Ocean Mixing

as an Emerging **Essential Ocean Variable** (EOV)

Arnaud Le Boyer (SIO), **Nicole Couto** (SIO),
Laura Cimolli (SIO), Bruce Howe (UH)

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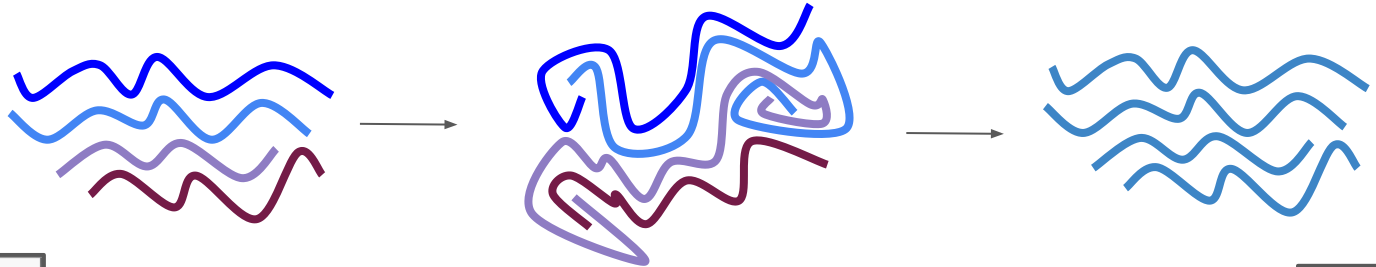
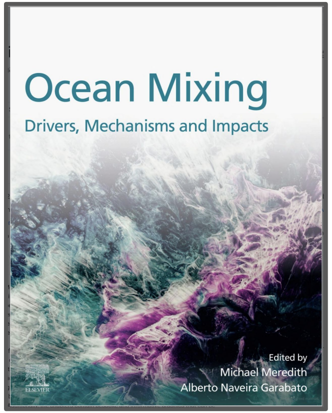




"the three-dimensional turbulent interleaving and blending of oceanic waters with different properties."

Ocean Mixing as an Essential Ocean Variable

Le Boyer, Couto, et. al (in prep.)

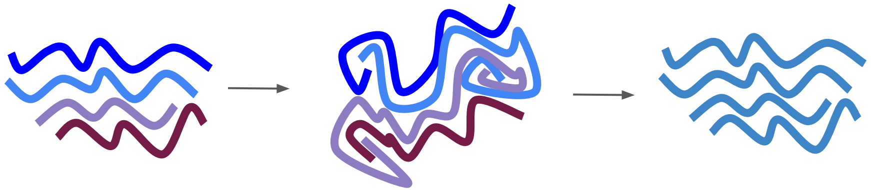
Ocean Mixing as an emerging EOV

✅ **Relevance:** The variable is effective in addressing the overall GOOS Themes – Climate, Real-Time Services, and Ocean Health.

📈 **Feasibility:** Observing or deriving the variable on a *global scale* is technically feasible using proven, scientifically understood methods.

📈 **Cost effectiveness:** Generating and *archiving data* on the variable is affordable, mainly relying on *coordinated observing systems* using proven technology, taking advantage where possible of historical datasets.

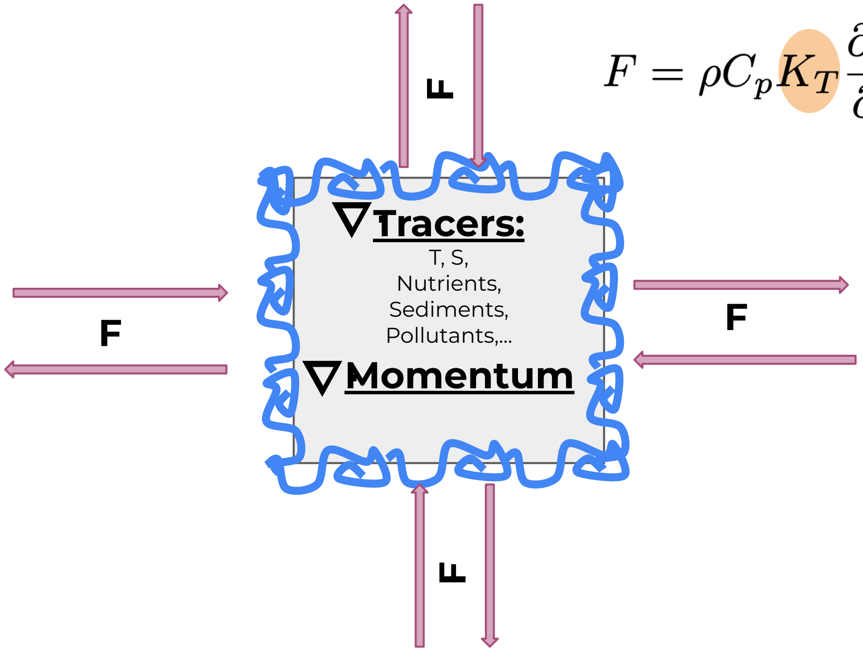
What is ocean mixing?



Ocean mixing refers to turbulent processes occurring at small spatial (1 m) and temporal (seconds to few minutes) scales that lead to the diabatic transformation of water masses.

Mathematically, we describe this with turbulent fluxes - the rate at which a tracer moves across a boundary.

$$F = \rho C_p K_T \frac{\partial T}{\partial z}$$



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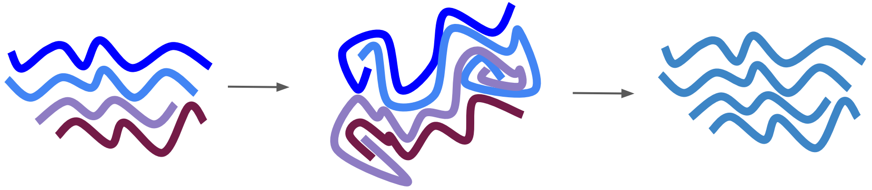

