Ocean boundary pressures: Its significance and sensitivities

OceanBound

Andrew Styles[1], Emma Boland[1], Chris Hughes[2]

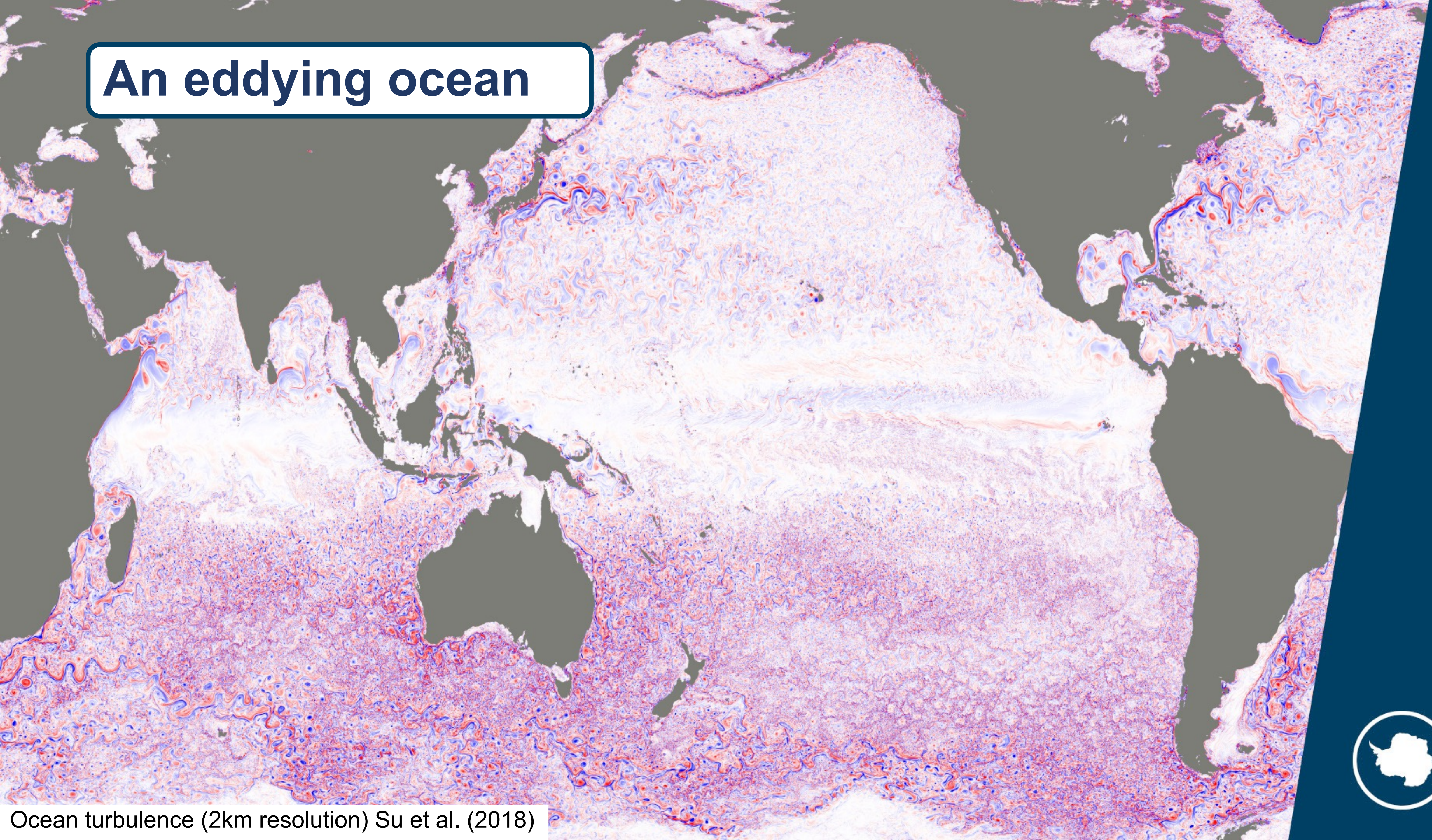
[1] British Antarctic Survey, UK

[2] University of Liverpool, UK

15th April 2024

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
