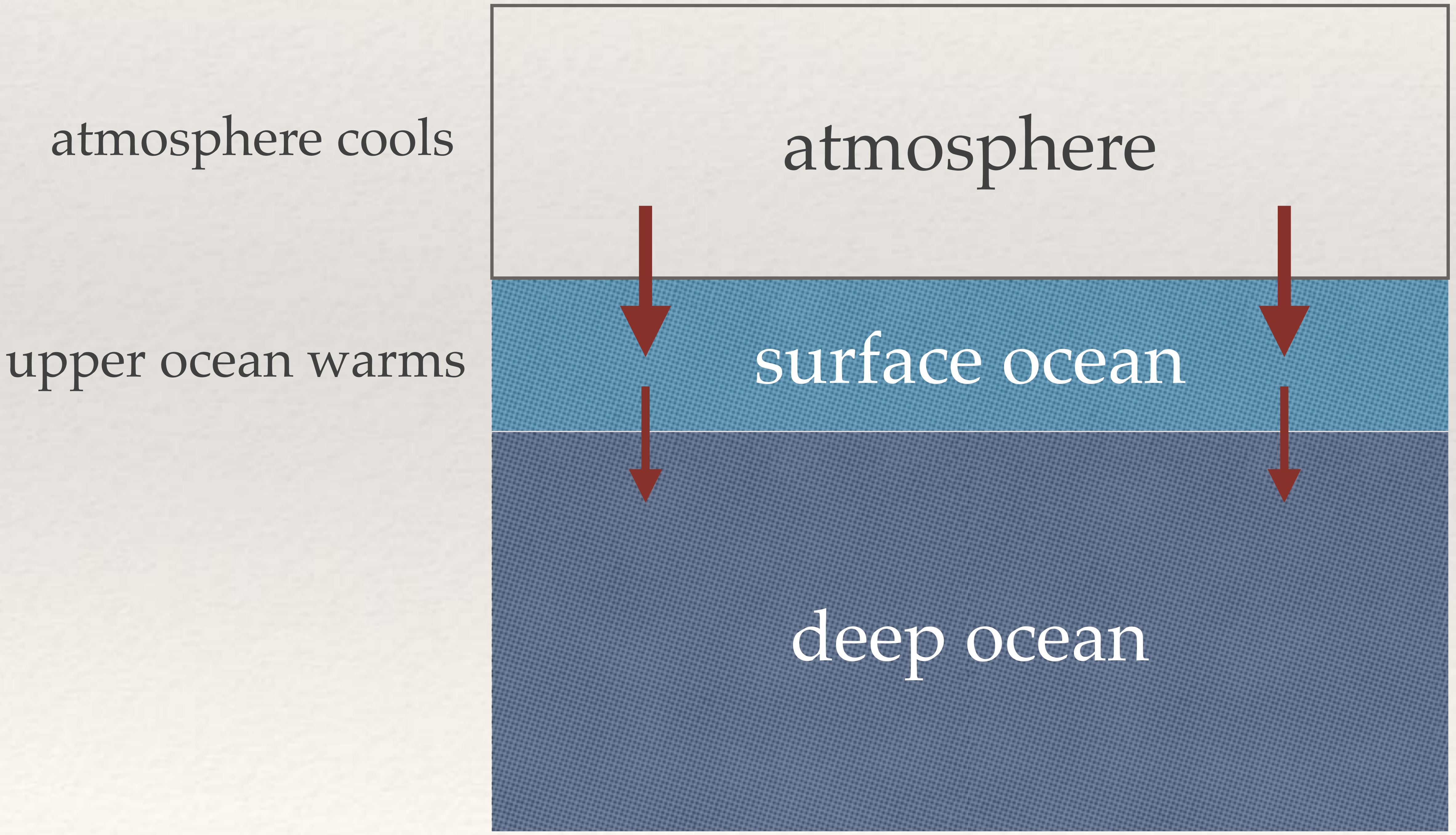
Persistent mass of warm water is reshuffling ocean currents, marine ecosystems, and inland weather



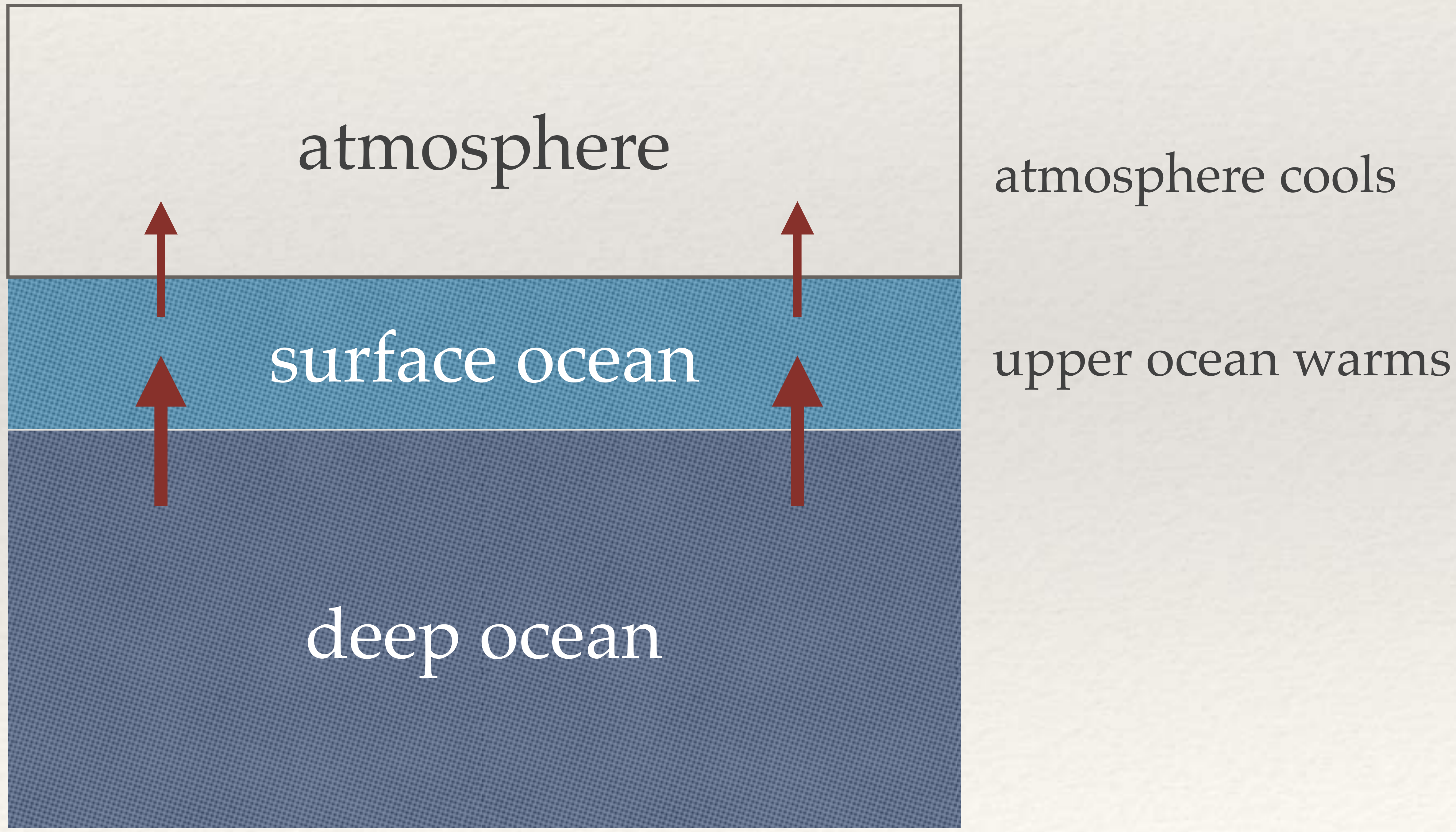
Hiatuses and Blobs

Contrasting modes of internal variability

“Hiatus”



“Blob”



What drives upper ocean heat content variability?