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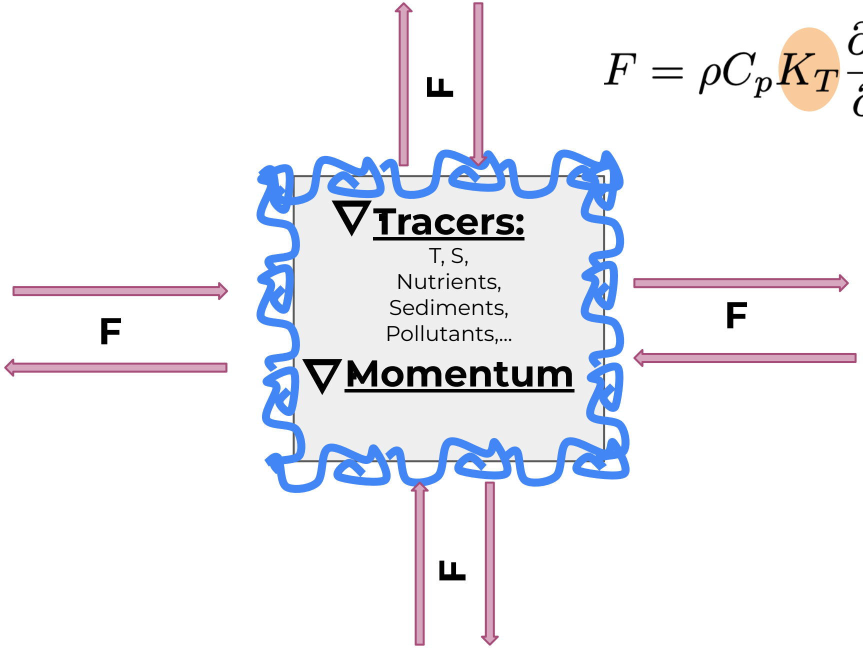


$$F = \rho C_p K_T \frac{\partial T}{\partial z}$$

Diffusivity describes how readily temperature, salinity, dissolved nutrients, etc can move across isopycnals in the ocean.

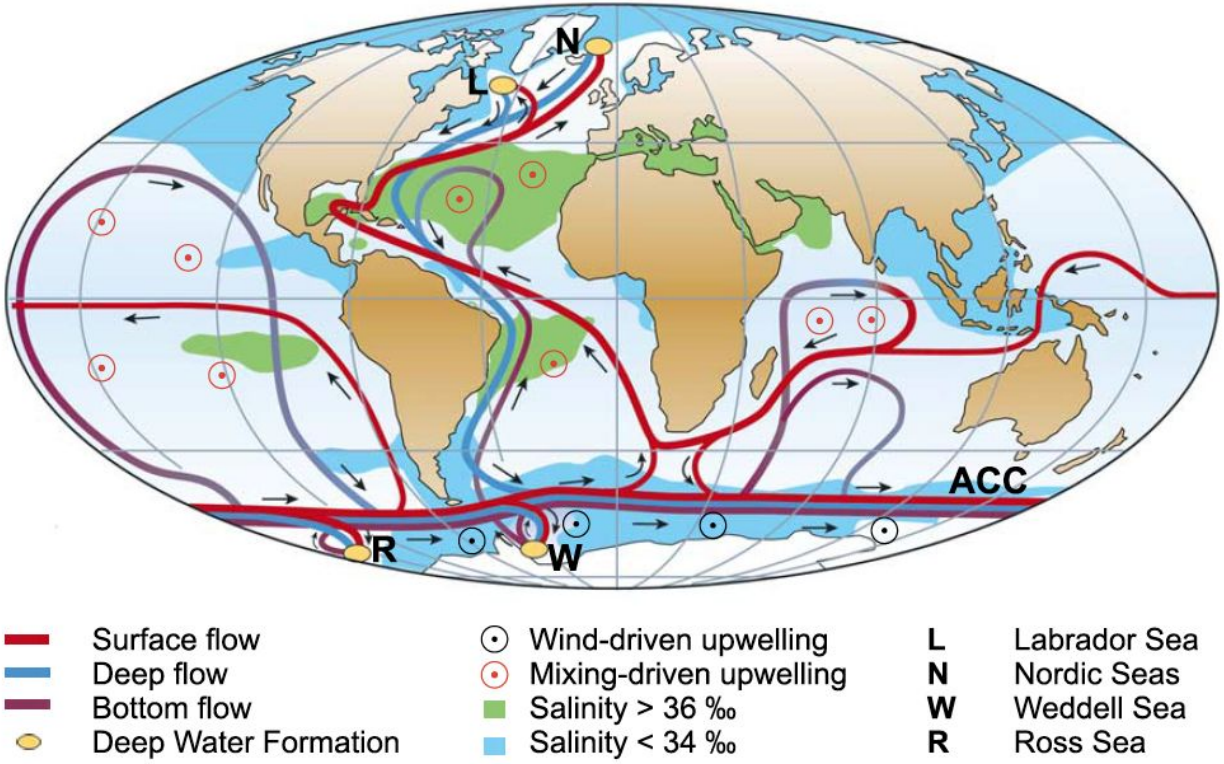
Mixing rates describe how quickly energy is dissipated.

$$K_\rho = \frac{\Gamma \langle \epsilon \rangle}{\langle N^2 \rangle}$$

$$K_T = \frac{\langle \chi \rangle}{6 \langle \frac{\partial T}{\partial z}^2 \rangle}$$

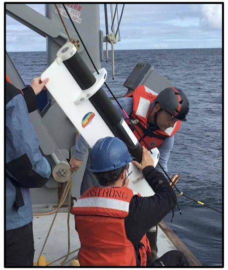
Scientific Relevance

- The upwelling branch of the thermohaline circulation relies on turbulent mixing.

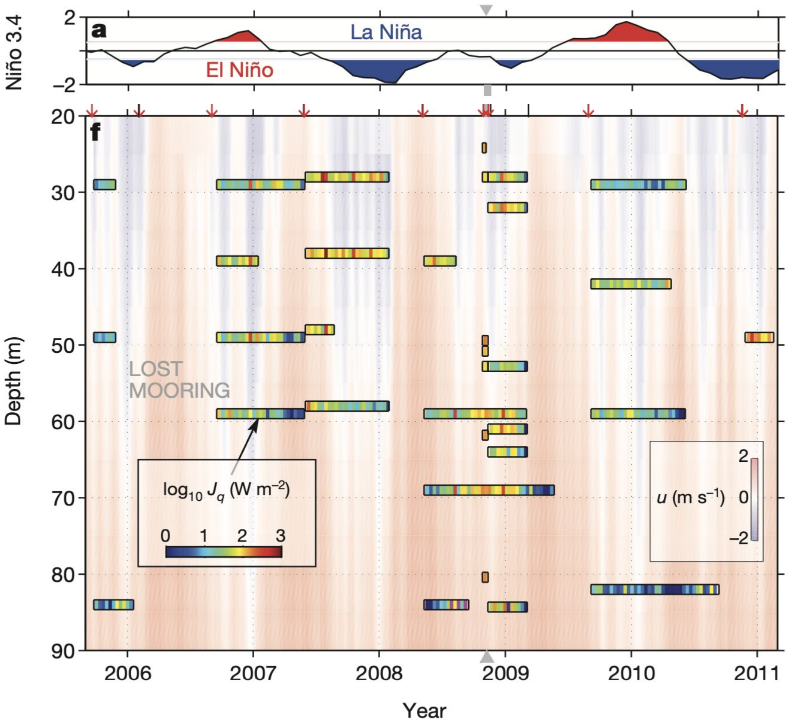


Scientific Relevance

χpods on moorings at the TAO array



- Many climate models fail to accurately simulate the seasonal cycle of the sea surface temperature in the equatorial cold tongue.



