Observations in the deep ocean to address the grand societal issues of climate change prediction and adaptation, ecosystem conservation, and sustainable management in the deep ocean.
WEBINAR OBJECTIVES

- Deep Ocean Observing Strategy
  - Introduction and History
- Motivators and Rationale for Deep Observing
- What is the Deep Ocean Observing Strategy?
  - Terms of Reference
- Status of Deep Observing (Inventory)
- Dec. 2016 Workshop Overview and Outcomes
- Actions Going Forward
Develop a common statement of requirements and an initial strategy for sustained global deep-ocean observations; considering all Essential Ocean Variables (EOVs), regions, technologies, and societal imperatives so as to extract high priority, feasibility, and GOOS fit-for-purpose actions for the next 5-10 years.

** We may also want to look towards the next 20-50 years
1. **Build understanding of what is most important to observe.**
   
   Key science and societal questions and relevant variables; High priority processes and phenomena

2. **Provide a hub for integration opportunities.**
   
   Coordinate existing deep observing activities across disciplines; create linkages among research, intergovernmental, industry, regulatory and funding agencies; foster multi-disciplinary observing at multi-use sites.

3. **Coordinate observations.**
   
   Utilize existing platforms for new or integrated sensors, document deep observing status, ID standards and best practices.

4. **Develop deep observing requirements.**
   
   Identify deep EOVs, gaps, emerging systems, add specs

5. **Build readiness in observing technology and techniques.**
   
   Promote new technology developments and assess their suitability, promote usability, facilitate transfer of technology to developing countries

6. **Foster availability, discoverability, and usability of deep-ocean data.**

7. **Create a common community science implementation plan for deep-ocean observing that advocates for deep observations.**
What Depths?

ARGO

A FOCUS > 2000 m, but with necessary observations above

Potential phosphate mining

Oil & gas drilling

Observatories

DEEP ARGO

CONTINENTAL SHELF

Largely national jurisdiction

CONTINENTAL MARGIN

National & international jurisdiction

Potential manganese nodule mining

SEAMOUNT

National & international jurisdiction

ABYSSAL PLAIN

Largely international jurisdiction

TRENCH

Mengerink et al. 2014

ARGO DEEP OBSERVATION NETWORK

Largely international jurisdiction

National & international jurisdiction

Largely national jurisdiction
HISTORY of the Deep Ocean Observing Strategy


Consultative Draft Preparation
Leadership Team/COL
Scoping Workshop
Inventory
Community Feedback
IMPLEMENTATION
GLOBAL OCEAN OBSERVING MTG
SUSTAINED DEEP OCEAN OBSERVATIONS
Deep Ocean Observing Strategy
Workshop Planning Committee

- Lisa Levin*
- Patrick Heimbach*
- Henry Ruhl*
- Antje Boetius /Felix Janssen
- Albert Fischer
- Masao Fukasawa
- Greg Johnson
- Bernadette Sloyan
- Sun Song
- Toste Tanhua
- Rik Wanninkhof

Distributed Project Office:
Andrea McCurdy (Proj. Manager)
Nicholas Rome
Kruti Desai
Kristen Yarincik
+ Leslie Smith
Guillermo Mendoza

Contact: McCurdy@ucar.edu

*Project Leadership

[STEERING COMMITTEE BEING FORMED]
What Are We?

- GO SHIP
- SPACE OBS.
- ARGO
- DEEP ARG0
- BIO ARG0
- TIME SERIES
- MOORINGS
- SMART CABLES
- GLIDERS
- OBSERVATORIES
- SUBMERSIBLES
- ROVS
- AUVS
- ANIMAL TAGS
- PASSIVE
- ACOUSTICS
- ESP
Motivators - Physics: Energy imbalance and overturning circulation, ventilation and turbulence

- Matsumoto et al., 2007
- Talley, 2013
- IPCC; Purkey and Johnson, 2010
- Turbulence
- Tracers

www.deepoceanobserving.org
Ardron & Warner, in *Handbook of Ocean Resources*, Earthscan Books
Expanded extraction of deep-sea resources