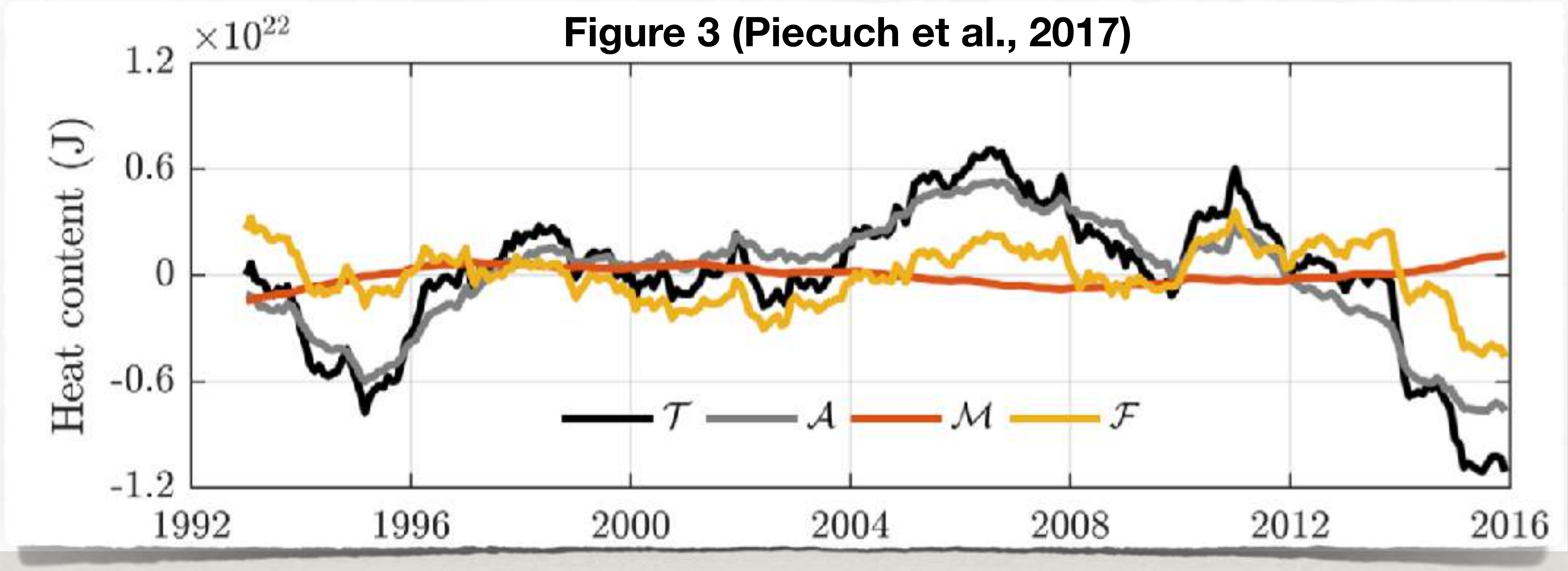
- What is the relative role of air-sea forcing vs. internal ocean processes?
- "Advection of anomalies" vs. "anomalous advection"?
- How does the balance of terms depend on the spatial and temporal aggregation scale?

Heat Budget

- ECCO is well suited for answering these questions because it has a closed heat budget with detailed diagnostic capability
- ECCOv4 even adjusts mixing coefficients

$$\frac{\partial s^* \theta}{\partial t} = -\nabla_h \cdot (s^* \theta \mathbf{u}_{res}) - \frac{\partial}{\partial z}(\theta w_{res}) + s^* F_\theta + s^* D_\theta$$

Comparison to Piecuch et al. (2017)



- Calculate full diagnostic budget
- Integrate spatially over SPNA
- integrate cumulatively over time
- detrend
- remove seasonal cycle

ftp://ecco.jpl.nasa.gov/Version4/Release3/doc/

Anomaly Budget

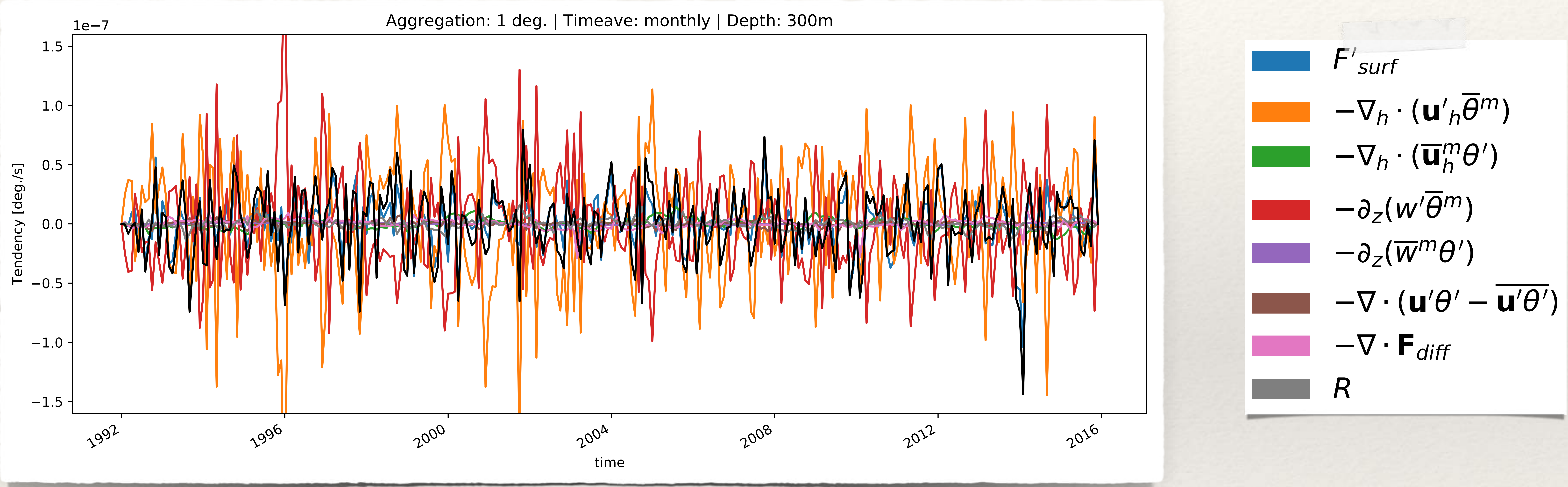
$\overline{\theta}^m, \overline{\mathbf{u}}^m$ Monthly mean climatology

$\theta', \mathbf{u}'$ Monthly anomalies

$$\frac{\partial \theta'}{\partial t} = F'_{surf} - \nabla_h \cdot (\overline{\mathbf{u}}_h^m \theta') - \nabla_h \cdot (\mathbf{u}'_h \overline{\theta}^m) - \frac{\partial}{\partial z}(\overline{w}^m \theta') - \frac{\partial}{\partial z}(w' \overline{\theta}^m) - \nabla \cdot (\mathbf{u}'\theta' - \overline{\mathbf{u}'\theta'}) - \nabla \cdot \mathbf{F}'_{diff} + R$$

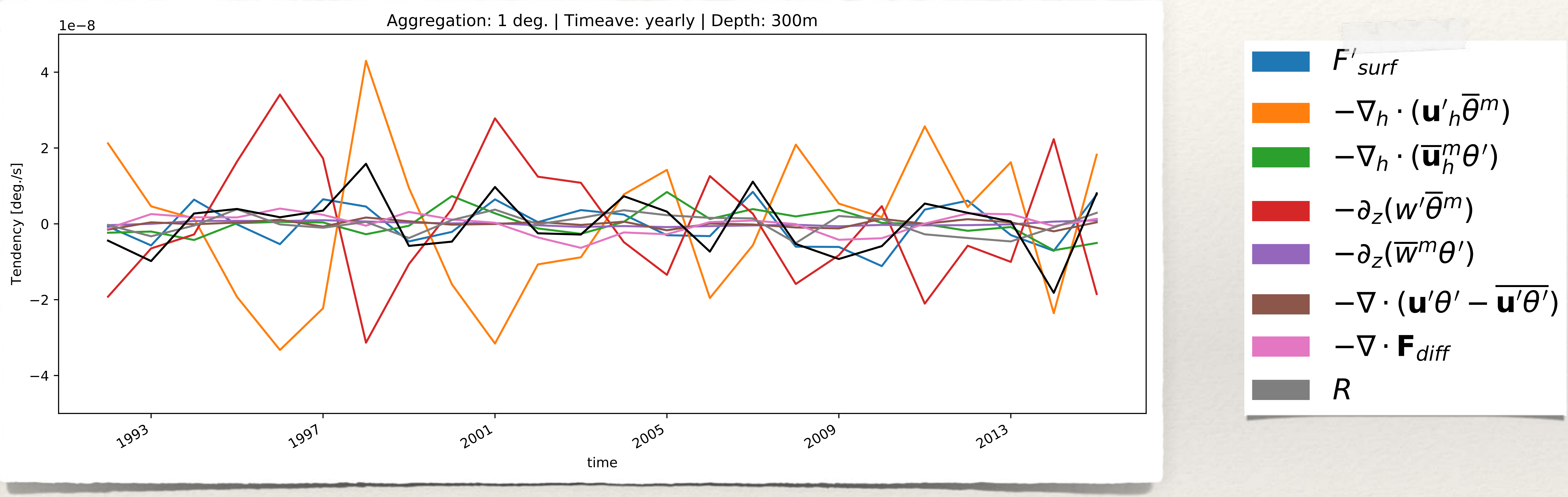
- Surface forcing
- Anomalous horizontal advection of mean
- Mean horizontal advection of anomalies
- Anomalous vertical advection of mean
- Mean vertical advection of anomalies
- Nonlinear advection
- Diffusion
- Residual

Example Timeseries



North Atlantic: 17 W, 45 N

Example Timeseries



North Atlantic: 17 W, 45 N

Regression Analysis

What are the dominant terms in any particular timeseries?

