Southern Ocean Budgets: Inventories and Satellite-based Surface Fluxes

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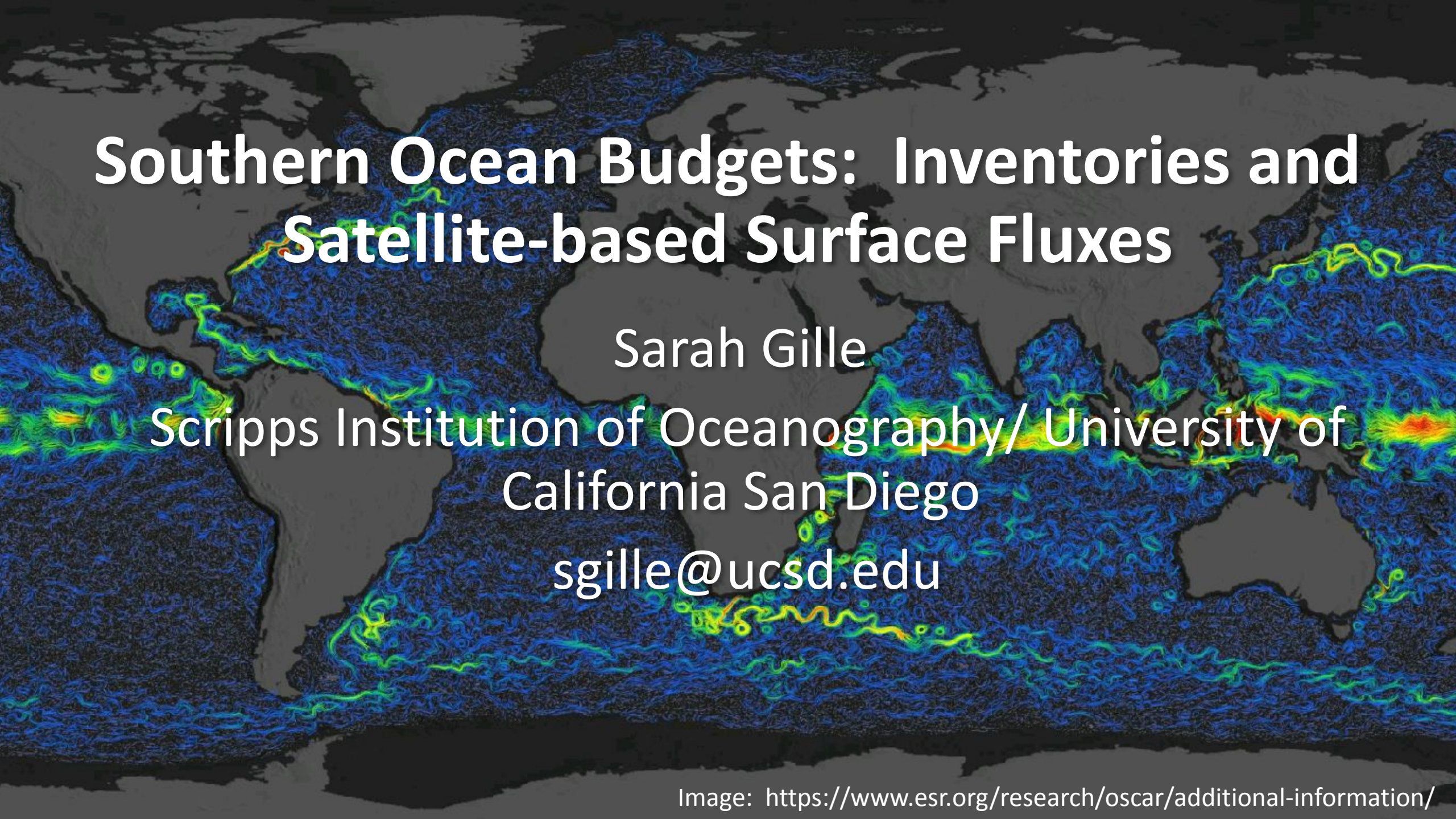
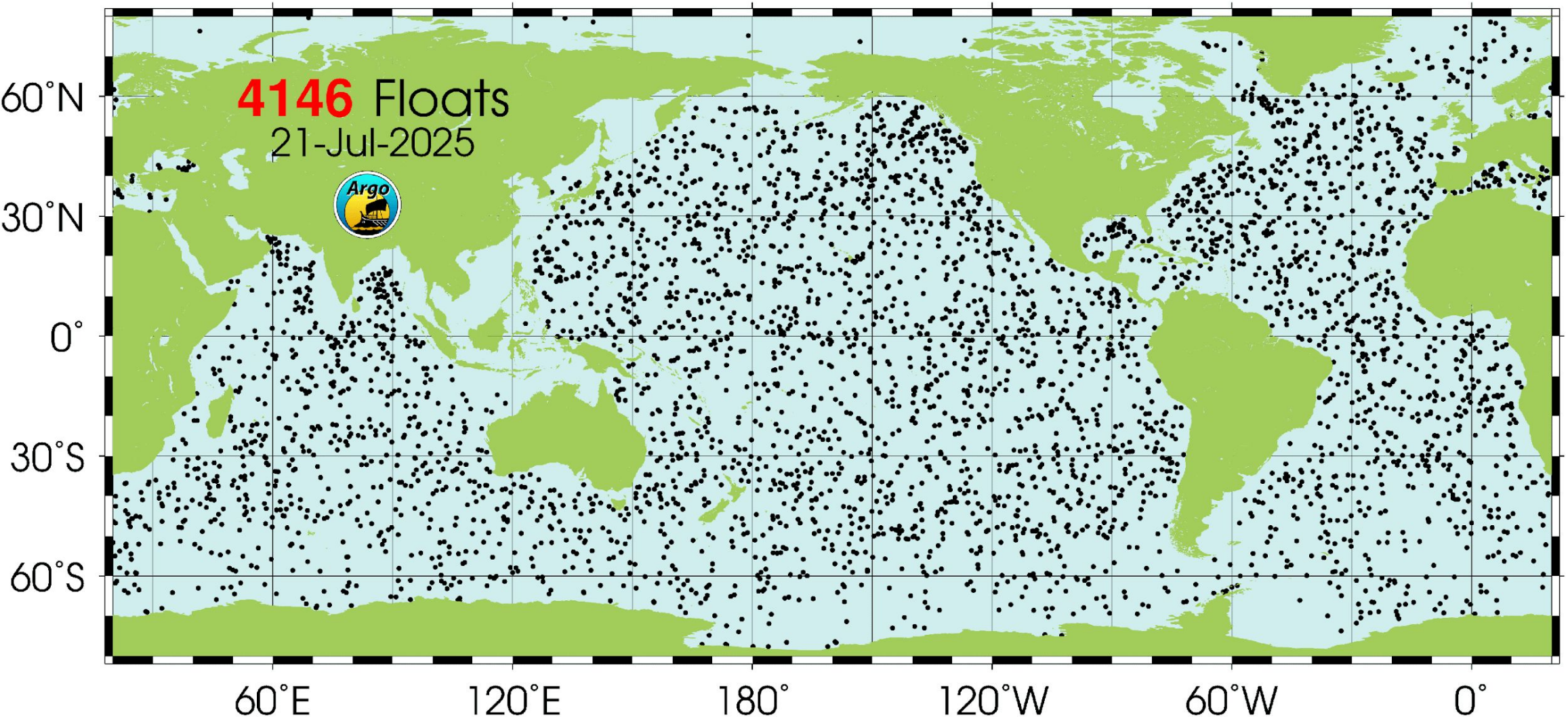


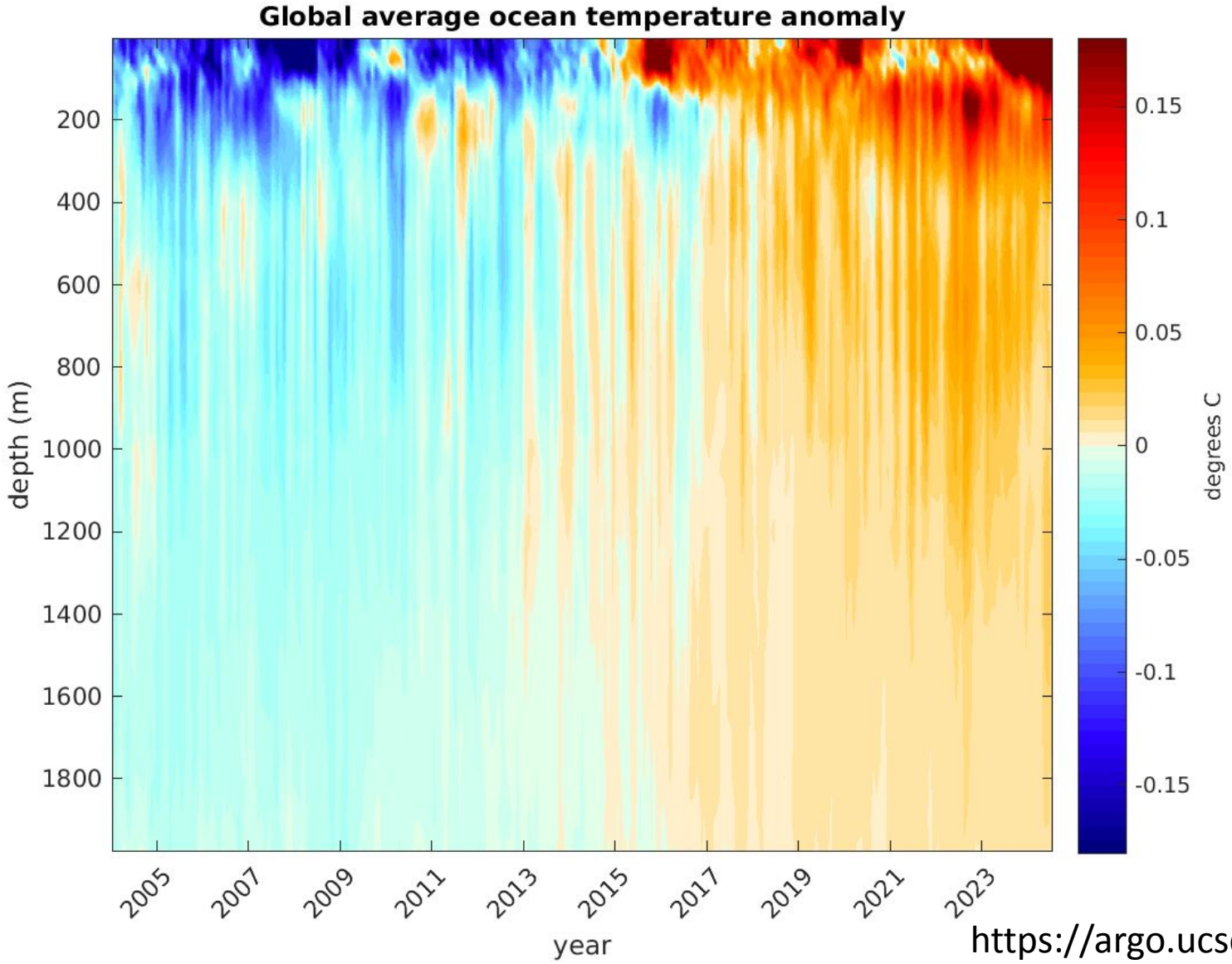
Image: https://www.esr.org/research/oscar/additional-information/