- Moum et al used a multi-year timeseries of heat flux computed from χpods to show that SST is related to mixing in the thermocline.

Moum 2013

Scientific Relevance

- Jan-Jun: surface heat flux > flux across thermocline
- Jul-Dec: flux across thermocline > surface heat flux

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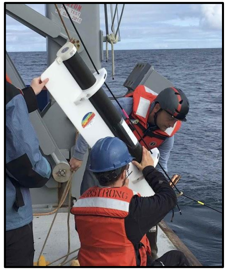
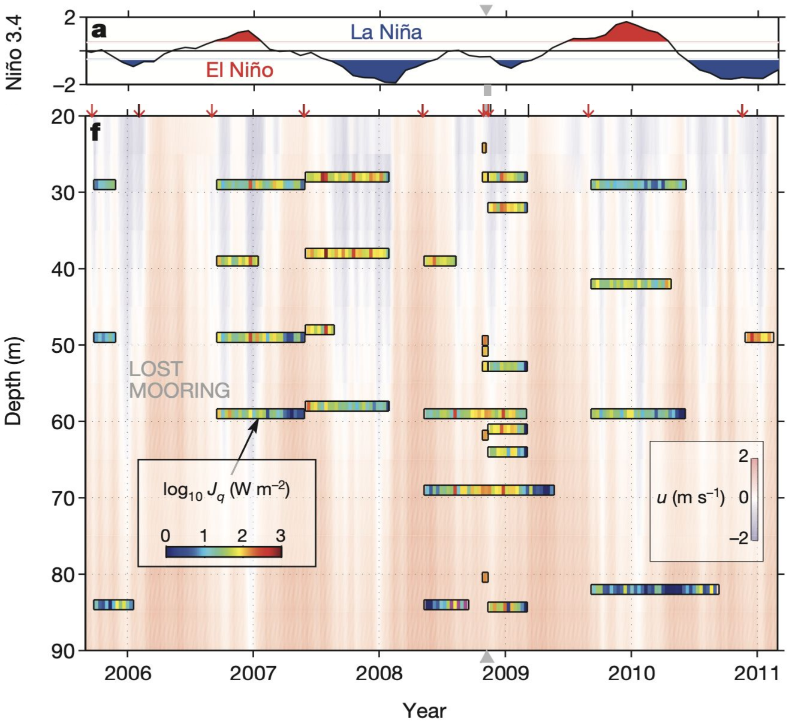
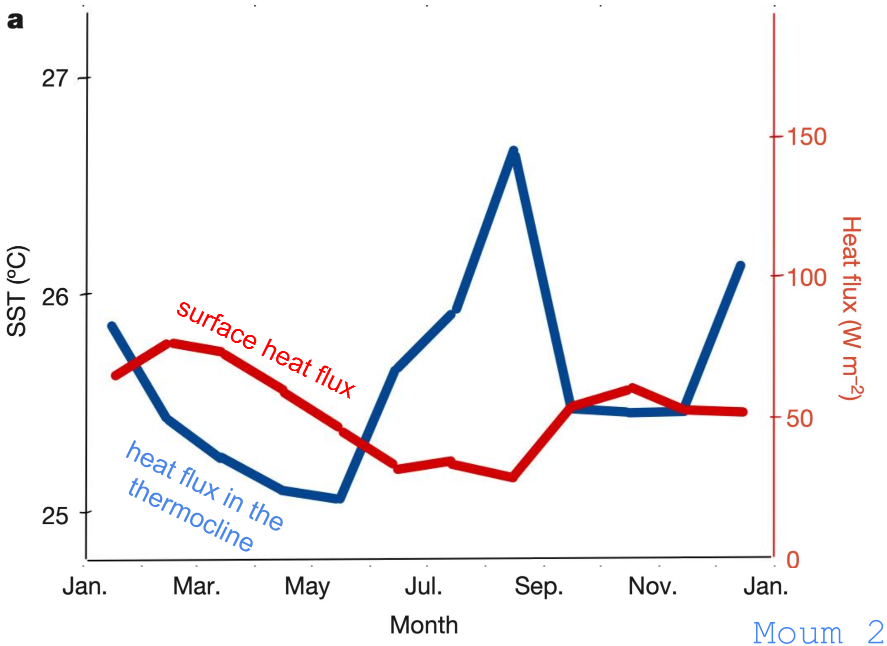




