Future Global Ocean Observing System
Built on requirements, promoting alignment, delivering relevant information

Maciej Telszewski, IOCCP and GOOS
The Global Ocean Observing System

- the system GOOS
  - **collaborative system of sustained observations**
    - built on requirements
    - in situ and satellite
    - operational and research funding
    - linked to data management and product generation activities
    - global-scale and coastal

- the GOOS programme
  - advocacy for all elements of the system
  - provide a **platform for collaboration through development of common observing strategies**
  - promote **global participation** through capacity development
Framework for Ocean Observing

Why a Framework?

- OceanObs’ 09 identified tremendous opportunities and significant challenges for the global ocean observing system.

- Called for a framework for planning and moving forward with an enhanced global sustained ocean observing system over the next decade, integrating new physical, biogeochemical, biological observations while sustaining present observations.
Why a Framework?

- OceanObs'09 identified tremendous opportunities and significant challenges for the global ocean observing system.
- Called for a framework for planning and moving forward with an enhanced global sustained ocean observing system over the next decade, integrating new physical, biogeochemical, biological observations while sustaining present observations.
Framework for Ocean Observing

A simple system

Input (Requirements)

Process (Observations)

Output (Data & Products)

Framework for Ocean Observing

Sustained System
Global Observations

Requirements

PICES 2016 Annual Meeting

2-11 November 2016, San Diego, USA
Framework for Ocean Observing

A simple system
Framework for Ocean Observing

Societal drivers prior to OceanObs’09

Climate and Weather
Framework for Ocean Observing

Societal and scientific drivers expanded

- Fisheries
- Regional priorities
- Climate and Weather
  - Real-time services
- Assessments and management of ecosystem services

Data Products

- Climate and Weather
- Real-time services
- Fisheries
- Regional priorities

Requirements

Expanded EOVs

Expanded observing systems and networks
GOOS Application Areas

Climate
(through GCOS for IPCC, UNFCCC, GFCS and national monitoring, mitigation, adaptation)

Real-time Services
(through JCOMM services, GODAE OVs to specific benefit areas)

Ocean Health
(with GEO BON and others for IPBES, WOA, CBD, and national applications)

GOOS separation of responsibility for disciplines (ocean variables)

Physics  Biogeochemistry  Biology

Strength of disciplinary contribution to application area
GOOS Application Areas

Climate
(through GCOS for IPCC, UNFCCC, GFCS and national monitoring, mitigation, adaptation)

Real-time Services
(through JCOMM services, GODAE OV to specific benefit areas)

Ocean Health
(with GEO BON and others for IPBES, WOA, CBD, and national applications)

GOOS Biogeochemistry: Panel for Biogeochemical Variables and Climate Theme Support
Ocean Health Theme Support

GOOS Biology: Panel for Biology Variables, and Ocean Health Theme Lead
Climate Theme Support

GCOS-GOOS-WCRP
OOPC: Panel for Physics variables, and Climate Theme Lead
RT Services Theme Lead
Ocean Health Theme Support
Societal needs and scientific requirements for the global ocean observing system

**Physics**

- The ocean component of the earth’s energy balance and freshwater cycle;
- The ocean ability to **redistribute key climate variables** and the change and variability of this circulation;
- Ocean and Ocean-Atmosphere exchange as controls, driver, and mediator of major climate model. High, mid and low latitude climate modes;
- **Severe climate** – sea level rise, coast inundation, wave and storm damage.
Societal needs and scientific requirements

Biology and Ecosystem

International organizations / conventions*
Societal needs and scientific requirements

Biogeochemistry

• The role of ocean biogeochemistry in climate
  – Q1.1 How is the ocean carbon content changing?
  – Q1.2 How does the ocean influence cycles of non-CO$_2$ greenhouse gases?

• Human impacts on ocean biogeochemistry
  – Q2.1 How large are the ocean’s “dead zones” and how fast are they changing?
  – Q2.2 What are rates and impacts of ocean acidification?

