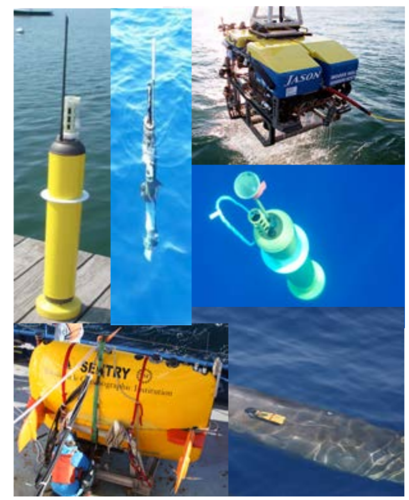
DEEP OCEAN OBSERVING STRATEGY

The Global Ocean Observing System



Deep Ocean Observing Strategy (DOOS)
Essential Ocean Variables
Physics EOVs

Bruce Howe, University of Hawaii at Manoa, Member, DOOS Steering Committee
With contributions from many!

OOI Deep Ocean Observing Workshop
27-29 August 2018
Seattle, Washington

Physical EOVs

Current

- Sea state
- Ocean surface stress
- Sea ice
- Sea surface height
- Sea surface temperature
- Subsurface Temperature
- Surface currents
- Subsurface currents
- Subsurface Salinity
- Ocean surface heat flux

Proposed

1. Ocean Bottom Pressure
2. Ocean Turbulence
3. Geothermal Fluxes
4. Ocean Bottom Boundary Fluxes

Combine

- Review/Edit existing (velocity)
- Proposed
- Need bathymetry
- **Solid Earth EOVs?**
- **Coordinate re Ocean Sound EOV**

EOV Task Team: Physics

Chair: Bruce Howe, University of Hawaii at Manoa

- TT considering deep-ocean EOVs for scientific questions related to bottom pressure, turbulence, geothermal and bottom boundary fluxes
- Work with GOOS Physics Expert Panel (OOPC) to contribute deep-ocean specific content to the Physics EOV specification sheets
  - Late June 2018 feedback from OOPC

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EOV Task Team: Physics

DOOS Physical EOVs Task Team		
Lead, SC	**Affiliation**	**Nominal expertise/role**
Bruce Howe	UHawaii	DOOS Physics, technology, lead
Ocean Bottom Pressure		
Doug Luther	UHawaii	OBP, Ocean Turbulence, lead
Jerome Aucan	IRD-LEGOS	OBP, infragrav, JTF SMART
Shane Elipot	Umiami	OBP, MOC
Chris Hughes	ULiverpool	OBP, MOC
Richard Ray	NOAA	OBP, tides
Randy Watts	URI	OBP, PIES
Mark Zumberg	SIO	OBP, instrumentation
Ocean Turbulence		
Rob Pinkel	SIO	Ocean Turbulence
Eric D'Asaro	APL-UW	Ocean Turbulence
Raffaele Ferrari	MIT	Ocean generalist
Sonya Legg	Princeton	Ocean Turbulence
Andreas Thurnherr	LDEO	Ocean Turbulence
Jim Moum	OSU	Ocean Turbulence
Ocean Bottom Fluxes		
Daniela Di Iorio	UGeorgia	Geothermal fluxes, lead (initial)
Robert Harris	OSU	Geothermal Fluxes
Geoff Wheat	MBARI	Ocean Bottom Boundary Fluxes
Andy Fisher	UCSC	Ocean Bottom Boundary Fluxes
Raffaele Ferrari	MIT	Ocean Bottom Boundary Fluxes
From SC	**Affiliation**	**Nominal expertise/role**
Felix Jannsen	AWI	DOOS Biogeochem - liaison
Henry Ruhl	NOC	DOOS Bio-ecology - liaison
Simone Baumann-Pickering	SIO	DOOS Bioacoustics - liason
Adam Soule	WHOI	DOOS Geophysics - liaison
Patrick Heimbach	UTexas	DOOS Physics and modeling
Bob Weller	WHOI	DOOS Physics, OOPC, OceanSites

