Guidelines for an integrated ocean observation system for ecosystems and biogeochemical cycles

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Presentation outline

- The context and the challenges
- The « bio » variables to be measured.
- The various component / platforms of a sustained *in situ* observations system.
  - Gliders
  - Floats
  - Animals
  - Eulerian Time Series
  - Ship-based repeated hydrography
- The OCR satellite observation component.
- The issue of data flow, data management and data policy.
- Towards integration
- Recommendations
The context and the challenges

- Ocean biology and biogeochemistry under increasing stress.
- Ocean biology and biogeochemistry heavily depend on physical forcing.
- Physical forcing and associated “bio” response: a continuum of spatial (sub-meso / meso / basin / global) and temporal (diurnal / seasonal / decadal) scales.
- The last century: a century of undersampling, especially for “bio”: a large part of the variability in oceanic biological processes missed by traditional sampling.
- Rapid technological advances in ocean observations: physical oceanographers have been the first taking benefit from it (i.e. Argo floats).
- With a certain time lag, biological and biogeochemical oceanographers are undertaking a similar technological rupture; development of “bio” sensors that fit with the requirement of the new platforms (low consumption, miniaturization, endurance).
- Biological oceanography is emerging from its data-limited foundations.
- Based on these new technologies, pilot projects have been launched.
- If, from these emerging (individual, national) initiatives, we begin to coordinate in terms of networks, arrays, data sharing and management, a revolution can be expected in observation for biological and biogeochemical oceanography.
The context and the challenges

- Two main expected outcomes from such an *in situ* observation system:
  - **Scientific outcomes** are: enhanced exploration, improved understanding of change and variability in ocean biology and biogeochemistry (over a large range of spatial and temporal scales), reduction of uncertainties in biogeochemical fluxes.
  - **Operational outcomes** are: ocean biogeochemistry and ecosystem predictability; provide (real time) open data to scientists, users and decision-makers.

- Both scientific and operational objectives for biology require the “in situ” part to be designed and implemented in tight synergy with two other essential bricks of an ocean observation system:
  - **Biogeochemical / Ecosystem modeling**: from NPZ models to Plankton functional Types (PFT) models.
  - **Satellite observation of Ocean Colour Radiometry (OCR)**. Global, synoptical, time-series.
The core ecosystem and biogeochemical variables: which ones?

“For biogeochemical time-series, the list of potential measurements is nearly endless and justifying inclusion / exclusion is difficult. Decisions as to what to measure, as well as how to measure, are never trivial. The list of “essential” measurements for time-series can grow to the point that sustainability of the entire enterprise is put at risk”.

from Send CWP

- Observation valid for any kind of observation platform.

- Mandatory: selection (labeling) of core variables of the future system.  
  - Scientific relevance (also with respect to modelers needs and OCR remote sensing products)  
  - Routinely and autonomously measurable by a variety of platforms (sensors) 
  - Data quality: agreement between established (discrete) protocols

- At the moment, potential core variables over the vertical dimension are: O₂, NO₃, Chla, POC. Their progressive implementation in the integrated system can be envisaged.

- Variables of the CO₂ system operational for surface (ship-based underway, VOS, drifting buoys, ) or fixed depth (moorings). Not vertically resolved.

- Progressive implementation / labeling of additional variables with the maturation of sensor technology.

CWP: Send, Gruber, Claustre, Byrne, Schuster
The core ecosystem and biogeochemical variables: which ones next?

Variables of the CO$_2$ system

- pCO$_2$ sensor on floats (Arne Kortzinger’s talk)

- pH: ion sensitive-field effect transistor (ISFET) (Martz and Johnson)

- required: DIC and TA sensors

- Particulate Inorganic Carbon (PIC). Birefringence method (Bishop)

Mid-trophic Automatic Acoustic Sampler (MAAS)

- missing link between plankton and fisheries

Plankton functional types

- imaging systems

- particle counting

- Hyperspectral / multispectral radiometry, spectrofluorometry

Nutrients: MicroSystem Technology

CWP: Byrne, Feely, Sieracki, Schuster, Handegard, Adornato
Floats with $O_2$, $NO_3$, Chla, POC: growing number of individual projects being funded.

Coordination of various groups:

- O2-Argo (IOCCP)
- Bio-optical floats on Argo (IOCCG)
- The Euro-Argo initiative
- Observing Biogeochemical cycles with floats and gliders (US OCB)
- IMBER WG?