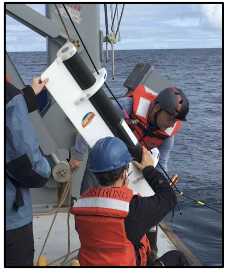


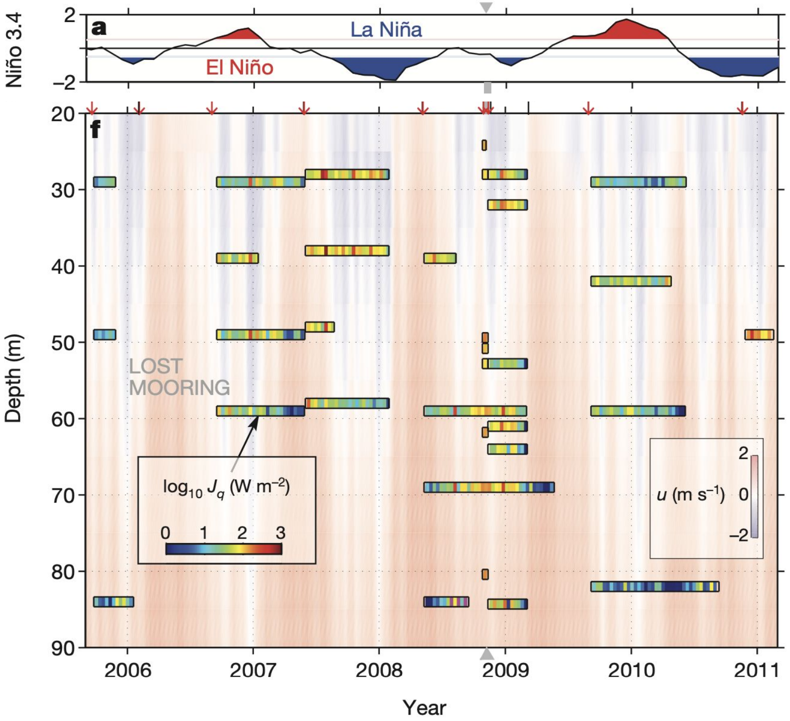
Moum 2013

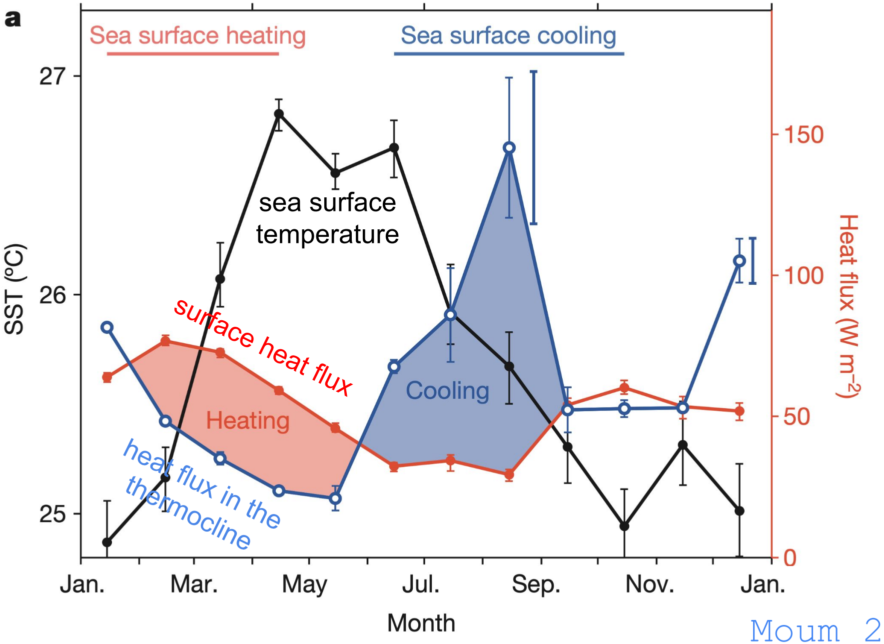
Scientific Relevance

- Equatorial SST warms when atmospheric heating exceeds cooling from mixing below, and cools when mixing exceeds atmospheric heating.

χpods on moorings at the TAO array



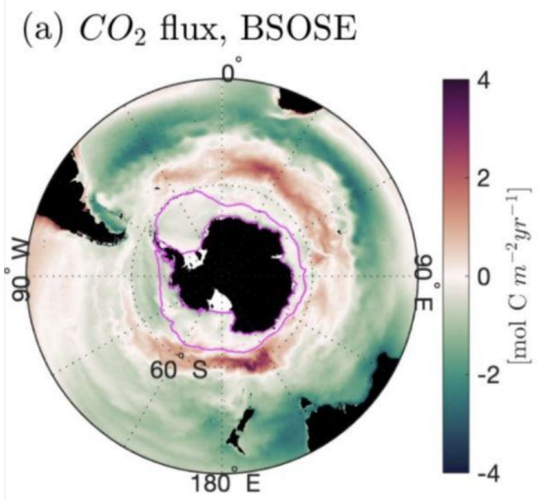


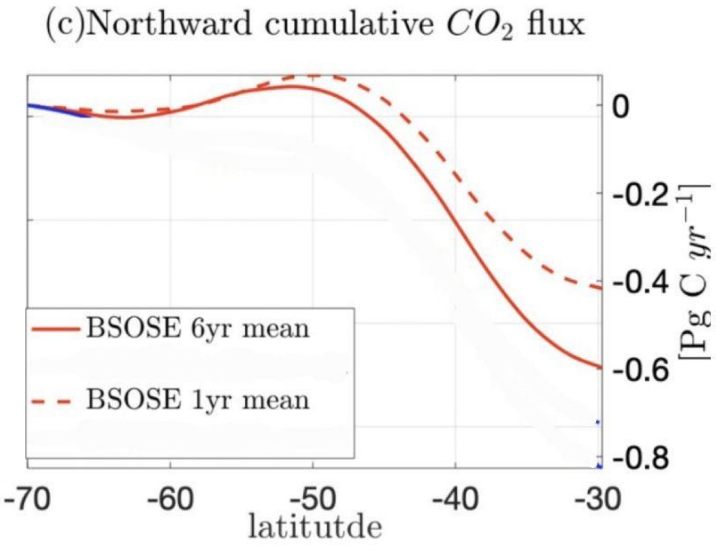


Moum 2013

Scientific Relevance :

- Turbulent mixing has a significant impact on air-sea fluxes

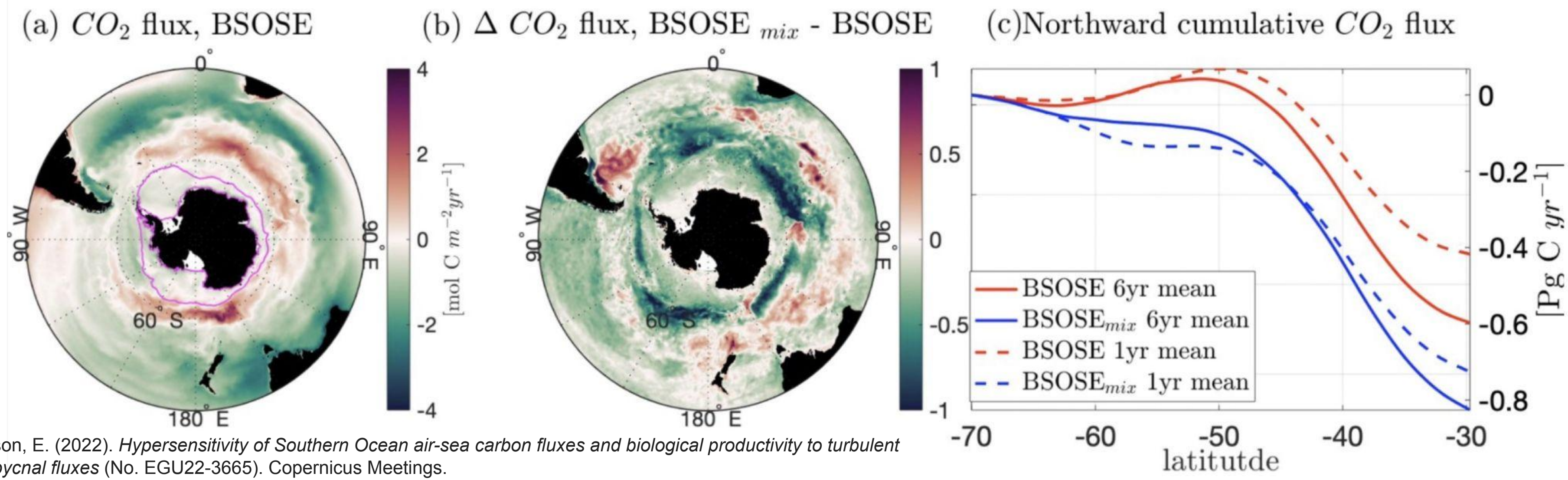




Ellison, E. (2022). *Hypersensitivity of Southern Ocean air-sea carbon fluxes and biological productivity to turbulent diapycnal fluxes* (No. EGU22-3665). Copernicus Meetings.