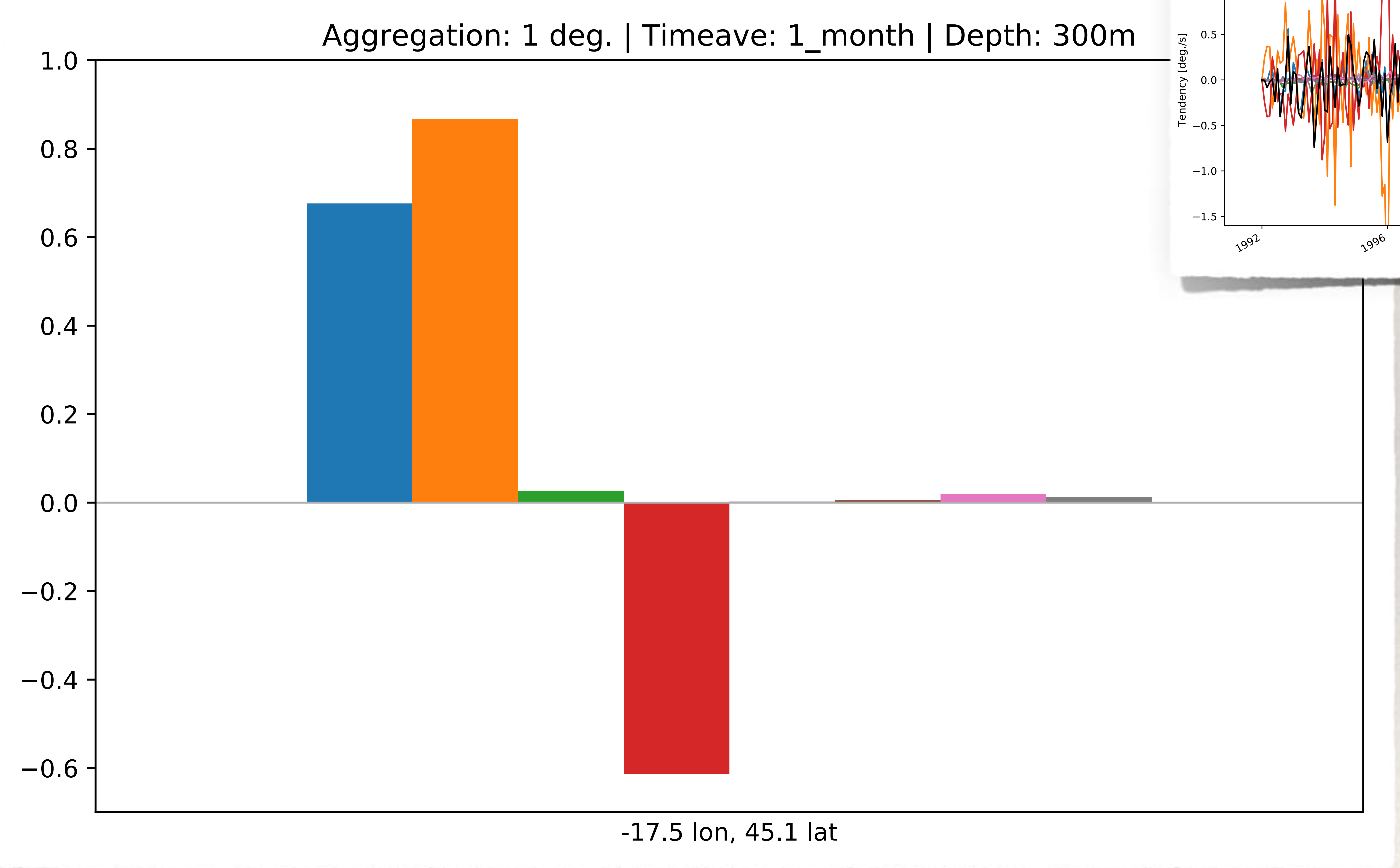
$$\frac{\partial \theta'}{\partial t} = F'_{surf} - \nabla_h \cdot (\mathbf{u}'_h \overline{\theta}^m) - \nabla_h \cdot (\overline{\mathbf{u}}_h^m \theta') - \frac{\partial}{\partial z}(w' \overline{\theta}^m) - \frac{\partial}{\partial z}(\overline{w}^m \theta') - \nabla \cdot (\mathbf{u}'\theta' - \overline{\mathbf{u}'\theta'}) - \nabla \cdot \mathbf{F}_{diff} + R$$

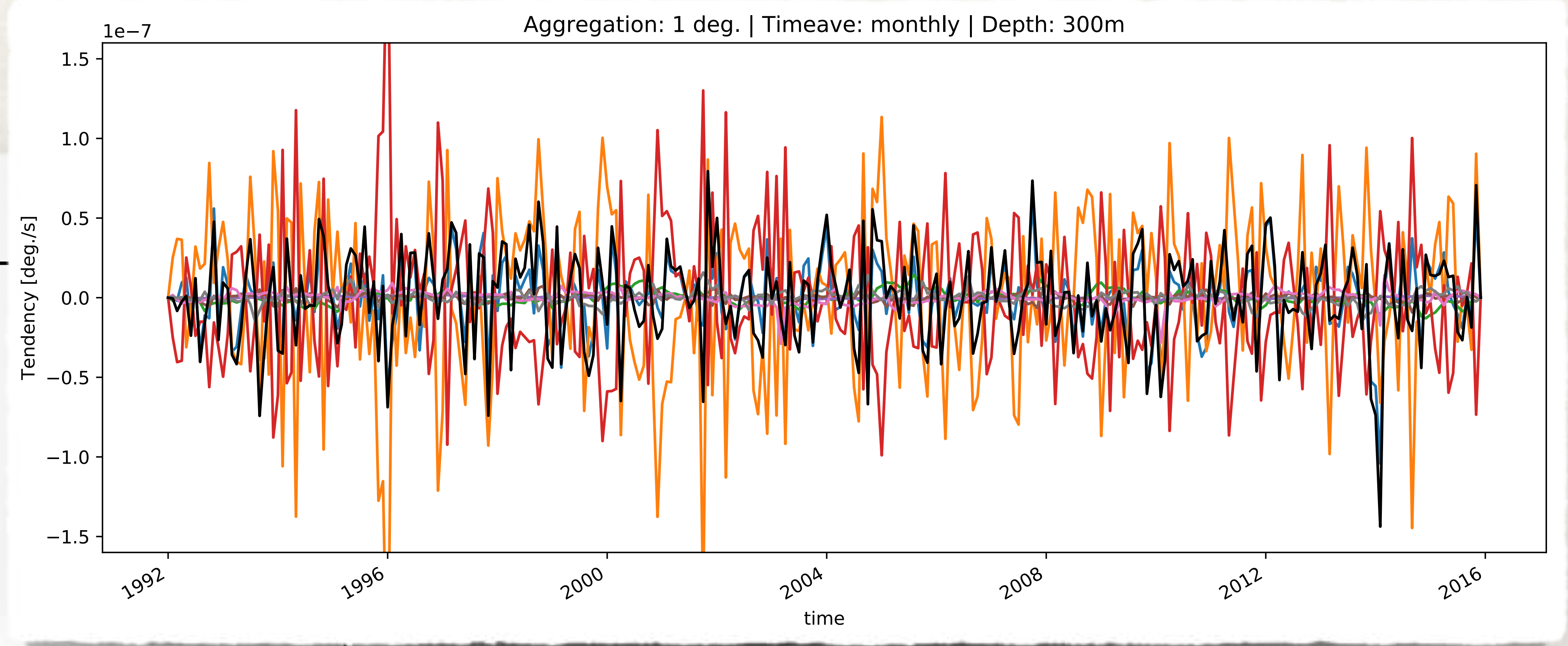
Think of this as: $y(t) = x_1(t) + x_2(t) + ... + x_n(t)$

$$r_1 = \frac{\int_{t_0}^{t_1} x_1(t)y(t)dt}{\int_{t_0}^{t_1} y(t)y(t)dt} \qquad r_2 = \frac{\int_{t_0}^{t_1} x_2(t)y(t)dt}{\int_{t_0}^{t_1} y(t)y(t)dt} \qquad \text{etc.}$$

