September 2014 Update

- DOOS was endorsed by the GOOS Steering Committee as one of its development projects (the first of two – the other being the Tropical Pacific Observing System).
- DOOS will have a dedicated secretariat in 2015 and beyond.
- Suggestions/candidates are being sought for a DOOS Steering Committee.
- Funds are being sought for a DOOS workshop in 2015.
- The Ocean Observation Panel for Climate (OOPC) will be providing an in-depth review of the DOOS Consultative Draft in Fall 2014.
- Work continues on the data and roadmap sections of the Consultative Draft.
Toward a Deep Ocean Observing Strategy

Eric Lindstrom
(Co-Chair GOOS Steering Committee)
July 2014

Advisory Team

Climate and Physical Observations
Gregory C. Johnson
Patrick Heimbach
Bernadette Sloyan

Carbon, Biogeochemistry Observations
Toste Tanhua
Rik Wanninkhof

Biodiversity and Ecosystem Observations
Antje Boetius
Lisa Levin
Myriam Sibuet

DOOS Consultative Draft: www.ioc-goos.org/deepocean
Rationale for deep ocean observations

Abyssal & Deep Heat Content Changes

(Purkey & Johnson, 2010)

<table>
<thead>
<tr>
<th>Region</th>
<th>Global Heat Gain (W m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abyssal Ocean (z &gt; 4 km)</td>
<td>0.027 (±0.009)</td>
</tr>
<tr>
<td>Southern Ocean (1 &gt; z &gt; 4 km)</td>
<td>0.068 (±0.062)</td>
</tr>
<tr>
<td>Total (Abyssal + Southern)</td>
<td>0.095 (±0.062)</td>
</tr>
</tbody>
</table>

Deep ocean ~1/7 of upper ocean change 1990s-2000s: source or limit to predictability?

Rationale for deep ocean observations

Naturally low saturation state at depth requires only little $C_{\text{anthro}}$ to reach the “tipping point”
Rationale for deep ocean observations

Over 180 new species, 25 new genera and 2 new families have been described from deep-water chemosynthetic ecosystems since 2002.
Developing a Scientific Strategy for the Societal Challenge of Deep Ocean Observation

- Deep ocean observation is a science and technology challenge addressing the grand societal issues of climate change adaptation, ecosystem conservation and sustainable resource management

- We must communicate the need for deep ocean observation and infrastructure to stakeholders (science communities, funding agencies, industry, NGOs)
  - Highlight the need for disciplinary breadth – physics/climate, biogeochemistry, biodiversity/ecosystem, geophysics – and interdisciplinary tasks (Earth sciences meet economics and sociology)
  - Use innovative observation technologies, and take maximum advantage of existing observing networks.
  - Formulate a global strategy for deep ocean from component elements (SOOS, OceanSites, Euro, USA, Japan, etc)

Objective and Approach

**Objective:**
- Develop a common statement of requirements and an initial strategy for sustained global deep ocean observations; considering all Essential Ocean Variables, regions, and technologies so as to extract high priority and feasible actions for the next 5-10 years.

**Approach:**
- Catalyze coordination among existing efforts and use the Framework for Ocean Observing as our strategic guide.
Timeline

- **Year 2012**: Identify Writing Teams
- **Year 2013**: Draft Report Content
- **Year 2014**: Agree on core needs
- **Year 2015**: Roll-out Plan Conducted
- **Year 2016**: Agreement on a proposed project
- **Year 2017**: Roll-out Conduced
- **Year 2018**: Test-bed Identified
- **Year 2019**: Initial Funding Identified
- **Year 2020**: Implementation
- **Year 2021**: Expansion/Refinement
- **2021 onwards**: Global Sustained Observations
Capability for Sustained Observing (Examples)

- **Existing:**
  - Go-Ship- Ship-based repeat hydrography and other deep hydrography
    - platform for many variables
  - Moored arrays (timeseries)/OceanSites
  - Cabled Observatories/Deep Sea Cables

- **Potential:**
  - Deep Argo
  - Deep gliders
  - Moored water sampling
  - Argon-39 as tracer
Deep Hydrography
Improved Model Estimation: Ocean Abyssal Thermal Changes

In situ data >= 3600m (WOA)
1992-2011
1992-2000
2001-2010
2011

Heat content monthly values
700, top bottom
2000m to bottom
3600m to bottom
Top to bottom

Heat content change, 2011 from 1993
2000m to the bottom

Heat content change, 2011 from 1993
3600m to the bottom

Blue dots are the estimate, red dots are residual of the straight-line fit.
Deep Argo

1st prototype Deep SOLO deployment by RV Bell Shimada
Deployed at CalCOFI Station 77.90, 24 Jan 2013
Initial dives shallow for examination of engineering data
Gradually deepening to 4000 m
Plan is to collect rapid dives to 4000, terminate & recover if:
(i) problems develop
(ii) float drifts into shallower water
(iii) batteries are mostly expended
2nd prototype float is completed; 2nd deployment will be > 5000 m.
Present float does not yet have compressibility compensation or bottom detection.
Argon-39 as a Tracer of Deep Ocean Ventilation

* Inclusion of Ar-39 data increases the accuracy in transit time distribution estimates,
* Argon-39 allows for ventilation estimates of deep water where CFC has not yet penetrated.