Scientific Relevance

- Turbulent mixing has a significant impact on air-sea fluxes
- Altering the mixing in an eddy-permitting ocean model alters the distribution of inorganic carbon, alkalinity, temperature, and salinity
- These changes alter the biological productivity, which affects the total carbon flux



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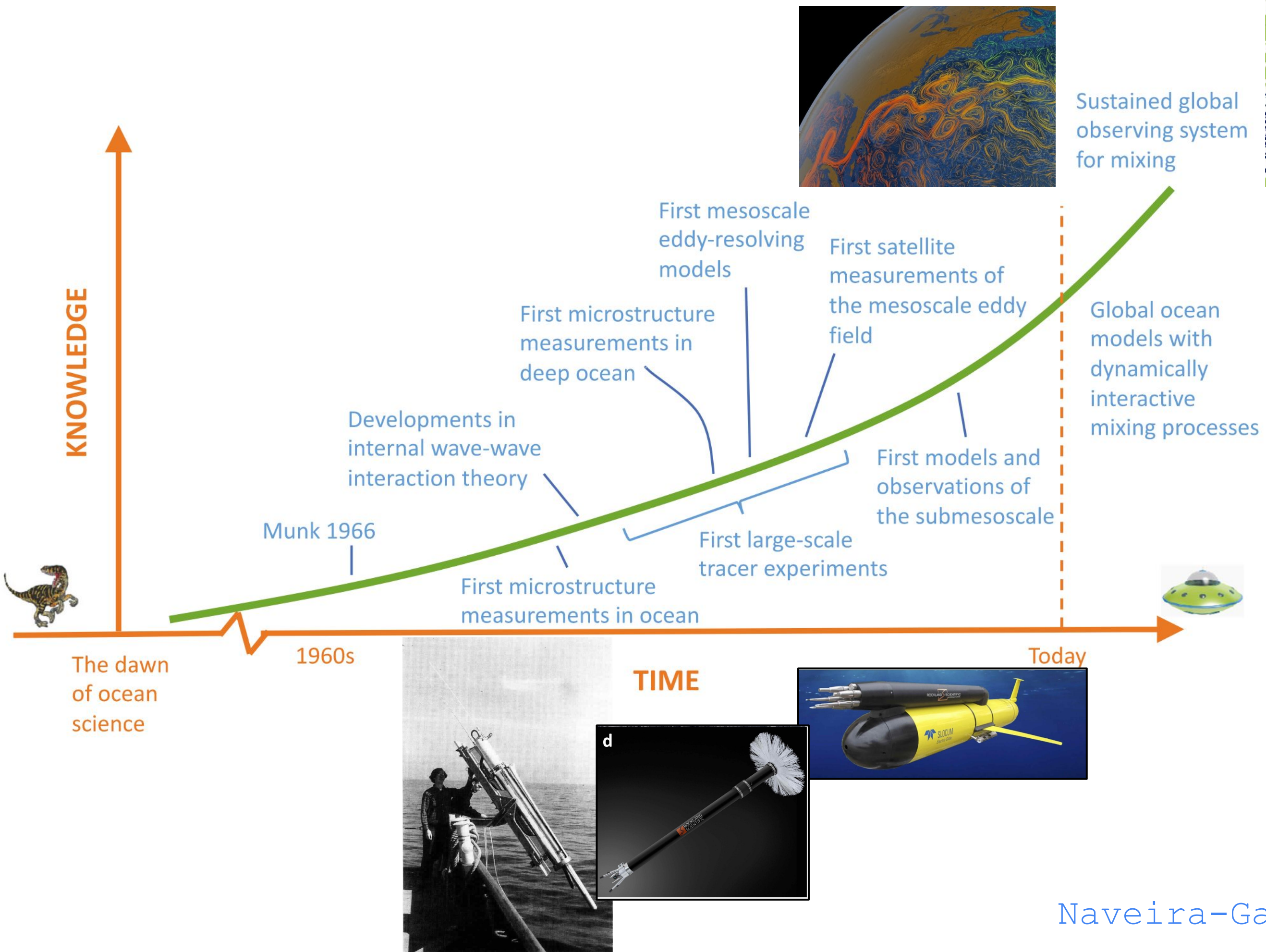
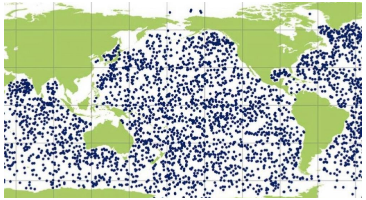
Feasibility / Technological maturity