UNIVERSITY OF LIVERPOOL
POLAR SCIENCE FOR A SUSTAINABLE PLANET

An eddying ocean

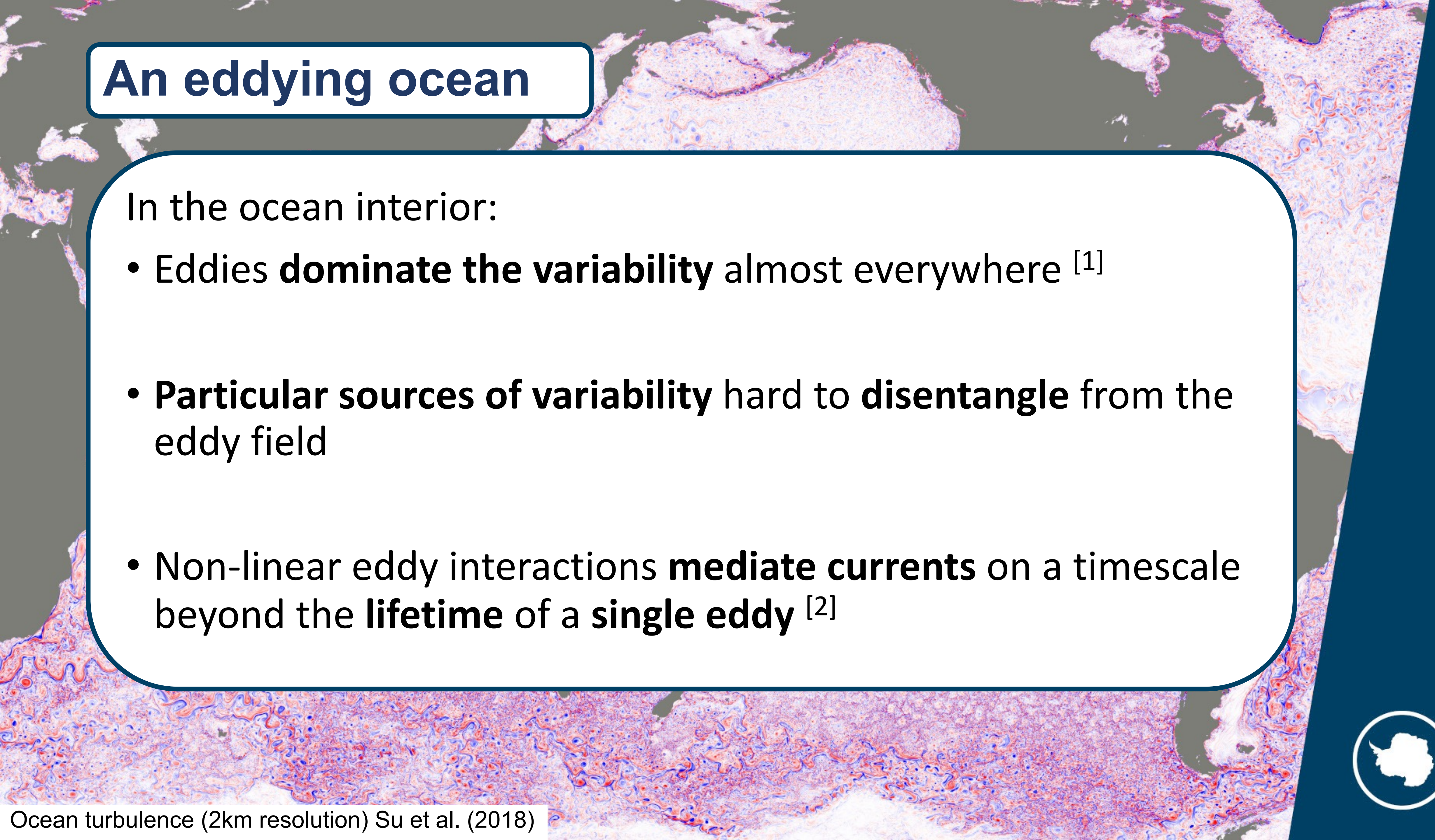


Ocean turbulence (2km resolution) Su et al. (2018)

An eddying ocean

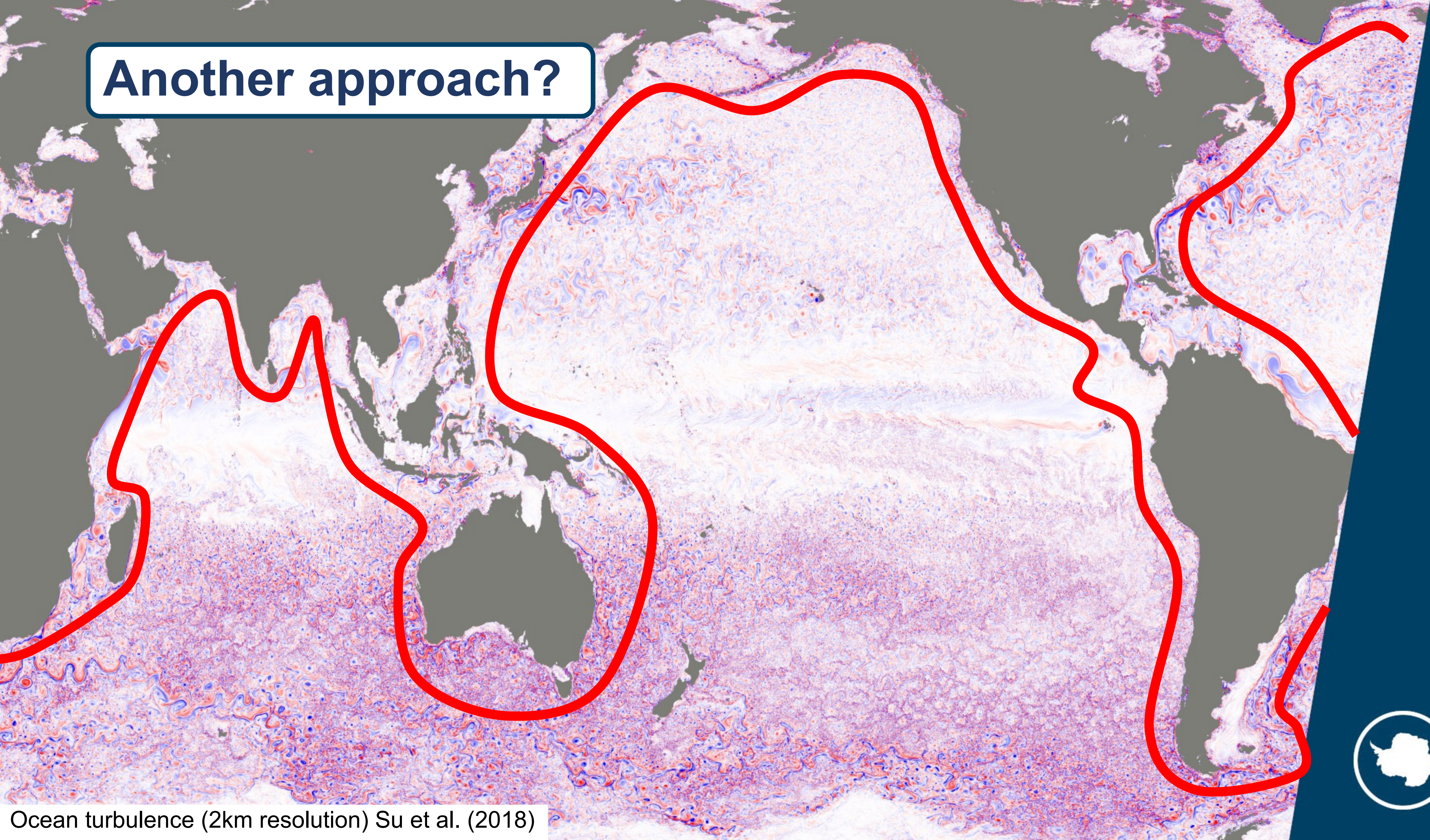
In the ocean interior:

- Eddies **dominate the variability** almost everywhere [1]
- **Particular sources of variability** hard to **disentangle** from the eddy field
- Non-linear eddy interactions **mediate currents** on a timescale beyond the **lifetime** of a **single eddy** [2]



Ocean turbulence (2km resolution) Su et al. (2018)

Another approach?

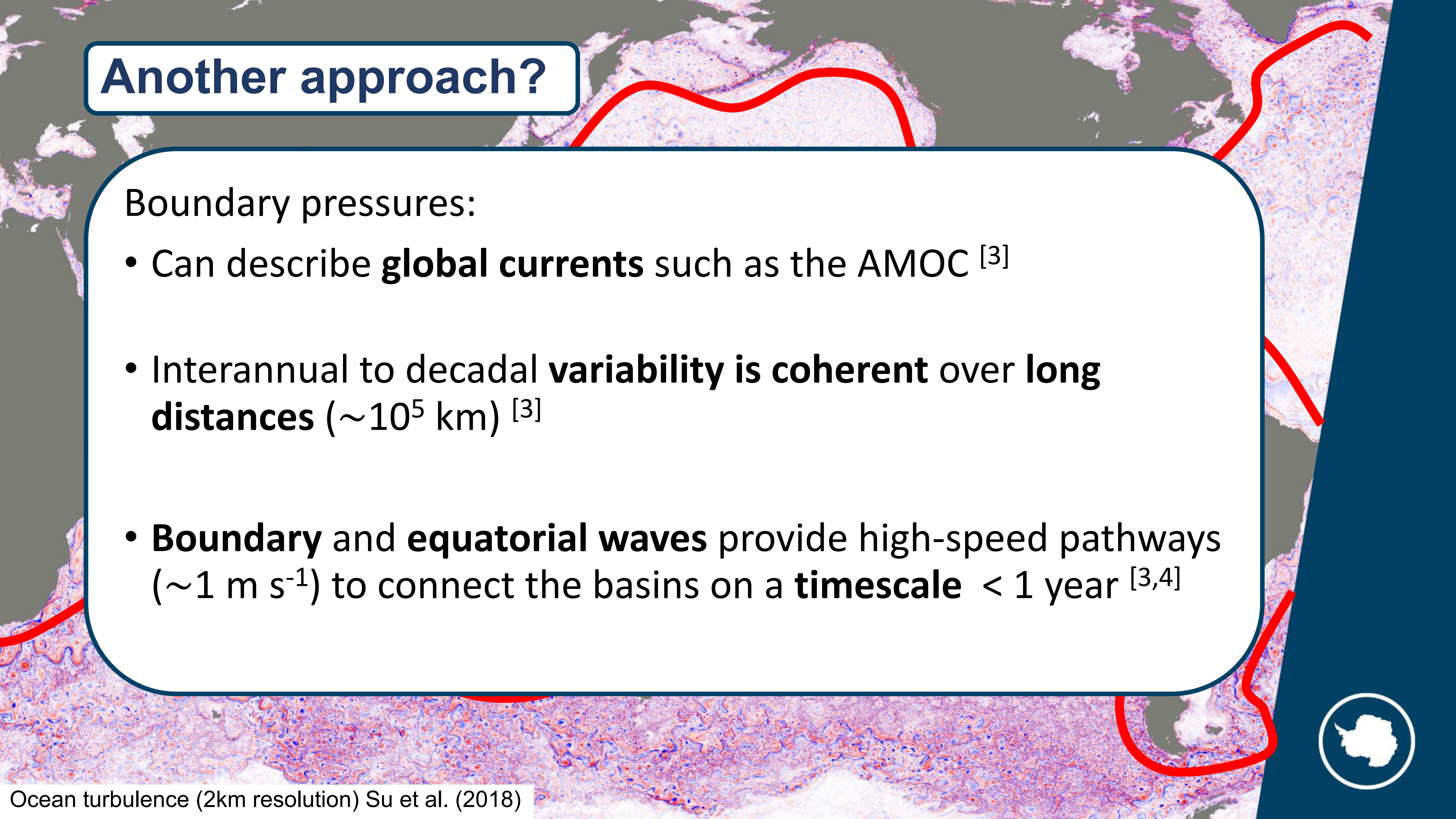


Ocean turbulence (2km resolution) Su et al. (2018)

Another approach?