The ½ life-time of Argon-39 is 269 years and fills a gap in the transient tracer capacity between the CFCs and C-14, just in the range of deep ocean ventilation time-scales.

Low abundance and slow decay makes measurements of Ar-39 difficult, but new exciting techniques (Atomic Trap Trace Analysis - ATTA) opens new possibilities; Single atoms can be detected.
Assessing the impacts of climate change on deep-sea habitats
(PIs: A. Sweetman, C. Smith, L. Levin, A. Thurber)

- Assessing the current environmental conditions ($O_2$, pH, $^\circ$C, food supply) at the deep seafloor
- Modelling the future environmental conditions at the deep seafloor in the yr 2100
- Predicting the impact of future environmental changes on deep-sea biological diversity and ecosystem function by 2100

Sweetman et al. (in prep)

Developing DOOS via the Framework for Ocean Observing

- **Framework Structure**: Used to coordinate the writing team activities

- **Readiness Levels**: Are used to assess the fitness-for-purpose as related to the EOVs and associated observations and data products

- **Community Organization**: Oversight Panels, Expert Panels, and Implementation Teams will be used to facilitate conversation related to requirements, observations, and data products needs going forward
Framework Overview

Requirements Setting
What to Measure

Essential Ocean Variables

Issues

Data Assembly

Data Products Creation

Issues Impact

Observations Deployment and Maintenance

Argo
OceanSITES
Satellite Constellation

VOS
IMOS
SOOP

IOOS

Satellite

DEEP OCEAN OBSERVING STRATEGY
Societal Conventions and Science Challenges

Science Challenges:
Climate and Physical Community
• Understanding Heat & Freshwater Transports
• Understanding Mass Transports
• Closure of the Earth’s Energy Budget
• Understand the Global Fresh Water Balance
• Understand Global & Regional Sea Level
• Deep Ocean Mixing & Fluxes in Heat and Salinity

Carbon and Biogeochemistry Community
• Determine the Anthropogenic Carbon Load
• Determine the Strength of Ocean Ventilation
• Assess the sources and sinks for potential greenhouse gases

Biodiversity and Ecosystems Community
• Exploration and Observation
• Prediction of Future Biological Responses
• Understand the Functioning of Deep Sea Ecosystems
• Understanding the Roles and Relationships of Ecosystem and Ecosystem Engineers

Societal Conventions
• UNFCCC: Climate Variability and Change
• CBD: Marine and Coastal Biodiversity
• UNCLOS/Law of the Sea: Common Heritage to Mankind

### 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:
- Chlorophyll/Surface Productivity
- Element fluxes
- Remineralization Rates
- Secondary Productivity
- Abundance and diversity of organisms
- Trophic Interactions
- Physiological Adaptation
- Functional Diversity
- Community Turnover
- Habitat Dimension
- Evolutionary Context
- Community Structure

---

**Implementation of Observations**

**Deployment and Maintenance**

### Ship-based
- Temperature, Salinity, Velocity, Tracers (CFC, SF6, C-14, AR-39)

### Moorings
- Temperature, Salinity, Velocity, Ocean Bottom Pressure (OBP)
- Tide gauges, Oxygen

### Deep Argo
- Temperature, Salinity, \( V \) (Lagrangian),

### Deep Gliders
- Temperature, Salinity, \( V \) (Lagrangian),

### ROVs/Submersibles
- Temperature, Salinity, \( V \) (Lagrangian),

### Cabled Observatories
- Temperature, Salinity, Velocity, OBP,

### Habitat Laboratories

### Periodical Biological Sampling

### Satellites
- Altimetry, Gravimetry

### Models/Data Assimilation
- Temperature, Salinity, OBP, SSH, Passive tracers

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## Implementation of Observations Deployment and Maintenance

