# Oceanic observation requirements for biogeochemistry

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# Why Biogeochemical Observations?

- Global carbon cycle: fluctuations at many time scales
- Ocean acidification
- Bio-engineering (e.g. ocean fertilisation)
- Marine bio-diversity and function
- Validation and improvement of Earth System and ocean biogeochemical models
- Data assimilation to improve model performance
- Data for assessing impact and adaptation of marine ecosystem to climate change*
- Bio-feedback mechanisms, understanding Earth System
- Flow of material through the marine food webs, implications for marine resources
- Marine pollution

*Notably, the IPCC Impacts and Adaptation Assessments (WGII)

AR5 WGII Summary for Policymakers: "Open-ocean net primary production is projected to redistribute and, by 2100, fall globally under all RCP scenarios. Climate change adds to the threats of over-fishing and other non-climatic stressors, thus complicating marine management regimes (high confidence)."

Over the years, many bodies have identified observational requirements for ocean biogeochemistry

GCOS — GLOBAL CLIMATE OBSERVING SYSTEM

SYSTEMATIC OBSERVATION REQUIREMENT FOR SATELLITE-BASED DATA PRODUCTS FC CLIMATE

2011 Update

Supplemental details to the satellite-based component of the "Implementation Plan for th Global Observing System for Climate in Suppc of the UNFCCC (2010 Update)"

December 2011

GCOS – 154

GUIDELINES TOWARDS AN INTEGRATED OCEAN OBSERVATION SYSTEM FOR ECOSYSTEMS AND BIOGEOCHEMICAL CYCLES

OBSERVATIONAL NEEDS OF DYNAMIC GREEN OCEAN MODI

INTERNATIONAL OCEAN CARBON COORDINATION PROJECT — IOCCP

REPORT

First Technical Experts Workshop of the GOOS Biogeochemistry Panel: *Defining Essential Ocean Variables for Biogeochemistry*

13-16 November 2013, Townsville, Australia

The Global Ocean Observing System — GOOS


Biological Observations of the Global Ocean: Requirements and how to meet them

Report of a Workshop Held at Dartington, Devon, England 28 – 30 June 2001

Organised by pogo — *The Partnership for Observation of the Global Oceans* (POGO)

and co-sponsored by The Census of Marine Life (CoML)

GLOBAL CLIMATE OBSERVING SYSTEM

IMPLEMENTATION PLAN FOR THE GLOBAL OBSERVING SYSTEM FOR CLIMATE IN SUPPORT OF THE UNFCCC

October 2004

GCOS - 92

(WMO/TD No. 1219)

GCOS — GLOBAL CLIMATE OBSERVING SYSTEM

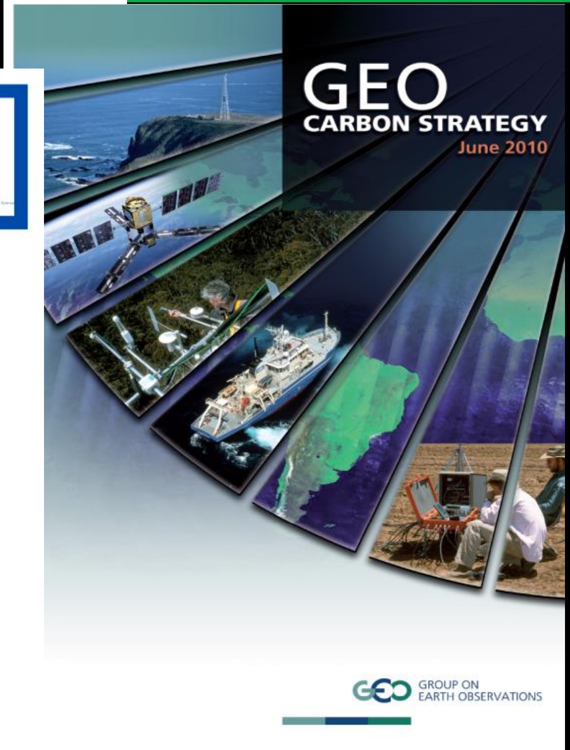
IMPLEMENTATION PLAN FOR THE GLOBAL OBSERVING SYSTEM FOR CLIMATE IN SUPPORT OF THE UNFCCC

(2010 UPDATE)

August 2010

GCOS-138

(GOOS-184, GTOS-76, WMO-TD/No. 1523)



# Considerations for identifying key observations

The reports have based their selections on a number of criteria, including:

- Important issues to be addressed
- Key questions to be answered
- Feasibility
- Cost
- Technology available for detection
- Platforms available for deployment
- Impact
- Spatial and temporal scales of interest

Findings in a cross-section of these reports are examined first.

# Biological Observations of the Global Ocean: Requirements and how to meet them (POGO & CoML 2001)

| Priority | Global Change & Carbon Cycle | Primary Production & Remineralisation | Biodiversity & Ecosystem Function |
|---|---|---|---|
| Highest | | | |
| | Ocean Colour | Ocean colour | Ocean Colour |
| | Chlorophyll *in situ* | Chlorophyll | CPR |
| | $pCO_2$ | CTD | CTD |
| | CTD | Light | |
| | Beam attenuation | | |
| High | | | |
| | Chlorophyll (lab) | Nutrients | DNA Probes |
| | 3-channel light | ADCP | |
| | NO3 | | |
| | P and SiO4 | | |
| | Dissolved Oxygen | | |
| | ADCP | | |
| Recommended for development to operational level | | | |
| | FRRF | FRRF | DNA Probes |
| | Flow cytometry | Zooplankton Grazing | Functional Groups (DNA) |
| | | Bacteria (FC) | DNA Chips |
| | | Respiration | Image analysis |
| | | | Molecular Data Bank |
| | | | Microscopy |
| Capacity Building | | | |
| | Microscopy | | |
| | Ocean Colour (phytoplankton community) | | |
| | Molecular techniques | | |