Deep-Sea Fishing

Deep-water oil and gas

Cordes et al. 2016

Genetic resources

Massive sulfides

Deep-seabed mining

Polymetallic nodules

Cobalt crusts

Phosphorites
Climate Change as a Criterion for Deep Marine Protected Areas

Improved model of climate change at the sea floor for assessing protection scenarios, and environmental impact assessment

SEABED MINING

pH projection

Mid Atlantic Ridge

Dunn, Halpin et al.

BOTTOM TRAWLING

BIODIVERSITY
A new treaty in ABNJ
Climate Policy

IPCC Special Report on Oceans & Cryosphere

Consensus on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) writes an Assessment Report (AR) that represents the international consensus on climate change.

1990 First AR (FAR)
1995 Second AR (SAR)
2001 Third AR (TAR)
2007 Fourth AR (AR4)
2014 Fifth AR (AR5)

www.deepoceanobserving.org
Sustainable Development

GOAL 14

CONSERVE AND SUSTAINABLY USE THE OCEANS, SEAS AND MARINE RESOURCES FOR SUSTAINABLE DEVELOPMENT

14 LIFE BELOW WATER

SUSTAINABLE DEVELOPMENT GOALS
More at sustainabledevelopment.un.org/sdgsproposal
Deep Biodiversity – a sampling challenge

Webb et al. 2010

0.1° grid stations with > 5 y time series
26,196 above 200m ; 393 below
Deep Ocean Observing Strategy Status?

- **Webpage**  [www.deepoceanobserving.org](http://www.deepoceanobserving.org)
  - format to solicit stakeholder comments

- **Consultative Draft – Precursor to Implementation Plan**

- **Deep-Ocean Inventory** – 70 Responses
  - An initial picture..

- **DOOS Workshop**
  - Scoping
  - Terms of Reference
  - Actions

Scripps Institution of Oceanography
Dec. 7-9, 2016
Deep-Ocean Observing Strategy
A Global Ocean Observing System Project Report

- Check it out at
- www.deepoceanobserving.org (Version 5)
- Introduction: Deep-Ocean Observing
- Rationale and Scientific Drivers
- Requirements Setting: Essential Ocean Variables for the Deep Ocean
- Deployment and Maintenance: Observing Platforms and Technologies Addressing the EOVs
- Data and Information Products: Strategy for Data Management
- [Strategic Roadmap]
WHAT IS THE CURRENT STATUS OF SUSTAINED OBSERVATIONS IN THE DEEP SEA?

- 70 responses, 39 organizations, 83 countries, 29 funding agencies
- 75% of all responses were projects with spatial coverage >100km
- **Key Platforms:** Research Ship Surveys, Bottle Samplers, and Moorings
- **Key Instruments:** CTD’s, Oxygen Sensors, and ADCPs
- **Most common EOVs:** Temperature, Salinity, Dissolved Oxygen, Carbonate System, and Primary Productivity

Ranges of Depth Responses
staging.deepoceanobserving.org/deep-ocean-observations/
• Encourage **increased partnerships** across the deep-ocean research community.

• Align, assess and **improve the readiness levels** of requirements, technologies, platforms, and data products that address societal imperatives.

• Expand **Global Ocean Observing System (GOOS) communities** to include diverse deep-ocean stakeholders.

_Determine –
WHAT IS the Deep Ocean Observing Strategy?_
Identify Science Challenges

- Constraining Earth’s energy imbalance and land-sea water redistribution on inter-annual to decadal time scales [closing the heat and fresh water budget, warming and freshening of the deep ocean, and their contribution to sea level change].