Physics – DOOS Science Challenges

- Deep Ocean ventilation and circulation and its variability
- Meridional Overturning circulation
- Deep ocean warming and freshening
- Impact on patterns of sea level rise
- Geothermal heating

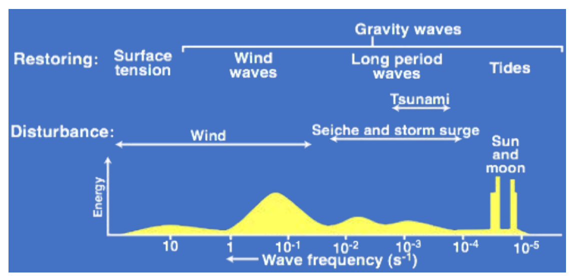
Physical EOVs – basics (full water column)

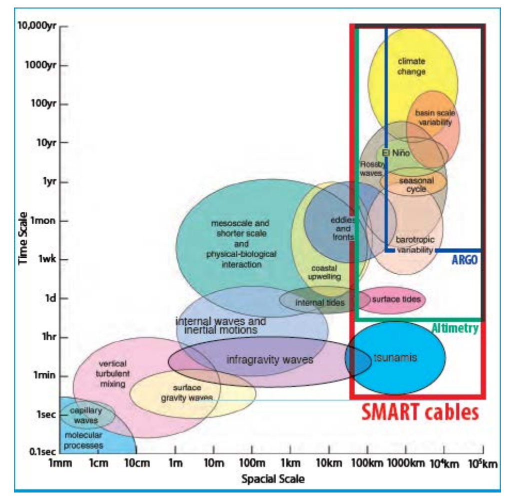
- Dynamics – Directly related to terms in the Navier-Stokes, continuity/mass, state equations with boundary conditions
- Velocity, density, pressure (x,t)   density(T,S,p)
- Fluxes of momentum (wind and bottom friction stress) and mass/buoyancy (heat and fresh water/salt/ice/geothermal)
- Parameterization of turbulent stresses - mixing
- Need geometry as well (bathymetry)
- Then get products like heat content, volume and heat flux, MOC, sea level, … Budgets/equations must balance
- Requirements flow – User requirements – EOVs – observations – products. OSEEs?

Physical EOV – Ocean Bottom Pressure

- Sea level, ocean mass
- Ocean circulation
  - Barotropic, eddies, waves
  - Thermohaline (MOC)
  - Wind driven
- Tides – barotropic and internal, secular change
- Tsunami
- Surface waves
- De-alias satellite measurements (altimetry and gravity)

- Sampling – necessarily fixed
  - DART ~60 stations
  - Other – very sparse, uncoordinated
  - OceanSites, CTBTO, cabled/SMART
- *New in situ calibration – motivates! Need <1 mm/y*





Physical EOV – Ocean Bottom Pressure

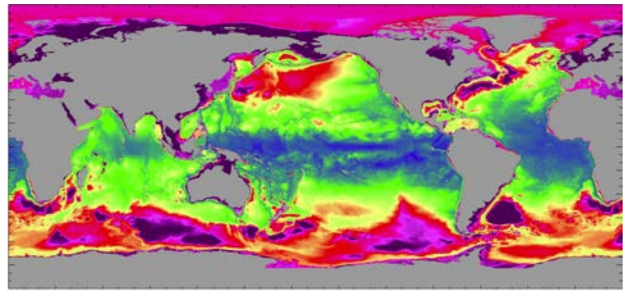
A window on the deep ocean: The special value of ocean bottom pressure for monitoring the large-scale, deep-ocean circulation
Chris W. Hughes et al., Prog. Oceanography, 2018

"… bottom pressure measurements … ocean circulation …most important for global scale ocean variability and climate. … component of the Global Ocean Observing System …"

