GOA-ON

Global Ocean Acidification Observing Network

Global Ocean Acidification Observing Network:

Requirements and Governance Plan

Second Edition

October 2015

J.A. Newton, R.A. Feely, E.B. Jewett, P. Williamson, J. Mathis

IOOS® Integrated Ocean Observing System

NOAA — National Oceanic and Atmospheric Administration, U.S. Department of Commerce

IAEA — Ocean Acidification International Coordination Centre OA-ICC

UNESCO — United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

GOOS — The Global Ocean Observing System

IOCCP — International Ocean Carbon Coordination Project

UK Ocean Acidification Research Programme

Blue Planet — Oceans and Society

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EXECUTIVE SUMMARY

The scientific and policy needs for coordinated, worldwide information-gathering on ocean acidification and its ecological impacts are now widely recognized. The importance of obtaining such measurements has been endorsed by the United Nations General Assembly[1], and by many governmental and non-governmental bodies who have recently assisted the scientific community in developing the Global Ocean Acidification Observing Network (GOA-ON). The design and foundation of the Network comes from two international workshops held at the University of Washington, Seattle, USA, in June 2012 and at the University of St. Andrews, UK, in July 2013 involving over a hundred participants and over 30 nations.

The policy need relates to the requirement for robust evidence on ocean acidification and its worldwide impacts, to inform appropriate management action at both national and international levels. The scientific need is for large-scale, long-term data, to improve understanding of relevant chemical and biological processes; assist in the design and interpretation of experimental studies; and thereby improve predictive skills.

Three high level goals of the Network aim to provide measurements for management while also delivering scientific knowledge: to improve our understanding of global ocean acidification conditions (Goal 1); to improve our understanding of ecosystem response to ocean acidification (Goal 2); and to acquire and exchange the data and knowledge necessary to optimize the modeling of ocean acidification and its impacts (Goal 3).

This GOA-ON Requirements and Governance Plan provides both broad concepts and key critical details on how to meet these goals. In particular, it defines: the Network design strategy; ecosystem and goal-specific variables; spatial and temporal coverage needs; observing platform-specific recommendations; data quality objectives and requirements; initial GOA-ON products, outcomes, and applications; GOA-ON's proposed governance structure; and Network support requirements.

[1] Paragraph 153 of Resolution 68/70, passed 9 December 2013: "… encouraged States and competent international organizations and other relevant institutions, individually and in cooperation, to urgently pursue further research on ocean acidification, especially programmes of observation and measurement…"

International OA data sharing arrangements are proposed based on defined data and metadata standards and open access to observing data. While the ocean carbon community has a relatively mature data-sharing process, it is recognized that the addition of coastal sites, as well as biological and ecological data to this framework, will take time and effort to structure.

The effort of GOA-ON to develop the optimal observing system to detect ecosystem impacts of ocean acidification on various types of ecosystem (including tropical, temperate, and polar regional seas; warm and cold-water corals; and nearshore, intertidal and estuarine habitats), and in the context of other stressors, has only started recently. Further work will be needed to refine detailed protocols for relevant biological observations on a habitat- or regionally-specific basis. The potential scope for such observations is extremely wide; it is therefore essential that GOA-ON builds on, and is conceptually part of, the Framework for Ocean Observation developed by the Global Ocean Observing System (GOOS) and the International Ocean Carbon Coordination Project (IOCCP), while also working closely with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the Ocean Acidification International Coordination Center (OA-ICC) of the International Atomic Energy Agency (IAEA), and other relevant bodies.

The GOA-ON website, , has been developed to include the latest version of the interactive of global ocean acidification observing activities. This map represents the best information available on the current inventory of GOA-ON observing assets, and provides a tangible means for increasing awareness and coordination between network partners and others with interests as well as access to ocean acidification data being collected around the globe.

Future actions of the Network include facilitating additional measurement efforts in geographic areas of high concern, together with associated capacity-building; strengthening of linkages with experimental and theoretical studies; maintaining and extending communications with the ocean observing community; establishing effective and quality-controlled international data management and data sharing, through distributed data centers; and encouraging the development of synthesis products based on GOA-ON measurements. All this will require that the Network secure the necessary level of support and resources to achieve these actions.

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1. Background and Introduction

The two main needs for worldwide information-gathering on ocean acidification[2] and its ecological impacts have been articulated by several bodies and organizations in the past five years. Such include the United Nations General Assembly who noted the work of the Intergovernmental Panel on Climate Change and "encouraged States and competent international organizations and other relevant institutions, individually and in cooperation, to urgently pursue further research on ocean acidification, especially programmes of observation and measurement[3]". Firstly, a well-coordinated, multidisciplinary and multi-national approach for ocean acidification observations and modeling would provide authoritative evidence to policy-makers on fundamental changes to marine ecosystems occurring from pole to equator, and from estuaries to ocean depths. Second, the collation and analysis of global-scale datasets documenting these chemical changes and associated biological responses would greatly increase understanding of the processes involved, allowing us to firmly establish impacts attributable to ocean acidification, assess the importance of associated climate change feedbacks, and improve the reliability of projections of future biogeochemical and ecological conditions, and their societal consequences.

National observational programs and activities to address such issues now exist or are under development in several countries. Their value, however, is greatly enhanced when they are brought together at global and regional levels, and explicitly linked with other field studies, manipulative experiments, and modeling.

This report, based on two international workshops, provides a consensus vision and strategy for such coordination through the Global Ocean Acidification Observing Network (GOA-ON). This report is expected to be a "living" document to be refined and updated periodically as the GOA-ON matures over the next several decades. The revisions to the document will be based on community input and consensus based recommendations from future GOA-ON workshops.

The first workshop, held at the University of Washington in Seattle, USA (26-28 June 2012), defined the goals and requirements of a global observing network for both carbon and ocean acidification in the context of an overall framework for ocean observing responding to societal needs. Building on that effort, a second GOA-ON workshop was held at the University of St. Andrews, UK (24-26 July 2013). The overarching goal of the second meeting was to refine the vision for the structure of GOA-ON, with emphasis on standardizing the monitoring of ecosystem impacts of OA in shelf and coastal seas. The sponsors of the Seattle and St Andrews workshops

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[2] The International Panel on Climate Change (IPCC) Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems (2011, p. 37) defines Ocean Acidification (OA) as "*a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean.*" The interests of GOA-ON focus on the changes in ocean chemistry and biology driven by anthropogenic increases of atmospheric CO_2 in the context of their future societal implications and their interactions with other perturbations.
[3] Extracted from Resolution 68/70 of the United Nations General Assembly (passed on 9 December 2013)

are identified in the Acknowledgements and their support is much appreciated. Without them, GOA-ON would not exist.

Participants in both workshops designed GOA-ON to monitor biogeochemical changes at sufficient detail to discern trends in acidification and determine relative attribution of the primary physical and chemical processes governing such changes. The consensus was that GOA-ON must also include a means of tracking changes in large-scale biological processes (changes in productivity, species distributions, etc.), which may be affected by ocean acidification, as well as other factors. GOA-ON will build on the existing global oceanic carbon observatory network of repeat hydrographic surveys, time-series stations, floats and glider observations, and volunteer observing ships in the Atlantic, Pacific, Arctic, Southern, and Indian Oceans.

Recognition of the importance of the continuity and quality of these foundational observations will help to assure their future support, while also providing the basis for a more comprehensive, multidisciplinary ocean acidification observing network. The further development of GOA-ON will require the adoption of advanced new technologies that will reliably provide the community with the requisite biogeochemical measures necessary to track ocean acidification synoptically. For example, incorporation of new carbon chemistry sensors developed and adapted for moorings, volunteer observing ships, floats and gliders, to be closely linked with satellite-based remote sensing. Such technologies will provide critically important information on the changing conditions in both open-ocean and coastal environments that are presently under-sampled.

As indicated above, GOA-ON is not just a pH monitoring program. A fully-realized network needs to have the capability to not only track changes in other chemical parameters, such as calcium carbonate ($CaCO_3$) saturation states and chemical speciation in the ocean, but also biological production rates and species functional group distributions. These additional measurements are needed to improve confidence in projected future ocean acidification, and better discern ecosystem responses. New technologies for monitoring dissolved inorganic carbon, total alkalinity and pH would be beneficial for tracking changes in the marine inorganic carbon system, including those resulting from non-carbon dioxide (CO_2) sources of acidification.

The biological measurements are admittedly more difficult and complex to measure repeatedly or remotely. However, measurements of net primary production and community metabolism, either directly or from carbon, nutrient or oxygen inventories, along with an understanding of hydrodynamics are important in order to identify biological impacts and adaptations to ocean acidification, especially in coastal zones where globally-driven changes in ocean acidification are augmented by local processes.

Implementation of GOA-ON requires coordination and integration both internally, within the network, and externally, through linkage to existing international research and observational programs. Leveraging existing infrastructure and monitoring (for carbon-related work and broader ecological activities) will improve efficiency; however, new infrastructure will be necessary given that considerable observational gaps remain. In addition to helping to sustain existing infrastructure and its capabilities, we must also identify and prioritize new time series stations, repeat surveys and underway measurements that are urgently needed in under-sampled marine environments. No single nation can address all these issues on a truly global basis: GOA-ON must therefore be developed as a collaborative international enterprise, stimulating additional effort and sharing expertise between nations to advance infrastructure development.

Capacity building and training of new scientists is essential to the GOA-ON effort. Guidance and workshops on methods and techniques for those new to OA observing must also be developed. The GOA-ON website will provide access to such products (e.g., guidance documents, training manuals). Such information will be incorporated into future versions of this document.

2. Paths to Creation of the Global OA Observing Network

The international efforts which led to the first GOA-ON workshop in Seattle are pictured in Figure 1. A Working Group on Ocean Acidification (with broad international representation) was jointly established in 2009 by the non-governmental Surface Ocean Lower Atmosphere Study (SOLAS) and the Integrated Marine Biogeochemistry and Ecosystem Research project (IMBER). This Working Group produced the initial proposal for the Ocean Acidification International Coordination Centre (OA-ICC) and associated activities, including a global observing initiative. The OA-ICC was announced at the Rio +20 United Nations Conference on Sustainable Development held in Rio de Janeiro, June 2012, and began its work in early 2013 under the auspices of the International Atomic Energy Agency (IAEA).

An additional key factor in the genesis of GOA-ON was the OceanObs '09 Conference (Venice, September 2009; Hall, Harrison & Stamer, 2010), involving a very wide range of sponsors and endorsers, and resulting in the publication of several plenary papers, community white papers and other contributions relating to the observing requirements for ocean acidification; these included Feely et al. (2010) and Iglesias-Rodriguez et al. (2010), providing a solid structural framework for the GOA-ON described in this document.