Boundary pressures:

- Can describe **global currents** such as the AMOC [3]
- Interannual to decadal **variability is coherent** over **long distances** (~10^5 km) [3]
- **Boundary** and **equatorial waves** provide high-speed pathways (~1 m s^{-1}) to connect the basins on a **timescale** < 1 year [3,4]



Ocean turbulence (2km resolution) Su et al. (2018)

Boundary Pressure Structure

NEMO (ORCA12)
Eddy-rich forced model
54-year time-average

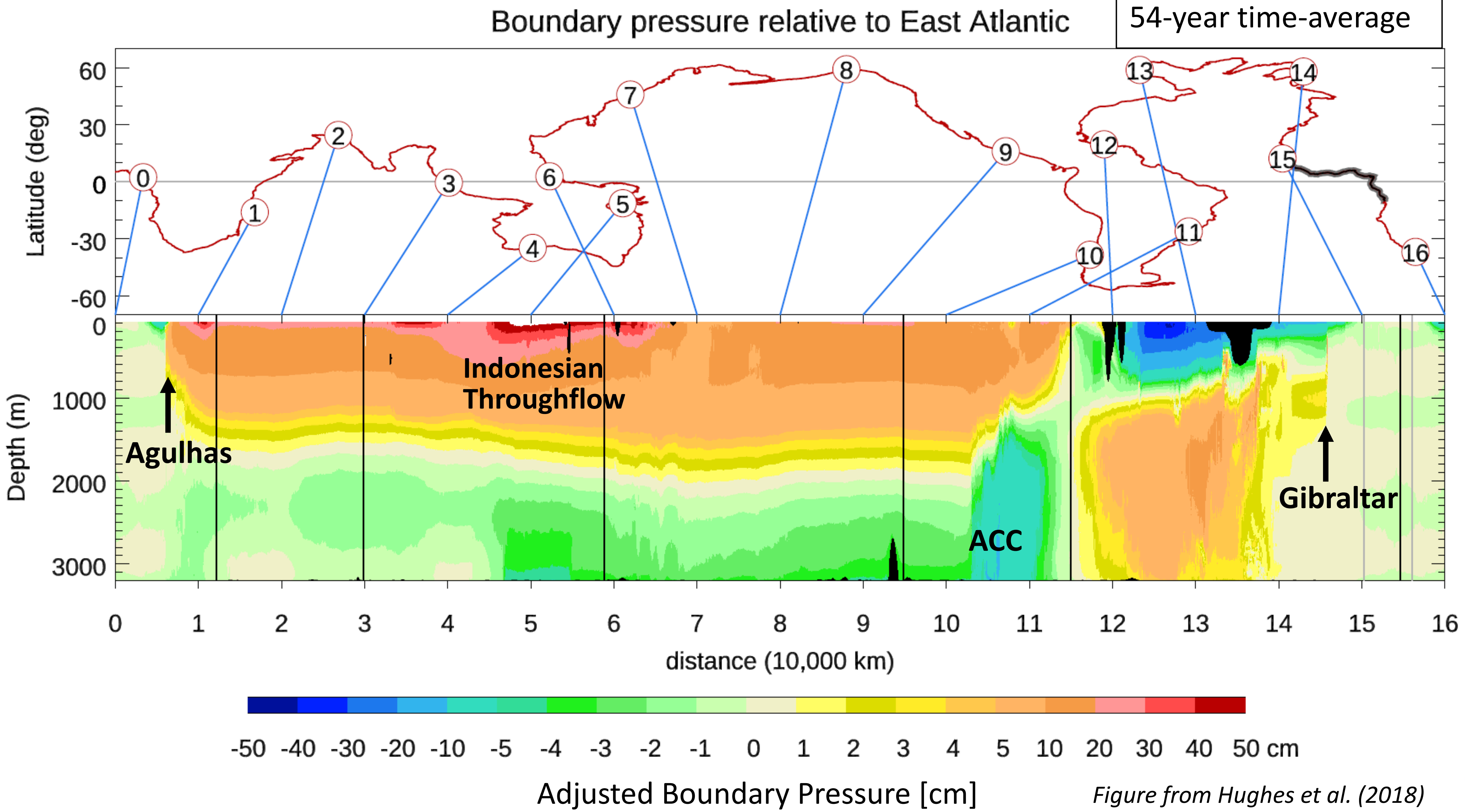
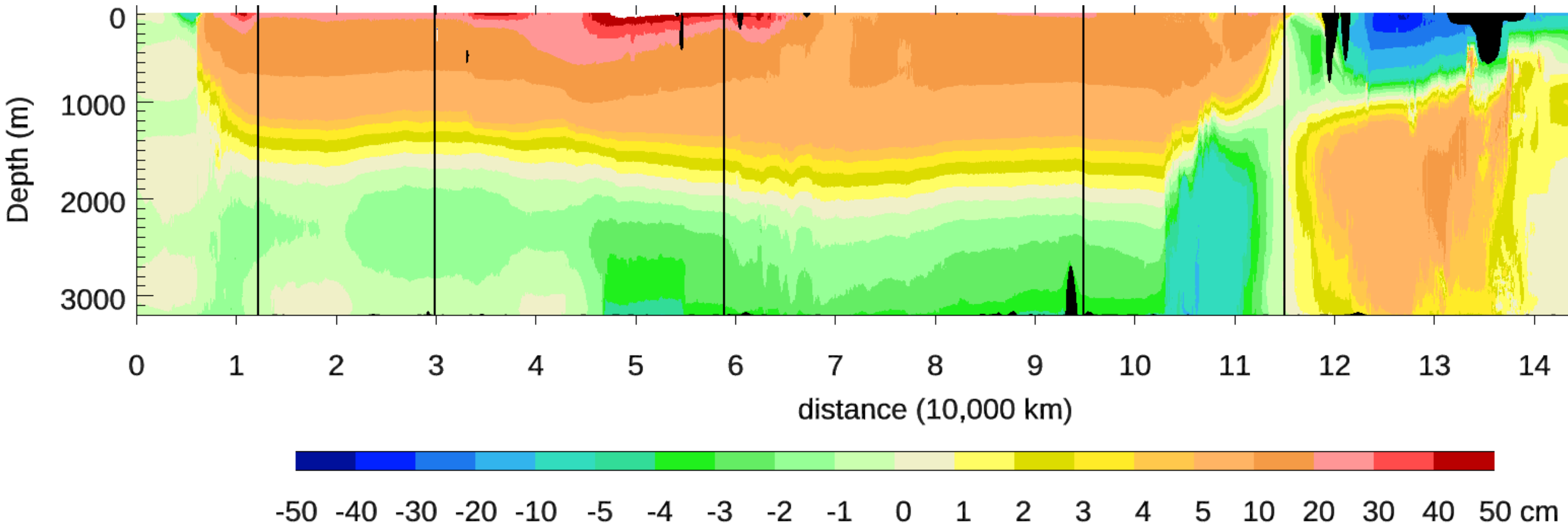