• Ocean ecosystem health
  – Q3.1 Is the biomass of the ocean changing?
  – Q3.2 How does eutrophication and pollution impact ocean productivity and water quality?
We cannot measure everything, nor do we need to.

Driven by requirements, negotiated with feasibility.

- Allows for innovation in the observing system over time.
Feasibility vs. Impact

We cannot measure everything, nor do we need to…
EOVs and readiness level

CONCEPT  PILOT  MATURE

**Physics**
- Sea State
- Ocean surface vector stress
- Sea Ice
- Sea level
- SST
- Subsurface temperature
- Surface currents
- Subsurface currents
- SSS
- Subsurface salinity

**Biology and Ecosystems**
- Phytoplankton biomass and productivity
- HAB incidence
- Zooplankton diversity
- Fish abundance and distribution
- Apex predator abundance and distribution
- Live coral cover
- Seagrass cover
- Mangrove cover
- Microalgal canopy cover

**Biogeochemistry**
- Oxygen
- Inorganic macro nutrients
- Carbonate system
- Transient tracers
- Suspended particulates
- Nitrous oxide
- Carbon isotope ($^{13}$C)
- Dissolved organic carbon
# The Essential Ocean Variables Specification Sheets

## Table 1: EOV Information

<table>
<thead>
<tr>
<th>Name of EOV</th>
<th>Carbonate System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sub-Variables</strong></td>
<td>Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), Partial pressure of</td>
</tr>
<tr>
<td></td>
<td>carbon dioxide (pCO₂) and pH; <em>[At least two of the four Sub-Variables are needed.]</em></td>
</tr>
<tr>
<td><strong>Derived Products</strong></td>
<td>Saturation state (aragonite, calcite), Dissolved carbonate ion concentration,</td>
</tr>
<tr>
<td></td>
<td>Air-sea flux of CO₂, Anthropogenic carbon, Change in total carbon</td>
</tr>
<tr>
<td><strong>Supporting Variables</strong></td>
<td>Temperature (T), Salinity (S), Wind speed, Atmospheric column-averaged dry-air mole fraction of CO₂ (xCO₂), Barometric pressure (P), Oxygen (O₂), Nutrients, Calcium concentration, Transient tracers, Oxygen to argon ratio (O₂/Ar)</td>
</tr>
<tr>
<td><strong>Contact and Lead Expert(s)</strong></td>
<td>Contact: IOCCP</td>
</tr>
<tr>
<td></td>
<td>Lead Experts: Ute Schuster (University of Exeter, United Kingdom), Masao Ishii (JMA-MRI, Japan), Richard Feely (NOAA PMEL, USA)</td>
</tr>
</tbody>
</table>
**Table 3: Current Observing Networks**

<table>
<thead>
<tr>
<th>Observing Network</th>
<th>Ship of Opportunity (SOO)</th>
<th>Repeat Hydrography (RH)</th>
<th>Surface Moorings (Msurf)</th>
<th>Drifters (D)</th>
<th>Ship-based Time-Series (STS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenomena Addressed</td>
<td>1,3</td>
<td>2,3</td>
<td>1,3,4</td>
<td>1,3</td>
<td>1,3,4,5</td>
</tr>
<tr>
<td>Readiness Level of the Network (as defined in the FOO)</td>
<td>Mature</td>
<td>Mature</td>
<td>Mature</td>
<td>Mature</td>
<td>Mature</td>
</tr>
<tr>
<td>Spatial Scales Currently Captured by the Observing Network</td>
<td>Every 10°, Denser in the coastal domain, Surface</td>
<td>20°, Full depth</td>
<td>Local</td>
<td>Regional</td>
<td>Local</td>
</tr>
<tr>
<td>Typical Observing Frequency</td>
<td>Weekly to decadal</td>
<td>Decadal</td>
<td>Sub-daily to seasonal and annual</td>
<td>Hourly to annual</td>
<td>Weekly to decadal</td>
</tr>
<tr>
<td>Supporting Variables Measured</td>
<td>Atmospheric / ocean pCO₂, T, S, Desired: TA or DIC (pH)</td>
<td>DIC, TA, pH, pCO₂</td>
<td>T, S, Wind speed, P, Atmospheric CO₂</td>
<td>T,S</td>
<td>Wind speed, TA/DIC, Atmospheric and ocean pCO₂</td>
</tr>
<tr>
<td>Sensor(s)/Technique</td>
<td>Equilibraitor, Permeable membrane, Infrared, CRDS</td>
<td>Benchtop instruments</td>
<td>Equilibraitor, Permeable membrane</td>
<td>Spectrophotometric</td>
<td>Titration, equilibraitor</td>
</tr>
<tr>
<td>Accuracy/Uncertainty Estimate (units)</td>
<td>pCO₂ ±2 μatm</td>
<td>TA/DIC ±2 μmol kg⁻¹</td>
<td>pCO₂ ±5 μatm</td>
<td>pCO₂ ±5 μatm</td>
<td>TA/DIC ±2 μmol kg⁻¹</td>
</tr>
</tbody>
</table>