In a closely-linked initiative, the International Ocean Carbon Coordination Project (IOCCP) developed a cooperative agreement with the Global Ocean Observing System (GOOS), and released the Framework for Ocean Observing, led by the Intergovernmental Oceanographic Commission of UNESCO (Lindstrom et al., 2012). All of the entities referenced above continue to provide the basic foundation for the network, as will international efforts that address portions of the GOA-ON aim, such as the International Group for Marine Ecological Time-Series (IGMETS). Regional-scale activities will also contribute to and complement GOA-ON activities, e.g., Commission for the Protection of the Marine Environment of the North-East Atlantic

(OSPAR)/International Council for Exploration of the Sea (ICES) (ICES, 2013; Hydes et al., 2013).

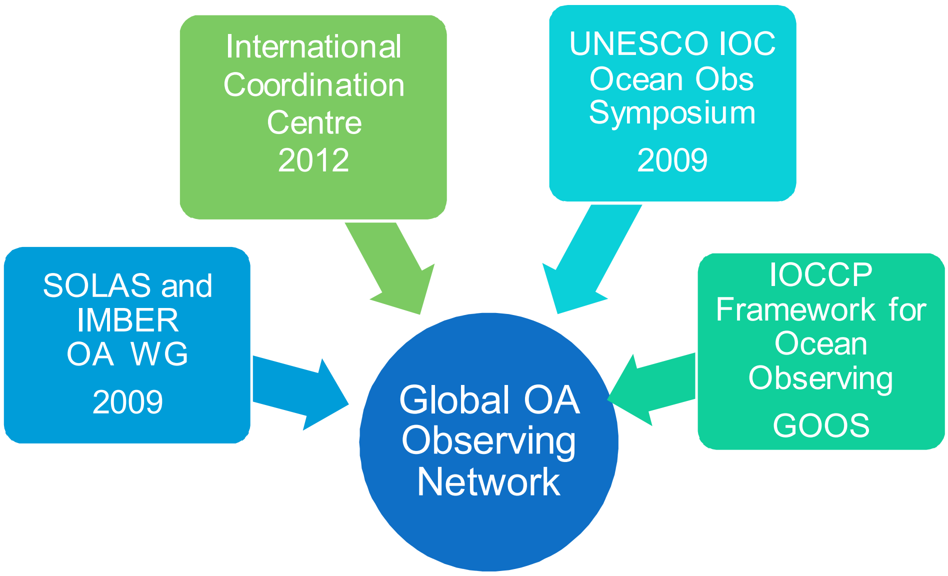

Figure 1. Schematic diagram of the international drivers that contributed to the development of a global observing network for ocean acidification and the first GOA-ON workshop. Source: Libby Jewett (NOAA OAP).

3. Workshop Goals and Community Input

The common goals of the international workshops at Seattle and St. Andrews were to:

1. Provide the rationale and design of the components and locations of a global network for ocean acidification observations that includes repeat hydrographic surveys, underway measurements on ships of opportunity (e.g., Ships of Opportunity, SOO, and Volunteer Observing Ships, VOS), moorings, floats and gliders and leverages existing networks and programs wherever possible;
2. Identify a minimum suite of measurement parameters and performance metrics, with guidance on measurement quality goals, for each major component of the observing network;
3. Develop a strategy for data quality assurance and data reporting; and
4. Discuss requirements for international program integration and governance.

At both workshops, participants included ocean carbon chemists, oceanographers, biologists, data managers, and numerical modelers. See Appendix 1 for participant lists and Appendix 2 for the workshop agendas.

At the **Seattle workshop** there were 62 participants from 22 countries and 1 international body. Countries represented were: Australia, Bermuda, Canada, Chile, China, France, Germany, Iceland, India, Israel, Italy, Japan, Rep Korea, Mexico, New Zealand, Norway, South Africa, Sweden, Taiwan, United Kingdom, United States of America, and Venezuela.

At the **St. Andrews workshop** there were 87 participants from 26 countries and 4 international bodies. Countries represented were: Australia, Bermuda, Brazil, Canada, Chile, China, France, Germany, Iceland, India, Ireland, Israel, Italy, Japan, Rep Korea, Malaysia, New Zealand, Norway, Philippines, South Africa, Spain, Sweden, Taiwan, Thailand, United Kingdom, and United States of America.

Collectively, the workshops represent roughly 100 unique participants from approximately 30 countries. Prior to each workshop, participants and their colleagues were requested to identify existing (red) and planned (green) OA observing assets, as shown in Figure 2, to provide the basis for the Network. As addressed later in this document (section 14), this map will be a resource on the GOA-ON portal, updated as current information changes and to incorporate new information from additional GOA-ON members. This resource will be highlighted in workshops and conferences to increase awareness of this information and to encourage wide participation.

4. Global OA Observing Network Justification and Goals

There was strong consensus in both workshops on why an ocean acidification observing system was needed, why it must be global in scale, why it should be integrated across physical, chemical, and biological observations and the goals of the GOA-ON.

Ocean acidification is a global issue with local effects, such as reduced coral growth or decreased shellfish settlement. Coastal pH and carbon conditions can be very different from those in the open ocean because of local drivers of variation, such as upwelling, eutrophication and river inputs. As a global observing community, we need measurements taken on local through global scales. This is because local issues cannot be understood or predicted outside of their global context and forcings. Furthermore, the global condition cannot be truly assessed without including the mosaic of localized conditions, which can vary substantially and compose parts of the global picture.

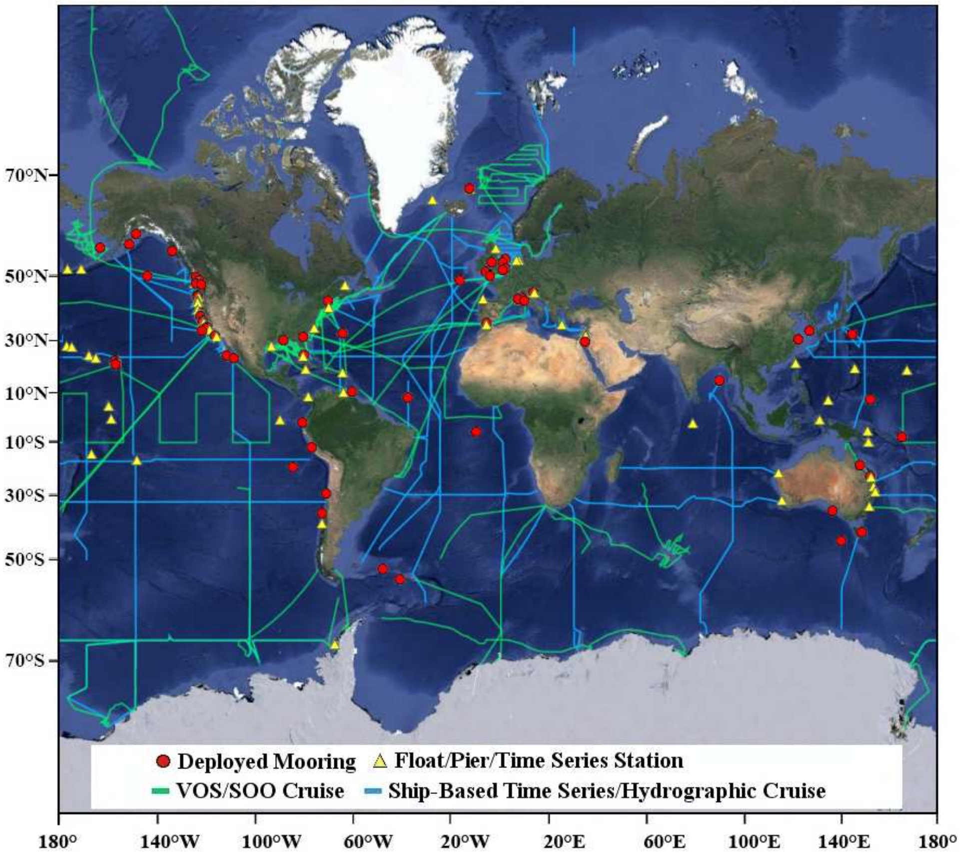

Figure 2. Map of current Global Ocean Acidification Observing Network (GOA-ON) components, last updated September 2014. The ship-based lines are occupied nominally every decade. Source: .

4.1 Why is a Global OA Observing Network needed?

- We need information and data products that can inform policy and the public with respect to ocean acidification and implications for the overall ecosystem health (status) of the planet.
- Ocean acidification processes are occurring at global scales; therefore, we need to go beyond local measurements and observe ocean acidification on global scales in order to understand its drivers correctly.
- Insufficient observations and understanding exists to develop robust predictive skills regarding ocean acidification and impacts. While we need enhanced coverage at local scales, successful international coordination of these observations will allow for nesting of these local observations within a global context.

4.2 What does the Global OA Observing Network aim to achieve?

The effort of the Network will be directed at achieving the following three goals and their component objectives:

- **Goal 1:** Improve our understanding of **global ocean acidification** conditions.
  - Determine status of and spatial and temporal patterns in carbon chemistry, assessing the generality of response to ocean acidification;
  - Document and evaluate variation in carbon chemistry to infer mechanisms (including biological mechanisms) driving ocean acidification;
  - Quantify rates of change, trends, and identify areas of heightened vulnerability or resilience.

- **Goal 2:** Improve our understanding of **ecosystem response to ocean acidification.**
  - Track biological responses to OA, commensurate with physical and chemical measurements and in synergy with relevant experimental studies and theoretical frameworks;
  - Quantify rates of change and identify areas as well as species of heighted vulnerability or resilience.

- **Goal 3:** Acquire and exchange data and knowledge necessary to **optimize modeling of ocean acidification and its impacts**.
  - Provide spatially and temporally-resolved chemical and biological data to be used in developing models for societally-relevant analyses and projections;
  - Use improved knowledge gained through models to guide Goals 1 and 2 in an iterative fashion.

5. System Design of the Global OA Observing Network: Conceptual

Conceptually, GOA-ON addresses each of these three goals through the use of a nested design encompassing observations from a very wide range of marine environments (from open ocean to coastal waters, including estuaries and coral reefs), and using a variety of integrated and interdisciplinary observing strategies appropriate to the environment of interest.

5.1. Global OA Observing Network Nested System Design

To address the goals, a **nested design** is proposed for measurements at stations:

- *Level 1:* critical minimum measurements; measurements applied to *document* ocean acidification dynamics.

- *Level 2:* an enhanced suite of measurements that promote understanding of the primary mechanisms (including biologically mediated mechanisms) that govern ocean acidification dynamics; measurements applied towards *understanding* those dynamic processes.