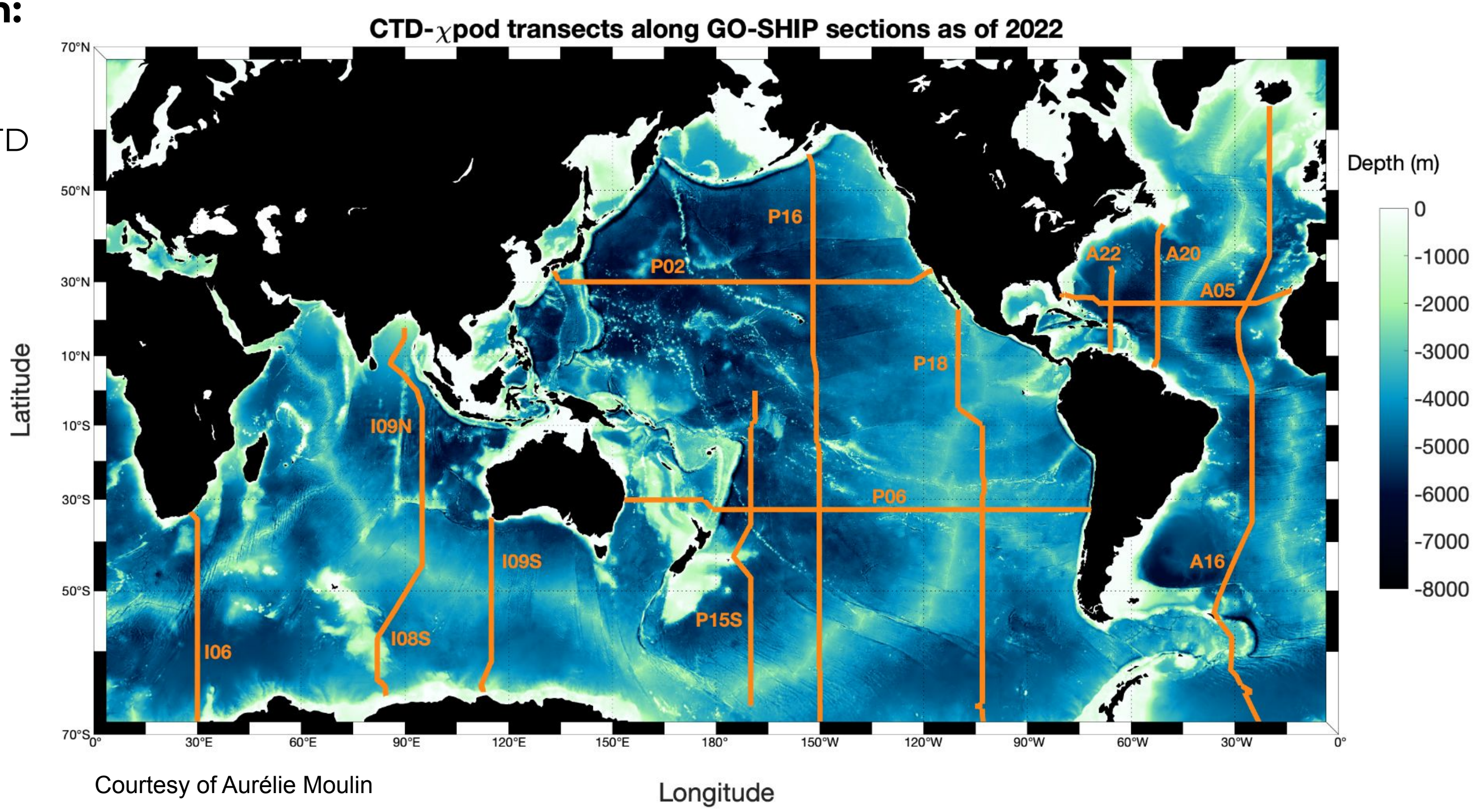


- Turbulence sensors have become less expensive and more user-friendly
- Increasing in-situ and remote observations, combined with increasing computation power has led to better models and parameterizations
- Now, the community is focusing on moving toward sustained global observations

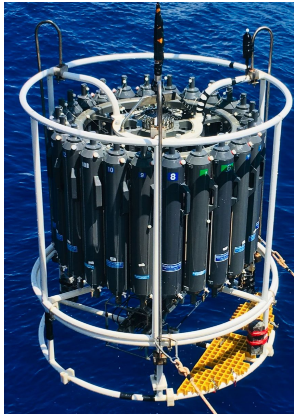
Naveira-Garabato and Meredith 2022

Coordinated efforts

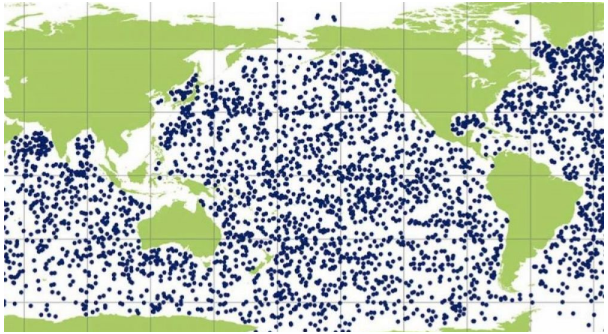
GO-SHIP program:
χ profiles can be measured with χpods attached to CTD rosette.



Courtesy of Aurélie Moulin

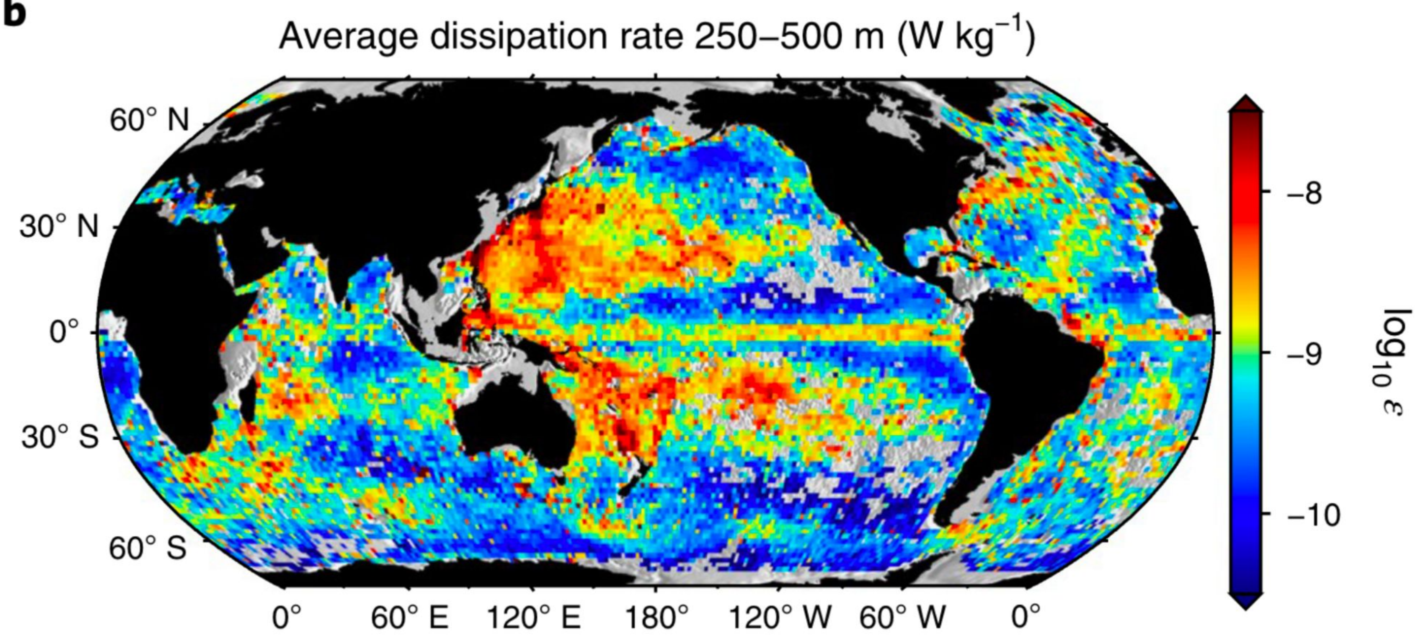


Coordinated efforts



ARGO network:
can make global estimates of dissipation from density profiles and strain parameterizations.