*By an Observing Network we understand a number of reasonably well coordinated observing platforms equipped with technology allowing measurements of this particular EOV.*
### Table 4: Future Observing Networks

<table>
<thead>
<tr>
<th>Observing Network</th>
<th>Profiling Floats (PF)</th>
<th>Surface gliders (Gsurl)</th>
<th>Subsurface moorings (Msubsurf)</th>
<th>Subsurface gliders (Gsubsurf)</th>
<th>Extended Ships Of Opportunity (ExtSOO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readiness Level of the Observing Network (as defined in the FOO)</td>
<td>pH Pilot</td>
<td>pCO2 Pilot</td>
<td>Conceptual</td>
<td>Conceptual</td>
<td>pCO2 Mature</td>
</tr>
<tr>
<td></td>
<td>pCO2 Conceptual</td>
<td>DIC Conceptual</td>
<td>TA Conceptual</td>
<td>pCO2 Conceptual</td>
<td>Underway DIC/TA</td>
</tr>
<tr>
<td></td>
<td>Underway pH</td>
<td></td>
<td></td>
<td>Underway pH</td>
<td></td>
</tr>
<tr>
<td>Spatial Scales Captured by the Observing Network</td>
<td>Every 10°, Denser in the coastal domain, Surface</td>
<td>20°, Full depth</td>
<td>1 km</td>
<td>10-1000 km</td>
<td>Every 10°, Denser in the coastal domain, Surface</td>
</tr>
<tr>
<td>Typical Observing Frequency</td>
<td>Weekly to annual</td>
<td>Daily to monthly</td>
<td>Sub daily to seasonal and annual</td>
<td>Daily to monthly</td>
<td>Weekly to annual</td>
</tr>
<tr>
<td>Time-Scale Until Part of Observing System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supporting Variables Measured</td>
<td>pH, pCO2, DIC, TA</td>
<td>pCO2, pH</td>
<td>pH, pCO2</td>
<td>pH, pCO2, DIC, TA</td>
<td></td>
</tr>
<tr>
<td>Sensor(s)/Technique</td>
<td>Spectrophotometry</td>
<td>Spectrophotometry &amp; Equilibrator</td>
<td>Permeable membrane</td>
<td>Spectrophotometry</td>
<td>DIC NDIR (CRDS)</td>
</tr>
<tr>
<td></td>
<td>Variety of sensors are being developed</td>
<td>Very dynamic field, variety of sensors are being developed</td>
<td>Very dynamic field, variety of sensors are being developed</td>
<td>Very dynamic field, variety of sensors are being developed</td>
<td>pCO2 Equilibrator</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>Permeable membrane</td>
<td>Spectrophotometry</td>
<td>pCO2 Equilibrator</td>
<td>pH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Networks*</th>
<th>Repeat Hydrography (RH)</th>
<th>Surface Moorings (Msurf)</th>
<th>Drifters (D)</th>
<th>Ship-based Time-Series (STS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOO</td>
<td>1,3</td>
<td>1,3</td>
<td>1,3</td>
<td>1,3</td>
</tr>
<tr>
<td>RH</td>
<td>2,3</td>
<td>1,3</td>
<td>A</td>
<td>1,3</td>
</tr>
<tr>
<td>Msurf</td>
<td>1,3,4</td>
<td>2,3</td>
<td></td>
<td>1,3</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>STS</td>
<td>1,3,4,5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Mature**: Every 10°, Denser in the coastal domain, Surface
- **Mature**: 20°, Full depth
- **Local**: Decadal Sub-daily to seasonal and annual Hourly to annual Weekly to decadal
- **Regional**: Wind speed, TA/DIC, Atmospheric and ocean pCO2
- **Local**: Benchtop instruments Equilibrator, Permeable membrane, Infrared, CRDS
- **Local**: Spectrophotometric Titration, equilibrator
- **Global**: GOOS Implementation Plan (?) IIOCCP Report