- *Level 3:* Opportunistic or experimental measurements that may offer enhanced insights into ocean acidification dynamics and impacts; measurements under *development* that may be later adapted to Level 2.

The system design of the Network is further nested because observing investments designed to address Goal 2 should be implemented at a subset of the Goal 1 stations.

5.2 Global OA Observing Network Design Attributes

The following attributes characterize the GOA-ON design:

- GOA-ON will comprise observing assets within multiple ecosystem domains, including the ***open ocean, shelf seas, coasts (including the nearshore and estuaries), and warm and cold-water coral habitats****.* The open ocean, shelf seas, and coasts can also be subcategorized into polar, temperate and tropical regions with their associated ecosystem types.
- The Network will make use of a variety of observing platforms, classified here into three categories that share similar capabilities. These are: *1)* ***ship-based sampling*** *including survey cruises and ships of opportunity; 2)* ***fixed platforms****, including moorings and piers; and 3)* ***mobile platforms****, including marine gliders (both profiling and wave) and floats (possibly others, such as animals).*
- Use will be made of existing platforms wherever possible and appropriate.
- The Network will be interdisciplinary in approach, including in particular: *carbon chemistry, meteorology, oceanography, biogeochemistry, ecology, and biology.* Such integration will be much more effective from a system design standpoint if carried out from the start. For instance, while typically ocean chemistry is measured to assess effects on biology, an equally critical question is "How is biology affecting ocean chemistry?" and the design of the Network must reflect such needs. Eventually, social sciences should play a stronger role as well.

6. System Design of the Global OA Observing Network: Data Quality

The measurement quality goals of the GOA-ON may differ from site to site depending on the intended use of the observations, with differing intended uses requiring different measurement uncertainties (Box 1).

6.1 Data Quality Objectives

Conventionally, long-term sustained carbon observations have been the purview of carbon inventory and flux studies focused on documenting small changes within 'blue water', oligotrophic oceanographic settings over decadal time-scales. Such measurements demand an exacting quality necessary for identifying small changes over decadal time-scales. However, participants recognized that differing measurement quality goals are appropriate for the observations proposed here for observing ocean acidification depending on the intended application, the relative 'signal-to-noise' with respect to the environment and the processes being examined. For example, the uncertainty of measurement required for observations intended to track multi-decadal changes at a long-term time-series open ocean station is inherently different from the needs of data collected for determining the relative contributions of the acidification components within an estuary or to inform assessments of biological response. Each application has associated measurement quality goals that need to be met. Analogous to terminology adopted in atmospheric sciences, it was agreed at the Seattle workshop that the Network would provide separate measurement quality goals specific to "climate" and "weather", defined here (Box 2) both in general and in the context of ocean acidification.

Box 1. MEASUREMENT UNCERTAINTY AND GOA-ON

A key goal for any observing network is to ensure that the measurements made are of appropriate quality for their intended purpose, and that they are comparable one with another- even though such measurements are made at different times, in different places, and in many cases by different instruments, maintained by different groups. It is thus as important to communicate the uncertainty related to a specific measurement, as it is to report the measurement itself. Without knowing the uncertainty, it is impossible for the users of the result to know what confidence can be placed in it; it is also impossible to assess the comparability of different measurements of the same parameter (de Bièvre & Günzler, 2003).

The term *uncertainty* (of measurement) has a particular technical meaning (ISO, 1993; Ellison & Williams 2012). It is a parameter associated with the result of a measurement that permits a statement of the dispersion (interval) of reasonable values of the quantity measured, together with a statement of the confidence that the (true) value lies within the stated interval. It is important not to confuse the terms *error* and *uncertainty*. Error refers to the difference between a measured value and the *true* value of a specific quantity being measured. Whenever possible we try to correct for any known errors; for example, by applying calibration corrections. But any error whose value we do **not** know is a source of uncertainty.

It is therefore essential to ascertain (and report) the *uncertainty* of measurements made as part of GOA-ON, and to characterize GOA-ON measurement quality goals in terms of such uncertainties. Hence GOA-ON must establish clear guidelines for estimating this uncertainty for each of the separate measurement procedures to be used in the Network, and ultimately must also emphasize the need for formal quality assurance procedures in the various participating laboratories responsible for the instruments comprising GOA-ON to ensure that the various measurements quality goals are met.

Throughout this document, the term "uncertainty" should be taken to mean the standard uncertainty of measurement; that is with the associated confidence interval equivalent to that for a standard deviation.

Box 2. MEASUREMENT QUALITY GOALS FOR GOA-ON

"Climate"

- Defined as measurements of quality sufficient to assess long term trends with a defined level of confidence
- With respect to ocean acidification, this is to support detection of the long-term anthropogenically-driven changes in hydrographic conditions and carbon chemistry over multi-decadal timescales

"Weather"

- Defined as measurements of quality sufficient to identify relative spatial patterns and short-term variation
- With respect to ocean acidification, this is to support mechanistic interpretation of the ecosystem response to and impact on local, immediate OA dynamics

6.2 Data Quality Requirements

For GOA-ON to succeed at delivering its goals, observations must be of a verifiable quality and consistency. Three critical data quality requirements must be followed:

- Observations provided to the Network (whether measured, estimated, or calculated) will be accompanied by a statement of their uncertainty
- Observations will be calibrated to a community-accepted set of reference materials, when available
- All constants applied in the derivation of calculated parameters will be documented and reported, along with the units and scale. The uncertainties of such constants will need to be incorporated into the estimate of the uncertainty of each derived parameter.

7. System Design of the Global OA Observing Network: Measurements

In this section we present the measurements needed to attain GOA-ON goals. Measurement requirements are thus conveyed in terms of attaining the goals, not as a requirement for participation in GOA-ON. It is understood and anticipated that GOA-ON members may not be attaining all measurements required for the goals, but are still contributing toward achieving this.

7.1 Measurements for GOAL 1: understanding global OA conditions

Contributors to the GOA-ON will provide the hydrographic conditions and carbon chemistry data necessary to provide for:

i. At a minimum, a basic understanding of the local, immediate spatial and temporal OA dynamics (weather).

ii. Optimally, detection of the long-term anthropogenically-driven changes in hydrographic conditions and carbon chemistry over multi-decadal timescales (climate).

At each GOA-ON measuring site, a complete description of the seawater carbonate system will be needed. Such a description can be achieved in a variety of ways, involving alternate combinations of measurable parameters together with values for various equilibrium constants. Measurement quality goals are given below in terms of constraining the measurement uncertainty for the observed parameters used for calculating the saturation state of aragonite (a form of calcium carbonate).

7.1.1 GOAL 1 Level 1 Measurements

The following five parameters were considered to be the minimum suite of Goal 1 Level 1 measurements (in addition to time and space coordinates, as detailed as practically feasible), applicable to all marine environments:

- Temperature
- Salinity
- Pressure (water depth at which measurement is made)
- Oxygen concentration
- Carbon-system constraint, achievable in a number of ways, including combinations of direct measurements and estimates of other parameters, such as nutrients or alkalinity (see Box 3).

Two further parameters were considered necessary, except where the platform is not appropriate or available for such measurements:

- Fluorescence
- Irradiance

The **weather** objective (see Box 2) requires the carbonate ion concentration (used to calculate saturation state) to have a relative standard uncertainty of 10%. This implies an uncertainty of approximately 0.02 in pH; of 10 μmol kg^{-1} in measurements of total alkalinity (TA) and total dissolved inorganic carbon (DIC); and a relative uncertainty of about 2.5% in the partial pressure of carbon dioxide (pCO_2). Such precision should be achievable in competent laboratories, and is also achievable with the best autonomous sensors.

The **climate** objective (see Box 2) requires that a change in the carbonate ion concentration be estimated at a particular site with a relative standard uncertainty of 1%. This is smaller than the uncertainty in the carbonate ion concentration itself, since uncertainties in the various equilibrium constants largely cancel out when estimating the uncertainty of the difference between two values.

It implies an uncertainty of approximately 0.003 in pH; of 2 μmol kg^{-1} in measurements of total alkalinity and total dissolved inorganic carbon; and a relative uncertainty of about 0.5% in the partial pressure of carbon dioxide. Such precision is only currently achievable by a very limited number of laboratories and is not typically achievable for all parameters by even the best autonomous sensors.

As noted above, observations provided by the Network will report corresponding values for the uncertainty in measured, estimated, and calculated parameters, regardless of quality objective. Observations will be calibrated using a community-accepted set of reference materials.

The addition of fluorescence and irradiance is because biological processes (primarily photosynthesis) may affect the chemical status of OA and its attribution to underlying mechanism. However, as noted above, not all platforms (such as underwater gliders) can accommodate these measurements. Thus, while these remain highly desirable Level 1 measurements, it is understood that in some cases they will not be made.

Box 3. OCEAN ACIDIFICATION AND ITS MEASUREMENT

The International Panel on Climate Change (IPCC) Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems (2011, p. 37) has defined Ocean Acidification as "a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean."

In more detail, the chemical reactions underlying the process of ocean acidification start with carbon dioxide (CO_2) in the atmosphere exchanging across the air-sea boundary and dissolving into seawater. Once in seawater, the dissolved CO_2 reacts with water (H_20) to form a weak acid known as carbonic acid (H_2CO_3). This weak acid quickly dissociates into a hydrogen ion (H^+) and a bicarbonate ion (HCO_3^-). A net result of ocean acidification, therefore, is an increase in the hydrogen ion content in the seawater, or the acidity.

In general, acidity is measured on the pH scale, which is defined as the negative log of the hydrogen ion concentration, in which a lower numerical value translates to a stronger acidity. Because pH is measured on a logarithmic scale, small changes in pH mean large changes in acidity. Since the beginning of the industrial era around 1750 the global mean surface seawater pH decreased from 8.2 to 8.1, corresponding to a 30% increase in acidity. The projected seawater pH decrease to around 7.8 by 2100 would correspond to an increase in acidity of about 150%. With current and anticipated levels of ocean acidification, seawater is still basic and not acidic. However, the effect of the added atmospheric CO_2 increases the seawater acidity as measured on the pH scale, so this effect is correctly termed "ocean acidification."

The increase in hydrogen ions in seawater from ocean acidification drives an additional reaction involving the carbonate ion (CO_3^{2-}). The additional hydrogen ions react with carbonate ion to form bicarbonate ion (HCO_3^-), thus reducing the availability of carbonate ions in seawater. This means there is less carbonate ions in seawater available for formation of calcium carbonate, and as a result, the "saturation state" of calcium carbonate is lowered. The saturation state of a mineral defines whether the chemical equilibrium favors dissolved or solid forms of the mineral. Two mineral forms of calcium carbonate, aragonite and calcite, are used by marine organisms (e.g., shellfish such as oysters and plankton such as pteropods that live inside their thin shells). During ocean acidification, the saturation state of these minerals is shifted toward dissolution. If the effect is strong enough, shell formation is prevented or dissolution of existing shells occurs.