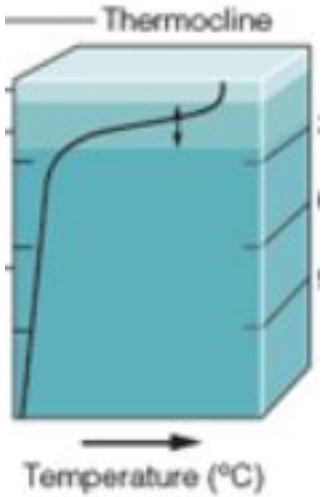
Observing the ocean with Argo



https://argo.ucsd.edu/about/status/

Warming extends over 2000 m in depth

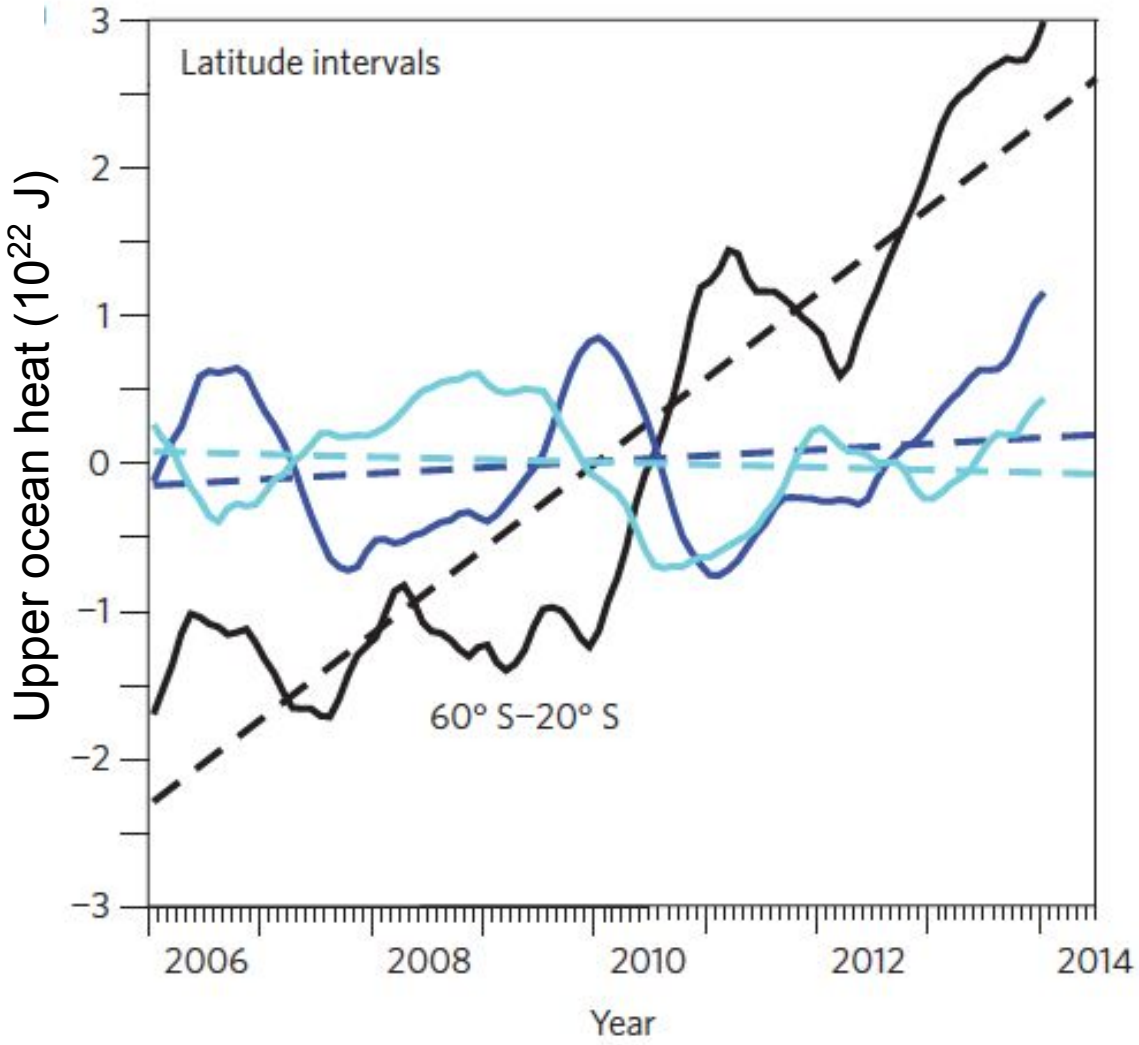




https://argo.ucsd.edu/science/argo-and-climate-change/

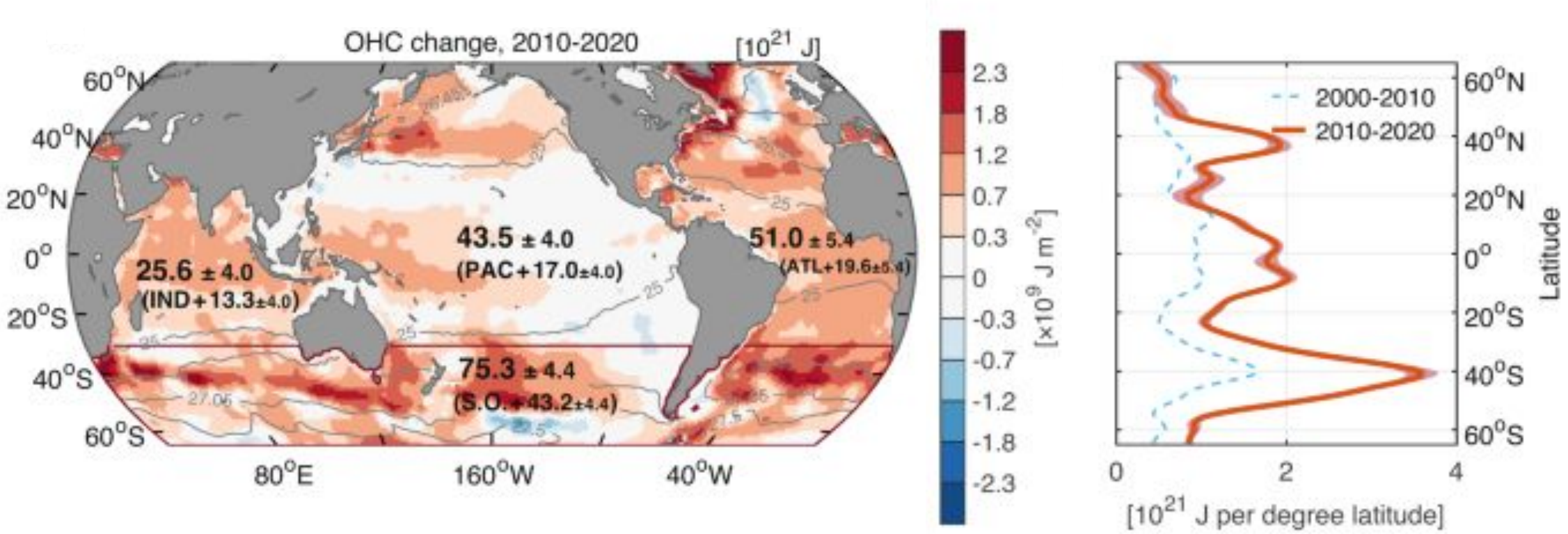
Warming concentrated in Southern Ocean

- OHC = $\rho\, c_p \iiint_{2000\ dbars}^{0} T'(x,y,z)dz\, dx\, dy$



(Roemmich et al, *Nature Climate Change*, 2015)