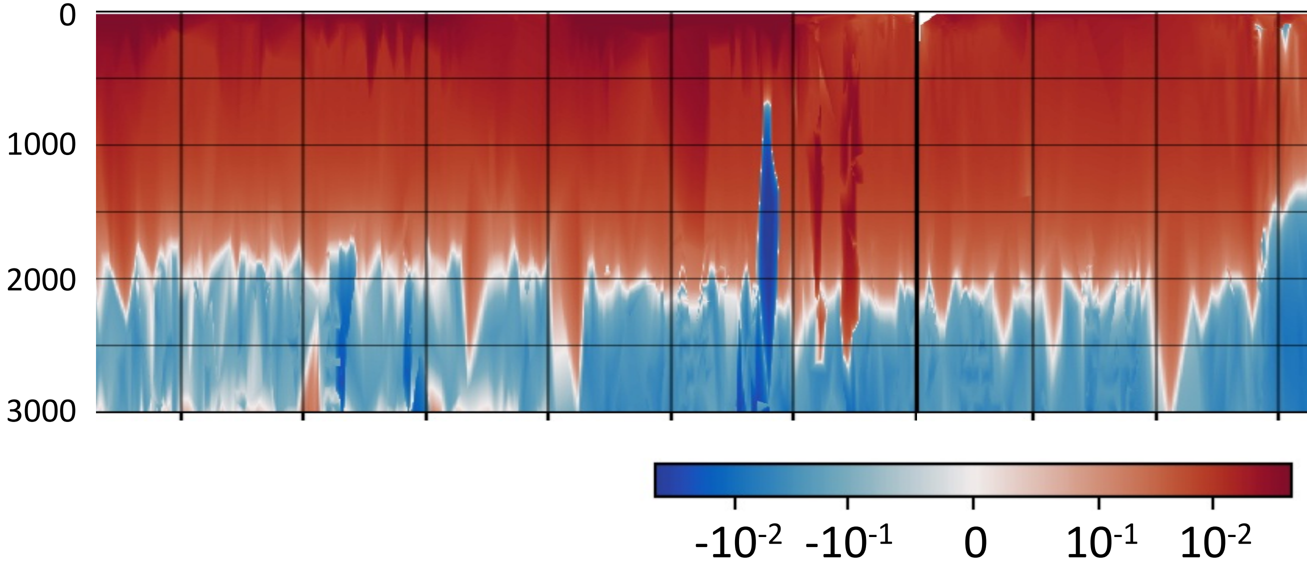
Figure from Hughes et al. (2018)

Boundary Pressure Structure



Eddy-rich forced model

Adjusted Boundary Pressure [cm]



Eddy-parameterized **State Estimate (ECCOv4r4)**

Adjusted Boundary Pressure [cm]

Adjoint models

- **Adjoint models** effectively run "backwards"
- Relate **ocean behaviors** to **physical causes** in the past via automatic differentiation
- Identify the linear sensitivities of an **objective function**

$\mathcal{J}$ → Adjoint Model ECCOv4r4 → $\frac{\partial \mathcal{J}}{\partial \mathcal{F}_1}, \frac{\partial \mathcal{J}}{\partial \mathcal{F}_2}, \dots$

Objective function
e.g. Mean pressure difference between two regions

Linear sensitivities
Sensitivity of $\mathcal{J}$ to external force, $\mathcal{F}_i$, as a function of **space and time**