Assessing ocean acidification and calcium carbonate mineral saturation state is not straightforward due to technological and logistic limitations. There are four variables that "constrain" the carbon system relative to ocean acidification: pH, carbon dioxide partial pressure (pCO_2), total alkalinity (TA), and dissolved inorganic carbon (DIC). Common practices include the following approaches.

- Collection of seawater samples for laboratory analyses of DIC and TA is a standard practice if ship or fixed platform access to the water allows. Parameters of interest, such as pH and aragonite saturation, can be derived via commonly available software (e.g., CO2SYS). Some calculations require nutrients and other variables.
- As of 2014, commercially available sensors are only common for measurement of pH and pCO_2 in the ocean. Sensors capable of measuring either with the high precision required to detect the ocean acidification signal currently are relatively expensive and sophisticated, though work is underway to develop lower cost and more accurate sensors.
- Use of empirical proxies, such as more easily and accurately measured variables (salinity, temperature, oxygen), to estimate pH and aragonite saturation has skill in oceanic waters but has yet to be established for estuarine waters where other factors may interfere.

Coral habitats: For habitats dominated by photosynthetic calcifiers (warm-water corals, coralline algae), in addition to the above 'generic' Goal 1 Level 1 measurements, the following additional measurements are considered necessary:

- Biomass of biota
  - Corals or coralline algae, other photosynthesizers (macro-algae, seagrasses)
- Changes in net ecosystem processes
  - Calcification/dissolution (NEC: net ecosystem calcification)
  - Production/respiration (NEP: net ecosystem production).

For non-photosynthetic cold-water corals, typically occurring at depths of 200-2000 m, it is highly desirable that biomass and changes in net ecosystem processes are also measured in a standardized way.

7.1.2 GOAL 1 Level 2 Measurements

The optimal suite of Goal 1 Level 2 measurements is conditional on site location, season, and hydrographic conditions; they are also question-dependent. Recommended measurements include:

- Nutrients
- Bio-optical parameters (beam C, backscatter, turbidity, absorption)
- Currents
- Meteorology
- Net community metabolism (NCM)
- Trace metals
- ^{18}O and ^{13}C
- Export production
- Particulate inorganic carbon (PIC) and particulate organic carbon (POC)
- Atmospheric pCO_2
- Phytoplankton species

In reality, some of these measurements are currently more likely Level 3 measurements (see definition, above), and that distinction may actually vary in different systems.

For warm-water coral habitats, the following measurements were specified as necessary in some areas or instances:

- Processes
    - Freshwater input
    - Nutrient input (especially for inshore reefs)
    - Sediment input
- Wind (for oxygen-derived net primary production)

7.2 Measurements for GOAL 2: understanding ecosystem response to OA

There are two aspects when considering the interface of biology and ocean acidification:

i. What are biological responses to ocean acidification (i.e. how will ecosystems respond to OA with regard to metabolic rates, morphology, and community composition)?

ii. What effect does biology have on ocean acidification (i.e. how do species, communities and ecosystems affect local carbon chemistry)?

The second question needs to be considered in the context of both Goals 1 and 2. This question notes the biological contribution to pH and other aspects of carbonate chemistry. As reflected in the Goal 1 sections above, some biologically relevant measurements are required. Thus, fluorescence and light are defined as generic Goal 1 Level 1 measurements to help assess photosynthesis and respiration, along with the other Goal 1 Level 1 measures, including oxygen (for respiration) and salinity (for freshwater input). While the remainder of the discussion in this section is focused on the first question only (Goal 2: the biological/ecosystem responses to OA), there is inherent coupling of these two questions.

In the context of Goal 2, a conceptual structure for the effects of OA on ecosystems is depicted in Figure 3 that illustrates direct effects of CO_2 and pH on organisms, as well as indirect effects of OA on ecosystems and ecosystem services.

GOA-ON will focus on specific measurements within this conceptual structure to resolve thresholds of response to ocean acidification in relation to site-specific baselines. We acknowledge, however, that defining and making the biological measurements required for Goal 2, at current levels of technology, are more difficult than for the physical and chemical measurements required for Goal 1.

Experimental work on biology plays an important role in determining which aspects of the marine ecosystem will likely be vulnerable to changing chemical conditions. While experiments are not explicitly part of GOA-ON (since we are establishing an "observing" network), the Network will help inform experimental site selection, experimental laboratory treatment levels (identify conditions the species studied are already encountering in their natural environments), and identify rapidly changing eco-regions where more intensive, experimental studies are needed., Results from experimental work will be used to inform GOA-ON, by updating core observational parameters (e.g., identify aspects of the biological system that are most sensitive to OA, and aspects of the changing carbon chemistry – CO_2, bicarbonate, saturation state, protons – that have greatest effect on biology) and may be used in combination with the chemical observing data to generate global biological vulnerability maps.

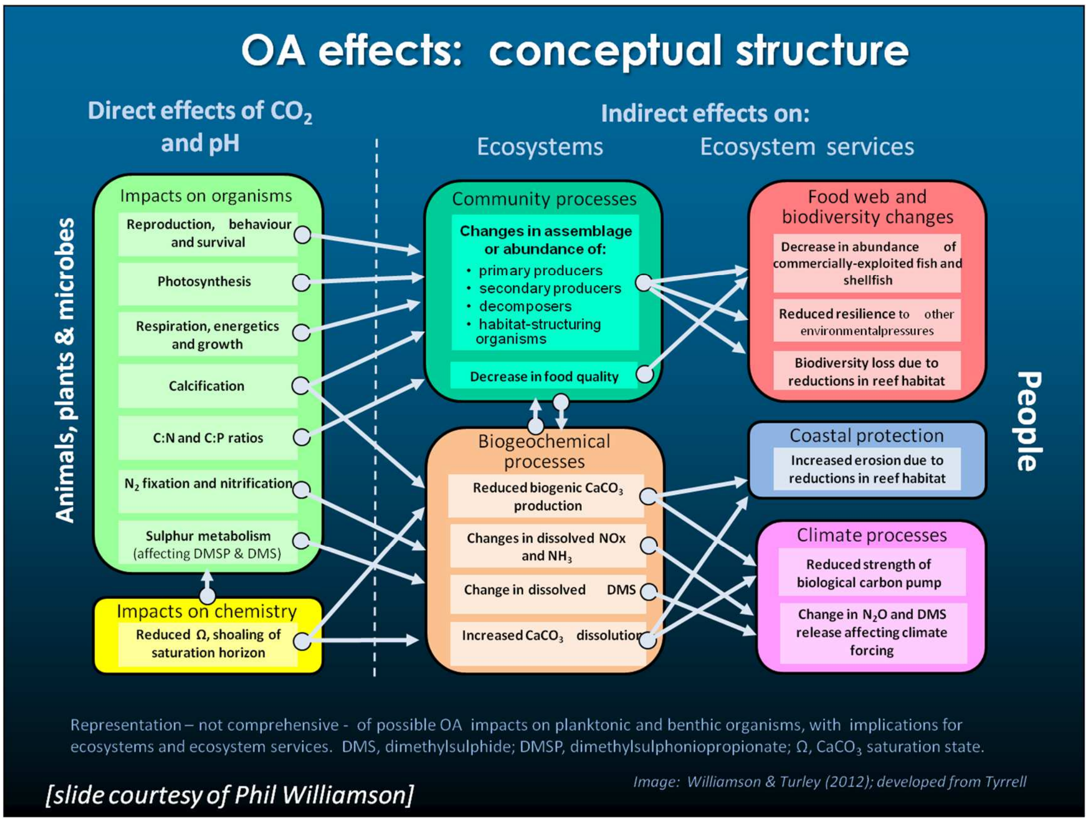

Figure 3. Conceptual model of the effects of ocean acidification on ecosystems illustrating direct effects of CO_2 and pH on organisms, as well as indirect effects of OA on ecosystems and ecosystem services. Source: adapted from Williamson & Turley, 2012.

7.2.1 GOAL 2 Level 1 measurements

Addressing Goal 2 at the broadest scale requires the measurement of biomass or abundance of functional groups, listed below, contemporaneous with the physical and chemical measurements for Goal 1 that achieve at least 'weather' data quality.

- Biomass/abundance of:
  - Phytoplankton
  - Zooplankton
  - Benthic producers and consumers (shelf seas and nearshore)

Biomass of calcified versus non-calcified species is desired, as is measuring the timing of changes in abundance, e.g., blooms, community shifts, pigment changes. Zooplankton should include both micro- (e.g., protists) and meso- (i.e., multicellular) plankton as well as meroplankton, where applicable.

Further recommendations for Goal 2 Level 1 measurements for broad climatic regions and specific ecosystem types are as follows:

Polar: Phytoplankton and zooplankton biomass/abundance; phytoplankton functional types; particulate inorganic carbon (PIC); sunlight (e.g., photosynthetically active radiation, (PAR))

Temperate: Phytoplankton and zooplankton biomass/abundance; calcified to non-calcified plankton abundance; phytoplankton functional types; PIC; sunlight (PAR)

Tropical: Phytoplankton and zooplankton biomass/abundance; size fractionated chlorophyll; sunlight (PAR); turbidity; colored dissolved organic material (CDOM, including via remote sensing)

Nearshore: Phytoplankton, zooplankton, and benthic producers and consumers abundance/biomass; calcified to non-calcified plankton and benthos abundance; chlorophyll; total suspended solids (TSS)/turbidity; CDOM; nutrients; sunlight (PAR).

Coral habitats: For Goal 2 Level 1, most of the necessary measurements for warm- and cold-water coral habitats have already been specified above under Goal 1 Level 1; i.e. biota biomass and distribution; net ecosystem calcification/dissolution; net primary production (if applicable), net production, and respiration rates. Additionally for Goal 2 Level 1, it is recommended to obtain information on:

- Biota: The population structure of corals; the population structure of macroalgae; the biomass, population and trophic structure of cryptobiota; population structure of urchins; and architectural complexity
- Processes: The NEP:NEC ratio, food supply rate and quality and bioerosion rates at specific sites.
- Habitat: Further characterization of the chemical habitat through sediment mineralogy/composition; organism mineral content; alkalinity anomalies; and the vertical profiles of saturation state over time (for cold-water corals)

7.2.2 GOAL 2 Level 2 measurements

Goal 2 Level 2 measurements primarily add measurements to help elucidate more information about the biota functional groups and responses to OA including:

- Processes and rates (e.g., production and export)
- Chemical speciation (e.g., C, N, P and phase)
- Species distributions (e.g., key species or groups)

For specific regions and ecosystem types, Goal 2 Level 2 recommendations are:

Polar: Primary production; export flux rate; net community production (NCP); net community calcification (NCC); nutrient uptake rates; taxonomy; sea algae.