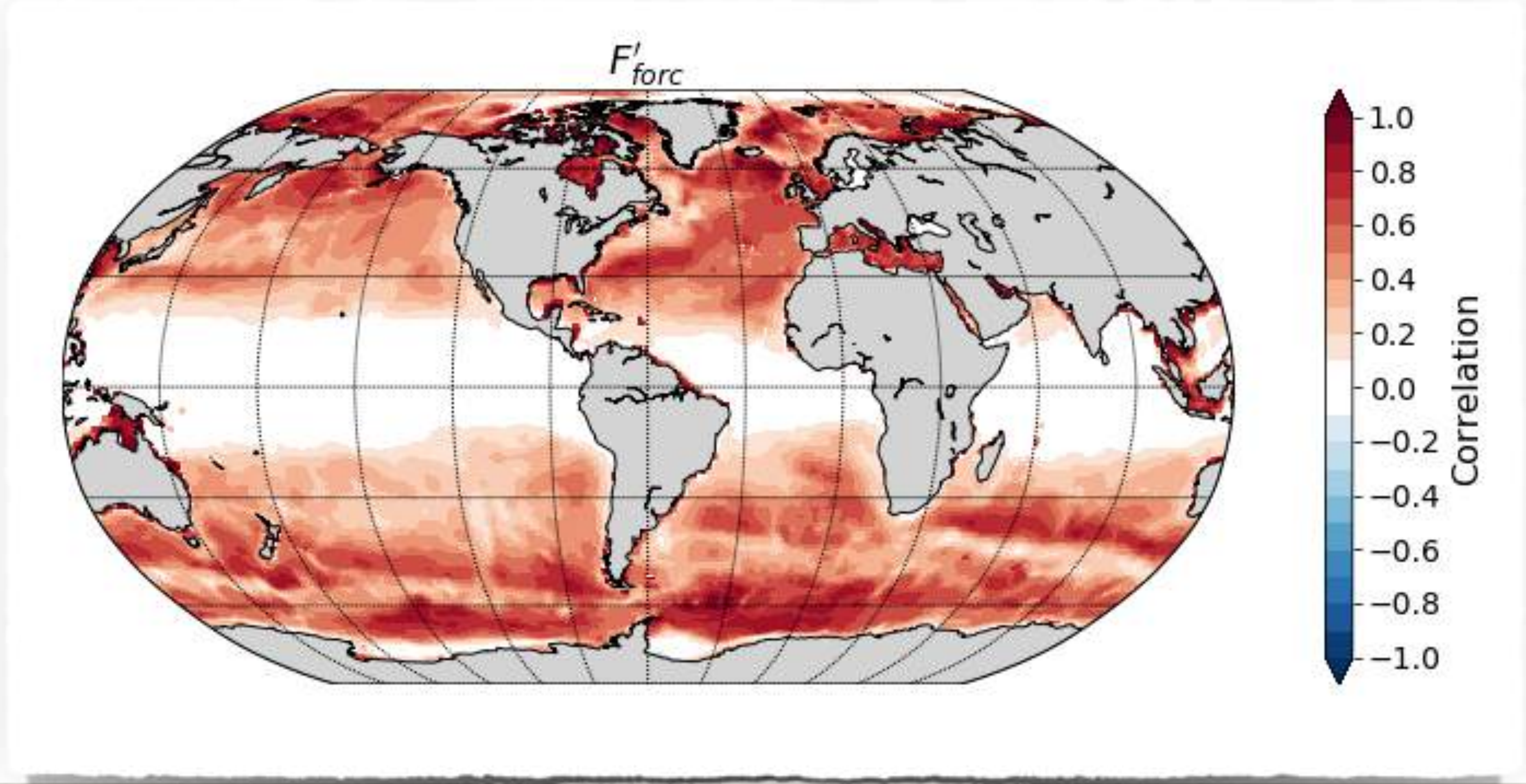
$$r_1 + r_2 + ... + r_n = 1$$

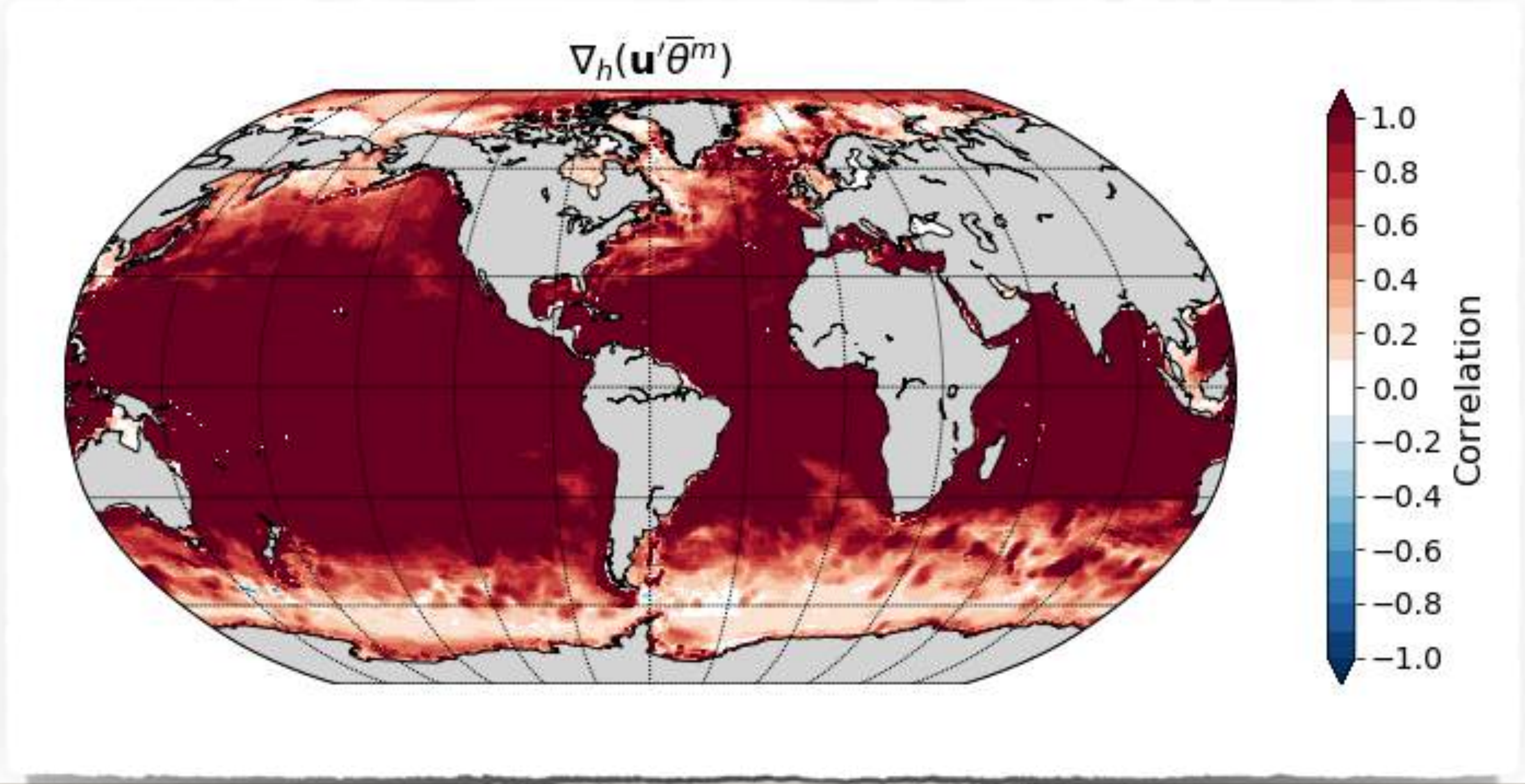
Regression Analysis

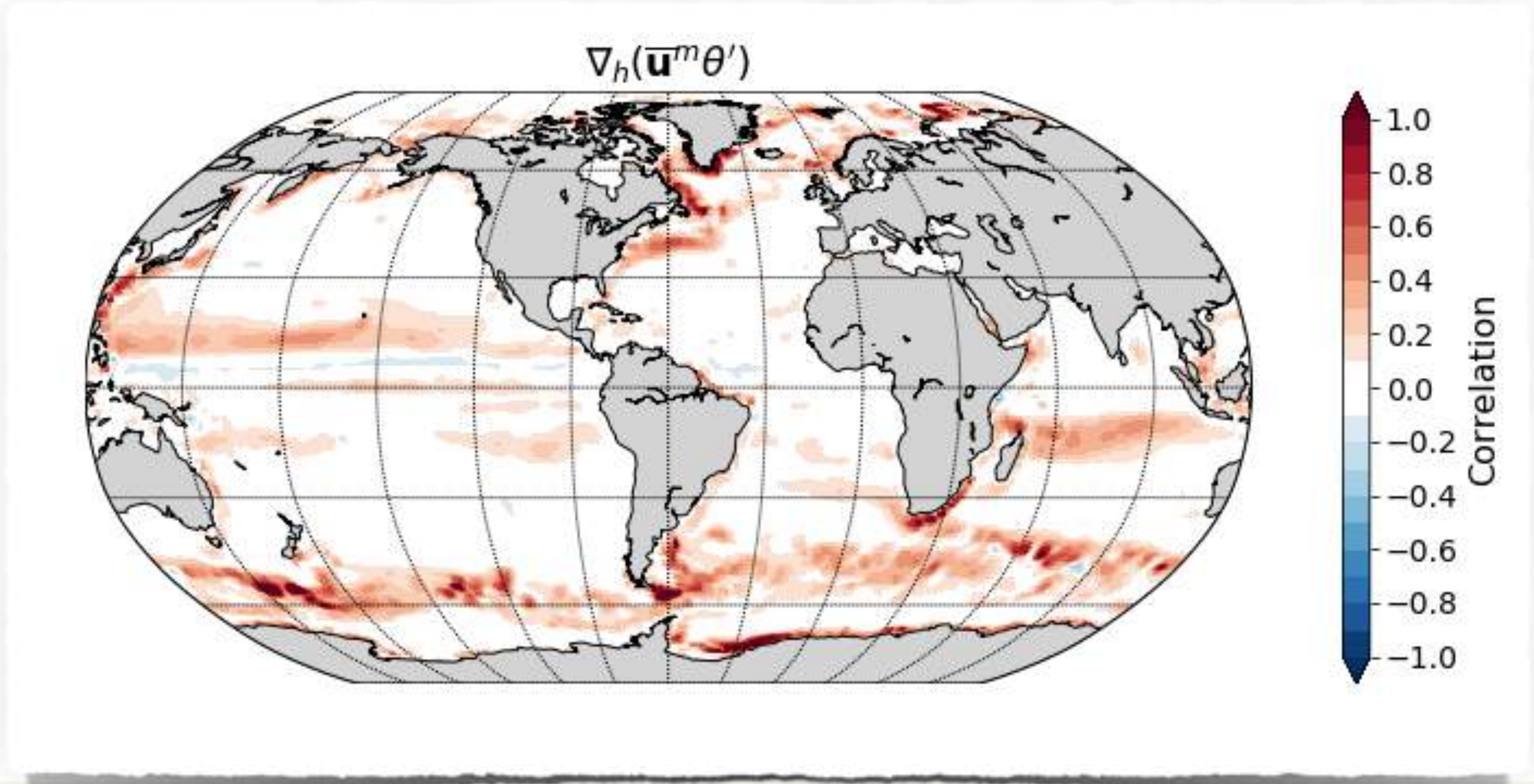