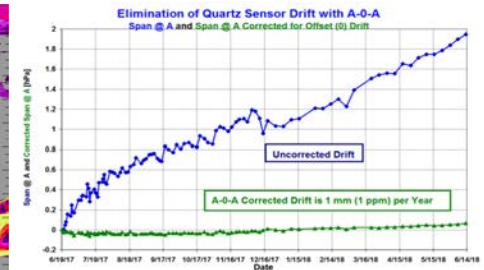
Seminal work, decade in preparation – directly applicable
Chris Hughes on team

www.deepoceanobserving.org

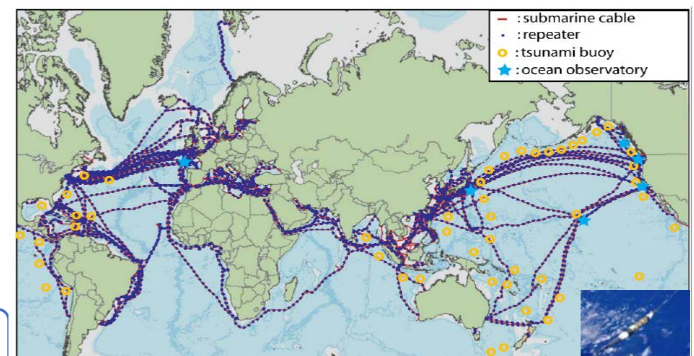
In situ enabled - Wilcock et al., ~1 mm/y



RMS ocean bottom pressure 4 cm model, de-trend, -season



SMART Cables – one way to measure globally



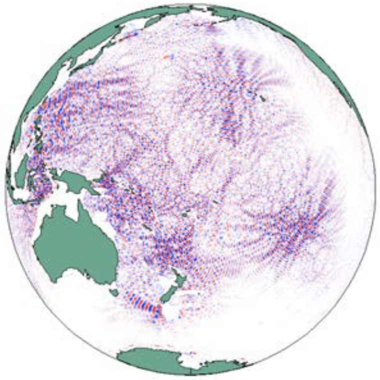
Physical EOV – Ocean Bottom Pressure

OOPC DECISION: Bottom Pressure

approve as an emerging EOV.

We recommended the DOOS undertake the process of developing an EOV specification sheet, and consider regional pilot studies and plans for development and support of the global array.

Physical EOV – Turbulence



- Ocean – advective-diffusive balance.
- Diffusion – micro-scale mixing, central: formation and modification of water masses, distribution, flow of heat, and fluxing of nutrients and oxygen to biological populations.
- Mixing processes – central role in earth's carbon cycle.

- Ability to directly measure ocean mixing, only recently.
- Ability to *routinely* collect the microscale observations emerging rapidly.
- Future global ocean observing must progress with awareness of this developing capability, cost effectiveness of adding to existing observational assets.
- Understanding co-variability of chemical, biological and physical parameters across wide range of space-time scales will have enormous societal payoff.

Physical EOV – Turbulence

A Chi-Pod for mooring, Moum, OSU

- Incorporation of a very simple bottom-enhanced mixing eddy diffusivity into existing climate models results in a major change in predicted deep ocean structure (MacKinnon et al, 2017).
- Existing parameterizations that relate fine-scale variability (5-100 m) to mixing are known to be in error at intense topographic mixing sites (Klymak et al, 2008).
- The challenge is to develop parameterizations that remain accurate through major departures from our present climate.
- It is clear that deep mixing will vary as stratification and bottom currents change (Melet et al, 2016).
- The observations required to quantify these effects must be obtained.
- With the advent of user-friendly instruments for the direct measurement of microstructure (Figure 3), the global space-time variability of mixing can now be documented as an aspect of routine observation programs.