I understand a number of reasonably well coordinated observing platforms owing measurements of this particular EOV.
Global synthesis and gridded products of surface ocean fCO$_2$

- in uniform format with quality control;
- V4: 18.5 million fCO$_2$ values, accuracy < 5 μatm from 1957-2015 (flags of A-D);
- Plus calibrated sensor data (< 10 μatm, flag of E);
- Interactive online viewers;
- Downloadable (text, NetCDF, ODV, Matlab);
- Documented in ESSD articles;
- Community activity with >100 contributors worldwide.

Bakker et al. (2016) ESSD

PICES 2016 Annual Meeting
2-11 November 2016, San Diego, USA
Ocean Interior Data Synthesis

- A global collection of CO₂ relevant data from 724 cruises
  - 45 306 stations
  - 999 488 sampling depths
  - 1972 -2013 GEOSECS-TTO-WOCE-CLIVAR
  - Corrected for biases
  - Extensively documented

- Released Jan 19. 2016

PICES 2016 Annual Meeting
2-11 November 2016, San Diego, USA
Ocean Acidification

Ocean Acidification Data Portal

A small technical working group lead by Benjamin Pfeil (IOCCP Data Manager) was established to investigate possibilities to create a dedicated portal for ocean acidification observing data. A workplan and initial goals of this group were turned into an agenda for a small workshop held in Monaco in June 2015. The group works on the report that will incorporate the recommendations made by the OA-ICC Advisory Board, the GOA-ON Executive Council and workshop participants. This document will be distributed across the community for comments and will serve as a baseline for a data portal implementation plan, which will be hopefully developed before May 2016.

Ocean Acidification Data Synthesis Products

As a global approach similar to SOCAT was deemed not feasible at the moment for such a fragmented and mostly coastal community, it was suggested that effort might initially be directed at a regional synthesis for the western Pacific (primarily involving China, Taiwan, Japan and Rep Korea), and for the NE Atlantic/European seas (expanding on a UK/North Sea synthesis that has just been finished by NERC/Defra and ICES).
Towards sustained system: requirements, observations, data management

Readiness

**Concept**
- Attributes: Peer review of ideas and studies at science, engineering, and data management community level.

**Pilot**
- Attributes: Planning, negotiating, testing, and approval within appropriate local, regional, global arenas.

**Mature**
- Attributes: Products of the global ocean observing system are well understood, documented, consistently available, and of societal benefit.
## Framework Processes by Readiness Levels