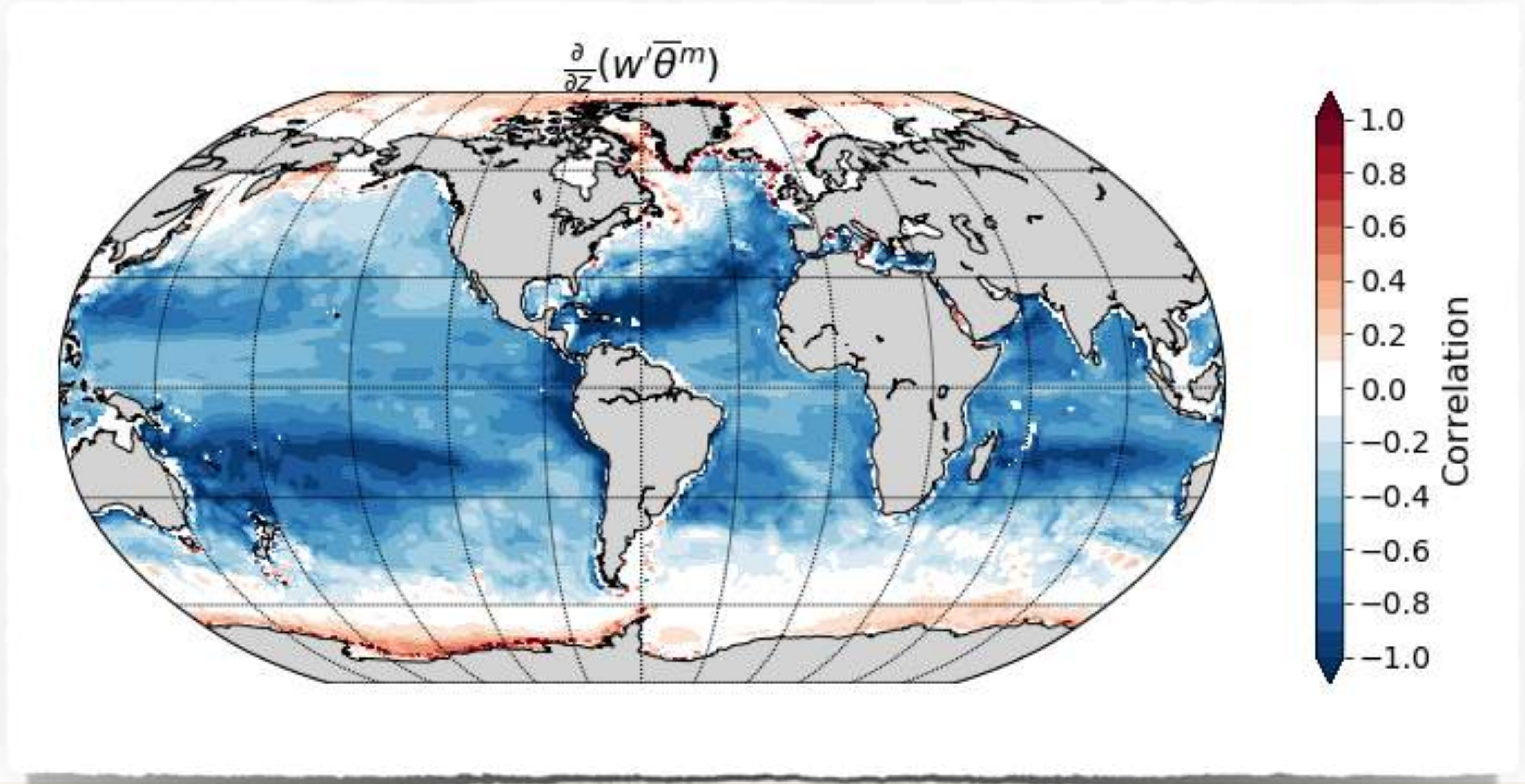


Regression Maps

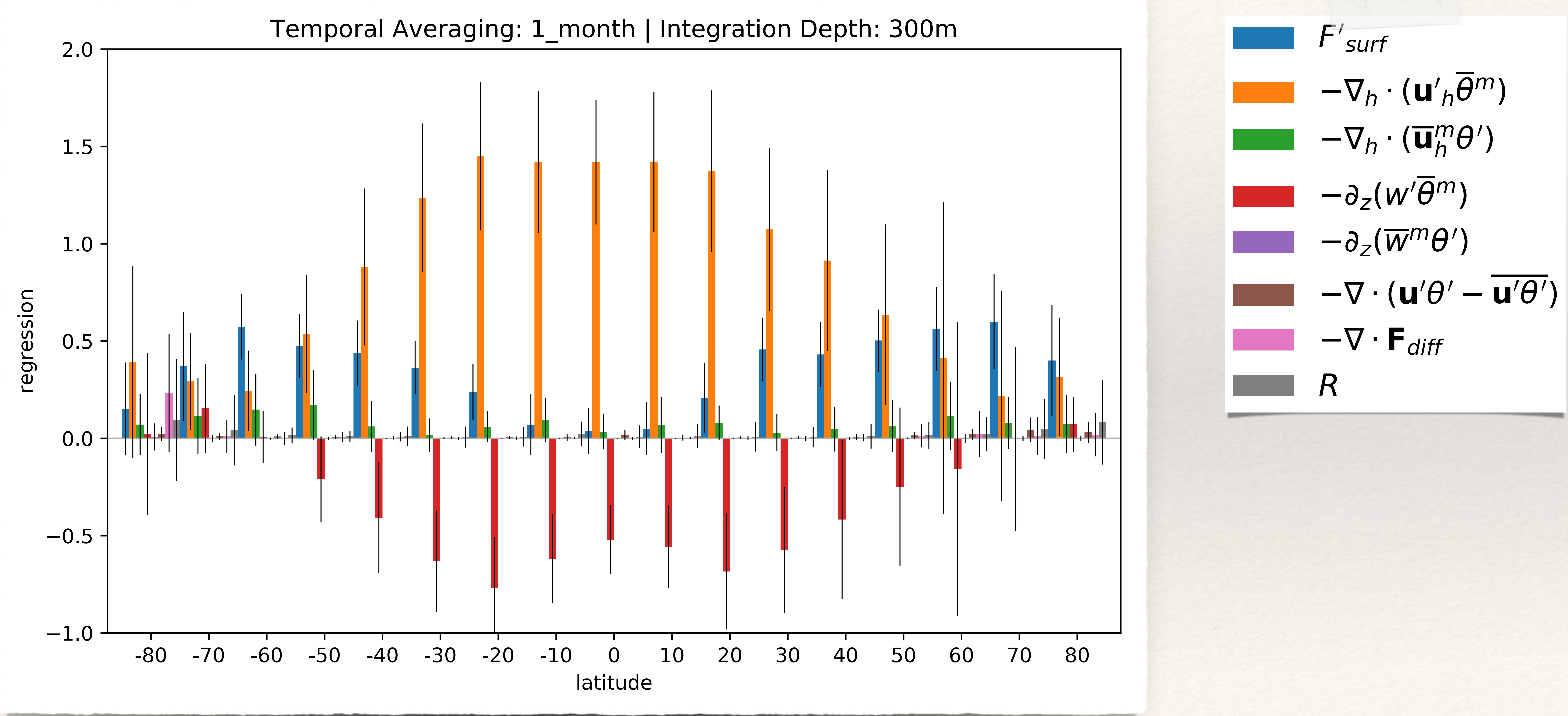






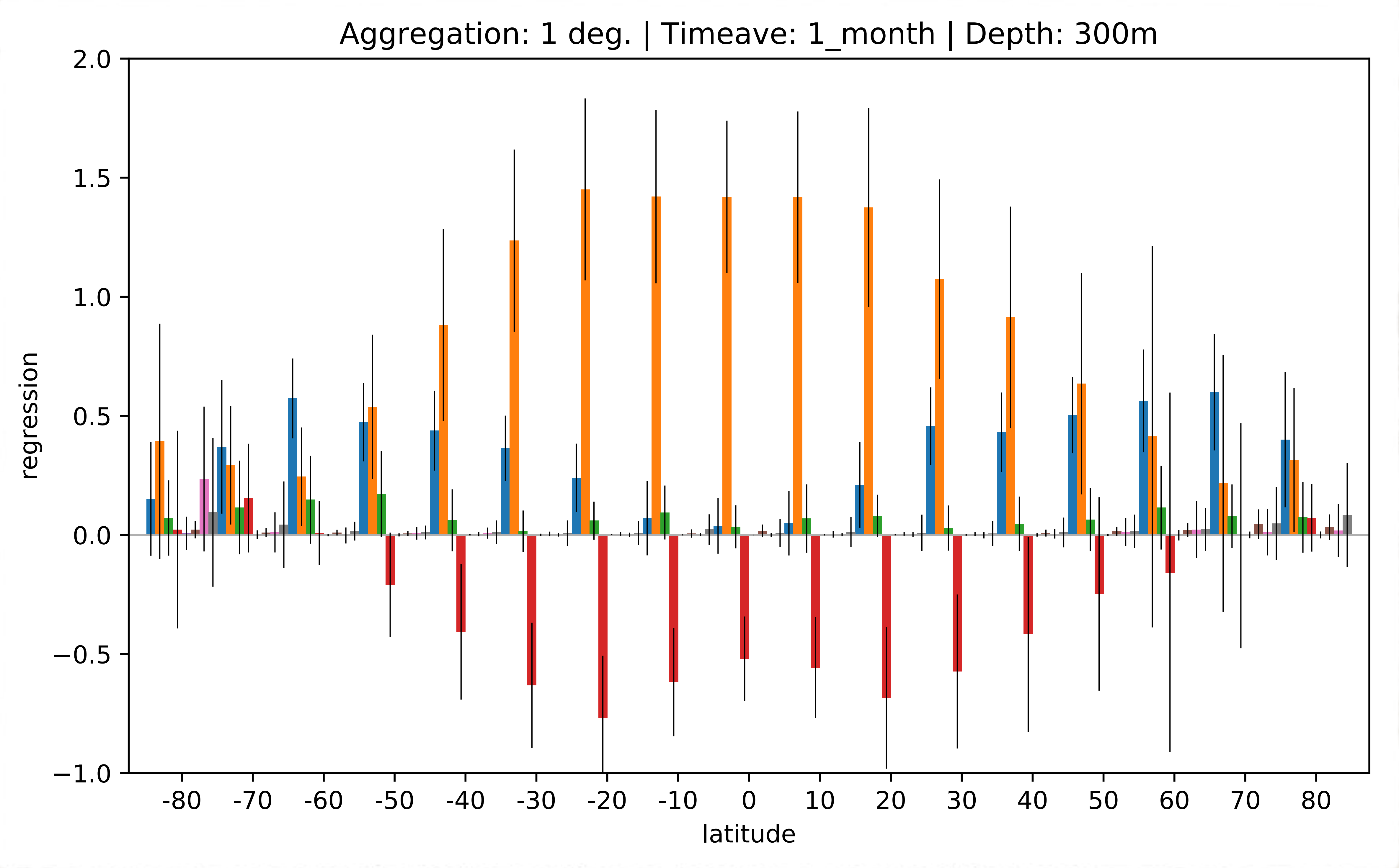