Biological Observations of the Global Ocean:
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CENSUS OF MARINE LIFE

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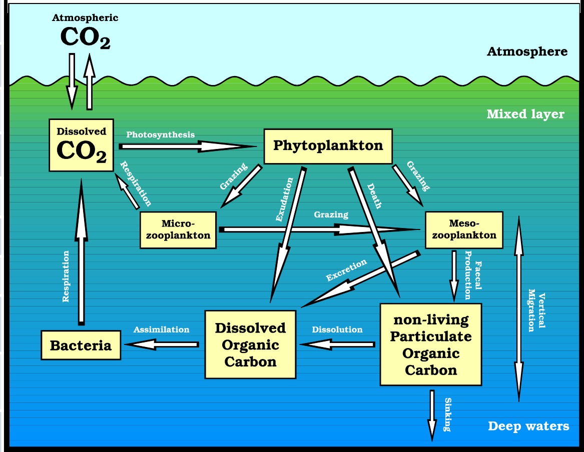



Report contains a longer list of variables that were considered. The list is worth revisiting.

# GCOS Implementation Plan (2004, 2011)

Essential Climate Variables (Oceanic)

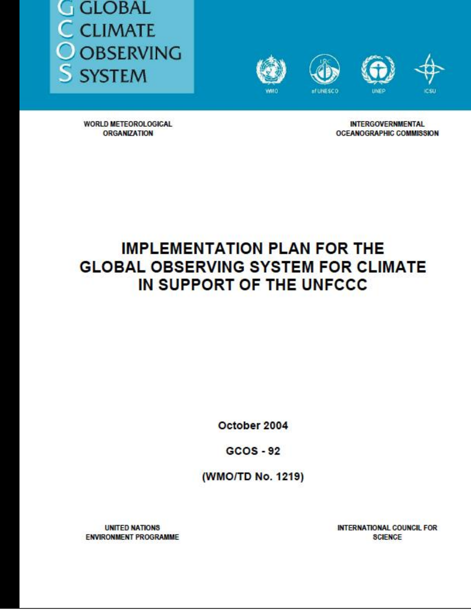
Surface: Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Surface current, Ocean colour, Carbon dioxide partial pressure, Ocean acidity, Phytoplankton

Sub-surface: Temperature, Salinity, Current, Nutrients, Carbon dioxide partial pressure, Ocean acidity, Oxygen, Tracers

Note: Some of the Atmospheric and Terrestrial ECVs are also relevant to ocean biogeochemistry

Climate and ocean biogeochemistry are intimately linked

Many ECVs are also essential for studying biogeochemical cycles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SYSTEM

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INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

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October 2004

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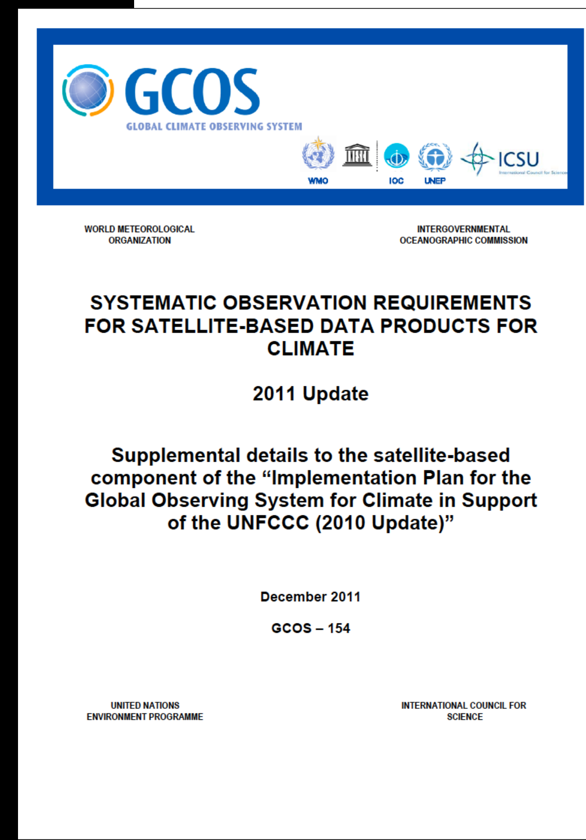
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UNITED NATIONS ENVIRONMENT PROGRAMME

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# Guidelines towards an Integrated Ocean Observation System for Ecosystems and Biogeochemical Cycles OceanObs'09 Plenary Paper

GUIDELINES TOWARDS AN INTEGRATED OCEAN OBSERVATION SYSTEM FOR ECOSYSTEMS AND BIOGEOCHEMICAL CYCLES


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ABSTRACT

The observation of biogeochemical cycles and ecosystems has traditionally been based on ship-based platforms. The obvious consequence is that the measured properties have been dramatically undersampled. Recent technological advances in miniature, low power biogeochemical sensors and autonomous platforms open remarkable perspectives for observing the "biological" ocean, notably at critical spatio-temporal scales which have been out of reach until recently. The availability of this new observation technology thus makes it possible to envision the development of a globally integrated observation system that would serve both scientific as well as operational needs. This in situ system should be fully designed and implemented in tight synergy with two other essential elements of an ocean observation system, first satellite ocean color radiometry and second advanced numerical models of biogeochemical cycles and ecosystems.