b

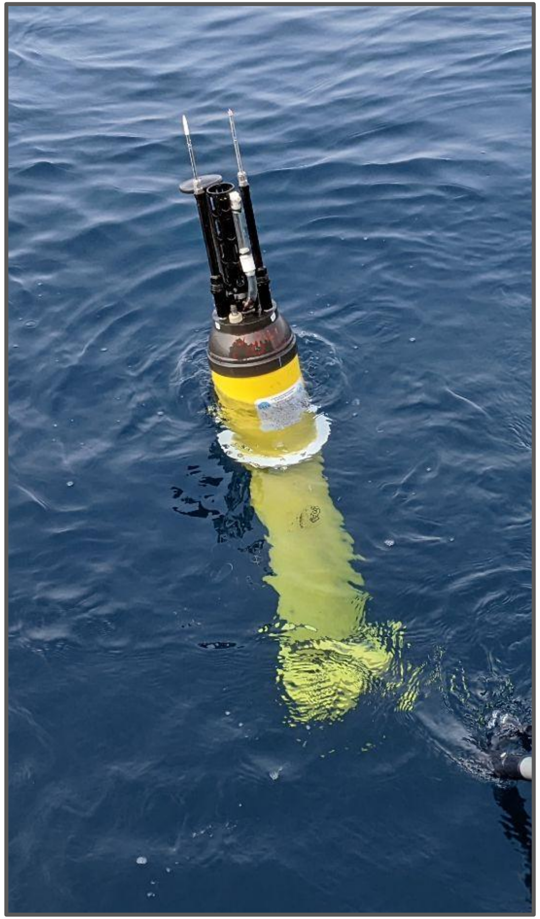


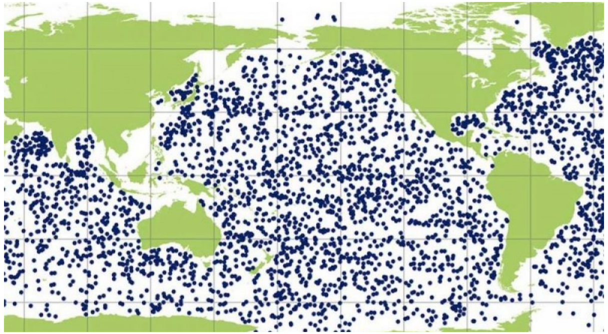
Whalen 2018

Coordinated efforts

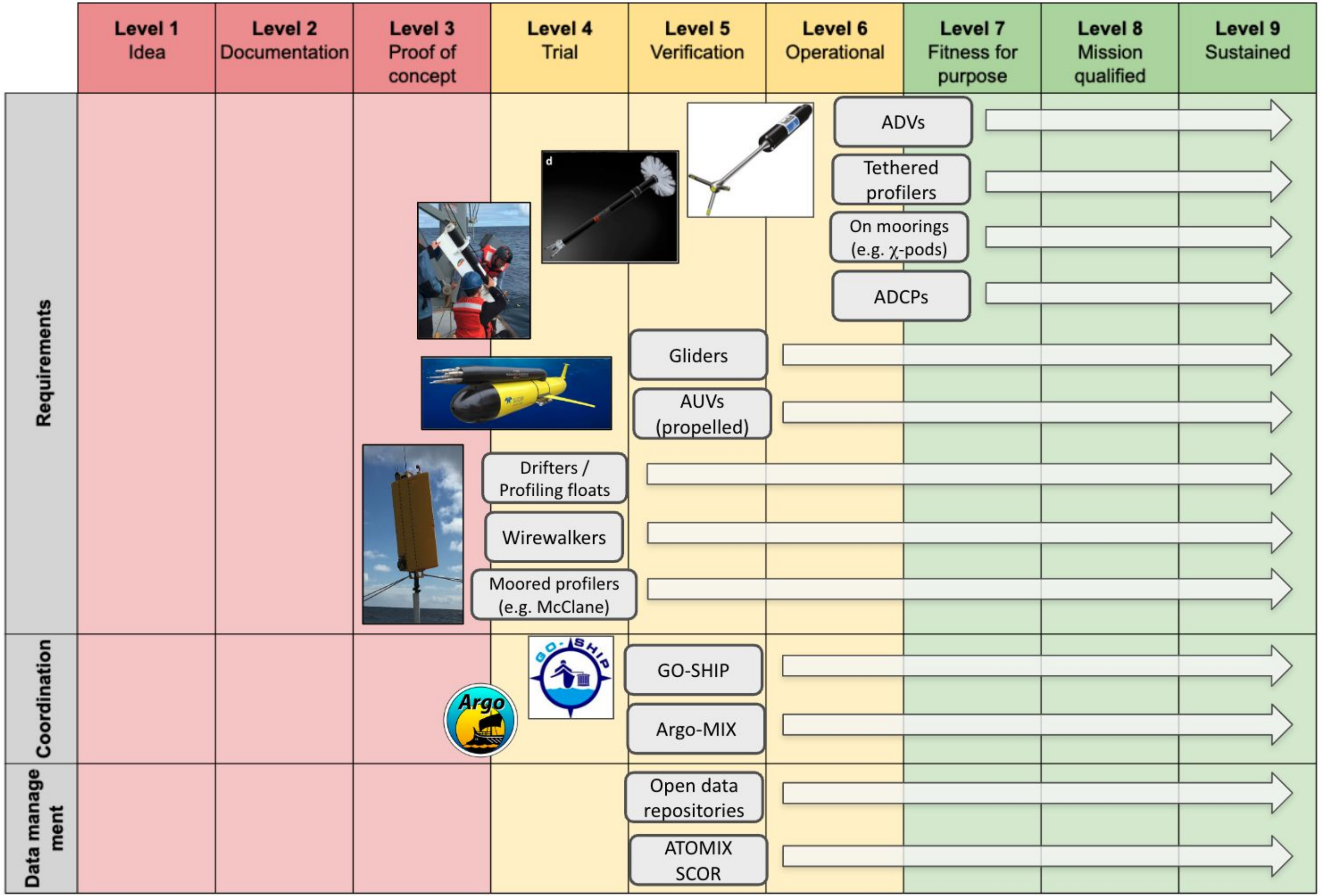
ARGO network: can make global estimates of dissipation from density profiles and strain parameterizations.