Ocean heat content change, 2010-2020 relative to 1980-2000



Li, England, and Groeskamp, *Nature Communications*, 2023

JGR Oceans

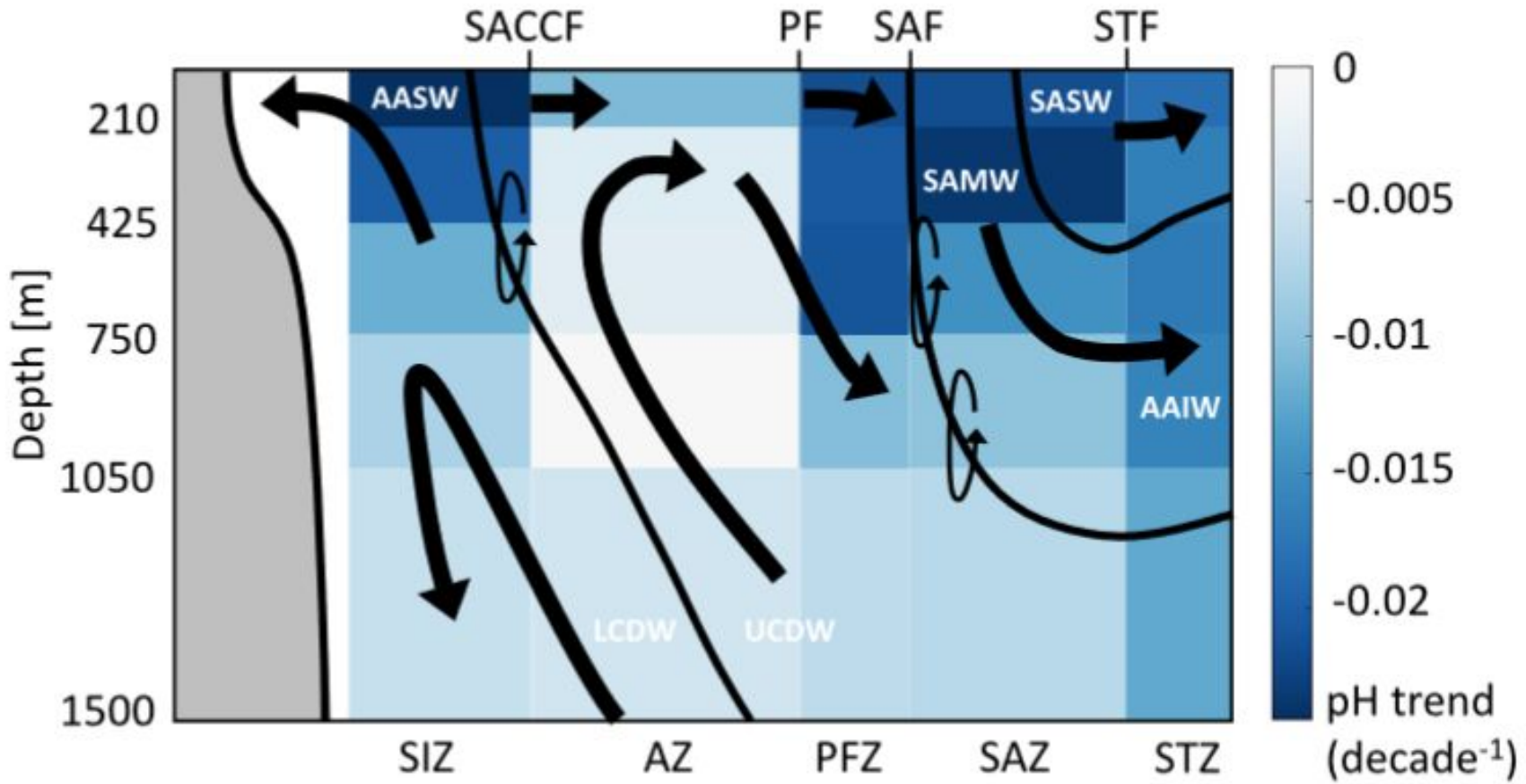
RESEARCH ARTICLE
10.1029/2022JC019530

Southern Ocean Acidification Revealed by Biogeochemical-Argo Floats

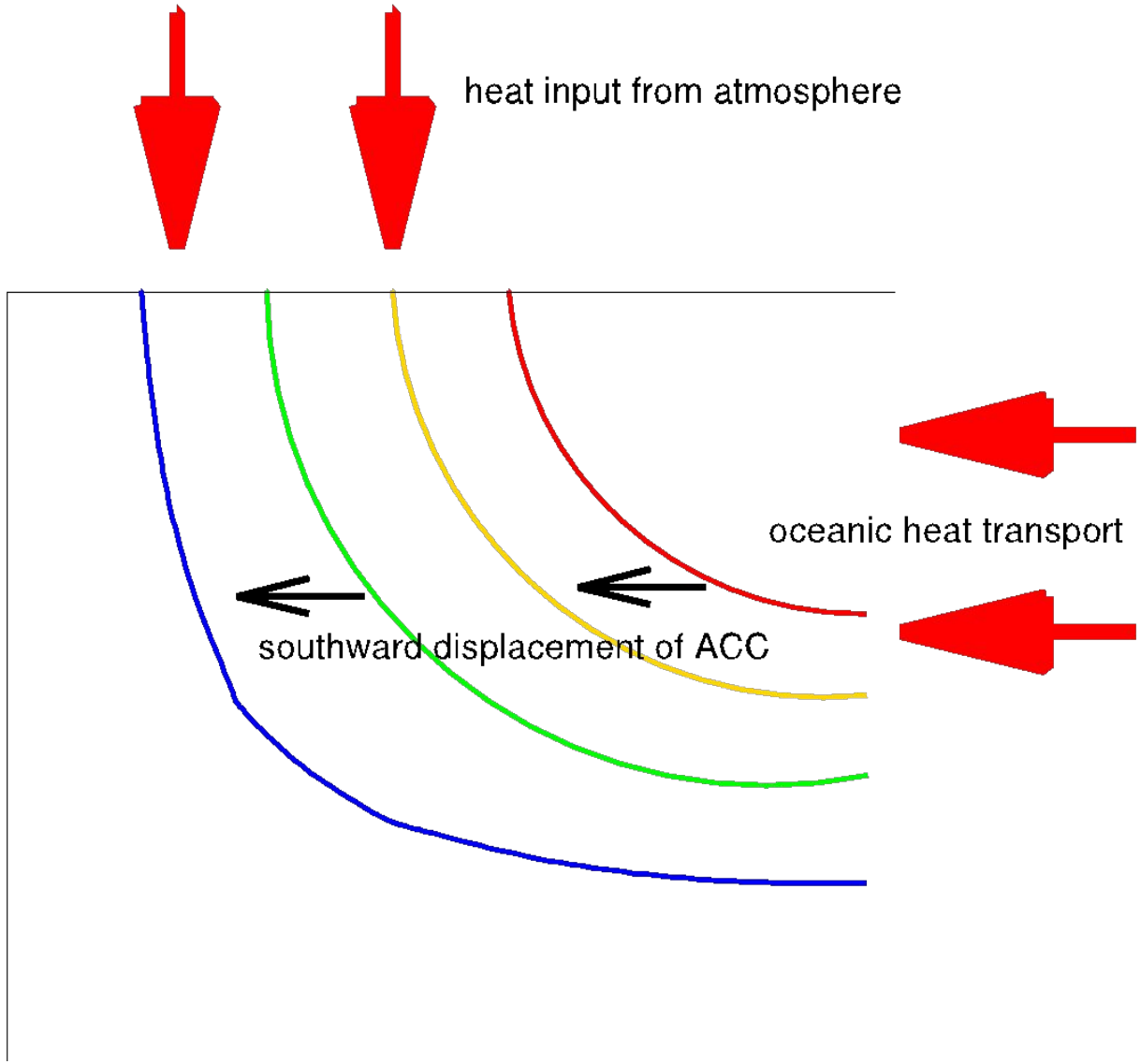
Matthew R. Mazloff[1], Ariane Verdy[1], Sarah T. Gille[1], Kenneth S. Johnson[2], Bruce D. Cornuelle[1], and Jorge Sarmiento[3]

Key Points:

- We present a novel 12-month Southern Ocean pH mapped product,



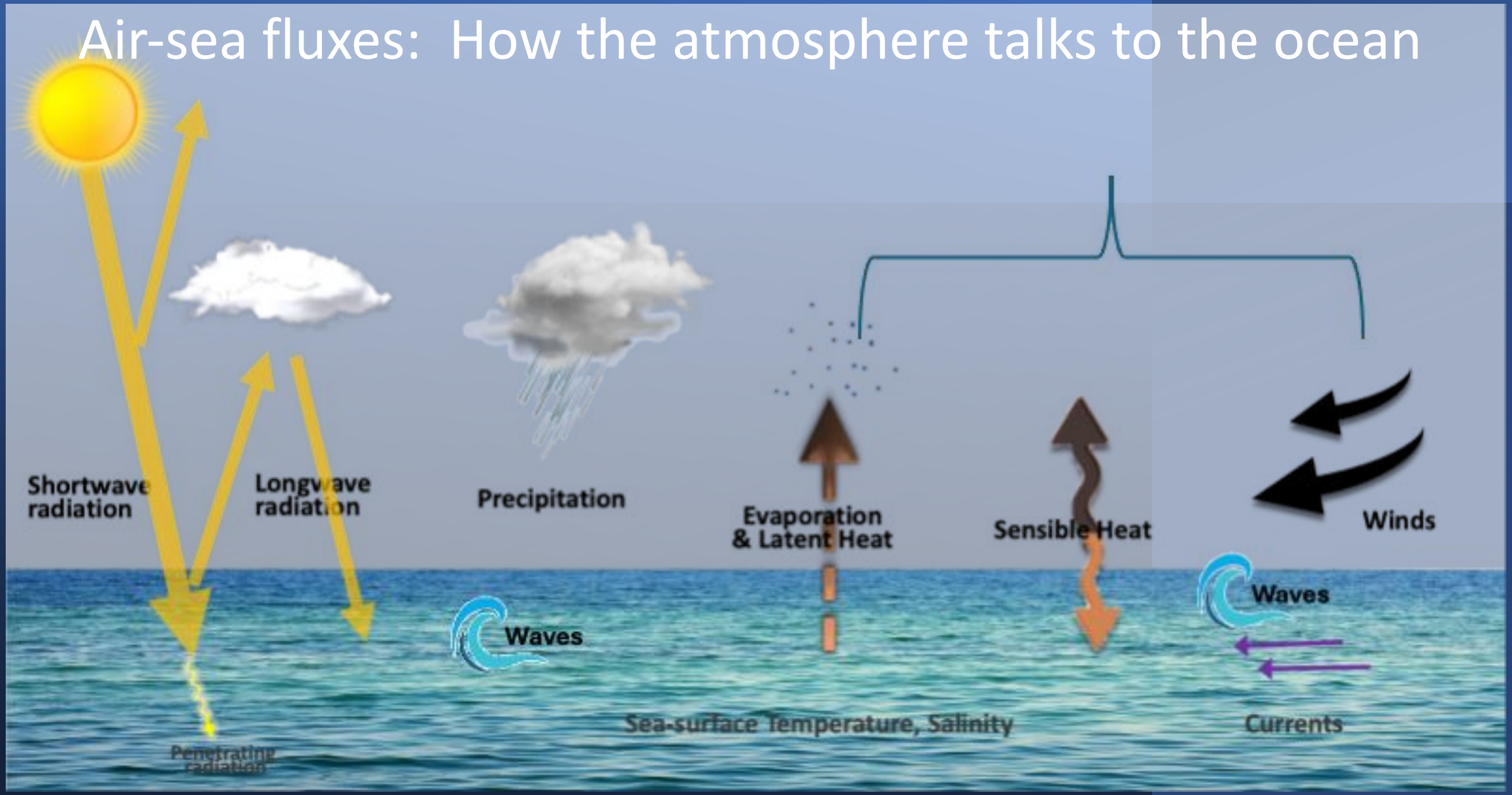
Mechanisms for Southern Ocean change



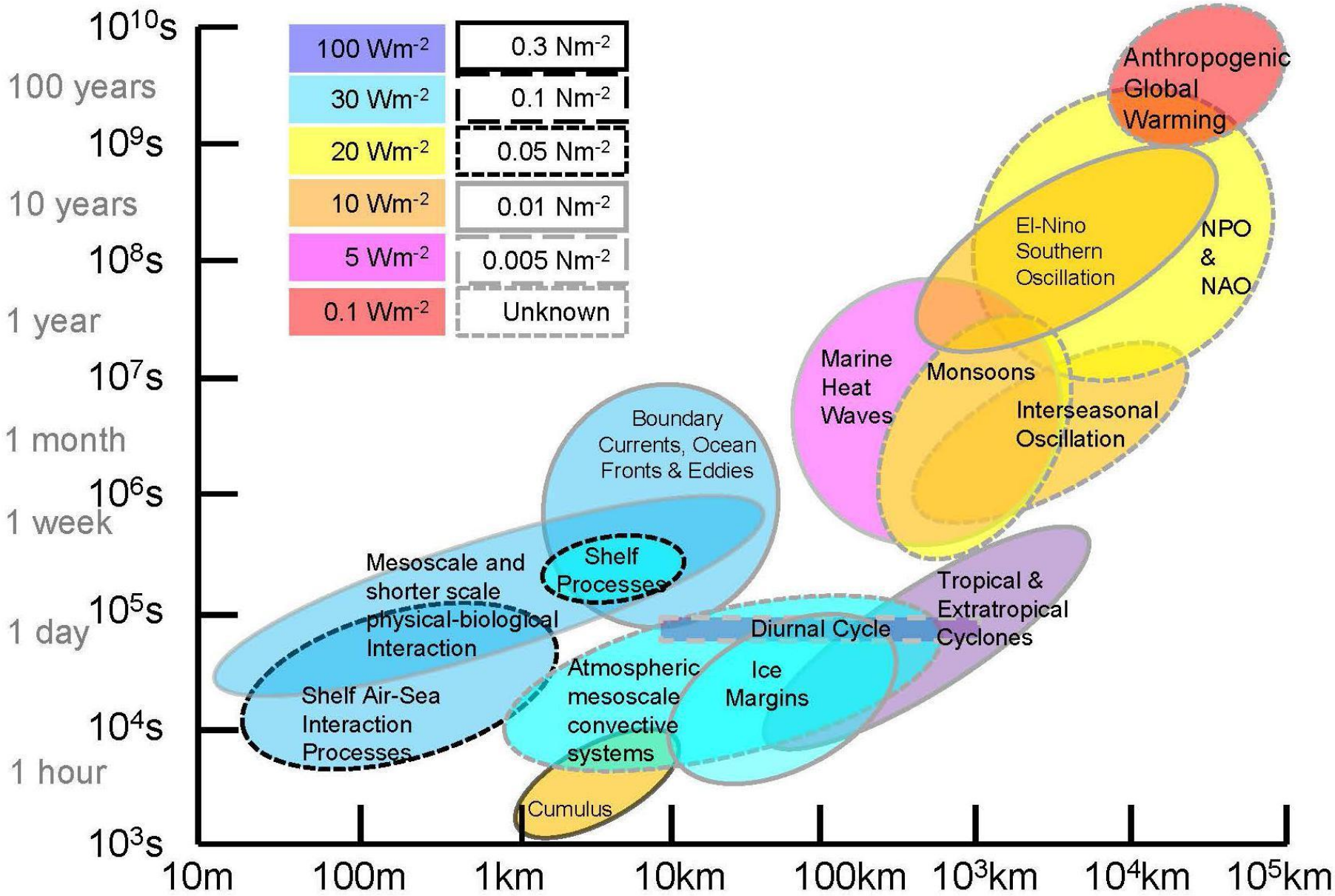
For full Southern Ocean

- Advection by mean flow?
- Advection by eddies?
- Air-sea fluxes (heat and evaporation minus precipitation)?

Air-sea fluxes: How the atmosphere talks to the ocean

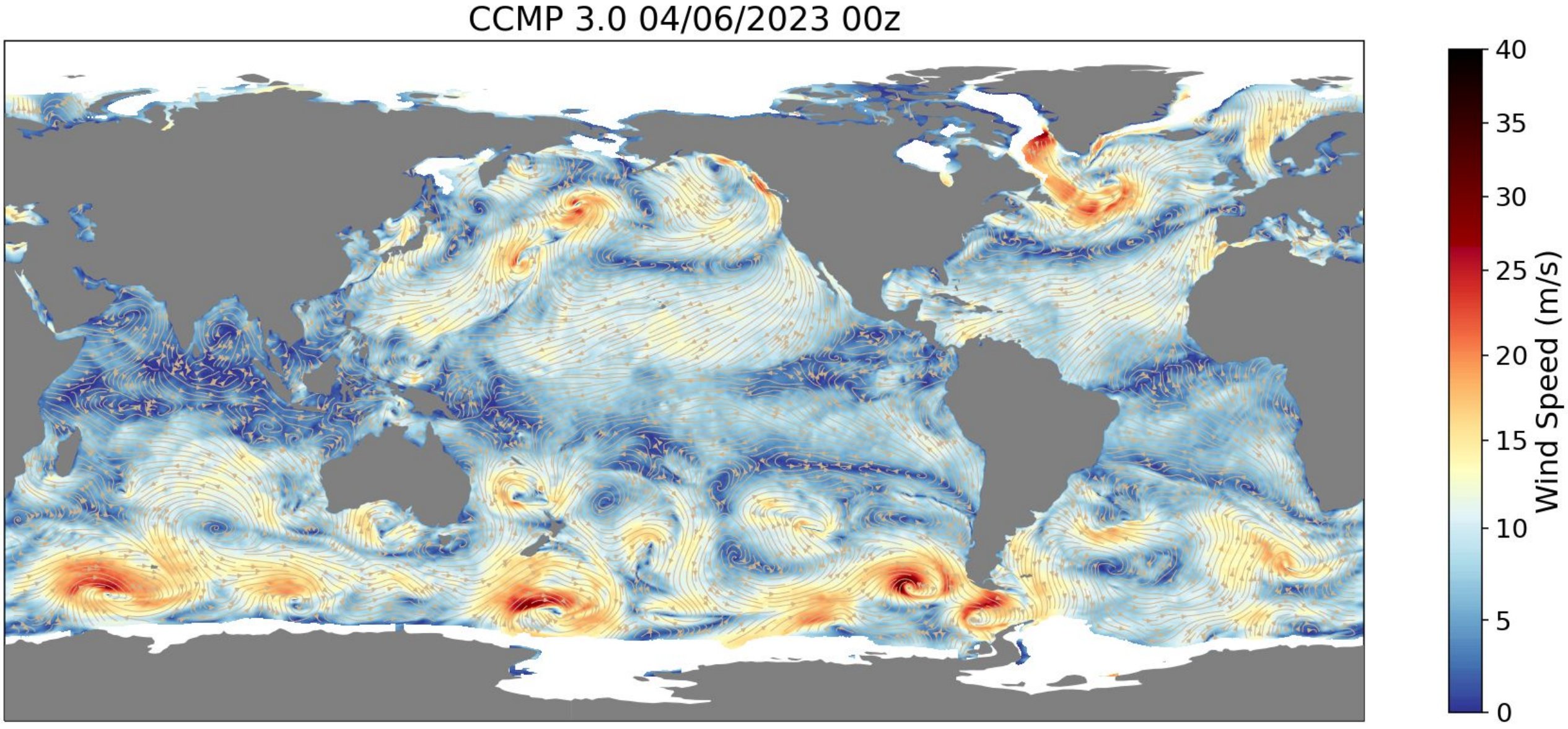


Flux Accuracies and Processes



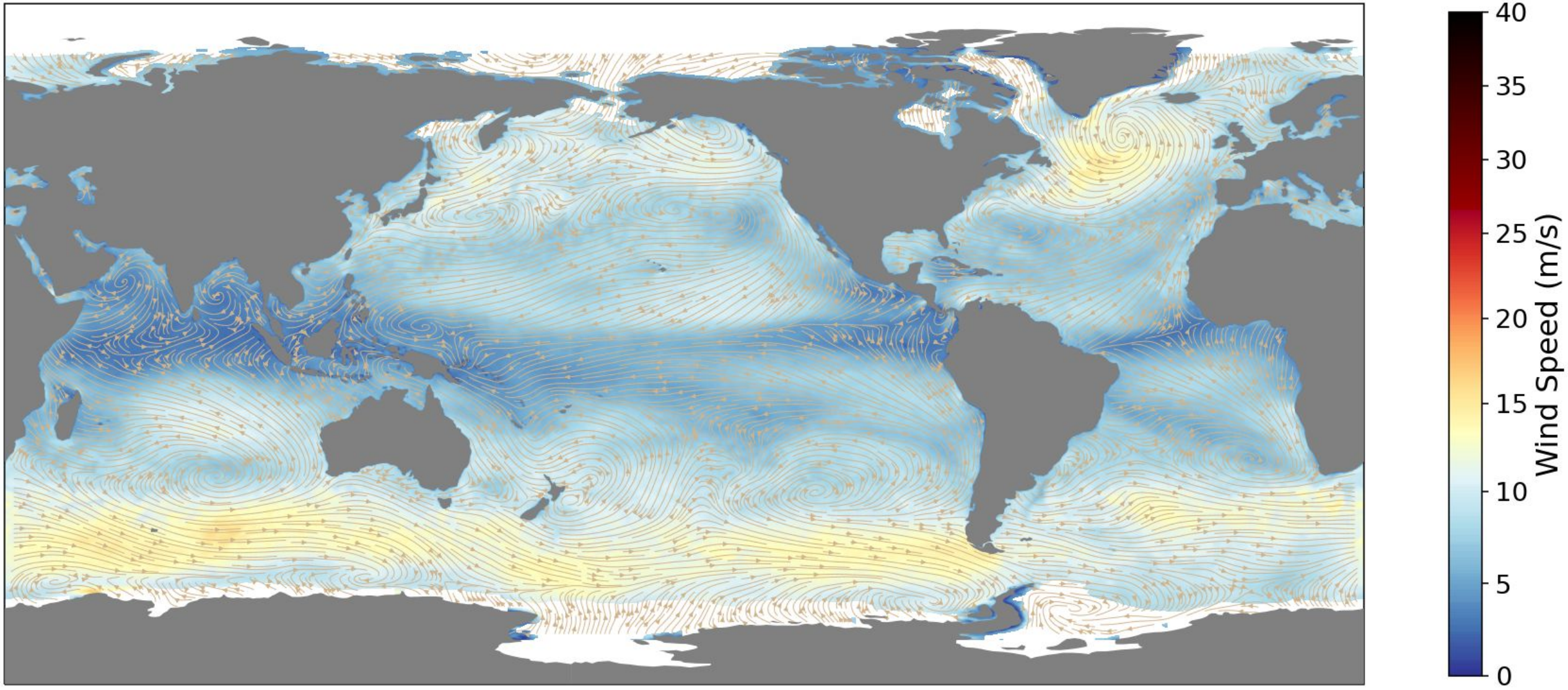
Cronin et al, *Frontiers in Marine Science*, 2019