This paper gives guidelines and recommendations for the design of such system. The core biological and biogeochemical variables to be implemented in priority are first reviewed. Then, the variables for which the observational demand is high although the technology is not yet mature are also identified. A review of the five platforms now available (gliders, floats, animals with sensors, mooring at eulerian site and ships) identifies their specific strengths with regards to biological and biogeochemical observations. The community plans with respect to ongoing implementation of these platforms are pointed out. The critical issue of data management is addressed, acknowledging that the availability of tremendous amounts of data allowed by these technological advances will require an


## The core ecosystem and biogeochemical variables (possible now):

Primarily selected because they are amenable to non-intrusive and automatic measurements, ideally through miniature, low-power, *in situ* sensors (already developed or in development).

- Chemical variables and variables of the $CO_2$ system: Nitrate, Oxygen, CO2 system at fixed depth
- Bulk bio-optical variables: Chlorophyll-a, Optically-resolved particulate organic carbon

## The core ecosystem and biogeochemical variables (possible soon):

Based on present status and on-going and planned development with respect to other key measurements.

- Variables of the $CO_2$ system over the vertical dimension
- Nutrients
- Plankton or particulate functional types
- Mid-trophic Automatic Acoustic Sampler for meso-zooplankton and micronekton

# Observational Needs of Dynamic Green Ocean Models (OceanObs'09 Community White Paper)

**OBSERVATIONAL NEEDS OF DYNAMIC GREEN OCEAN MODELS**


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**ABSTRACT**

The numerical modelling community is an important user group of ocean observations requiring data of global coverage for model parameterisation and evaluation. Dynamic Green Ocean Models (DGOMs) are a class of ocean biogeochemistry models that represent various types of plankton with distinct functions in food webs and biogeochemical cycles. DGOMs are used to study the feedbacks between climate and ocean biogeochemistry, particularly those mediated by ecosystem dynamics that influence $CO_2$, DMS, and $N_2O$ fluxes to and from the atmosphere. DGOMs require experimental data for the parameterization of plankton growth and loss rates and of ecological interactions, and a range of observations for their evaluation. The most urgent data needs are: (1) decadal trends in surface ocean $pCO_2$ and sub-surface $O_2$, (2) biomass (in carbon concentration) and (3) growth rates as a function of temperature for the important plankton types, and (4) sinking flux of particulate organic carbon. A global coverage is essential to evaluate the model mean state. Repeated measurements for all seasons are most useful to evaluate the model response to environmental change. These data can be obtained by a combination of platforms, including remote sensing, repeat sections and gliders, and oceanic and atmospheric time-series stations.


**1. INTRODUCTION**

Dynamic Green Ocean Models (DGOMs) are a new class of models that strive to represent more realistically the biota that influence and in turn are influenced by global biogeochemical cycles [7], [5]. DGOMs explicitly represent various types of plankton that have distinct functions in food webs and biogeochemical cycles. DGOMs were originally built to help understand how marine ecosystems respond to climate change, and how ocean biogeochemistry, particularly biological feedback mechanisms, may modulate climate change [7]. Such models are designed to project the future state of the marine ecosystems and ocean biogeochemistry under various climate-change scenarios. They can contribute to addressing the following questions:

- What are the impacts of climate change and ocean acidification on ocean biogeochemistry and marine ecosystems?

List of the most important data needed to parameterise and evaluate Dynamic Green Ocean Models (biogeochemical models)

Parameterisation Data:

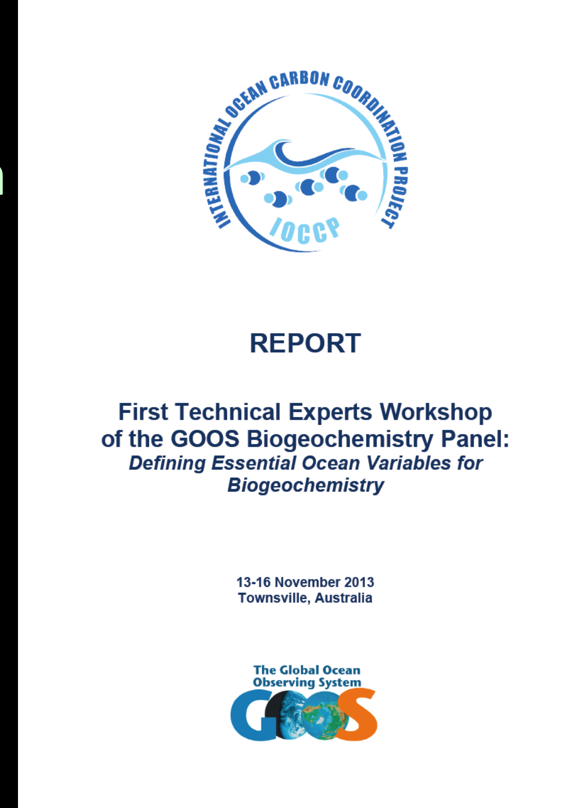
- Growth rate for all PFTs
- Loss rates for all PFTs

Evaluation Data:

- Global cycles: surface $pCO_2$, DIC, TALK, pH, DMS, $N_2O$, sub-surface $O_2$, N, P, Si, Fe
- Biomass (or related): Total chlorophyll, diatoms, coccolithophores, *Phaeocystis*, $N_2$-fixers, picophytoplankton, bacteria and Archaea, protozooplankton, mesozooplankton, macrozooplankton
- Ecosystem fluxes: primary production, secondary production, POC export, $CaCO_3$ export, Si Export

Note: The modelling perspective highlights the requirements for observing not just the relevant variables, but their fluxes, and rate parameters. Many rate parameters are poorly known, and priority for the information is high.