Temperate: Primary production; export flux rate; NCP; calcification rates; remineralization; dissolution; particulate organic carbon/dissolved organic carbon (POC/DOC, especially size fractionated); particulate organic nitrogen/dissolved organic nitrogen (PON/DON, especially size fractionated); transparent exopolymeric particles (TEP); particulate organic phosphorus (POP); fatty acid measurements; benthic processes: burial deposition, benthic respiration, calcification, and production.

Tropical: Primary production; export flux rate; NCP; DOC; DOM; N/P ratios; nitrate/phosphate ratios; satellite imagery; algal pigments (especially via high-performance liquid chromatography, HPLC); currents (e.g., via acoustic doppler current profilers, ADCPs); zooplankton vertical/spatial and temporal variation; zooplankton grazing rates.

Nearshore: Phytoplankton primary production; pelagic and benthic NCP; community structure; trophic interactions/del ^{18}O; disease; phytoplankton species (for harmful algal blooms, HABs, include species and toxicity).

7.3 Measurements for GOAL 3: data to optimize modeling for OA

7.3.1 Global/Basin and Climate Scales

To improve the capacity of existing models to yield widespread information on global/basin scale ocean acidification status and trends, the following recommendations are made:

- Carry out large scale surveys – a snapshot of ocean acidification conditions – to constrain models, with coordination of information at basin-scale using, repeat hydrography, ships of opportunity and historical sections.
- Achieve better spatial coverage of moorings with OA-relevant physical, chemical, and optical measurements, matched with targeted process studies (rate measurements, budget, community structure) at time series stations and key locations to improve biogeochemical model structures and parameters.
- Include bio-optical and chemical sensors (e.g., nitrate, oxygen, and pH) on more Argo floats, with temporal sampling frequencies appropriate to establishing interconnections of water masses.
- Extend spatial coverage of gliders, based on modeling simulations and experiments to establish new glider and survey sections.

- Connect global/basin ocean acidification conditions with shelf seas and coastal processes, using coastal OA observing networks and modeling capabilities to examine impact of coastal seas on the open ocean.

7.3.2 Shelf Seas/Coastal – Weather and Climate Scales

To improve our capability to use coastal models for physical, chemical, and biological applications relevant to OA and to optimize a coupled monitoring-modeling network for the coastal and shelf seas, the following recommendations are made:

- Make better use of regional and coastal physical modeling capabilities, especially near-real time and short-term (weather) forecasting information, using coastal OA observations to provide necessary information to establish and improve physical-biogeochemical models.
- Evaluate and constrain model performance at ocean acidification observing locations (moorings, glider and survey sections); produce near-real time and short-term forecasts of OA conditions; extract and simplify model results to develop a set of usable OA indicators for the key locations.
- Identify new ocean acidification observing locations and modify existing OA monitoring networks, based on physical-biogeochemical model results and numerical experiments, including observing system simulation experiments (OSSE).
- Integrate ocean acidification measurements with water quality information (oxygen, nutrients/loading, turbidity, etc.) and plankton community structures (survey data, bio-optical and remote sensing measurements); incorporate this information into physical-biogeochemical models to produce three-dimensional (3-D) distribution on dominant temporal scales.
- Develop models for pelagic and benthic organisms with connections to the habitat and ocean acidification conditions; contribute to the development of ecosystem models to link with living marine resource management (integrated ecosystem assessment).

7.3.3 Warm-water Coral Systems – Weather and Climate Scales

To provide for the capability to assess ocean acidification impacts on coral reef systems the following recommendations are made.

- Develop very high spatial resolution (e.g., 100 meters scale) circulation models for coral reef ecosystems; these models will need to address connectivity related issues, linking with basin/regional models.
- Incorporate wave models into circulation models, which will address impact of extreme weather events.
- Obtain OA observing information to constrain initial and boundary conditions for targeted reef systems (smaller spatial domain and shorter temporal simulations).

- Achieve multiple model simulations and future projections of OA conditions and key physical processes (temperature, sea level, light, frequency and intensity of extreme events) for coral reef systems.
- Use models to capture habitat conditions and ecosystems connections.

8. Global OA Observing Network Design: Spatial and Temporal Coverage

The current and proposed spatial and temporal coverage of GOA-ON is considered below with regard to three broad ecosystem domains: the open ocean, shelf seas and coasts (including estuaries and the nearshore), and warm-water coral reefs. Issues discussed include: the desired spatial and temporal resolution of the measurements; identification of gaps and high vulnerability areas; and priorities for filling gaps or building capacity for new measurements.

8.1 Current status

8.1.1 Current status: Open ocean

On a global scale, the main building blocks of a network for assessment of ocean acidification in the open ocean are well established and quality-controlled by the ocean community (e.g., CLIVAR/CO_2 Repeat Hydrography Program (GO-SHIP) , OceanSITES, SOOP, SOCAT), but there is need for filling-in certain areas, some components lack sustained funds, and some components need enhancements.

8.1.2 Current status: Shelf seas and coasts

For these environments, a global network for assessment of ocean acidification needs to be constructed. At the regional level, there are some systems in place with some ability to leverage OA observations on existing infrastructure (e.g., World Association of Marine Stations, International Long-Term Ecological Research Network), but also many gaps. These elements need a globally consistent design which must also be coordinated and implemented on a regional scale. In some areas, there is a need for significant infusion of resources and infrastructure to build the necessary capacity.

8.1.3 Current status: Coral reefs

For assessment of ocean acidification and its impacts on warm-water coral reefs, a globally consistent coral reef OA observing network needs to be constructed. On a regional scale, there is some observing capacity in some regions but observing assets may not cover the extent of variability that organisms observe and should be supplemented by site-specific studies. The U.S. National Coral Reef Monitoring Program (maintained by NOAA) for Atlantic and Pacific coral reefs can serve as a model.

8.2 Recommendations for Spatial-Temporal Network Design

8.2.1 Network design recommendations: Open ocean

A framework for GOA-ON in the open ocean largely exists but components need further attention in order to bring this to full realization. Recommendations utilizing existing programs and technologies are:

i. Utilize the **GO-SHIP** global plan (Figure 4) and similar research cruises for critical OA components of the Network. The existing repeat hydrography program provides essential foundation to establish OA conditions at global scale. Expansions include a sampling density sufficient to map aragonite saturation horizon and addition of bio-optical measurements for calibrating Argo floats.

ii. Participate in **VOS and SOO** global planning (Figure 5; bimonthly temporal resolution at roughly 10-15° latitude spacing at some locations) and enhance its coverage, especially to the southern hemisphere, Indian Ocean, Arctic, and other locations to be scoped.

iii. Contribute to **OceanSITES** deepwater reference stations (Figure 6; roughly half have OA sensors now) and enhance this plan to address gaps (e.g., high latitudes, Labrador Sea, South Pacific gyre, Bermuda-Atlantic timeseries (BATS), etc.) or keep operational (e.g., Japanese site at 60° S). High vulnerability sites with insufficient coverage include the Arctic and Southern Oceans, the 'coral triangle' in south-east Asia, and off Peru.
   - Optimize this for GOA-ON by the OA community adding/sharing funding, operational effort/cost/ship time/people, sensors, data processing/management, or in a few cases taking ownership of complete moorings.

iv. Collaborate with IGMETS to introduce carbon measurements at time series stations where they are not yet conducted, and ensure that relevant time-series are included in the GOA-ON efforts.

v. Participate in ongoing developments to collect OA relevant data with sufficient quality from **floats,** such as Argo floats (Figure 7)**.**
   - Comparison with ship-based measurements is essential to the success of this effort. Utilize a smaller number of additional biogeochemistry-ecosystem Argo floats (Figure 8) that would have shorter profile intervals (e.g. 6 hours) more relevant to biological processes

vi. Contribute to development of **glider** technology for deployment, especially to target high vulnerability areas. Will need attention to address biofouling and depth restrictions for the subsurface gliders.

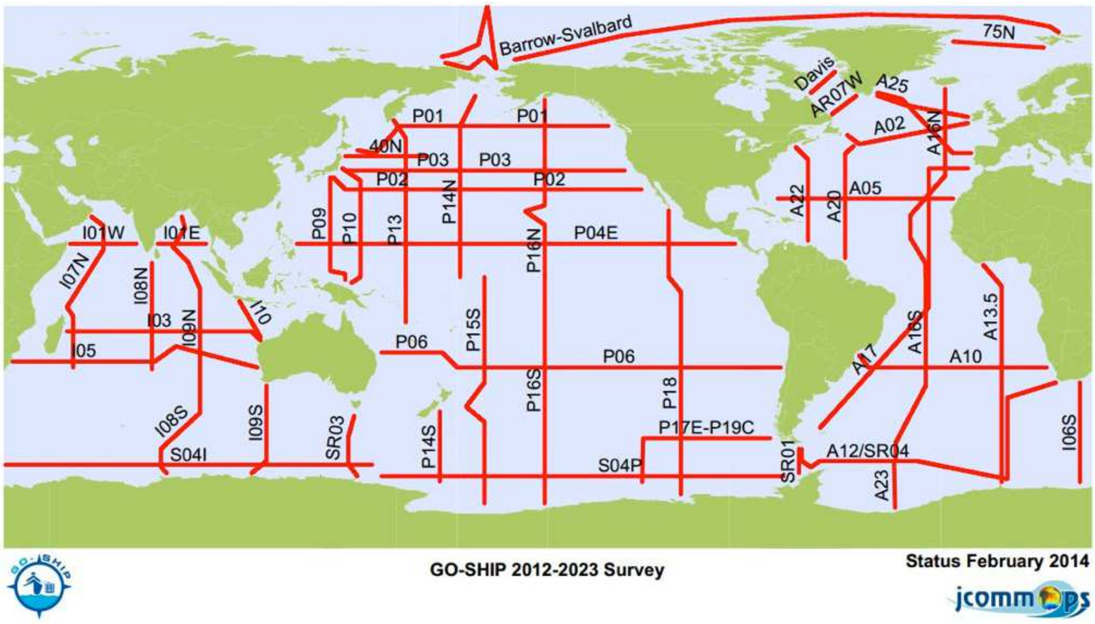

Figure 4. Map of GO-SHIP Repeat Hydrographic Surveys; current status as of February 2014. Source: .