Global winds over the ocean: 1 day



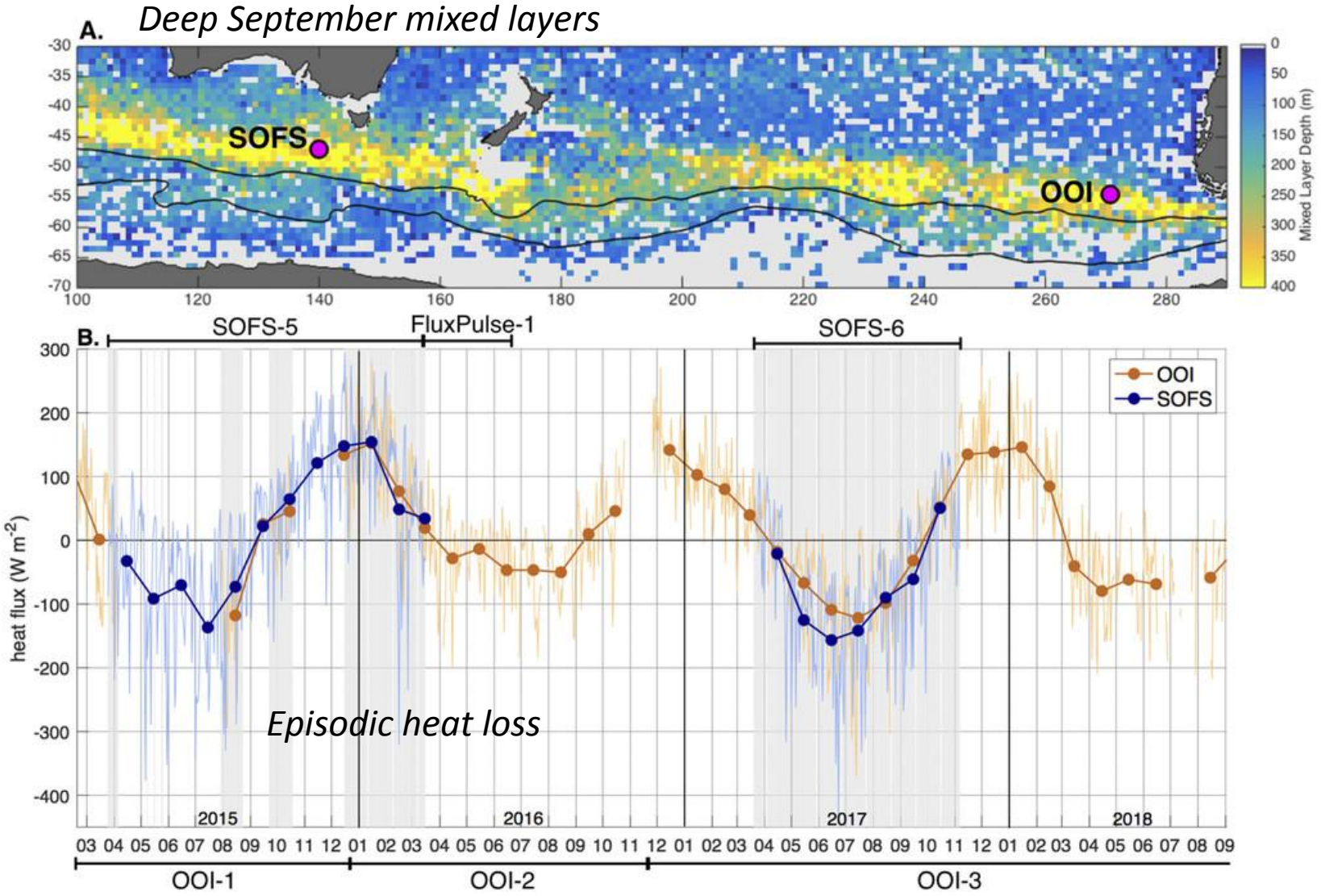
https://images.remss.com/graphics/ccmp/v03.1/y2023/m04/d06/CCMP_31_Wind_Analysis_2023_04_06_00z_stream.png

Global winds over the ocean: 1 month



https://images.remss.com/graphics/ccmp/v03.1/y2023/m04/CCMP_31_Wind_Analysis_2023_04_stream.png

Winds: Extremes govern air-sea exchange

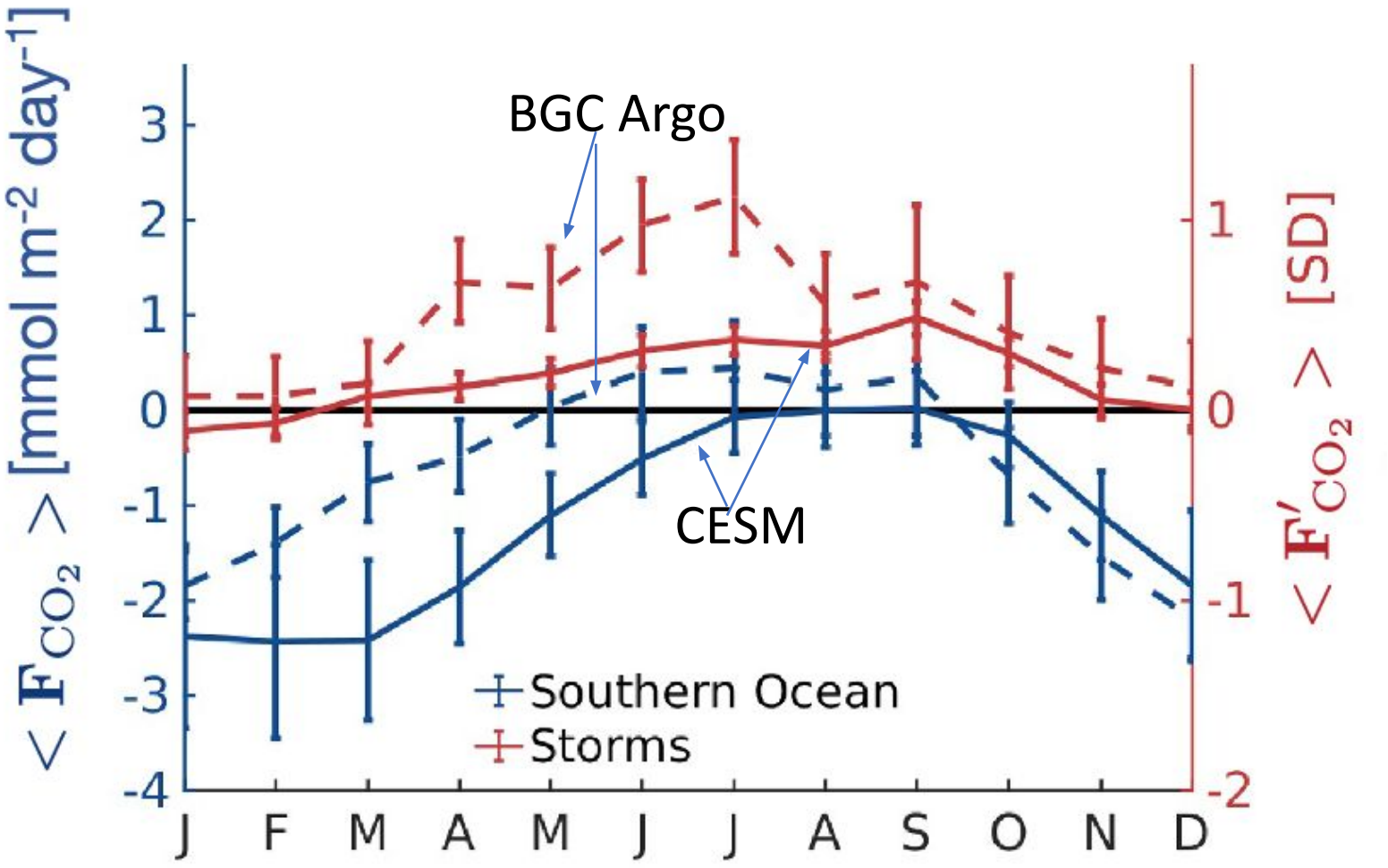


- At Southern Ocean flux moorings, highly episodic heat loss from ocean
- Heat loss leads to deep mixed layers, drives air-sea exchange with ocean interior
- Heat loss events linked to strong winds from south

Tamsitt et al, J. Climate, 2020

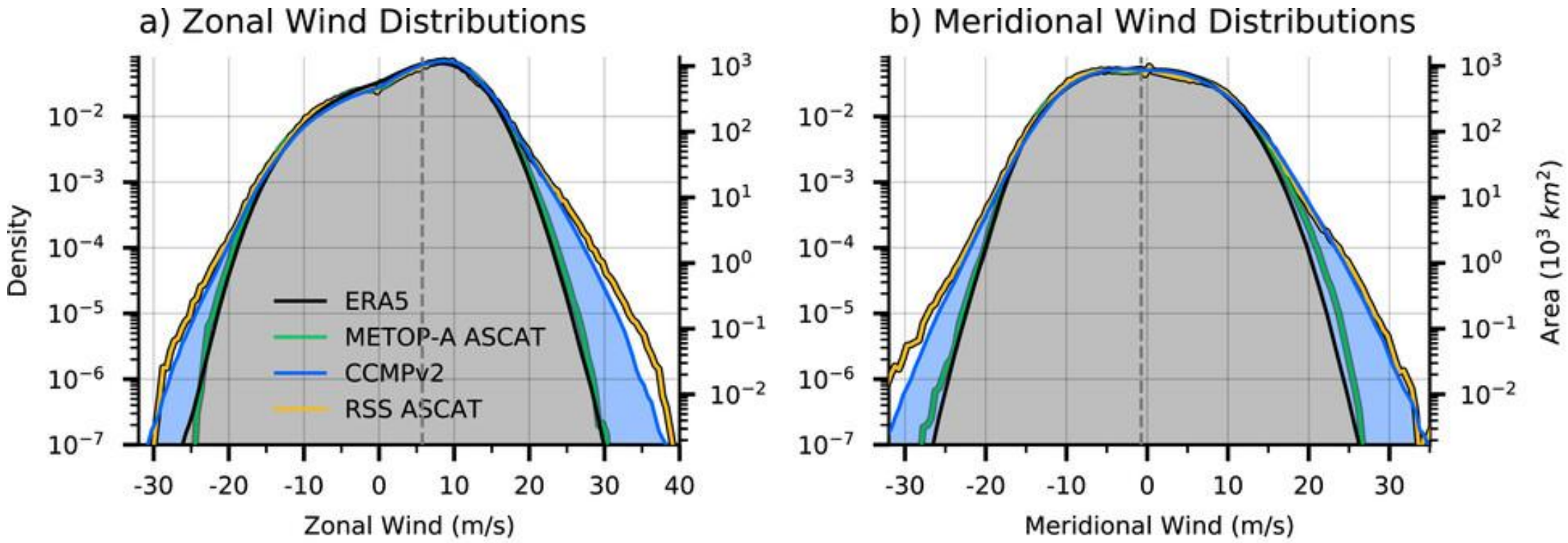
Southern Ocean storms modulate CO_2 flux