# First Technical Experts Workshop of the GOOS Biogeochemistry Panel: Defining Essential Ocean Variables for Biogeochemistry (Draft Report)


INTERNATIONAL OCEAN CARBON COORDINATION PROJECT

IOCCP

REPORT

First Technical Experts Workshop
of the GOOS Biogeochemistry Panel:
*Defining Essential Ocean Variables for Biogeochemistry*

13-16 November 2013
Townsville, Australia

The Global Ocean Observing System
GOOS

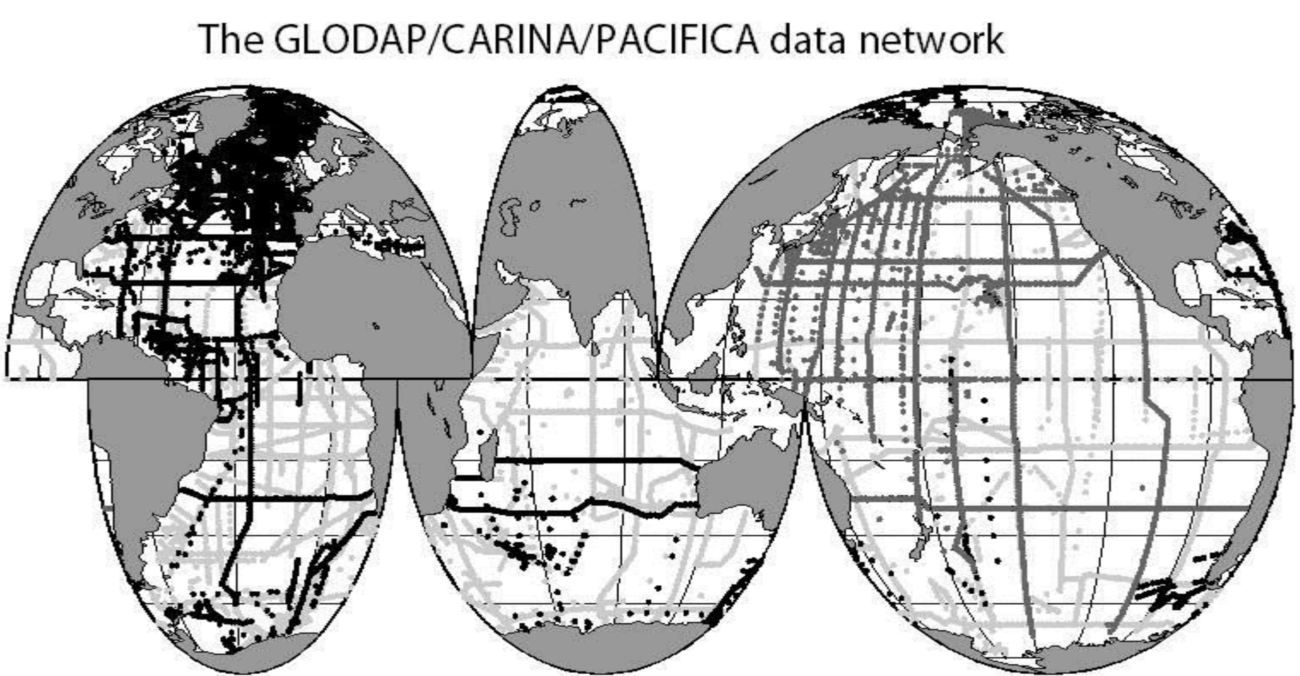
Proposed Essential Ocean Variables for Biogeochemistry

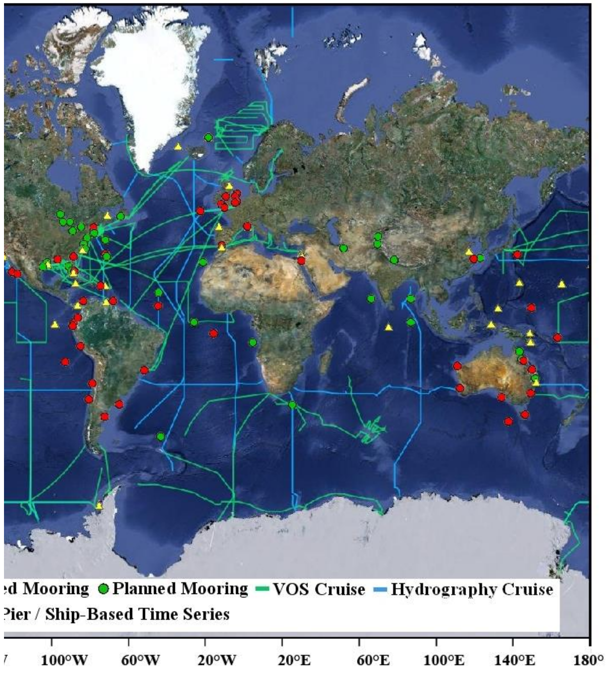
- Oxygen
- Macro Nutrients (NO3, PO4, Si, NH4, NO2)
- Carbonate System
- Transient Tracers
- Suspended Particulates (including inorganics)
- Particulate Matter Export (organic and inorganic)
- Nitrous Oxide
- Carbon-13
- Dissolved Organic Matter (DON, DOP, DOC)

The work led by International Ocean Carbon Coordinating Panel (IOCCP).
The proposed list of Essential Ocean Variables for Biogeochemistry is based on ranking observables according to impact and feasibility.
Note: *Bio-optics not EOV for Biogeochemistry in this report. Discussions will be held to include pigments in work done by the Biology and Ecosystem Panel. Need to study this list alongside requirements from Biology Panel (to come).*