<table>
<thead>
<tr>
<th>Readiness Levels</th>
<th>Requirements Processes</th>
<th>Coordination of Observational Elements</th>
<th>Data Management &amp; Information Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mature</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 9 “Sustained”</td>
<td>Essential Ocean Variable:</td>
<td>System in Place:</td>
<td>Information Products Routinely Available:</td>
</tr>
<tr>
<td></td>
<td>Adequate sampling specifications</td>
<td>Globally</td>
<td>- Product generation standardized</td>
</tr>
<tr>
<td></td>
<td>Quality specifications</td>
<td>Sustained indefinitely</td>
<td>- User groups routinely consulted</td>
</tr>
<tr>
<td>Level 8 “Mission qualified”</td>
<td>Requirements “Mission Qualified”:</td>
<td>System “Mission Qualified”:</td>
<td>Data Availability:</td>
</tr>
<tr>
<td></td>
<td>Longevity/stability</td>
<td>Regional implementation</td>
<td>- Globally available</td>
</tr>
<tr>
<td></td>
<td>Fully scalable</td>
<td>Fully scalable</td>
<td>- Evaluation of utility</td>
</tr>
<tr>
<td>Level 7 “Fitness for purpose”</td>
<td>Validation of Requirements:</td>
<td>Fitness-for-Purpose of Observation:</td>
<td>Validation of Data Policy:</td>
</tr>
<tr>
<td></td>
<td>Consensus on observation impact</td>
<td>Full-range of operational environments</td>
<td>- Management</td>
</tr>
<tr>
<td></td>
<td>Satisfaction of multiple user needs</td>
<td>Meet quality specifications</td>
<td>- Distribution</td>
</tr>
<tr>
<td></td>
<td>Ongoing international community support</td>
<td>Peer review certified</td>
<td></td>
</tr>
<tr>
<td><strong>Pilot</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 6 “Operational”</td>
<td>Requirement Refined:</td>
<td>Implementation Plans Developed:</td>
<td>Demonstrate:</td>
</tr>
<tr>
<td></td>
<td>Operational environment</td>
<td>Maintenance schedule</td>
<td>- System-wide availability</td>
</tr>
<tr>
<td></td>
<td>Platform and sensor constraints</td>
<td>Servicing logistics</td>
<td>- System-wide use</td>
</tr>
<tr>
<td>Level 5 “Verification”</td>
<td>Sampling Strategy Verified:</td>
<td>Establish:</td>
<td>Verify and Validate Management Practices:</td>
</tr>
<tr>
<td></td>
<td>Spatial</td>
<td>International commitments and governance</td>
<td>Draft data policy</td>
</tr>
<tr>
<td></td>
<td>Temporal</td>
<td>Define standardized components</td>
<td>Archival plan</td>
</tr>
<tr>
<td>Level 4 “Trial”</td>
<td>Measurement Strategy Verified at Sea</td>
<td>Pilot project in an operational environment</td>
<td>Agree to Management Practices:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Quality control</td>
</tr>
<tr>
<td><strong>Concept</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3 “Proof of concept”</td>
<td>Proof of Concept via Feasibility Study:</td>
<td>Proof of Concept Validated:</td>
<td>Verification of Data Model with Actual Observational Unit:</td>
</tr>
<tr>
<td></td>
<td>Measurement strategy</td>
<td>Technical review</td>
<td>- Technical capability</td>
</tr>
<tr>
<td></td>
<td>Technology</td>
<td>Concept of operations</td>
<td>- Interoperability strategy</td>
</tr>
<tr>
<td></td>
<td>Sensors</td>
<td>Technical capability</td>
<td>- Delivery latency</td>
</tr>
<tr>
<td></td>
<td>Sensitivity</td>
<td>Feasibility testing</td>
<td>- Processing flow</td>
</tr>
<tr>
<td></td>
<td>Dependencies</td>
<td>Documentation</td>
<td></td>
</tr>
<tr>
<td>Level 1 “Idea”</td>
<td>Environment Information Need and Characteristics Identified:</td>
<td>System Formulation:</td>
<td>Specify Data Model:</td>
</tr>
<tr>
<td></td>
<td>Physical</td>
<td>Sensors</td>
<td>- Entities, Standards</td>
</tr>
<tr>
<td></td>
<td>Chemical</td>
<td>Platforms</td>
<td>- Delivery latency</td>
</tr>
<tr>
<td></td>
<td>Biological</td>
<td>Candidate technologies</td>
<td>- Processing flow</td>
</tr>
</tbody>
</table>

*Figure 9. A Detailed View of Framework Processes for Varying Levels of Readiness.*
THANK YOU!