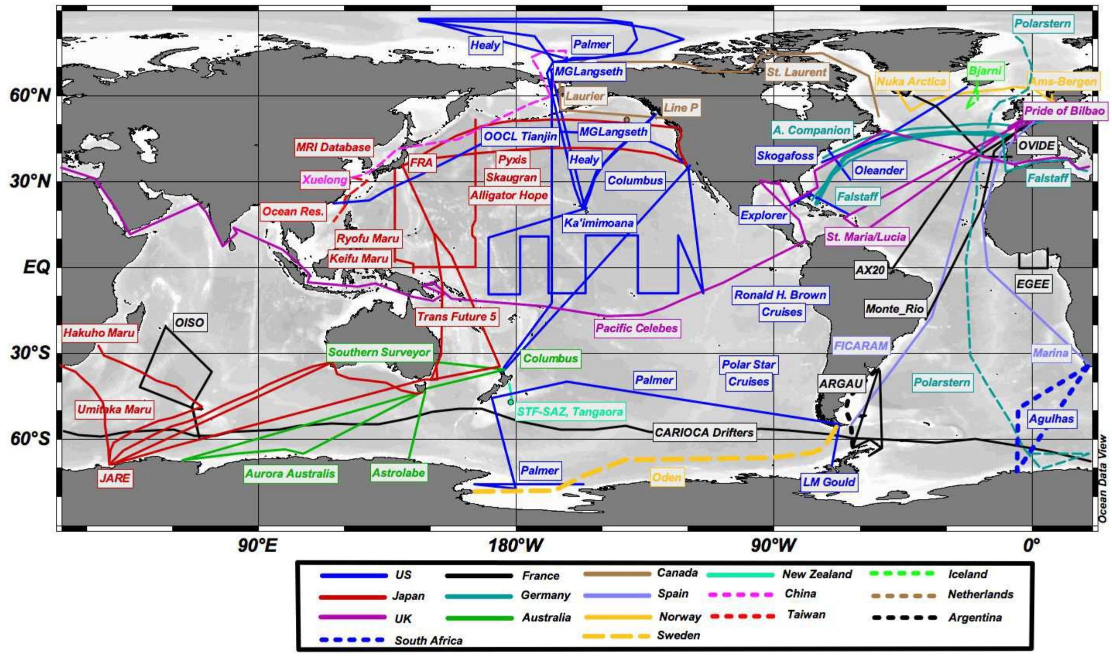

Figure 5. Map of global ship of opportunity/CO_2 cruise tracks for underway measurements, current status as of March 2014. Source: .

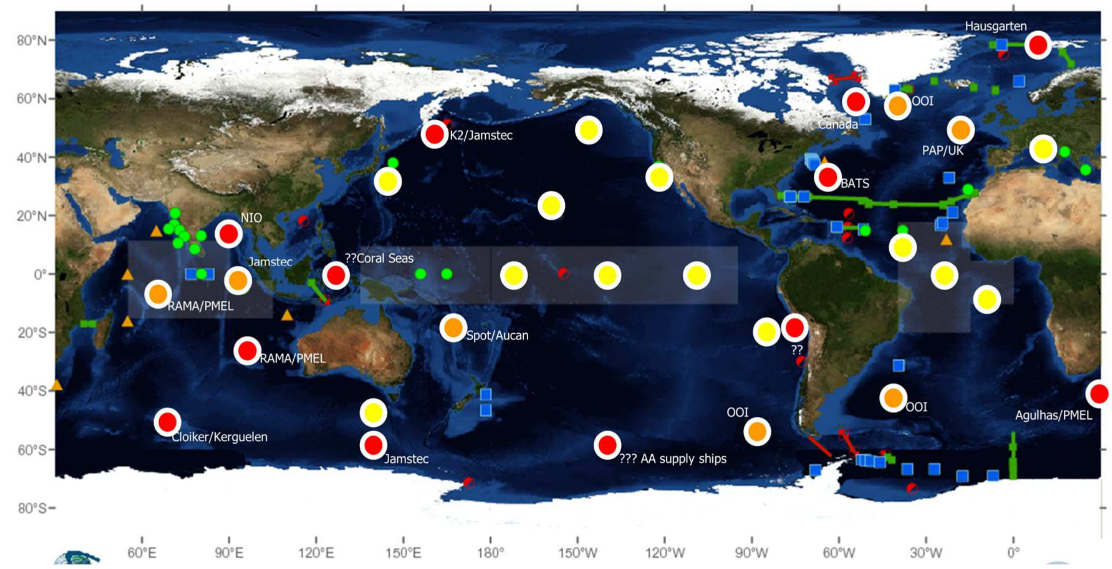

Figure 6. Map of OceanSITES mooring locations for time-series measurements. The large colored dots with white border denote where OA assets potentially exist; color coding denotes status of OA variable measurements: Yellow = some OA variables during 2012; Orange = likely to start soon; Red = unlikely to occur without strong push from OA community. Ignore small green, blue and red symbols for purpose presented here. Source: Uwe Send (Scripps Institute of Oceanography, CA, USA).

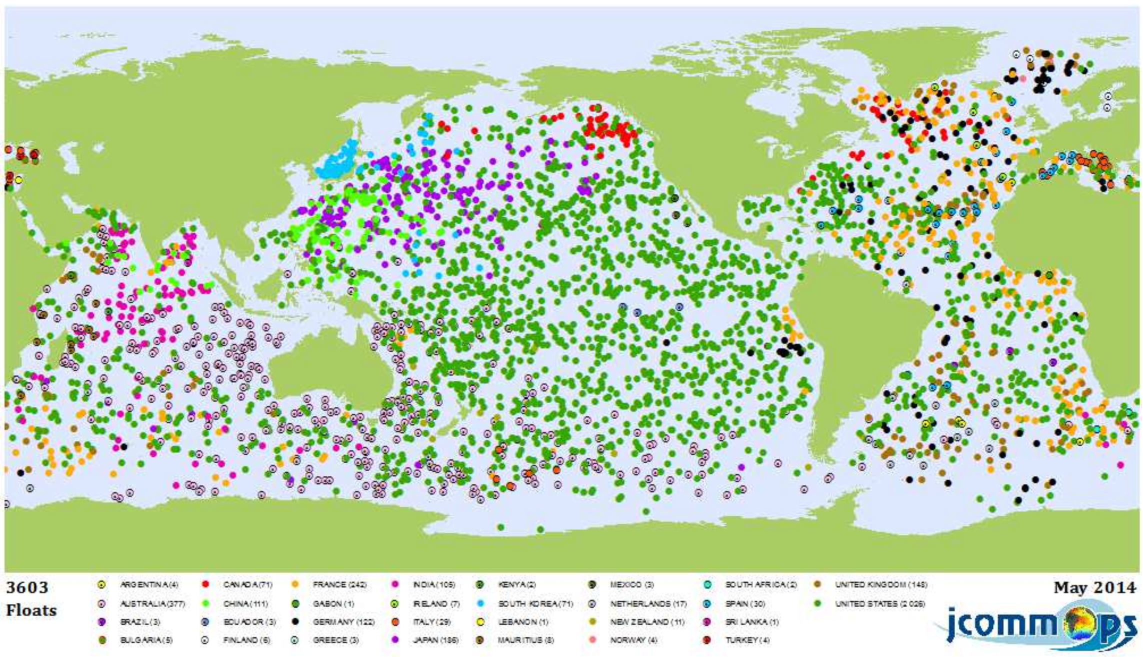

Figure 7. Map of ARGO Float locations, current status as of May 2014. Some of the floats are equipped with biogeochemical sensors, as shown in Figure 8.
Source: .

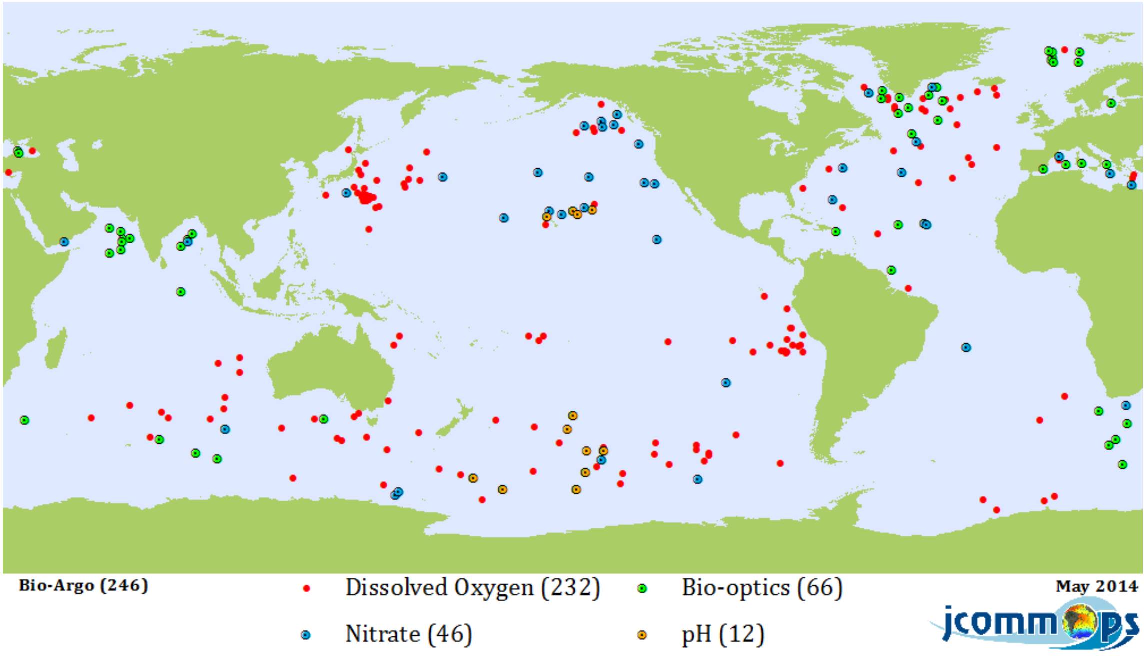

Figure 8. Map of ARGO floats with biogeochemical sensors, current status as of May 2014. Source: .