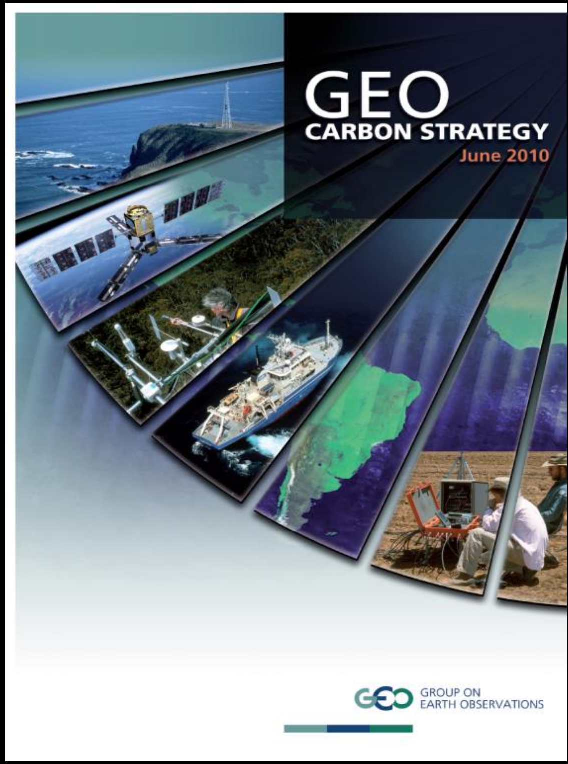
# International Ocean Carbon Coordinating Project

The IOCCP promotes the development of a global network of ocean carbon observations for research through technical coordination and communication services, international agreements on standards and methods, and advocacy and links to the global observing systems. The IOCCP is co-sponsored by the Scientific Committee on Oceanic Research and the Intergovernmental Oceanographic Commission of UNESCO



# GEO Carbon Strategy (2010)




The most urgent need is to develop and implement a network of routine observations to monitor ocean carbon. This requires:

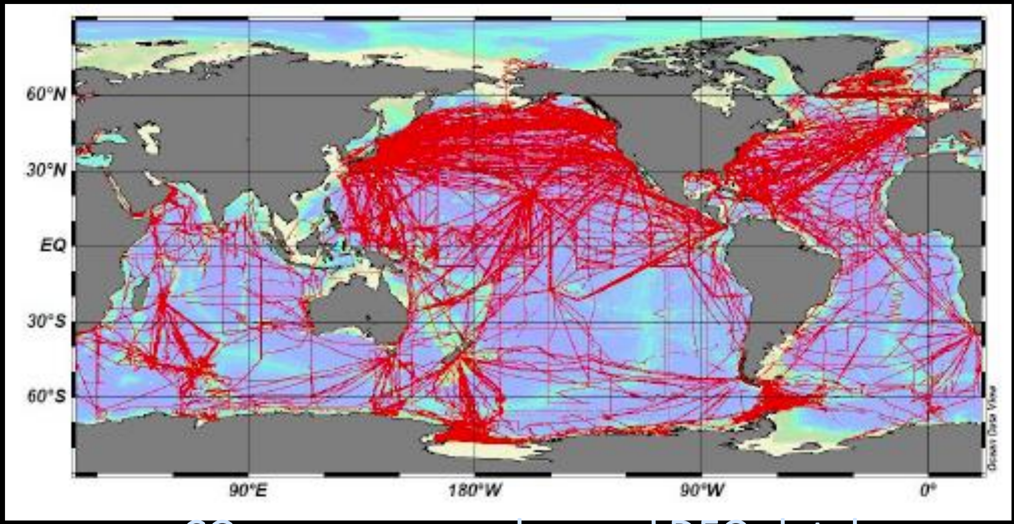
- new automated measurement techniques and
- the integration of existing ocean carbon observations into an homogenized network.

Sustained observing systems for carbon variables are essential in quantifying the global carbon cycle and a necessary backbone for the further research that must proceed in parallel.

Specifically, the report mentions:

- Surface $pCO_2$
- Ship-based hydrography: full water-column physical, chemical and biological measurements
- Carbon time series (fixed stations)
- Oxygen from autonomous platforms
- Ocean colour

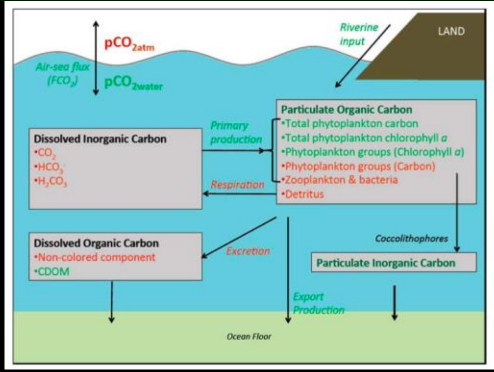
Highlights the need for integration.