- Improving understanding of the global meridional overturning circulation and its variability [deep and bottom water formation rates and water properties, circulation and deep ocean mixing, geothermal heating, and ecosystem impact]

- Constraining Earth’s carbon cycle through quantifying deep ocean carbon uptake and storage through time, their impact on ocean acidification & deoxygenation, changes in the biological pump, and the sequestering of carbon in the deep ocean

- Understanding the role of geo-fluxes (heat, tracers) across the seafloor and the relative importance compared to fluxes from the surface on ocean physical and biogeochemical properties.

- Improving geohazard early warning, timeliness.

- Identifying the functional importance of the animals and microbes in the deep sea and at the seafloor, what environmental conditions they experience and how do they vary in space and time.

- How does the ecosystem in the deep pelagic respond to climate change/deoxygenation/acidification and direct human activities?
Articulation of EOVs and Measurement Requirements*

**Physical and Climate Science EOVs:**
- Sea Level
- Temperature*
- Salinity
- Transient Tracers: CFC, SF, C14
- Velocity/Ocean Currents*
- Transient Tracer: Argon-39
- Ocean Bottom Pressure
- Geothermal flux

**Carbon and Biogeochemistry Science EOVs:**
- *Inorganic:
  - C of Dissolved Inorganic Carbon (Alkalinity, PCO2, pH)
  - Inorganic Nutrients
  - Dissolved Oxygen*
- *Organic:
  - DOM
  - POM
  - DOC

**Biodiversity and Ecosystem Science EOVs:**
- Species-specific density/counts
- Quality of organic matter, C/N
- Bioturbation (Pb-210)
- Nitrogen/phosphorus efflux/influx
- Body size
- Microbial Biomass (diversity/activity)
- Oxygen consumption: O2, sediment profile /SCOD/
- Eddy correlation fluxes
- CH4 in water and sediment profile
- Substrate
- Sediment geochemistry
- Ocean sound
- Trophic Interactions
- Physiological Adaptation
- Functional Diversity
- Community Turnover
- Habitat Dimensions

*Biology listed

*Note these are still under discussion

www.deepoceanobserving.org
Global Energy Imbalance and Overturning Circulation

Problem:
- Constraining earth’s energy imbalance and land-sea water redistribution (warming and freshening of the deep ocean, contribution to sea level change)
- Global overturning circulation (deep and bottom water formation rates, deep ocean mixing, geothermal heating, and impact on deep ecosystem)

WHAT:
- Deep Argo floats, 5x5 degree grid
- Role of Western Boundary Currents
- Turbulence measurements
- Moorings (OceanSITES), deep gliders, repeat hydrography lines
- Satellite observations and in-situ measurements for cal/val (e.g. seafloor pressure for GRACE)
- Role of high latitudes, under-ice observations.

Above: Sea level rise due to deep-ocean warming (Purkey and Johnson, J. Climate, 2010).
Left: Strength of Atlantic overturning (Baringer et al., in State of the Climate in 2015, BAMS 2016).
The Problem: Constraining the C cycle

**WHAT:** Observational needs include:

1) carbon inventory in the deep ocean
2) biological pump variation and related carbon remineralization/sequestration,
3) high-frequency EOV observations from fixed point reference stations

**HOW:**

- Inventory of DIC and constituent chemical species (pH, CO$_2$, carbonate, $^{14}$C, O$_2$, nitrate).
- In situ lab-on-chip and wet chemical reference capability.
- PIC and POC flux; C export ratio and the particulate C remineralisation length scale (RLS).
- Improve use of moored systems to collect BCP EOVs chl-a, nitrate, and deep POC and PIC flux.
- Improve diversity of EOVs with optical systems optical backscatter, size and type specific particle distributions.
- Add benthic sediment community oxygen consumption (SCOC) measures and time-lapse photography.
- Improving BioArgo and long range AUVs.
**Functional Importance of Deep Animals & Microbes**

**The Problem:**
- What is the functional importance of the animals and microbes in the deep sea and at the seafloor?
- What environmental conditions (e.g. water velocity/benthic storms, turbidity, T, pH, O$_2$, POC flux) do they experience?
- How do those conditions vary in space and time, and how does this variation influence biodiversity and function?