8.2.2 Network design recommendations: Shelf seas and coasts

The status of a Global OA Observing Network in the coastal area is much less developed than that for the open ocean. There is no existing framework for most regions and no global framework for coastal areas, so the Network's design needs a more fundamental approach.

i. Create OA capacity:
   - Make an inventory of current observing capacity and expand subset to include OA observations (building on existing OA or other related observing, where available)
   - Prioritize adding OA measurements to existing biological time-series, especially where variability is documented
   - Be proactive in treatment of geographic gaps (e.g., Africa, etc). Use statistical/quantitative analyses to target new assets to optimal locations, also to provide a means of filling gaps (data extrapolation in a resource-limited world).

ii. Aim for balanced representation:
   - Represent the full range of natural variability (and presumably ecosystem resilience); include high vulnerability areas and areas with important economic resources. For example, upwelling zones versus stable water

column areas should both be captured. While the former may see lower pH in surface waters, organisms may be better adapted to variation, thus more resilient.

iii. Work within regions to optimize capacity and relevance.

- Encourage use of coastal observational nodes as ideal locations to conduct explanatory process studies
- Improve upwelling indices for nearshore areas (to indicate upward transport of deep waters, thus useful in creating proxy methods for extrapolating sparse observations across complex coastal zones).

8.2.3 Network design recommendations: Coral reefs

Capacity is adequate in some areas, but non-existent in others; a better balance is needed for GOA-ON to be truly global.

i. Utilize current observing assets including moorings/buoys in:

Hawaii (Kaneohe Bay), Bermuda (Hog Reef, Crescent), Great Barrier Reef (Heron Island) and Ningaloo (W Australia), Chuuk, Florida Keys (Cheeca Rocks), and Puerto Rico (La Parguera). However, these do not cover the extent of variability that organisms observe, nor do they provide any coverage of the Coral Triangle region or non-U.S. Caribbean, and thus should be supplemented.

ii. Aim for balanced representation, monitoring across gradients of latitude, biodiversity, warm vs. deep coldwater systems, and relatively pristine vs. impacted.

iii. The observing system should also give us insight as to what reefs may look like in 50-60 years, so include natural-CO_2 seeps.

8.2.4 Network design recommendations: system wide

There are several items that the Network system design needs to address that are not specific to any one of the above ecosystem categories:

- Data coverage gaps – a global network requires adequate distribution over all sectors of the world, not currently achieved. To attain the global character of the Network, spatial gaps have to be filled.
- 'Threatened' ecosystems – such systems can be defined on the basis of proximity to perceived thresholds, rate of change in carbonate chemistry conditions, or socio-economic vulnerability of the ecosystem. Additional effort should be made by the global OA community, working with IOCCP, OA-ICC and others, to identify such 'hot spots' and initiate OA observations if currently lacking.
- Ecosystem function – because OA is an environmental condition with implications for biota, the ecosystem function must be a focal point for observations. Ecosystem function refers to the collective intraspecific and

interspecific interactions of the biota, such as primary and secondary production and mutualistic relationships, as well as the interactions between organisms and the physical environment, such as nutrient cycling and material exchange. This calls for integration of physical, chemical, and biological sensing.

- Data and information access – data from the Network should be available to and linked with the broad community including those sectors of society that benefit from the data in making business and management decisions. The Ocean Acidification international Reference User Group (closely linked to the Ocean Acidification International Coordination Centre) is expected to become a focal point for bringing messages to industry, governments and the public.

9. Data Quality Objectives in the context of Goals and Sampling Platforms

The various sampling platforms currently available to the community are differentially suited to the first two GOA-ON goals and its two data quality levels.

- Data satisfying Goal 1 'climate' data quality criteria currently can only be obtained from direct analysis of water samples, typically necessitating sampling from cruises or ships of opportunity. Cruise and ship of opportunity sampling can also offer sporadic validation of 'weather' quality measurements.
- Data of Goal 1 'weather' quality are often collected on moorings or fixed platforms, but must be calibrated, as noted above, by validation samples of 'climate' quality. The added benefit of mooring/fixed platforms is that these platforms can be used to obtain high temporal resolution data that is useful for elucidating mechanisms of variation. Such high temporal resolution measurements are also valuable in the 'climate' context to verify means in highly dynamic systems i.e. to increase knowledge on representativeness of spot sampling from cruises.
- Goal 1 is also aided by 'weather' quality data obtained from gliders or floats yielding high spatial resolution data that is useful for assessing vertical variation (shoaling of saturation horizons) and elucidating mechanisms. The same caveats as for moorings/fixed platforms apply, that these should be calibrated.
- Data for Goal 2 currently requires cruise-based sampling for all variables, except for some indicators relevant to phytoplankton and production, e.g., fluorescence and Photosynthetically Active Radiation (PAR).

Needs: In order to accurately satisfy goals in all environmental regimes, the applicability of method to environment is key, and should be documented. Important issues for consideration include:

- Need to prepare certified reference materials (CRMs) for a range of environments (including low salinity), with expansion of capacity for CRMs to match demand as the Network increases in size.
- Need to establish carbon system dissociation constants for lower salinity waters.
- Need for standard operating procedures (SOPs) for autonomous sensors and clear guidelines as to appropriate quality control for such sensors.
- Need for detailed documentation of what people are doing, including validation, SOPs, metadata. It is the intent of GOA-ON to build access to these items via the GOA-ON map server.

10. Global OA Observing Network Products

An important output of the GOA-ON is informational products on OA status that can inform scientists, managers, policy makers, educators, other stakeholders and the public at large. The products listed below will aid scientists and resource managers in environmental assessments. The suite of GOA-ON products will need to be expanded to products that also address societal and economic impacts, (e.g., Cooley and Doney, 2009; Turley and Gattuso, 2012; Mathis et al., 2014).

10.1 GOAL 1 priority products:

- For all environments:
  - Easy access to global OA data of known quality, made available in compatible formats, downloadable and interoperable, for use in development of products below.
- Open ocean
  - Seasonally resolved global and regional surface maps of pH, DIC, total alkalinity, saturation states, pCO_2
  - Interactive web-based maps of time series data
  - Products showing decadal changes in pH, DIC, total alkalinity, saturation states, and pCO_2 from repeat hydrography data
  - Maps of export production (e.g., of PIC and POC) below the winter mixed layer
  - Vertical sections showing subsurface carbonate saturation state.
- Shelf seas and coastal
  - Seasonally resolved surface maps of pH, DIC, total alkalinity, carbonate saturation states, pCO_2
  - Interactive maps of time series data near-real-time (NRT) data access
  - Alkalinity anomaly values
  - Maps of subsurface of OA-relevant variables (e.g., pH, total alkalinity, saturation states, pCO_2.
- Coral reefs
  - DIC/Alkalinity relationships for different coral reef sites
  - Biogeochemical model output for OA-relevant variables at coral reef sites

- Time series representation of alkalinity deviation from seawater salinity.

10.2 GOAL 2 priority products

These are desired ecosystem products from the GOA-ON, but recognizing that not all will be possible with Level 1 measurements only. Products would be spatially resolved and analyzed in relation to carbonate system variability.

- Benthic recruitment and recruitment variability
- Planktonic calcifiers (phyto- and zooplankton) abundance and variability
- PIC:POC (calcifiers:non-calcifiers) in planktonic and benthic organisms
- Phytoplankton biomass, primary production, and assemblage shifts
- Habitat compression/expansion of pelagic & benthic organisms
- Comparative resilience of managed vs. unmanaged ecosystems
- Susceptibility to phase shifts.

10.3 GOAL 3 priority products

Model predicted changes in seawater properties, biological population changes, and geographic regions of variability, especially for certain key biological functional groups:

- Keystone species (benthic, planktonic)
- Calcifying plankton

11. GOA-ON Data Management

11.1 Data Sharing: Consensus vision and solutions to roadblocks

GOA-ON data sharing is essential to achieving the payoff of the Network. The consensus statement regarding sharing of ocean domain GOA-ON data approved by participants of both GOA-ON workshops is:

> "The participants in the Global OA Observing Network agree to support in principle the construction of a web portal that
> - builds on current capacity and capabilities,
> - accepts data streams from relevant data centers,
> - provides visual and data link capabilities, and
> - exhibits synthesis products for the ocean scale."

Recommended metrics for data sharing for ocean data from the GOA-ON are to:

- Provide the quality controlled data for synthesis products
  - 6 months (desired) – 2 years (longest possible) after collection
  - Work to accelerate the quality control (QC) process of these data
- Post on-line the near-real-time (NRT) data
  - Visual graphic of data (realistically possible)

- Download of data (desired)
- Work to accelerate the QC process of these data

- Provide the data via public web portal

It is recognized this is sometimes problematic in shelf seas and coastal waters, due to national policies. Additional roadblocks to data sharing were identified by the workshop; however, solutions were also identified (Box 4).

Box 4: ROADBLOCKS AND SOLUTIONS TO DATA SHARING

1. Data Quality Assurance/Quality Control: it takes time; there are no standardized procedures; capacity lacking
- Solution: On the GOA-ON portal
  - Improve access to Data Centers e.g. CDIAC, and highlight role of data managers to facilitate data sharing,
  - Create standardized procedures for the Network
  - Engender trusting relationship between data providers and data managers
  - Post information on benefits of data sharing

2. Institutional boundaries or national regulations which limit open data sharing
- Solution:
  - Develop terms of reference for Global OA Network
  - Network provides contacts for EEZ paperwork to facilitate data collection across international boundaries
  - Assess if synthesis products can be shared even if actual data are quarantined

3. There is no consistent data portal
- Solution:
  - Develop a GOA-ON data portal

4. Scientists' reluctance to share data
- Solution:
  - Publication, acknowledgement
  - Highlight examples of benefits on portal
  - Provide version control
  - Provide DOI for datasets

5. Funding insufficient
- Solution:
  - Build data management funding into national scientific projects and programs
  - Outreach to scientists regarding data expectations
  - Provide relevant products to users that are highly valued

11.2 Data Management Plan

There is opportunity for the GOA-ON Data Management Plan to build on an existing data management plan for ocean acidification that NOAA has developed with other U.S. agencies (including DOE, NASA, NSF, and USGS) and with academic representatives. An "Interagency Ocean Acidification Data Management Plan: Draft One," has been developed and published on-line (NODC, 2012). The essence of that plan (also known as the "Declaration of Interdependence") was shared with the Seattle workshop participants, who welcomed it. The declaration is appended to this report (Appendix 3). There is ongoing activity led by the U.S. National Oceanographic Data Center (NODC) to begin implementing that plan.