$pCO_2$ coverage and gaps, LDEO database

# CEOS Strategy for Carbon Observations from Space (2014)

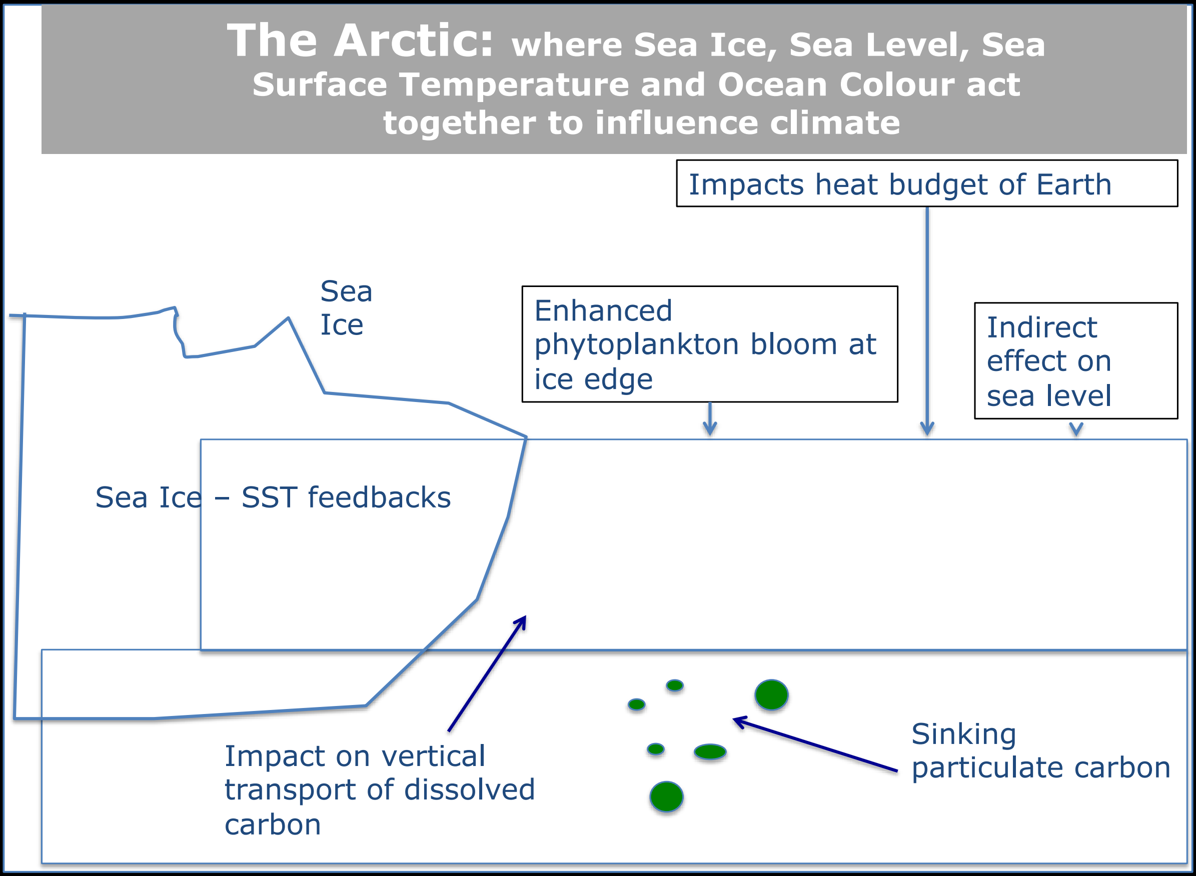
| Sensor | Products |
|---|---|
| Ocean Colour | Chlorophyll, Absorption by coloured dissolved organic matter, Daily photosynthetically-available radiation, Particulate organic carbon, Phytoplankton carbon, Primary production, Particle size distribution, Primary production, New (export production, Phytoplankton functional types |
| Infra-red radiometer, passive microwave | Sea-surface temperature |
| Active and passive microwave sensors | Wind speed, vector wind, sea state, Sea ice extent, ice edge structure |
| Altimeter | Surface geographic currents and eddies |


Remarks:

- Satellite requirements consistent with GCOS requirements
- But report emphasises the need for carbon products
- Requirements include both variables and fluxes