Regression Analysis

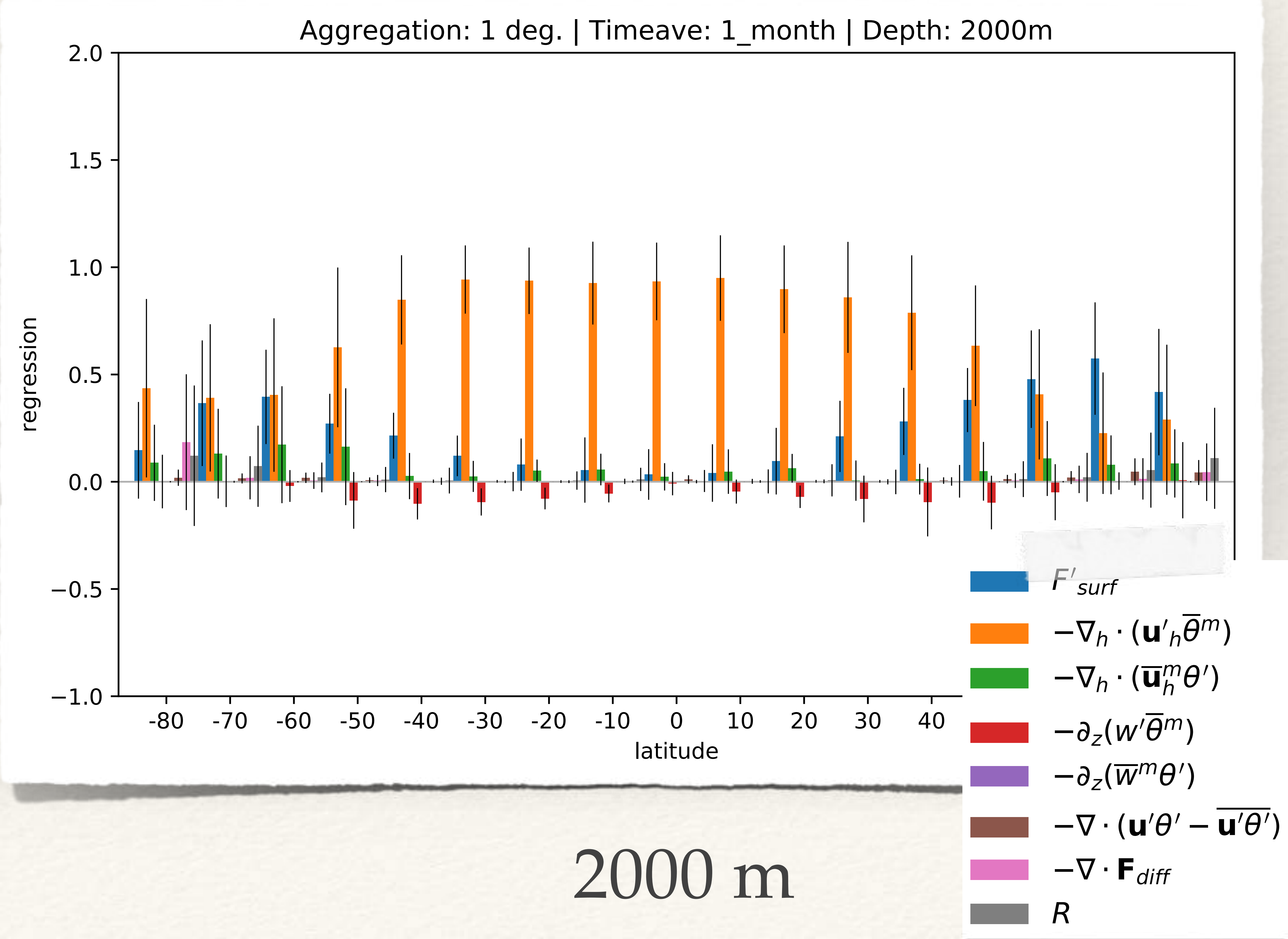


Depth Dependence

How does the budget change as we integrate over **deeper depths**?