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Physical EOV – Turbulence

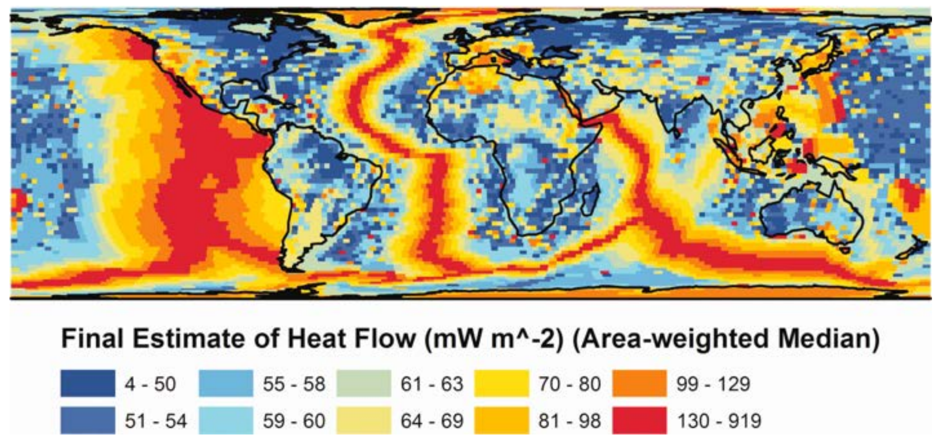
OOPC DECISION: Turbulence

not ready for consideration as an EOV.

Further work needed to justify the case for global sustained observations (Feasibility/Impact and cost effectiveness), and readiness of observing approaches.

Physical EOVs – Bottom Fluxes

- Heat – 100 mW/m^2 – significant wrt to global net radiative imbalance 0.5 W/m^2
- Effects on deep stability?
- Mass/water/salt – unknown
- Submarine ground water
  - Recirculation in crust
  - From continents, rivers
- Intermittent/episodic, space scales
- Cross over to Ocean Turbulence/BBL?
- Emerging EOV?



More to follow!

Davies, 2013

Wunsch, 2016

Period, depth	Temp change, 1 W/m2	Temp change 1 mm/y GMSL change
1 y, full depth	0.002 ℃	0.0015 ℃
10 y, full depth	0.02 ℃	0.015 ℃

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Physical EOVs – Bottom Fluxes

OOPC DECISION: Bottom Fluxes

not ready for consideration as an EOV.

The panel considered this to be excellent proposition for a focused research proposal to form the basis of developing the concept of bottom fluxes as an EOV.

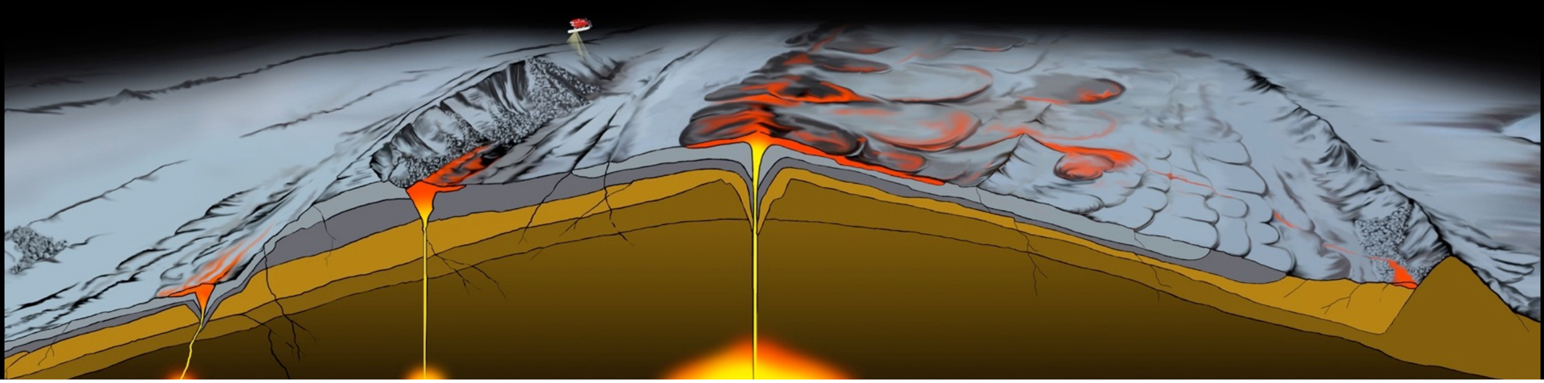
Issues and Questions

- Cross-group coordination for next steps
  - Within DOOS
  - Between OOPC, IOCCP, GOOS Bio/Eco – how done?
- Should DOOS (either DOOS, or EOV TTs) have formal liaison with major programs – Go-Ship, Argo? Or via JCOMM-OPS?
- EOV Ocean sound – need to coordinate with GOOS Bio/Eco
- Solid earth - NEXT!