- Poleward of 35S storms occur weekly
- If we want to understand how the ocean sequesters heat or CO_2, need extreme winds



Carranza et al, 2024, Nature Climate and Atmospheric Science

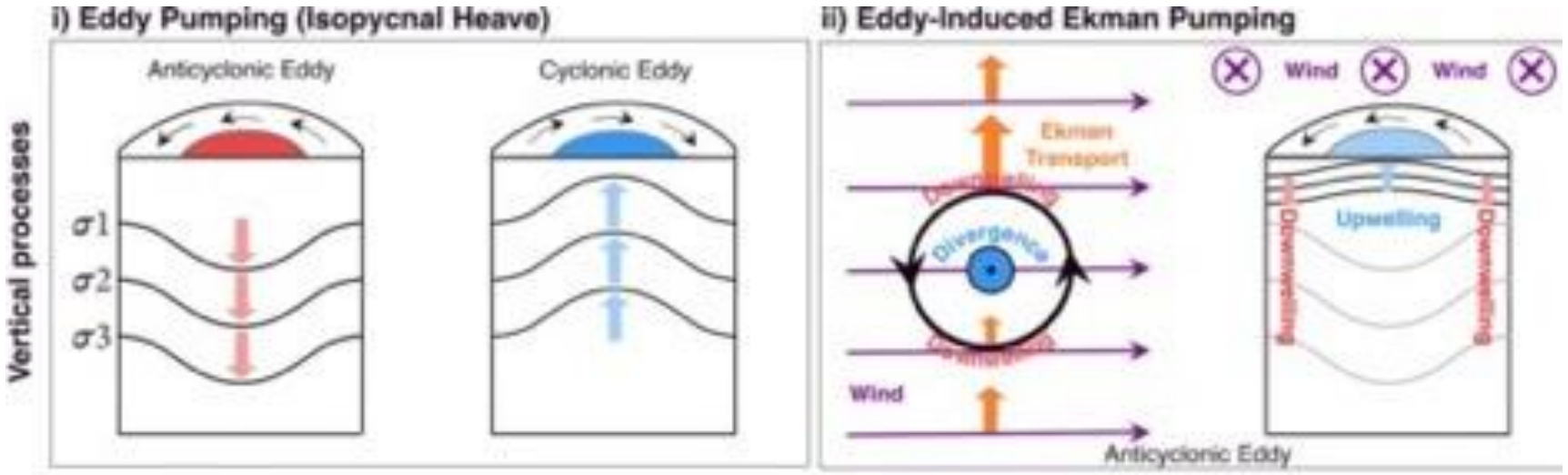
Winds: Wind products disagree for extremes

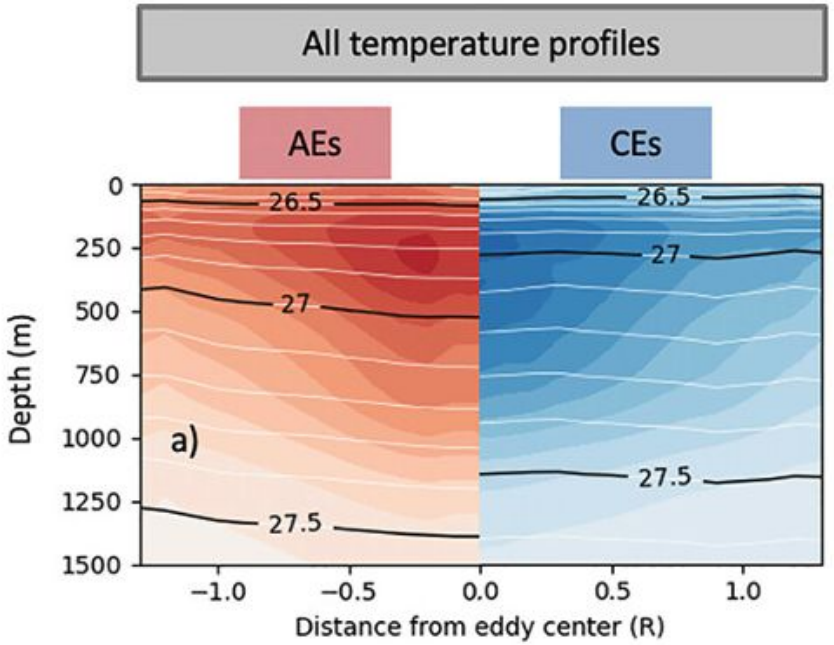


- Wind probability density for 4 products (ERA5, METOP-A, CCMP, Remote Sensing Systems ASCAT)
- Outliers that matter for climate not represented consistently

Hell et al, J. Climate, 2021

Ocean eddies modulate air-sea exchange





Temperature effects extend to nutrients, DIC, oxygen

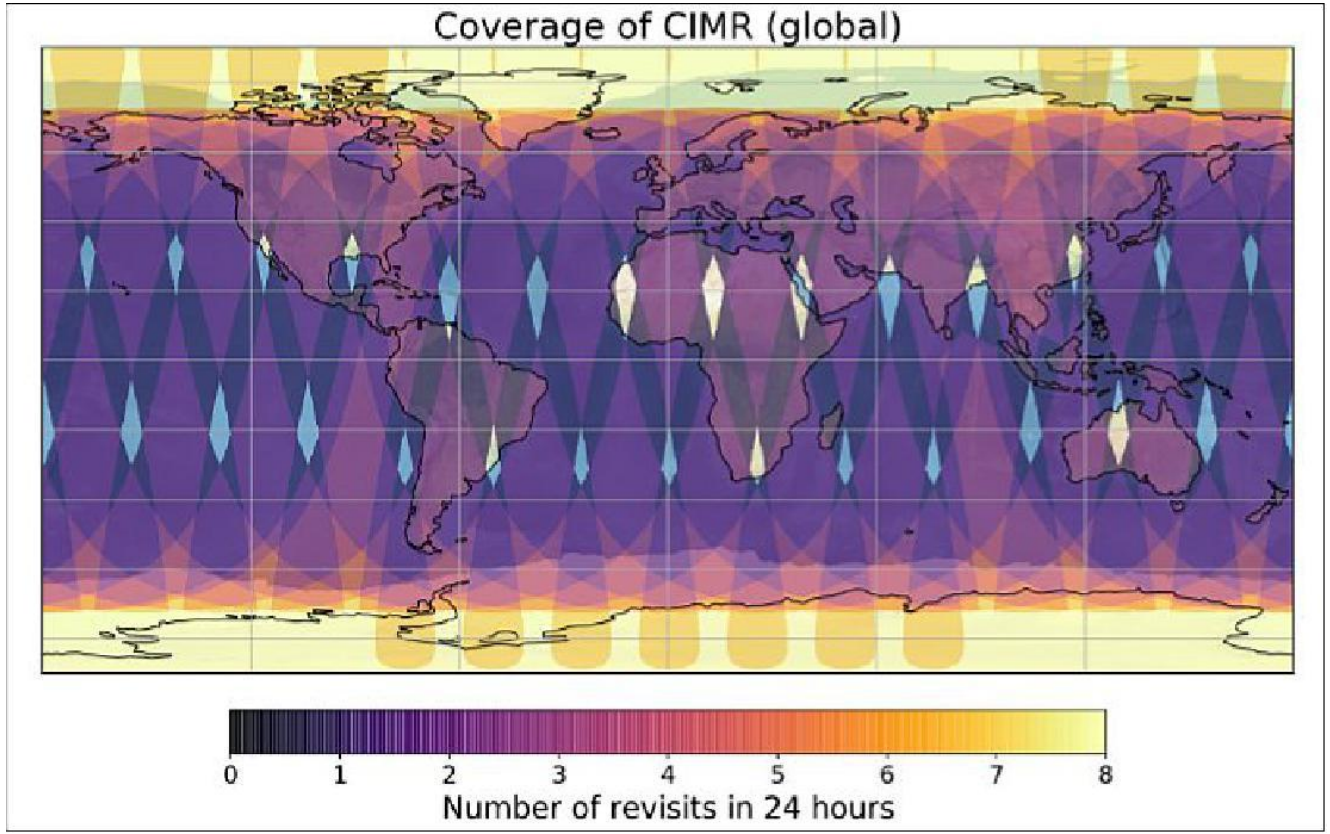
Keppler et al, JGR, 2024

Future satellite capabilities and concepts

- CMER: Copernicus Imaging Microwave Radiometer (launch 2029) *SST, winds, ice*
- Harmony: (launch 2029) *multi-look SAR for winds, waves, currents, ice*
- Butterfly: *concept for turbulent heat fluxes*
- ODYSEA: Ocean Dynamics and Surface Exchange with the Atmosphere *winds and currents, Step 2 competition this year for launch in 2030—2032 time frame*

CIMR: Higher resolution SST, wind, etc. *Copernicus Imaging Microwave Radiometer*

- **Concept:** New microwave radiometer provides more accurate and higher resolution all-weather SST, ocean wind speed, SSS, and SIC, with 15 km resolution SST.