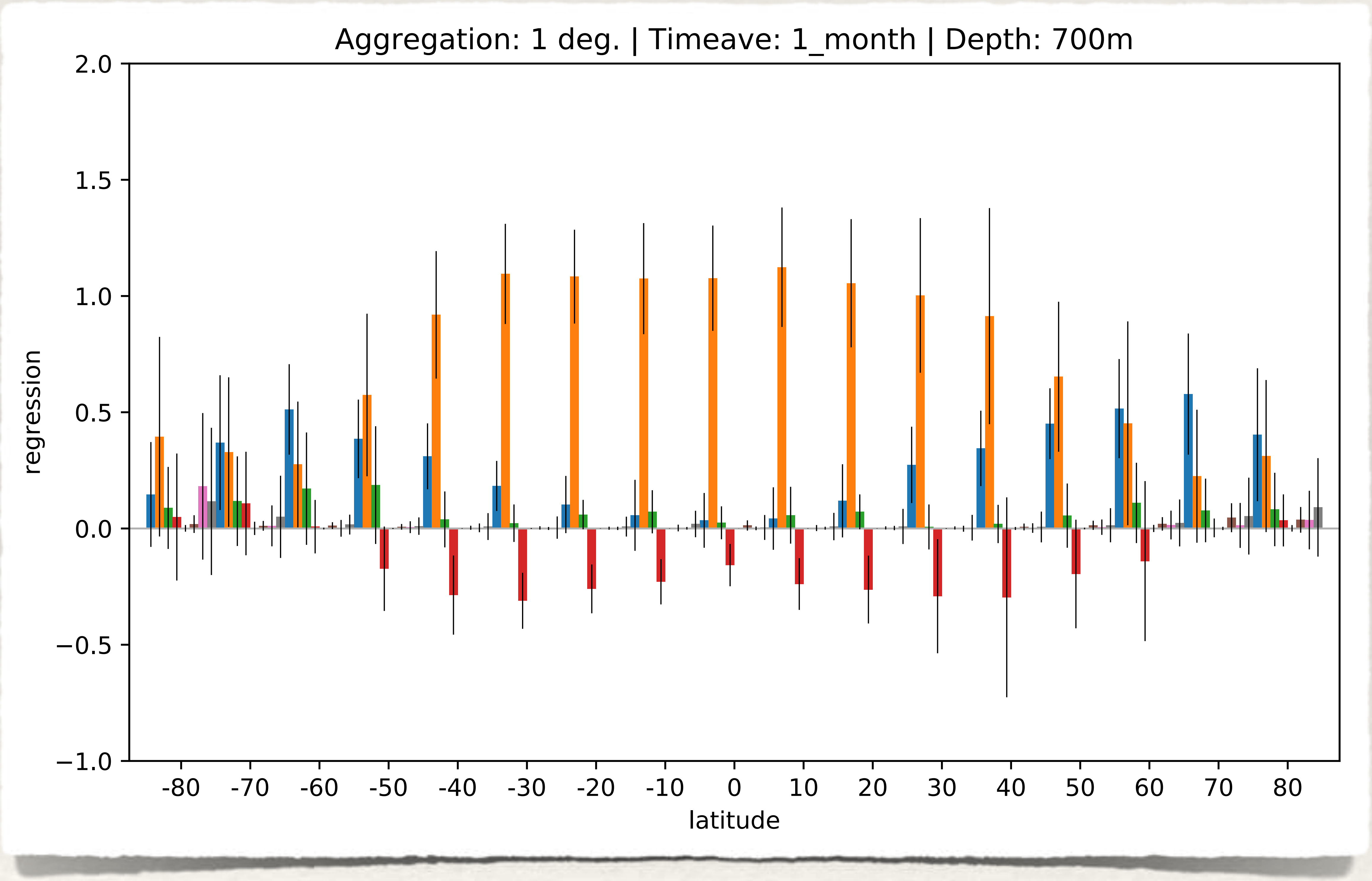
300 m



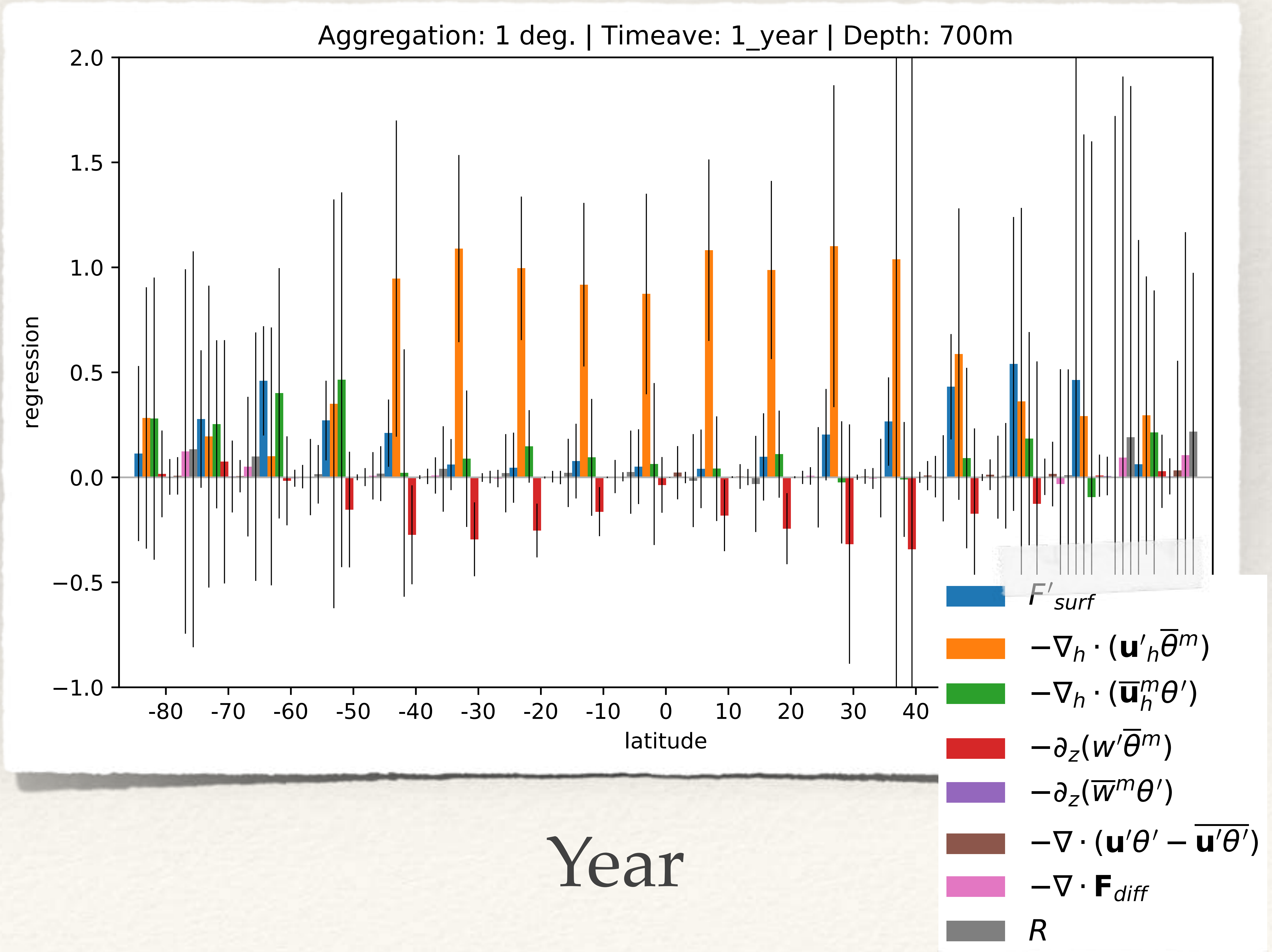
2000 m

Temporal Scale Dependence

How does the budget change as we average over **longer time intervals**?