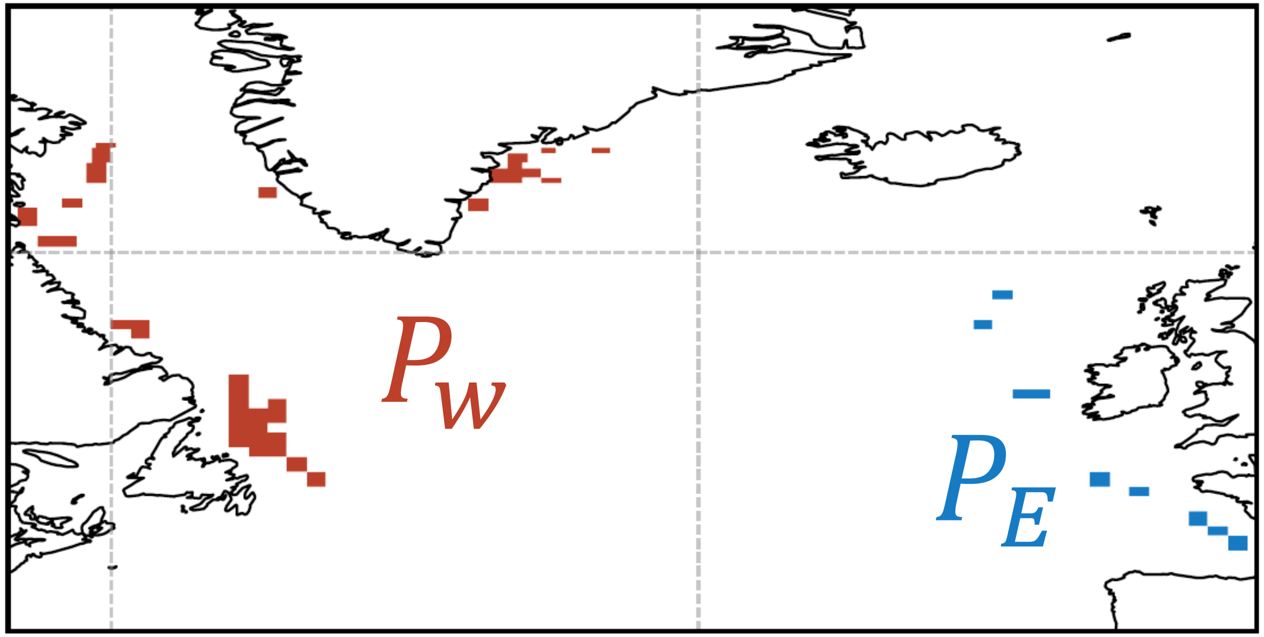
Results – North Atlantic Example

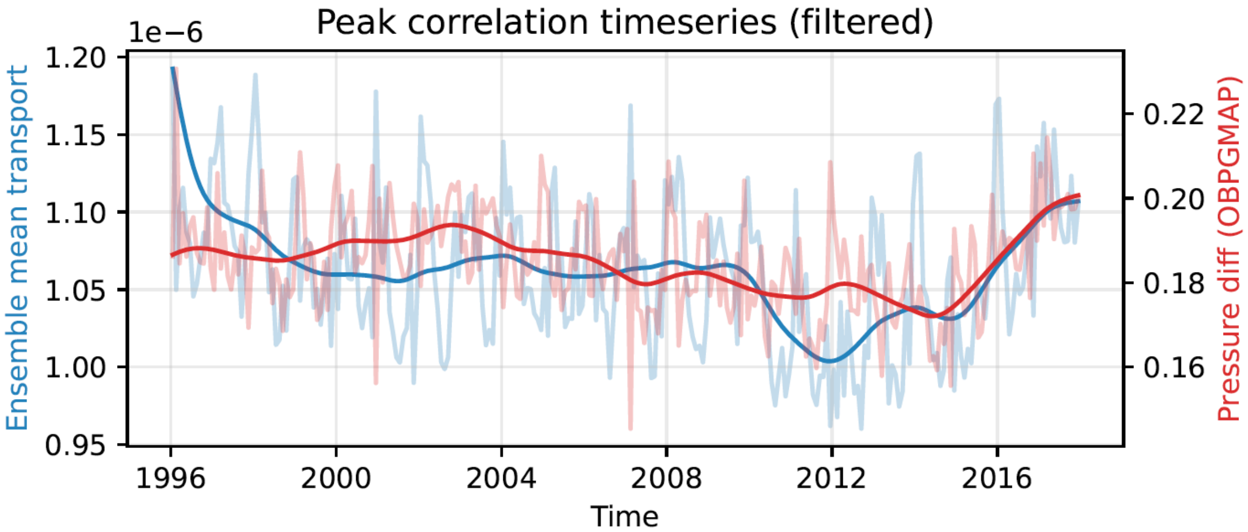
$$\mathcal{J} = P_w - P_E$$

P_w: **Mean pressure** on western boundary at depths between 300 and 400 m (**1 year average**)

P_E: Equivalent **eastern boundary** pressure

Objective function, $\mathcal{J}$, is correlated with transport between grid points (r=0.63) on interannual timescales