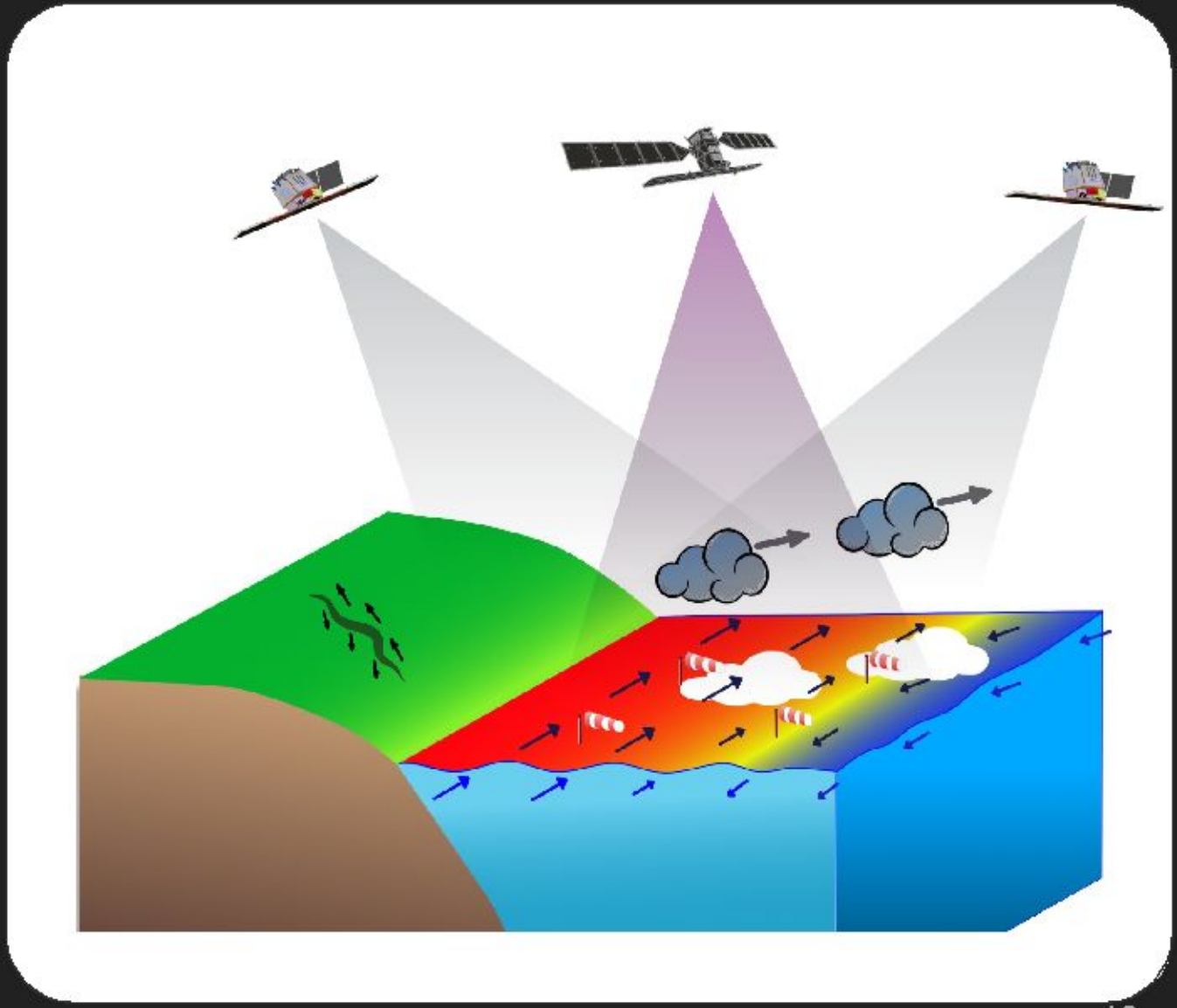


- In development with ESA
- Launch: 2029+
- Point of contact: Craig Donlon

Harmony: Wind stress, currents, waves, SST + more

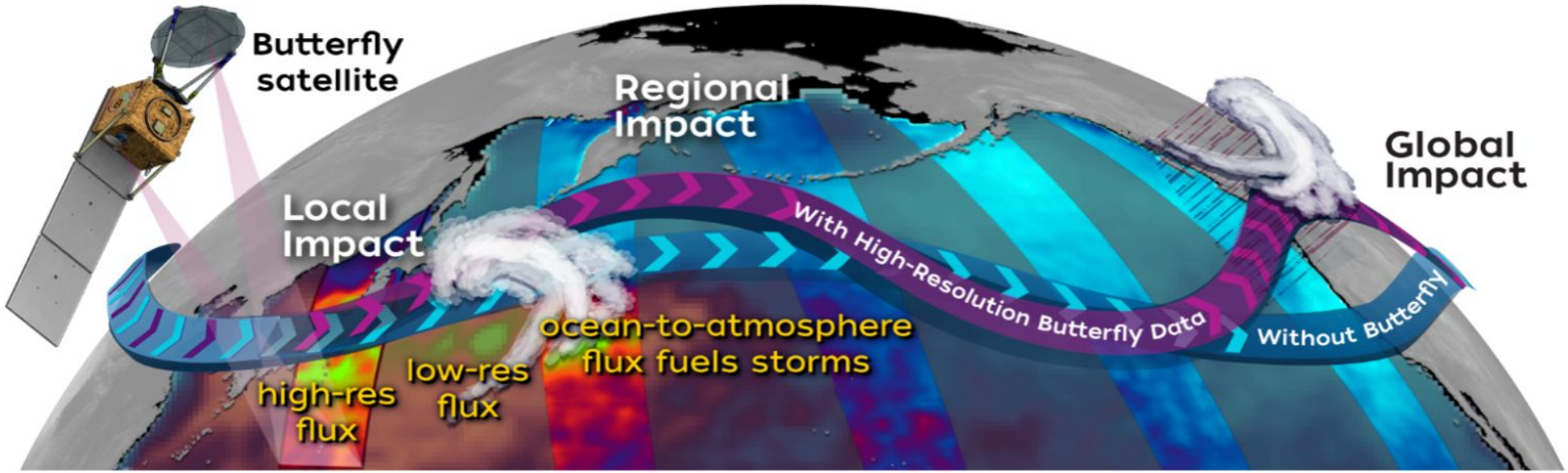
Line-of-sight diversity for high resolution

- 3-D surface deformation (DInSAR)
- Ocean surface motion (Doppler)
- Surface winds (scatterometry)
- Improved directional surface wave spectra
- Sea Surface (skin) temperature
- Cloud-top motion (TIR time-lapse) and height (TIR parallax)



BUTTERFLY

revealing the oceans' impact on weather & climate

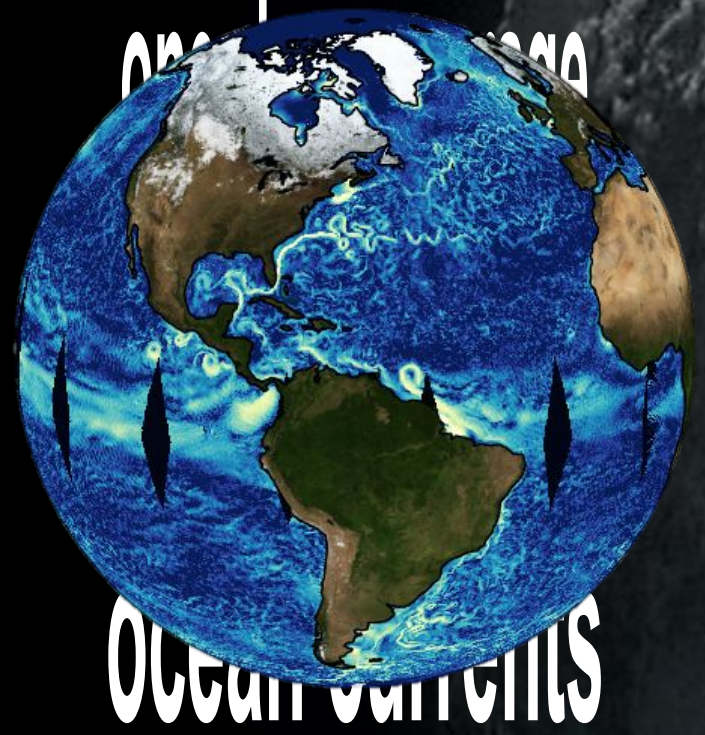


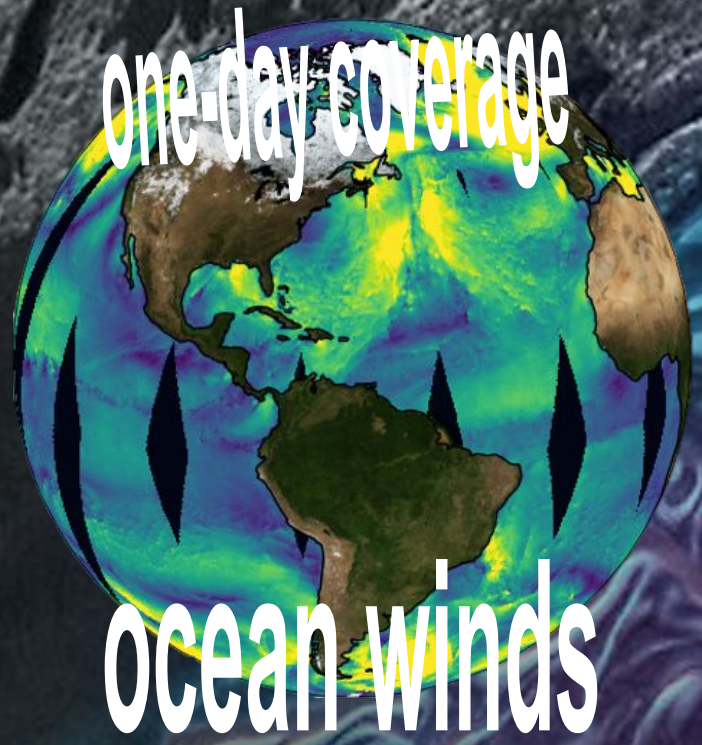
Principal Investigator: Dr. Carol Anne Clayson
Deputy Principal Investigator: Dr. Aneesh Subramanian
Project Scientist: Dr. Tony Lee
Deputy Project Scientist: Dr. Shannon Brown

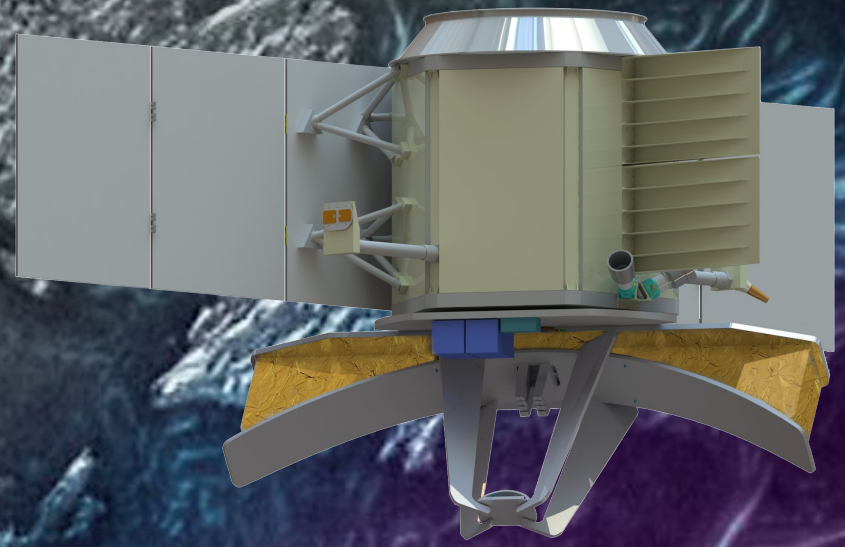
Science Team:
Mark Bourassa, Hyodae Seo, Kelly Lombardo, Sarah Gille, Tom Farrar, Rhys Parfitt

Air-sea interactions are key to weather on all time scales

Observations are essential for useful predictions







ODYSEA is one of four Earth System Explorer satellite concepts chosen by NASA for further study. ~~Two~~ One will be selected in 2025 for flight in ~~2030 and 2032~~ 2031?.