ARGO-MIX: can directly measure dissipation rates with new on-board processing capabilities





Based on Readiness Levels, Ocean Mixing should be considered an emerging EOV



iDOOS

Ocean Bottom Pressure

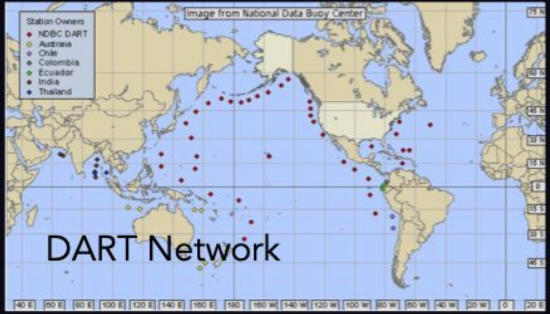
An advantage of OBP sensors is their ability to resolve time/space scales through regional arrays and the variability of large-scale circulation on time scales of *days*, *weeks*, and *months* (especially at latitudes >40° where surface/deep flows are coupled)

For periods <1 day, OBP is sensitive even to weak
- gravitational tides
- internal tides
- internal waves
- tsunamis and other infragravity waves
- storm surges

Observing tsunamis is a critical task for GOOS!

Determining accurate tidal constants, including secular changes, is possible due to low geophysical "noise" at the seafloor
- essential to de-aliasing and correcting other measurements (e.g. those from satellite altimetry)
- provides essential information about structure of Earth's crust and vertical deformation of the seafloor

Requirements Settings*					
Responsible GCOS/GOOS Panel	OOPC				
Reporting Mechanism	GCOS Implementation Plan/Status Reporting to UNFCCC				
Readiness Level[5]	Mature Level 8. [Several basin-scale and regional telemetering networks fully operational, e.g., DART; OOI RCN; ONC; DONET; ACO.]				
Phenomena to Capture	Sea Level	Circulation	Fronts and Eddies	Tides	Infragravity Waves and Tsunamis
Temporal Scales of the Phenomena (order)	Week to decade	Week to decade	Day to month	Hour to week	Minute to hour
Horizontal Scales of the Phenomena (order)	10 km to 10,000 km	10 km to 10,000 km	1 km to 100 km	10 km to 10,000 km	1 km to 1,000 km
Magnitudes of the Signals of the Phenomena (order)	0.01 dbar to 1.0 dbar	0.01 dbar to 1.0 dbar	0.01 dbar to 1.0 dbar	0.001 dbar to 1.0 dbar	0.001 dbar to 1.0 dbar



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Ocean Bottom Pressure

iDOOS

- Ocean bottom pressure (OBP) is the total pressure resulting from the mass of the column of seawater and the overlying atmosphere
  - Fluctuations in the atmospheric sea level pressure (the dynamic topography) and fluctuations in the mass of the fluid column between the unperturbed surface and bottom contribute to the observed OBP variability
  - OBP serves as a proxy of ocean mass variability
    ↳a key parameter needed in many geophysical applications (e.g. large-scale ocean circulation - important for climate) or variability in the Earth's gravity field
  - OBP observations can provide estimates of both basin-wide modes of transport between OBP sensors located on opposing continental slopes and local bottom current amplitudes related to local energetic circulation
    ↳OBP observations are needed to improve the accuracy of global ocean circulation and are a key parameter needed to calibrate and improve remote sensing missions that measure the mass changes in the ocean like Gravity Recovery and Climate Experiment (GRACE)

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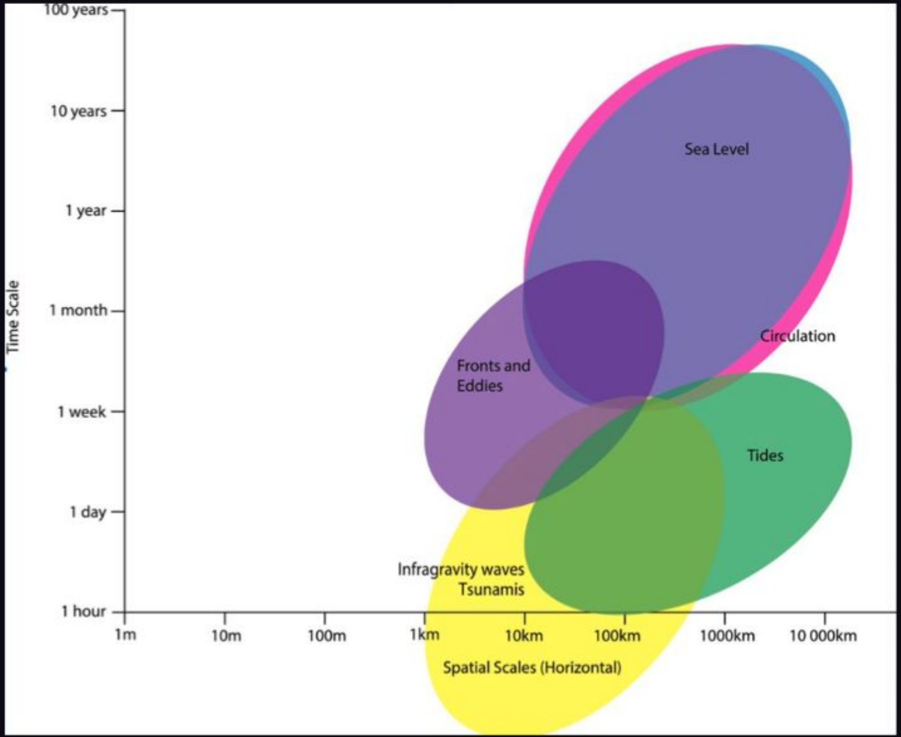
Ocean Bottom Pressure

iDOOS

Examples of available networks and datasets

Observation Deployment & Maintenance				
Observing Elements[6]	**DART Stations**	**DONET, OOI RCN, ONC, ACO**	**Moorings (OceanSITES, DBCP)**	**GRACE**
Relevant measured parameter	Pressure	Pressure	Pressure	Gravity perturbations
Measurement Type	in-situ	in-situ	in-situ	remote
Sensor(s)/Technique	SBE 54 Tsunami Pressure Sensor	SBE 54 and Paroscientific Nano-resolution Digiquartz Pressure Transducer	Paroscientific Digiquartz Pressure Transducer, e.g., incorporated in PIES instrument./	Inversion of relative positions and speeds of paired satellites.
Phenomena addressed	Infragravity waves Tsunamis Tides Sea level	Infragravity waves Tsunamis Tides Eddies Sea level	Tides Fronts and eddies Circulation Sea Level	Circulation Sea Level
Readiness Level	Mature Level 8	Mature Level 8	Mature Level 8	Mature Level 9
Spatial sampling	Specific locations; 100's of km spacing and up	Specific locations; 1 km to 100's of km spacing	Point samples; fixed locations at tens of km spacing and up	100's of km
Temporal sampling	15 s to 15 min	1 Hz	Better than 1 Hz to several samples per hour	Monthly gridded maps

Scales resolved by current technologies



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