Results – North Atlantic Example

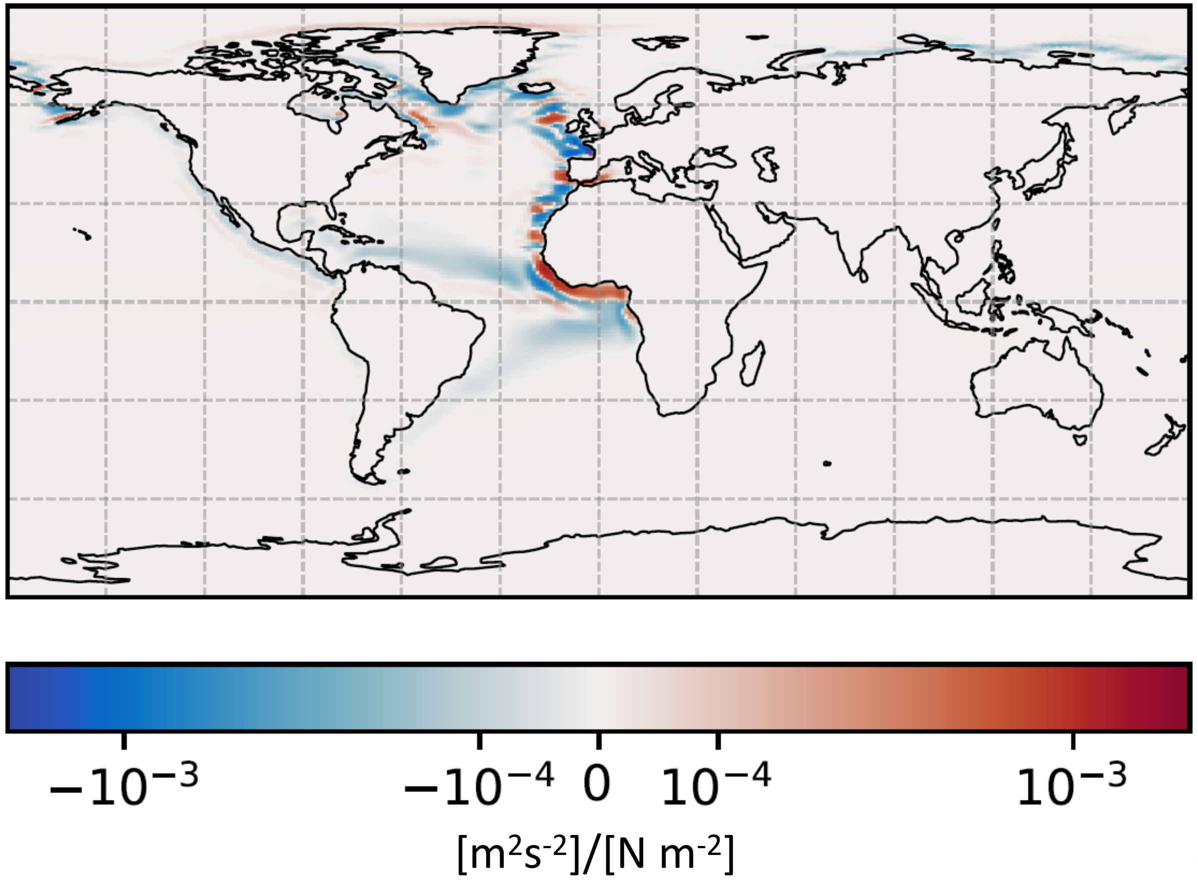
$$\mathcal{J} = P_W - P_E$$

The figure on the right shows the **spatial sensitivity** to **zonal winds**

Leading-order sensitivity is confined to the **boundaries** and **equator**

Also the case for **meridional winds**

Sensitivity of $\mathcal{J}$ to **zonal** wind stress



Snapshot of sensitivity when spatial pattern is most intense (minus 1 year)

Results – North Atlantic Example

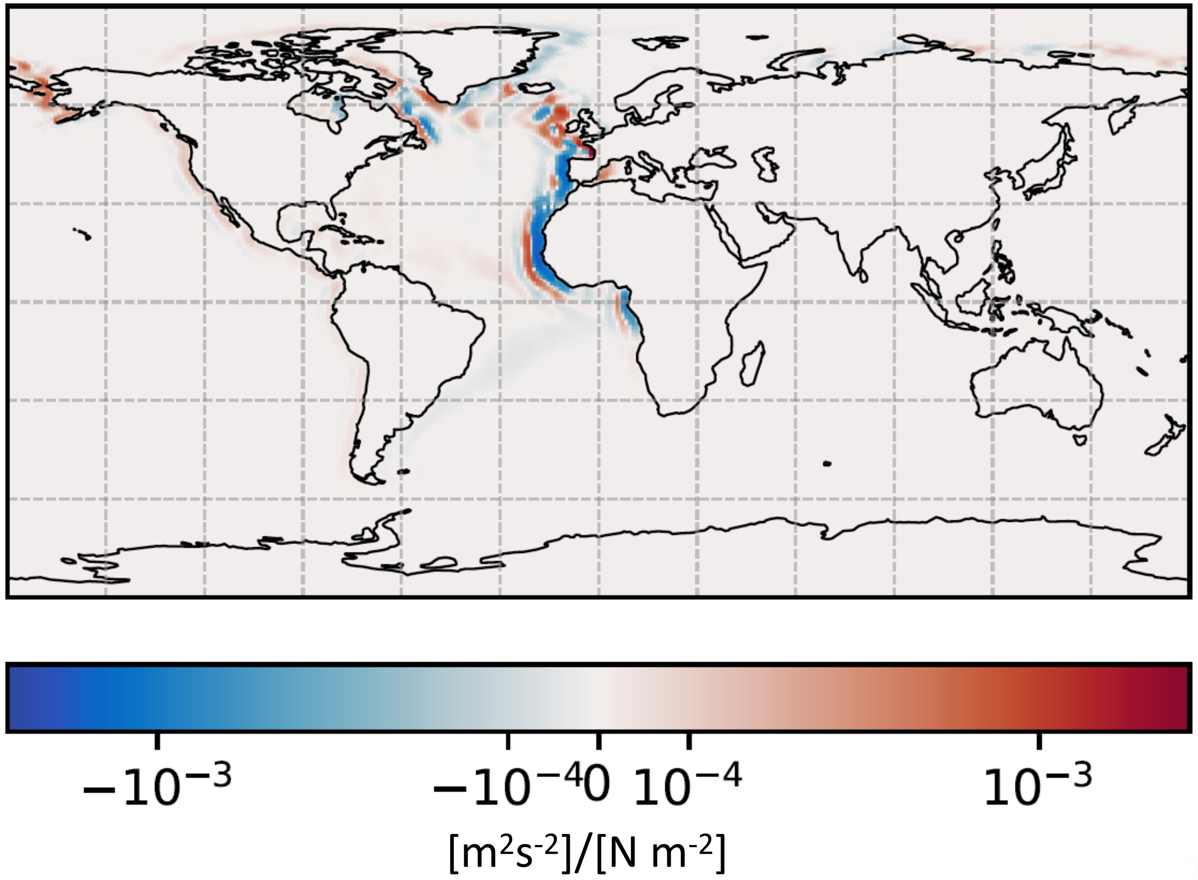
$$\mathcal{J} = P_W - P_E$$

The figure on the right shows the **spatial sensitivity** to **zonal winds**

Leading-order sensitivity is confined to the **boundaries** and **equator**

Also the case for **meridional winds**

Sensitivity of $\mathcal{J}$ to **meridional** wind stress



Snapshot of sensitivity when spatial pattern is most intense (minus 1 year)

Future work

- **Longer** adjoint experiments to explore sensitivities **further into the past**:
  - **Buoyancy forcing** becomes increasing relevant
  - Potential to reveal sensitivity hotspots **away from the boundaries**

- A **robust method** of selecting **cluster pairs**

- **Forward perturbation experiments** to reveal physical mechanisms

Thank you for listening

Scan for abstract and slides

Follow me on Twitter!
@AndrewFStyles

Oral | Tuesday, 16 Apr, 14:50–15:00 (CEST) Room L3

Remote influence of (or on?) the Atlantic Meridional Overturning Circulation: A boundary pressure perspective.