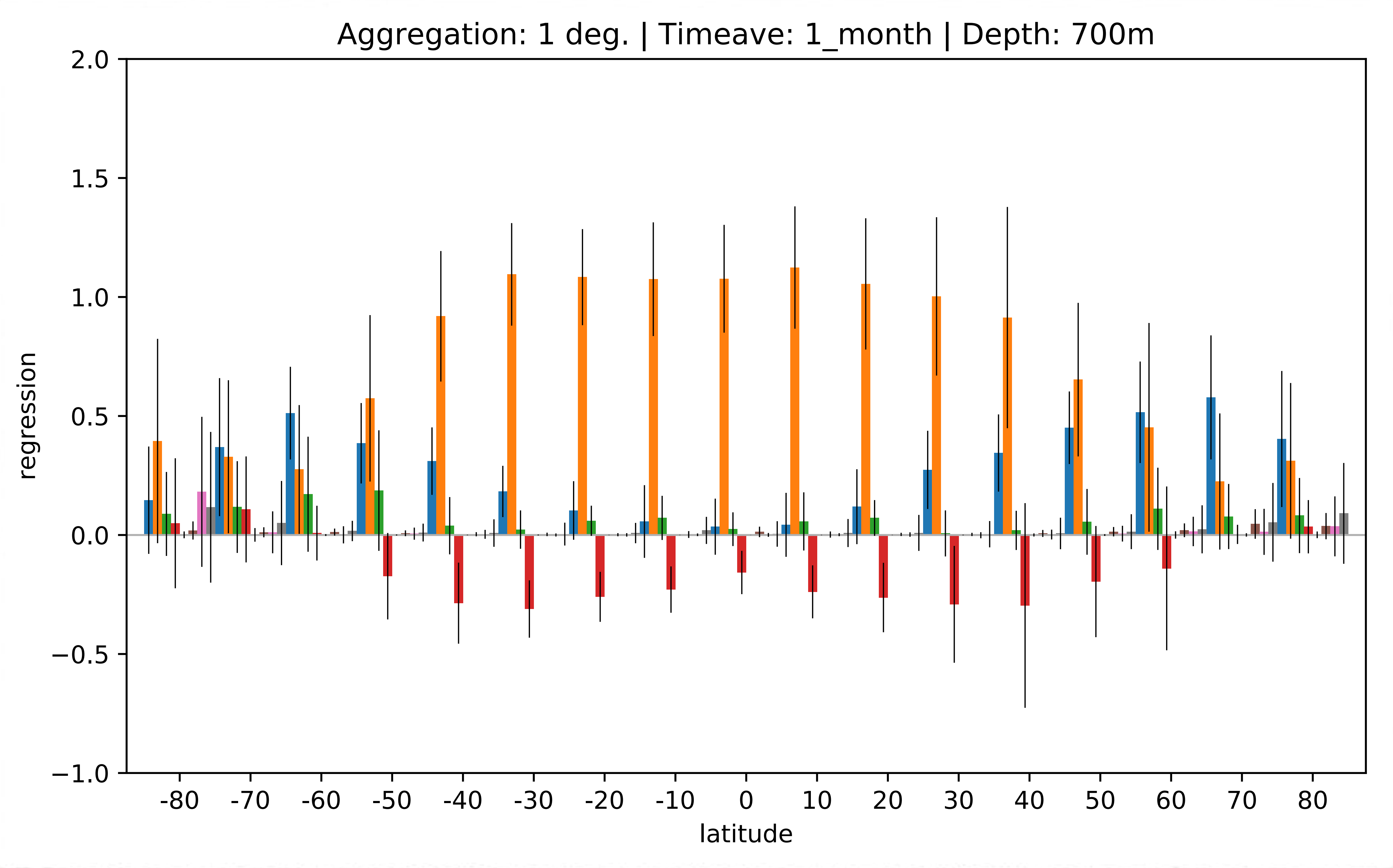
Month



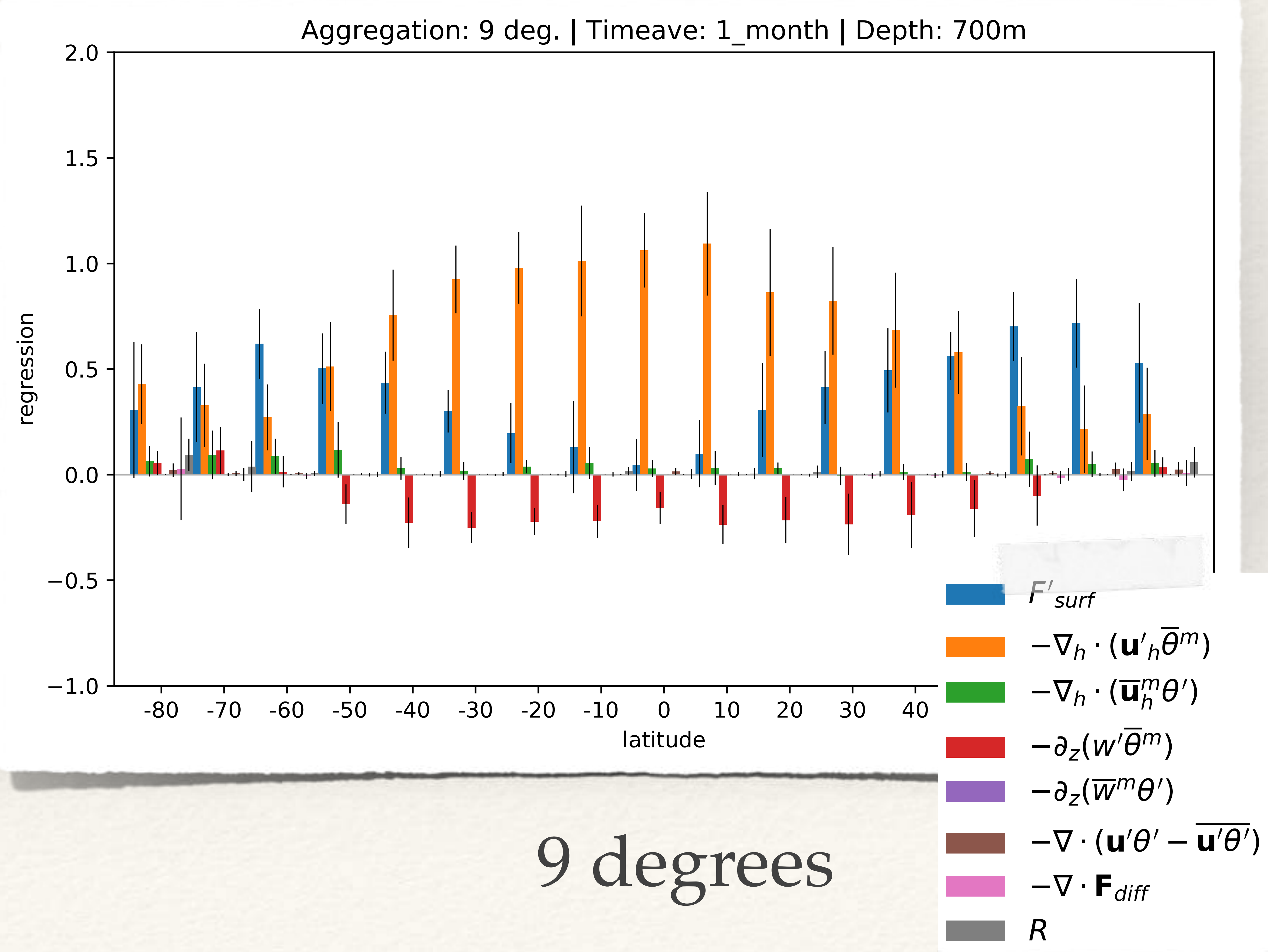
Year

Spatial Scale Dependence

How does the budget change as we aggregate over **larger spatial regions**?



1 degree



9 degrees

Conclusions

- Low latitudes: anomalous advection is the **sole driver** of OHC variability
- Anomalous vertical advection damps variability (diminishes with depth)
- **Forcing** becomes more important as you move to higher latitudes
- Picture is remarkably **insensitive to scale**