### Carbon, Biogeochemistry EOVs

<table>
<thead>
<tr>
<th>Instrument Type</th>
<th>EOVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship-based</td>
<td>DIC: Alkalinity, pCO2, pH, DOM</td>
</tr>
<tr>
<td>Moorings</td>
<td>DIC: Alkalinity, pCO2, pH, Oxygen</td>
</tr>
<tr>
<td>Deep Argo</td>
<td>DIC: Alkalinity, pCO2, pH, Oxygen</td>
</tr>
<tr>
<td>Deep Gliders</td>
<td>DIC: Alkalinity, pCO2, pH, Oxygen</td>
</tr>
<tr>
<td>ROVs/Submersibles</td>
<td>DIC, pCO2, pH, Oxygen</td>
</tr>
<tr>
<td>Cabled Observatories</td>
<td>Tracers /Isotopes, Oxygen</td>
</tr>
<tr>
<td>Habitat Laboratories</td>
<td>EOV TBD</td>
</tr>
<tr>
<td>Periodical Biological Sampling</td>
<td></td>
</tr>
<tr>
<td>Satellites</td>
<td></td>
</tr>
<tr>
<td>Models/Data Assimilation</td>
<td>Validation</td>
</tr>
</tbody>
</table>
# Implementation of Observations Deployment and Maintenance

<table>
<thead>
<tr>
<th>Ecosystem, Biodiversity EOVs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moorings</td>
<td>Chlorophyll/Surface Productivity, fluorescence, element fluxes, turbidity</td>
<td>Remineralization Rates</td>
</tr>
<tr>
<td>Deep Argo</td>
<td>Plankton abundance, Chlorophyll/Surface Productivity</td>
<td></td>
</tr>
<tr>
<td>Deep Gliders</td>
<td>Chlorophyll/Surface Productivity</td>
<td></td>
</tr>
<tr>
<td>ROVs/Submersibles</td>
<td>Remineralization Rates, Secondary Productivity, Abundance of Organisms, Trophic Interactions, Physiological Adaptation</td>
<td>Biodiversity, habitat mapping, ecosystem functions, Functional Diversity, Community Turnover, Habitat Dimension, Evolutionary Context</td>
</tr>
<tr>
<td>Cabled Observatories</td>
<td>Remineralization Rates, Biomass by cameras, acoustic measurements, bioluminescence, particle flux, respiration and remineralization</td>
<td>Community turnover, Functional Diversity</td>
</tr>
<tr>
<td>Habitat Laboratories</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>Periodical Biological Sampling</td>
<td>All</td>
<td></td>
</tr>
<tr>
<td>Satellites</td>
<td>Productivity</td>
<td></td>
</tr>
<tr>
<td>Models/Data Assimilation</td>
<td>Habitat suitability models, Energetic/metabolic models</td>
<td></td>
</tr>
</tbody>
</table>


Data Policy
• Delivery/Dissemination (Near Real-time)
• Quality (QA/QC Requirements)
• Archives
• Products

Observations
• Ship-based
• Moorings
• Deep Argo
• Deep Gliders
• ROVs/Submersibles
• Cabled Observatories
• Habitat Laboratories
• Periodical Biological Sampling
  • Satellites
  • Models/
• Models/ Data Assimilation

Physical and Climate EOVs
Carbon and Biogeochemistry EOVs
Biodiversity and Ecosystem EOVs
Proposed DOOS 2020 Governance and Project Structure.

GOOS SC.

DOOS Exec (chairs of SC, RF + Staffer)

DOOS SC.

DOOS RF
Agency Reps.

Task Team TBD

Models, Forecasts & Data Assimilation TT.

Task Team TBD

Task Team TBD

Focused Task Teams and Pilot Projects, overseen by the DOOS SC. Initial priorities TBD.
Measures of Success

- Year One & Two: June 2011 to June 2013
  - Strategy Report
    - Created small writing teams via initial workshop
    - Held several teleconferences
    - Materials placed on GOOS website
    - Drafted initial text for the strategy
  - Technology Vendor Buy-in via OceanSites
    - Sea-Bird conducting calibration pro bono on deployed deep moorings

- This year:
  - Identify follow-on, immediately executable activities
  - Identify oversight and coordination bodies
  - Informal roll-out of the concept to high-level groups

- In next two years:
  - Establish a development program with Steering Committee
  - Conduct design studies based on models, existing observation system and estimation frameworks
  - Incorporated into GCOS, CLIVAR, IMBER, Future Earth

- In five years:
  - Pilot program underway

- OceanObs 2019
  - Global sustained coverage in sight

GOOS SC and DOOS Actions

- GOOS SC approve Deep Ocean Observing Strategy as a GOOS development project
- DOOS collect names and functional connections for new DOOS Steering Committee
- Plan for DOOS Workshop in 2015
- Begin contributions to EOV templates
- Add DOOS to GOOS Strategic Mapping