In parallel move on the planning of a global float dissemination (by basin or global coverage).

Regional case or pilot studies required for demonstrating:

- Sensor accuracy and stability are sufficient for stated scientific objectives.
- Real-time and delayed mode QC capabilities for the community.

A “bio” float array: Likely the most cost-effective platform to acquire biological data at a global scale.

Implementation:

-...
“Bio” Glider network

- Same “bio” sensors / variables as for floats: Chl, O₂, POC, (NO₃).
- Complementary to floats for enhancing spatial / temporal coverage in critical areas:
  - Open ocean / coastal interface.
  - Regional seas.
  - Eastern boundary currents.
- Ideal for sub-meso / meso scale (1 km - 100 km) investigations.

Implementation

- Glider ports / centers emerge in various places.
- Rely on presently forming cluster of (individual / national / international) initiatives (e.g. EGO) to build the network for the next decade.
- Future: Transoceanic “ship repeated transect-like” lines from glider port to glider port.

CWPs: Testor, Roemmich
Animal-borne systems nicely complement gliders and floats at polar latitudes.

Implementing bio-sensors on animals even more complicated than on floats and gliders
- Argos telemetry, data reduction, sze and energy

Promising Chla measurements (Guinet).
- O₂ on the way.

**Implementation**
- ~100 animals for both polar regions.
- 20% equipped with fluorometers to start.

**CWP:** Boehme
Ship-based Repeat Hydrography and “Bio” measurements

- Already: the variable of CO2 system are “core variables”.
- Near future: implementation of new core biogeochemical variables (some of them not amenable to autonomous vertical profiling).
  - Some PFT proxies (cytometry, pigment), essential for validation of PFT models.
  - Bio-optical measurements (fluorescence, transmissiometer).
- Similar core variables on IMBER, SOLAS and GEOTRACES cruises (coordination required).
- Ideal cruises for deployment of biogeochemical floats (simultaneous reference discrete measurements required for QC).

**Implementation**

- Decadal survey requiring full basin synopticity (over <3 years)
- Sub-set of decadal survey line every 2-3 years

**CWPs:** Hood, Schuster, Feely,
Eulerian Time series and “Bio” measurements

- Provide critical measurements to observe episodic events and secular change
- From physical oceanography - oriented now moving to interdisciplinary investigations
  - carbon uptake storage / acidification
  - biogeochemistry and ecosystems
- Possibility to deploy large and power-hungry instruments (cable: in situ flow cytometer).

Implementation
- 10-15 selected sites in representative biogeochemical provinces.
- Core variables: pCO2, O2, NO3, optical measurement of phytoplankton biomass
- Other significant variables will join this minimal list within the next few years

CWPs: Send
To produce climate-research valuable data sets, it is critical that:

- There is no interruption in the OCR missions

Ocean Colour Radiometry Missions

Geostationary satellite: an avenue to explore the event scale / daily scale and potentially derive fluxes (e.g., phytoplankton production).

From Chla towards (many) “new” biogeochemical / ecosystems products, some of them also measured in situ by autonomous platforms:

- proxies for POC
- proxies for the composition of particles
- proxies for detrital / dissolved material

CWP: Sathyendranath, Yoder, Lequéré
The key to success: “Bio”-data management #1

- Tremendous amounts of “bio” data will be acquired in the near future.

- An integrated observation system will be operationally useful and scientifically relevant if and only if it is supported by an efficient data management system….BUT

- The “problem” of biologists with data management
  - we are not used to the management of huge datasets.
  - we are not used to make data publicly available
  - we are not used with real time

- A “revolution” is thus required in the way we will apprehend data management

- Very efficient data management (and a good example for the “bio” community): Ocean Color and Argo
  - Real-time delivery with real-time QC (operational data)
  - Delayed mode QC delivery after data reprocessing (scientific, climatic-trend value): real issue of climatologies for biology / biogeochemistry.
  - Generation of derived products

CWPs: Poulquen, Send, Lequéré and many others
The key to success: “Bio”-data management #2

- The management of “bio” data is likely a more complicated task than for physical variables because of the diversity of ways of measuring the variables.