**WHAT:**
- Generate a series of transportable arrays, (The DOOS Benthic Mobile Observatory Array) that includes moorings and landers that can be deployed at sites that address fundamental scientific questions and can be re-tasked based on evolving scientific interests
- Utilize existing infrastructure to create a standardized series of measurements to address key benthic ecosystem questions

**WHERE:**
Nutrient cycling hotpots: upwelling regions, abyssal plains (large area), canyons, Representative deep sea habitats, productivity end-members

**HOW:**
Enhance connections among existing deep ocean observatories, develop new sites, Move OceanSITES moorings? – Convene workshop to develop.
Deep Pelagic Ecosystems

The Problem:
Understand ecosystem responses to climate change; deoxygenation; acidification and human activities
E.g. Determine ecosystem changes caused by mining activities
• Investigate abundance, size, biomass of key ecosystem components

WHAT:
• Subprograms (video; sediment trap; acoustic)
• Establish baselines
• Time-series observations
• Hotpots (e.g. adjacent to CCZ)
• International science coordination and interdisciplinary collaboration

HOW:
• Temperature, oxygen, pH, POC, POM
• Acoustics; tagging; ROVs/AUVs/camera systems;
• Egg & larval surveys
• eDNA, genomics
Yellow: collecting SOME OA parameters, probably will be upgraded to tier 1
Orange: likely to happen in next years
Red: unlikely to happen without strong push from this community

What about biological sampling at these sites?
A Possible Integrated Pilot Study—Clarion Clipperton Zone (CCZ)?

- Address multiple DOOS goals related to human impacts in the deep-ocean from climate change and deep-sea mining

**The Goal**: Understand natural variations and trends in carbon cycling deep pelagic ecosystems, and benthic ecosystem functions, and to advance the agenda of the Tropical Ocean Observing System (TPOS).

**WHAT**: Long-term measurements at the benthic boundary layer and deep water column.

**Contributions to TPOS**: (a) estimate full-ocean-depth heat content anomalies (b) detect changes in temperature/salinity characteristics on interannual/decadal timescale (c) reduce the present 2000-m discontinuity in ocean observations for improvement of forecast model initialization and ocean data assimilation modeling.

**Carbon Cycle**: (1) evaluate carbon inventories (2) constrain natural variations and trends in the biological pump and (3) improve high-frequency EOV observations at fixed-point reference stations.

**Deep pelagic ecosystems**: (1) elucidate variability over time, (2) address the consequences of changes in ecosystem structure due to OMZ intensification, thinning of the pelagic oxygenated zone, and ocean acidification.

**Animal functions**: (1) Determining how environmental conditions vary in abyssal ecosystems targeted for mining, and (2) explore how this variation influence biodiversity and function?
Deep Ocean Observing Strategy
Terms of Reference

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Going Forward (Action Items)

Form a DOOS Steering Committee, Formalize Leadership

PLANNING

• Obtain further input to science questions – e.g., further engage the Earth Science community
• Finalize Deep EOVs – update specs and complete, Examine past EOV Coverage
• Develop task teams to identify gaps and emerging systems
• Generate pilot studies (that integrate key questions)
• Develop Science Guidance and Implementation Plan
• Develop Technology Roadmap for deep observing, include tech transfer and capacity building

DATA

• Form a deep data team, Complete the ocean inventory, Conduct a deep data audit
• Collate and post best practices for deep observing

COMMUNICATE AND COORDINATE

• Promote existing deep observing opportunities to the science community
• Raise awareness of deep observing importance - public and policy makers
• Identify linkages and conduct events with stakeholders (industry, intergovernmental agencies)
• Build partnerships to encourage use of deep observing data, incl. intergovernmental organizations (IOC, DOSI, IPBES, INDEEP, IPCC, WCRP, NGOs).
Thank you!

To provide input and express interest in participating please contact McCurdy@ucar.org