Solid Earth EOVs

A potential future category for DOOS/GOOS

Adam Soule (WHOI, DOOS S.C.) & Bruce Howe (UH Manoa, DOOS S.C.)



Solid Earth EOVs do not exist as a formal category, but many have corollaries in the other EOV categories (**Physics**, **Biogeochem**, **Bio-Eco**). The following is a partial list, others may suggest additional **Solid Earth EOVs.**

Solid Earth EOVs contribute to many fundamental basic-science questions about the oceans as well as the identified DOOS questions including…

- Deep-ocean and energy imbalance
- Geothermal heating impacts on deep-sea ecology
- Drivers for variation in seafloor heat, nutrient, tracers
- Impact of anthropogenic influences (e.g., seabed mining)
- *Geohazards* (not an identified DOOS question)

Some **Solid Earth EOVs** do not change on yearly, or even decadal, timescales and fall into a class of global cataloguing rather than temporal monitoring.

Seafloor Fluxes (shared with Physics and Biogeochem)

Hydrothermal flux (e.g., incidence of plumes, plume rise height, turbidity/particulates) influences ocean mixing and provides a proxy of magmatic heat sources. Presence along MORs is fairly well-understood, but can change over decadal timescales. Other hydrothermal sources (e.g., arcs, seamounts) need more documentation. Gas/methane flux at continental margins is influenced by tectonics and permeability structure of crust. Distribution of sources needs to be documented (e.g., gas plume surveys by ship-based sonar).

Hydrothermal fluid chemistry (overlap with Biogeochem)

Hydrothermal fluid chemistry influences ocean chemical budgets and provides energy sources for chemosynthetic ecosystems. Fluid chemistry is influenced by depth and temperature of hydrothermal systems, lithology of substrate, and extent of water-rock reaction.

Heat Flow (shared with Physics)

Heat Flow records both the presence of magmatic heat sources and the extent of hydrothermal circulation. Significant mismatch between predicted and measured heat flow is thought to reflect influence of fluid circulation, but is based on sparse measurements.

Seismicity

Seismicity in the oceans records active processes including: magma movement and eruption, fault formation, landslides. These processes influence benthic habitat stability (e.g., creation, destruction, connectivity). Current global seismic networks are biased towards land and poorly resolve seafloor seismicity. New instrumentation for seismic monitoring may be needed, possibly including accelerometers on SMART cables, Mermaid floats, hydrophones on existing or upcoming Argo floats.

Bathymetry (overlap with Physics ocean bottom pressure)

Bathymetry that can resolve seafloor features relevant to biological processes (i.e., <25m) is limited in the oceans. Other efforts to collect this data (e.g., Seabed 2030) could be aligned with DOOS/GOOS.

Substrate Type (some overlap Bio-Eco seafloor sponge habitat cover)

Substrate type including hard-bottom and sediment strongly influence benthic community structure. Seafloor reflectivity (collected concurrently with seafloor bathymetry or by sidescan sonar) can be used to define substrate or seafloor imagery may be used.

Seafloor Geodesy

Seafloor deformation can occur on short timescales at some locations and provides information on hazards (e.g., large earthquake precursors), and document changes in fluid circulation, tectonism. Requires regular bathymetric resurvey and/or new instrumentation including seafloor acoustic beacons coupled with autonomous surface vehicles.

Sediment Flux

Sediment flux to the seabed along with composition can inform hydrothermal sediment production, input from airborne terrestrial sources (e.g., dust and volcanic), input from riverine sources, submarine volcanic sources, and anthropogenic influence from land and sea (seabed mining). Documentation and sampling on a global scale is a big challenge.