- For example, [Chl a], the “universal” proxy of phytoplankton can be measured:
  - from space: reflectance ratios, fluorescence.
  - In situ, non-intrusively by sensors: (spectro)fluorescence, absorption (676 nm).
  - In situ, from filtered water samples: HPLC, (spectro)fluorometry, spectrophotometry.
  - In fine, [Chl a] should represent the same “bio” product regardless of the method of acquisition. Consider modelers who visit databases…

- It is thus mandatory to develop a unified format and language which is essential for streamline and interfacing datasets.

- Upstream of data management, QC and unified format, it will be essential to:
  - Establish reference material.
  - Support regular international intercomparison exercises.
  - Develop internationally agreed calibration centers.

CWP: Poulquier, Send, Lequeré, Sathyendranath
Integration

**Bio-physical integration**

- Integration is not just adding “bio”-sensors to an existing physical observational system.
- “Bio”-processes strongly dependent on physical forcing.
- Physical processes (generally) do not depend on biological and biogeochemical processes.
- A BIO-program (Bio-Argo, Bio-Glider, Bio-Time series…) should not be a side program, independent of the corresponding physical program. Optimally, it should be clearly defined and then implemented in close association with physical oceanographers.
- Gliders: operational maturity same time as biogeochemical / bio-optical sensor maturity. Spatial domain covers sub-meso and mesoscale, critical for biogeochemistry.
- Time series, Go-ship: core “bio-variables” now implemented in the physical system. New science can be easily developed.
- Floats: synergy / integration, a priori, less obvious.
  - Argo is well organized and mature, while the “BIO”-counterpart is in infancy.
  - New measurements: technically challenging, costly, generate their own issues (Law of the sea)
Satellite (OCR) in situ integration

- In situ data extend the satellite data into the ocean interior.

- Satellite data fills the gap of loose spatio-temporal resolution of in situ data.

- Essential to develop synergetic use of “bio” in situ and OCR satellite data:
  - Produce 3D/4D fields of some “bio”-variables for the global ocean: Chla.
  - “Initial climatologies” => required for developing delayed-mode QC procedures.
  - In situ data for validation of OCR products (e.g. “VAL-floats”).
At the moment, the “bio” community is mostly engaged in making the various platforms of the observation system mature.

Integration of the various “bio-platforms” into an integrated system requires the sizing of this system (density of bio-gliders, bio-floats, bio-animals…) according to:

- the scientific questions and their relevant spatio-temporal scales.
- the specificity of the various “bio-platforms” in resolving these scales.
Integration = “synergetic Interplay” of the various elements
an example
Integration = “Interplay” of the various elements #2

- While the global scale is obviously the target to set up the “final” observation system, the implementation of pilot studies on regional “hot-spot(s)” could be a first and reasonable step towards integration.

- There are indeed regional “hot-spots” that are “natural laboratories” for addressing key scientific questions of global relevance, and which would require to be tackled in a highly integrated way, *e.g.*:
  - **The eastern boundary currents**: upwelling and OMZ areas; biogeochemical cycles (C, N,..); fisheries; coastal / open ocean interface.
  - **The North Atlantic**: variability in MOC; decrease/variability in the CO2 sink over inter-annual, decadal time scales.
Regional studies at “super sites”: case studies towards global integration

To prepare the global integrated system, think first to redesign “JGOFS-like” process studies that were the first integrated approaches of oceanic biogeochemical cycles.

- **Ship** for detailed biogeochemical investigation essential for:
  - Key variables (e.g. microbiology, iron..) or fluxes (e.g. nitrogen) not amenable yet to autonomous sensor detection
  - Establish / refine parametrization of **BGC models**

- **Gliders**: bio-physical observations in a coherent spatial and temporal context.
- **Floats**: bio-physical observations in a coherent temporal and spatial context.
- **Time series**: bio-physical observations in a coherent temporal context.

- **Satellite**: the first process studies with OCR….
MESSAGE 1: Integration means a real synergy between physical and biological oceanographers.

MESSAGE 2: The implementation and the sustainability of the observation system rely on the critical choice of the “Bio” variables.

MESSAGE 3: The sustainability of the entire system will depend on the availability of QC data and hence on the rigor in setting the data management system.

MESSAGE 4: Consider to study “super sites” in key areas of global relevance as a first step towards integration.

Overall this is a collaborative effort with a broad international participation!
Thank you!