# CEOS Strategy for Carbon Observations from Space



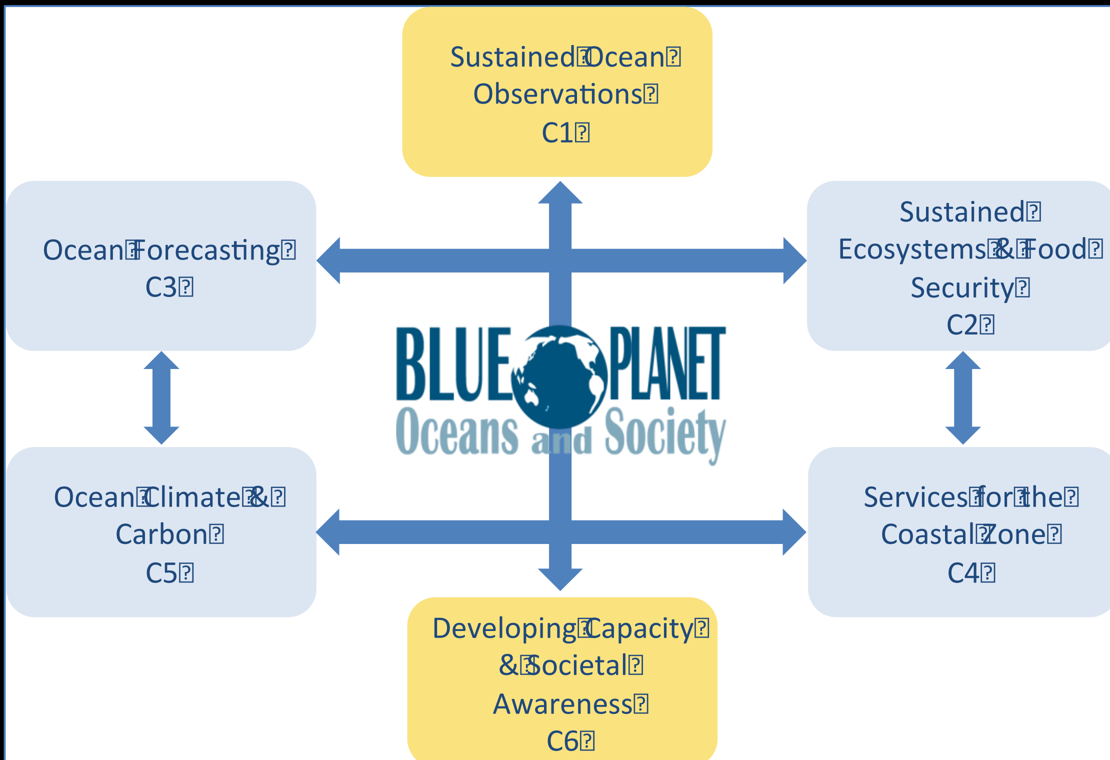


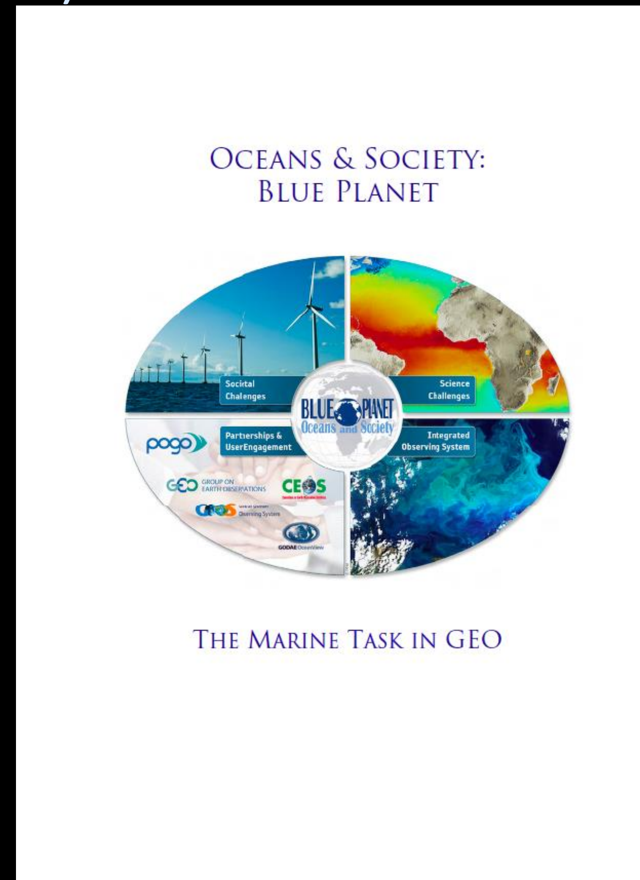
The Arctic as an example of rapid change, with many interactions across domains.

Importance of Integration at various levels:

- Satellite observations with in situ observations and modelling
- Across domains: land, water and air: Importance of interfaces and fluxes across domains; coasts as the interface between land and ocean; three-way coupling, feedbacks
- Data harmonisation, uncertainty, traceability and transparency
- Science, policy and implementation

# White Paper on Oceans & Society: Blue Planet
# The Marine Task in GEO (2014)

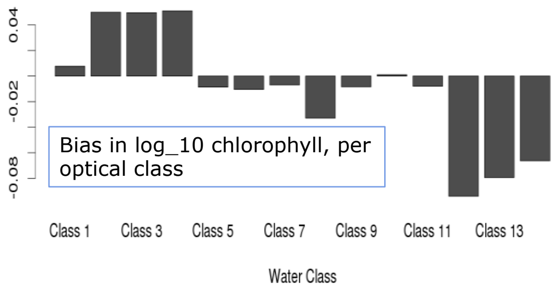


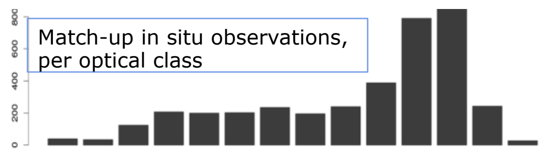



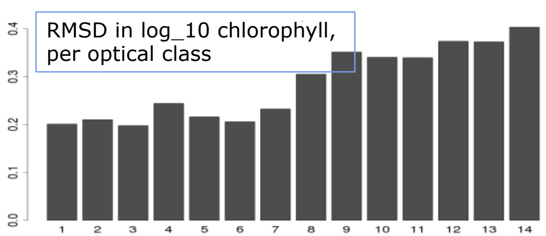

- Brings many interest groups, including data providers and the user community together
- Opportunity to speak with a common voice in an inter-governmental (non UN) forum
- Recognises the overlap in climate and carbon requirements. They reside together within Component 5 of Blue Planet
- Lead by POGO, major players include CEOS, GOOS, GODAE

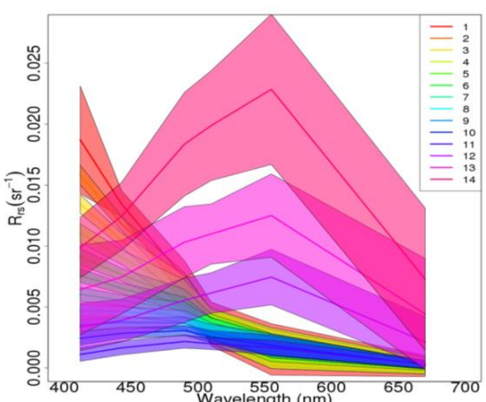
# Ocean Colour – CCI:

## Rising to the challenge of meeting user requirements

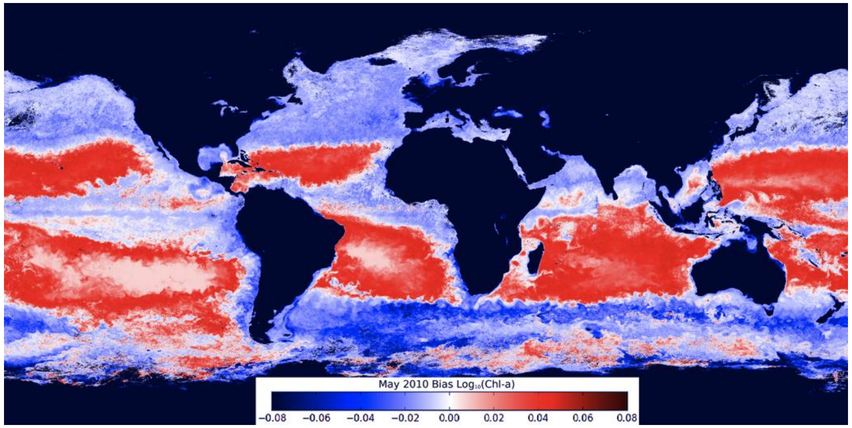


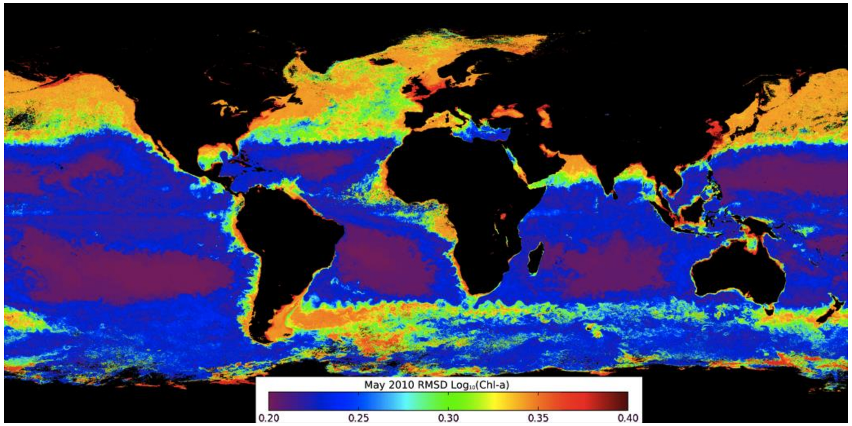



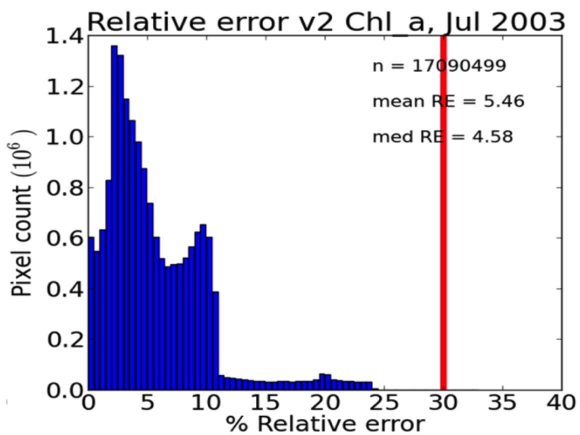




May 2010 bias, log_10 Chl




May 2010 RMSD, log_10 Chl




**Red vertical line: GCOS requirement for accuracy**

# Copernicus Marine Environment Monitoring Service

- ESA Ocean Colour CCI provide the global chlorophyll and Rrs products and the basis of the regional reprocessing made available through MyOcean/CMEMS portal.
- Ocean colour users in MyOcean exceed 450.
    - CMEMS aims to implement new test products based on the outcomes of specific R&D projects:
    - ESA STSE for Marine Photosynthesis Parameters; Ocean acidification parameters, $pCO_2$;
    - ESA SEOM Pools of Ocean Carbon for Particulate organic carbon;
    - SynSenPFT  and EU-PERSEUS for Phytoplankton functional types; and
    - - ESA Living Planet Fellowship for phytoplankton phenology

But what happens after OC-CCI is completed?

# Copernicus Marine Environment Monitoring Service: In situ data requirements

- Product quality information is provided for all CMEMS products. Assessment of data accuracy rely on referenced bio-optical dataset.
- Online validation. Requires access to bio-optical data acquired by autonomic systems: fixed boys measurements, bio-Argo, drifters, AERONET-OC data (e.g., optical and fluorescence measurements, sensors mounted on automatic systems).
- CMEMS start from L2 data provided by space agencies (EUMETSAT for OLCI) or projects (OC CCI). Hence, it is important that vicarious calibration be properly performed.

Ocean colour merits to be included in the CCCS satellite products: the quality is assured, user base exists, requirement is clear. But there should be a parallel research stream to support development of improved products, for example for complex coastal waters typically found in European seas, novel products for the open ocean, improved products for new sensors (e.g. Sentinel-3, PACE). Some of this can then continue to be integrated into marine services.

# Where are we now?

- The summary of community views presented here is incomplete. Reports that deal specifically with coastal concerns have not been presented, but merit consideration.
- The marine community has been consulted and has made its views known.
- The technologies exist for making a big step forward for observations relevant for ocean biogeochemistry.
- But infrastructure and capabilities at institutional level for making measurements at appropriate time and space scales lags behind.
- Resources for meeting these requirements on an operational basis is lacking.
- The scientific and societal justifications are many and irrefutable.
- Coordinating bodies exist.

# What is needed next?

- What is required now is to digest information from multiple sources and forge a common path ahead.
- Some requirements stand out as being priority for multiple groups (e.g. $pCO_2$, Ocean Colour), and it should be straightforward to adopt them.
- However, consolidating requirements is not a trivial task: selecting only the most frequently-mentioned observations may result in the requirements for a key group or application falling by the wayside.
- Requirements include not only variables, but fluxes, and rate parameters (for models).
- Problem is global, and has to be addressed at the global level: international coordination is important.
- Coordination among various interest groups is essential.
- Inter-connections and feedbacks with other domains should not be overlooked.