Chris Hughes[1,2] and Saranraj Gururaj[1]
[1]University of Liverpool, School of Environmental Sciences, Earth, Ocean and Ecological Sciences, Liverpool, UK
[2]National Oceanography Centre, Liverpool, UK

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF LIVERPOOL

POLAR SCIENCE FOR A SUSTAINABLE PLANET

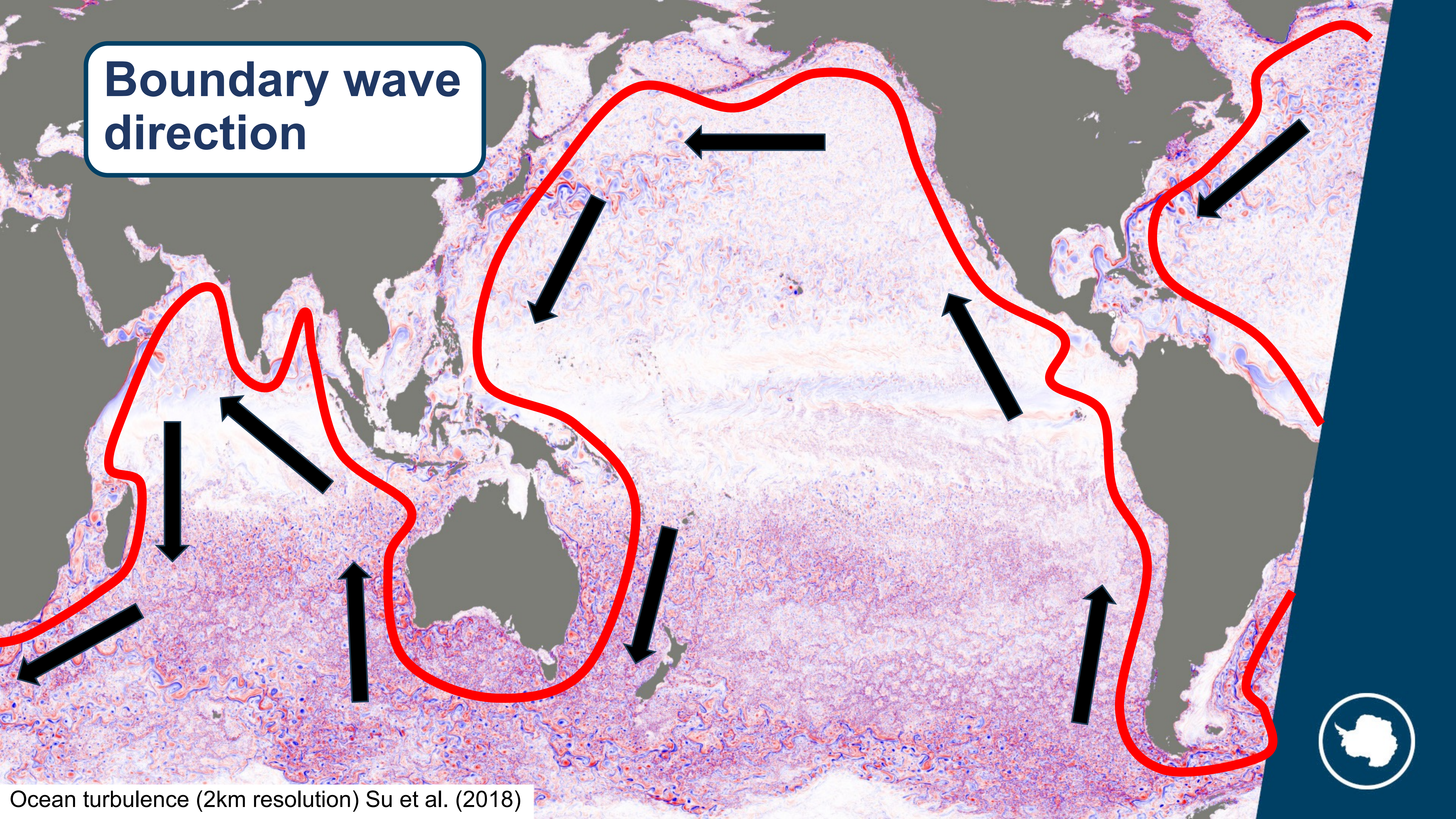
References

[1] Wunsch, C. (2008). Mass and volume transport variability in an eddy-filled ocean. *Nature Geoscience*, *1*(3), 165–168. https://doi.org/10.1038/ngeo126

[2] Close, S., Penduff, T., Speich, S., & Molines, J.-M. (2020). A means of estimating the intrinsic and atmospherically-forced contributions to sea surface height variability applied to altimetric observations. *Progress in Oceanography*, *184*, 102314. https://doi.org/10.1016/j.pocean.2020.102314

[3] Hughes, C. W., Williams, J., Blaker, A., Coward, A., & Stepanov, V. (2018). A window on the deep ocean: The special value of ocean bottom pressure for monitoring the large-scale, deep-ocean circulation. *Progress in Oceanography*, *161*, 19–46. https://doi.org/10.1016/j.pocean.2018.01.011

[4] Hughes, C. W., Fukumori, I., Griffies, S. M., Huthnance, J. M., Minobe, S., Spence, P., Thompson, K. R., & Wise, A. (2019). Sea Level and the Role of Coastal Trapped Waves in Mediating the Influence of the Open Ocean on the Coast. *Surveys in Geophysics*, *40*(6), 1467–1492. https://doi.org/10.1007/s10712-019-09535-x



Ocean turbulence (2km resolution) Su et al. (2018)