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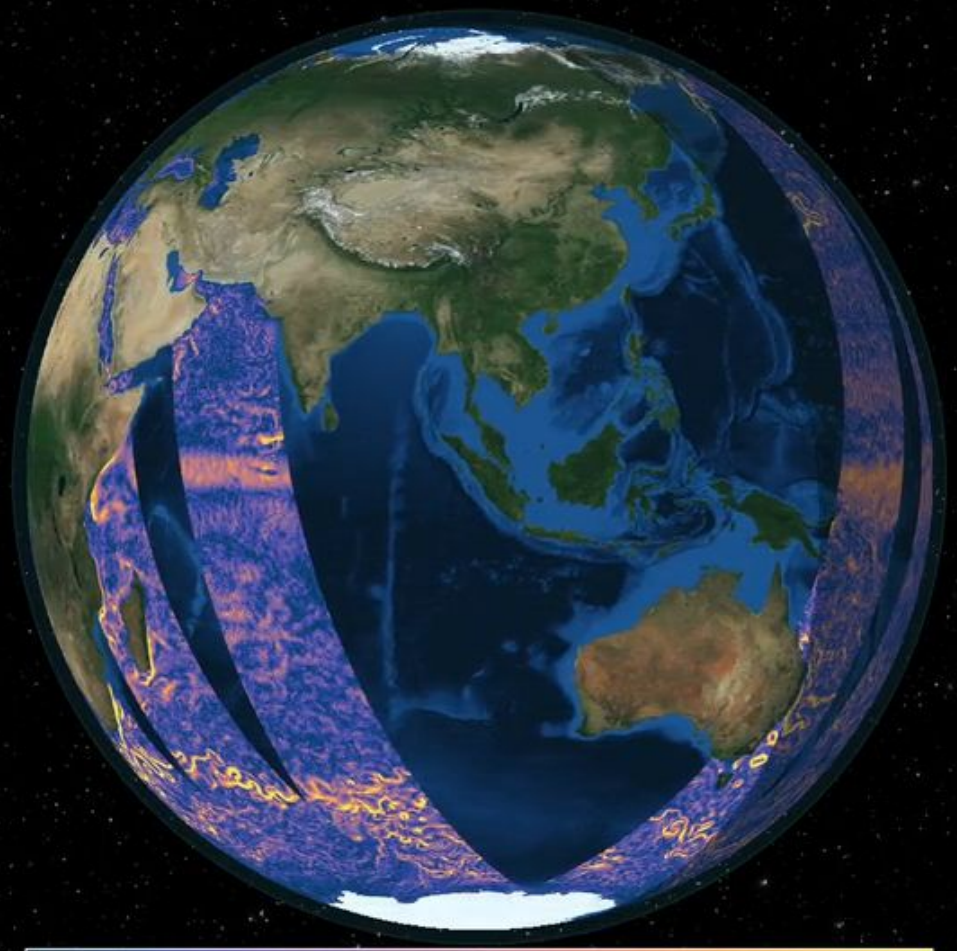
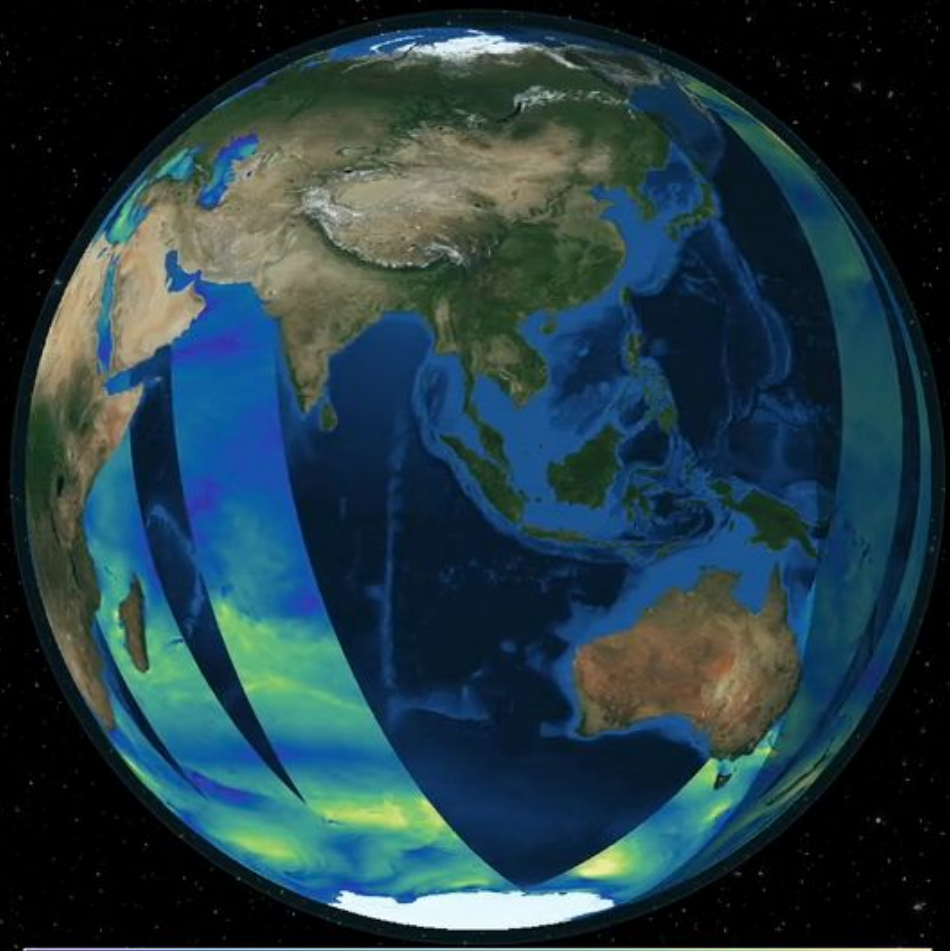
What can we do with winds and currents?

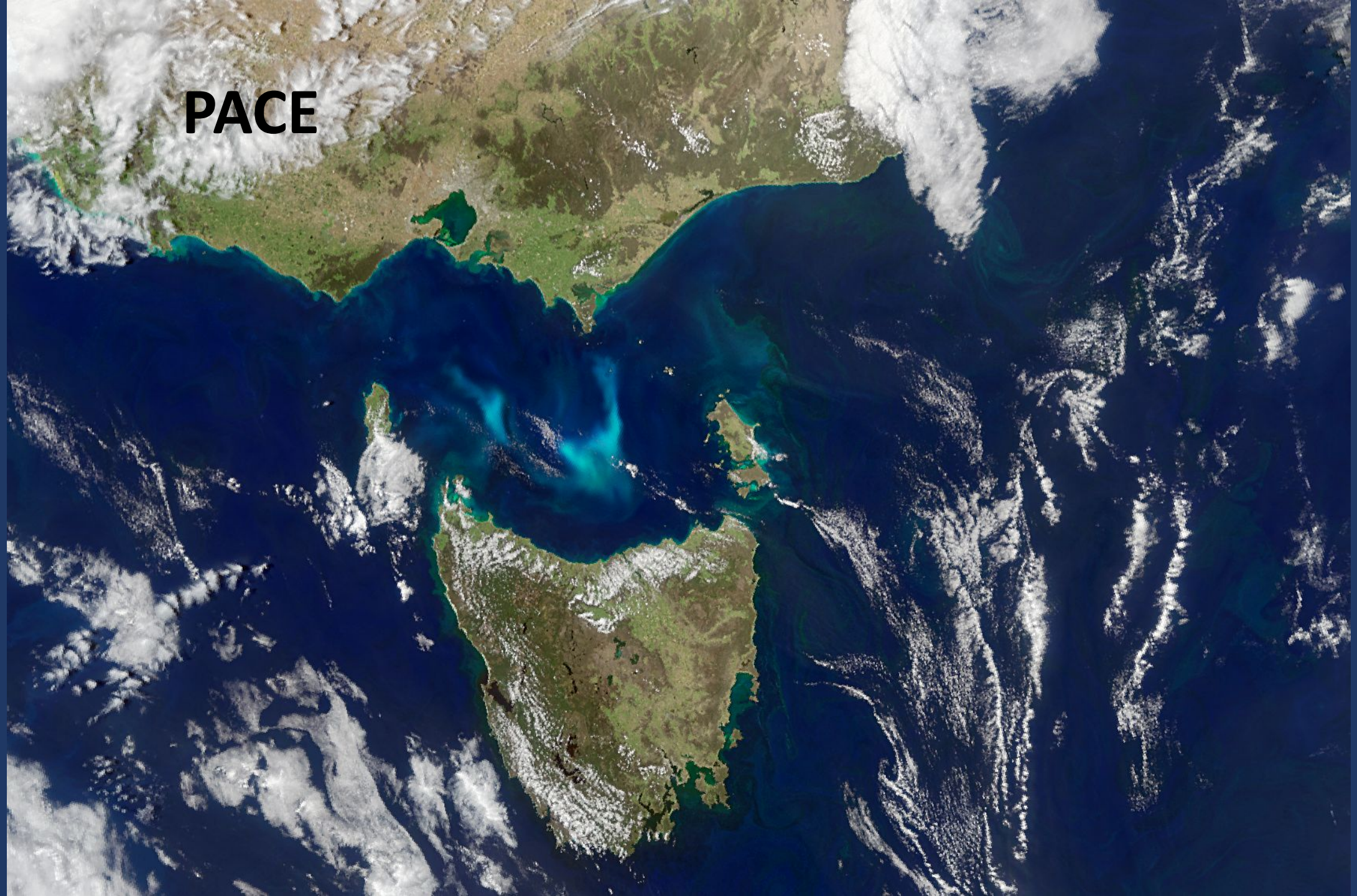




- 2 science objectives

Recap: Inventories and Fluxes

- Southern Ocean warming, acidification, and other changes
  - Inventories show statistically significant change
  - Attributable to air-sea fluxes
  - Inventory changes allow us to infer net fluxes
  - But
- Direct flux measurements
  - Turbulent fluxes depend on wind covarying with another quantity
  - Storm-driven extremes drive fluxes
  - Future satellites: high-resolution temperature, winds, air-sea turbulent heat and momentum fluxes


PACE