The data management vision for GOA-ON, building on recommendations from both GOA-ON workshops, is to provide effective long-term scientific data management using interoperable online data services allowing for human- and machine-to-machine data discovery and access. This vision includes specific considerations for:

- Provision of time limits to assure that data sharing of coastal, shelf sea, and open ocean data can occur on timescales appropriate to their need.
- Deployment of a web data portal allowing optimal data discovery, access, integration, and data visualization from collection to granular-level OA data and data products, using common inter-operable web data services. This web portal would build on current capacity and capabilities, accept data streams from relevant data centers, and provide visual and data link capabilities and data synthesis products for the ocean scale.
- Coordination of a scientific data management and data flow framework that builds on existing infrastructure and scientific requirements over the long-term in coordination with the OA-ICC.
- Adoption of best practice metadata procedures/protocols following international standards (e.g., ISO) to facilitate data discovery, use of DOIs or similar identifiers to provide clear data provenance and attribution.
- Adoption of international OA long-term archival centers for OA observational, biological, model data, and data products. These centers would provide data integration where possible using interoperable online data services consistent with the proposed web data portal.

12. GOA-ON Governance

A preliminary governance structure based on main working linkages was established at the St Andrews workshop (Figure 9). It was decided that, until more formal arrangements are made, the organizing committee of the 2nd workshop would provide the basis for the GOA-ON Executive Council (see Appendix 4 for members), representing both scientific and institutional (national and international) interests.

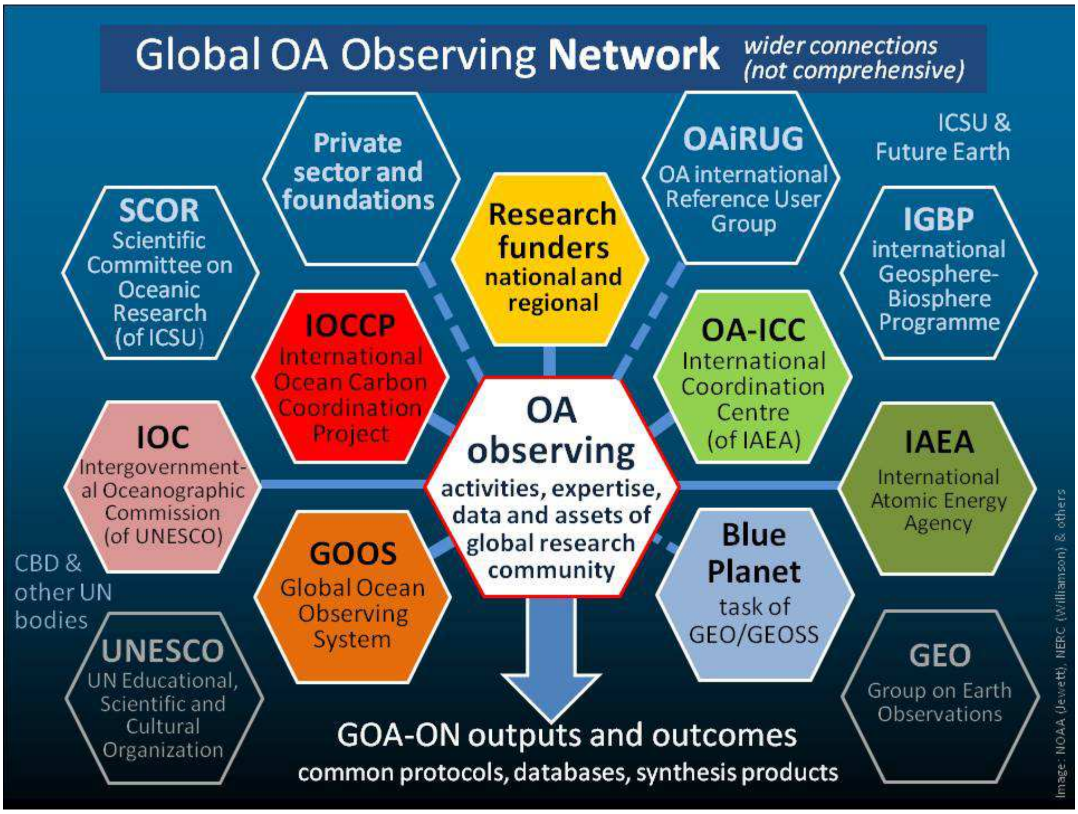

Figure 9. Representation of the basic matrix constituting GOA-ON and the primary entities responsible. The entities represented by colored shapes are represented on the Executive Council and have committed to providing either direct or in-kind support to core organizing activities. The outlined shapes are parent bodies.

The main national and international entities directly represented on the Executive Council are expected to continue to provide both in-kind and direct support for GOA-ON organizational activities, including future meetings and staff involvement, with additional support potentially available for training, technological infrastructure and other forms of capacity building.

The roles for the core components and entities of GOA-ON included in Figure 9 and as outlined in the St Andrews workshop include:

i. **OA observing activities, data, expertise and assets of global research community:** these components collectively represent the central and most important piece of the network which encompasses all the actual assets in the water, the data collected and, most importantly, the scientists who oversee their operation and interpret the data.

ii. **National and Regional Funders:** will provide the human, technical and financial resources for the actual implementation of the observing assets around the globe. Several, such as US/NOAA and Australia/CSIRO and

UK/NERC, are represented on the Executive Council. Staffing for the GOA-ON website and for management of the network will likely be provided by national funders but may also be supported by the OA-ICC (below).

iii. **Ocean Acidification International Coordination Centre (OA-ICC):** will coordinate the activities and expertise of scientists across national observing efforts; help develop standardized data management approaches; and promote capacity building for developing countries. A leadership role in the development of a global OA observing network has been identified as a priority task for the OA-ICC initiative.

iv. **International Atomic Energy Agency (IAEA):** will support the OA-ICC project as its parent body; it also provides state-of-the-art scientific facilities at its Monaco laboratory, and will also support development of new scientific observing capacity in under-observed regions through its global capacity building networks.

v. **Blue Planet task of the Group on Earth Observations**: includes an activity focused on the GOA-ON and provides access to: 1) novel international audiences (with emphasis on remotely-sensed data collection) and 2) their scientific networks in developing regions.

vi. **Global Ocean Observing System (GOOS, sponsored by IOC, UNEP, WMO and ICSU)**: is current developing the Framework on Ocean Observing (FOO) which will also guide the GOA-ON requirements. GOA-ON scientists are participating in the biogeochemical panels for the FOO.

vii. **Intergovernmental Oceanographic Commission (IOC, of UNESCO)**: supports GOOS as its main parent body but also has its own Ocean Acidification project which will, in near term, work on organizing the next GOA-ON scientific meeting. It will also connect other international initiatives on biogeochemical ocean observation with GOA-ON.

viii. **International Ocean Carbon Coordination Project (IOCCP, of IOC/UNESCO and SCOR)**: will, through its Ocean Acidification task, coordinate the development of requirements for the biogeochemical essential ocean variables for GOOS (see above) and with other international carbon observing efforts.

The GOA-ON Executive Council has responsibility for ensuring the core functioning of the Network. Its current roles and activities include to:

- Finish the Plan (this document), with input from the broader Network membership, and overseeing the process for its further refinement
- Maintain and extend the Network membership
- Liaise with other relevant bodies and organizations
- Promote awareness of the need for the Network at the regional, international and intergovernmental level and with potential funders

- Assist in obtaining resources for specific geographic areas of high concern
- Ensure international data management, to provide centralized access to distributed data centers
- Keep the map (currently supported by NOAA PMEL and NOAA OAP) of OA observing assets robust, current, and useful
- Encourage development of synthesis products based on data from GOA-ON
- Provide transboundary (across national boundaries) scientific sharing to ensure high quality observing
- Work with The Ocean Foundation to maximize the benefits of financial support provided through the Friends of GOA-ON (see section 13, below).

13. GOA-ON Support and Resource Requirements

GOA-ON needs to support, or facilitate the support of, a functional Network in its entirety. The Network is not just sensors in water; it also requires support for all of the following capacities:

- Physical infrastructure, i.e., the platforms and sensors
- Operations and maintenance, i.e., the humans and communities of practice that will run the network and keep it functioning
- Data Quality Assurance/Quality Control (QA/QC), i.e., the standards and application thereof to keep the data quality suitable to the intended use.
- Analytical and synthesis activities, i.e., the humans and models to analyze the data, synthesize it into useful data products, and interpret and publish its significance to a variety of audiences
- Capacity, i.e., the new infrastructure and job force that will have to be built and provided for in order to bring GOA-ON to a global reality.

It is recognized that individual countries are likely most interested in what is happening within their respective national waters, and are expected to provide financial resources to support ocean acidification observing within their Exclusive Economic Zones (EEZs). However, deployment of observing assets needs to be preceded by identification of local or regional scientific expertise to support the deployment. Furthermore, those countries with sufficient resources should also contribute to the support of observing activities outside EEZs, i.e. the open ocean and in other regions outside national jurisdiction, e.g. the Antarctic/Southern Ocean.

Although a wide range of bodies provided sponsorship support for the two GOA-ON workshops, and are continuing to assist in the Network development (Section 12), such support has to date been relatively modest and *ad hoc.* To date, GOA-ON itself does not have the resources to initiate new observations, nor does it have dedicated project staff or the equivalent of project office arrangements.

In recognition that the full implementation of GOA-ON would require a funding mechanism to receive income and commit expenditure for such purposes and to further develop GOA-ON and its products, the **Friends of the Global Ocean**

Acidification Observing Network was established in spring 2014, through **The Ocean Foundation (TOF).** This was announced at the international 'Our Ocean' conference, hosted by the US Department of State (Washington DC, 16-17 June 2014). TOF is US-based charity that works with a community of donors to promote healthy ocean ecosystems and benefit the human communities that depend on them. The creation of the Friends of GOA-ON as an affinity group will enable direct and indirect financial support through grants and services. Founding supporters include the Henry Foundation, the Oak Foundation and the Norcross Wildlife Foundation. Their support will complement the financial assistance obtaining through national and intergovernmental sources, providing additional flexibility to direct resources to where they are most needed.

14. GOA-ON Web Portal

Participants in the Network have agreed to support the GOA-ON web portal (http://www.goa-on.org/), currently maintained by US NOAA PMEL, which provides:

- A detailed overview of the GOA-ON goals, elements, governance, and network members, with relevant links to each of the components
- A visual and interactive map representation of the platforms in the network, building upon current capacity and capabilities; the interactive component for each platform will include:
    - a detailed summary of the project
    - a direct link to the project website(s)
    - a list of the parameters being measured
    - direct links to original data at data centers and/or project websites
    - direct links to data synthesis products
- Links to other relevant OA websites and portals, including visual and data link capabilities to process studies, manipulative experiments, field studies, and modeling activities
- Clear links to existing data centers, data management plans, and relevant data managers
- Access to graphics, data, and GOA-ON data synthesis products for a variety of users with specific OA information needs
- Links to workshops, references, and other relevant GOA-ON activities
- A means for new participants to join the GOA-ON.

Forthcoming links from the web portal will provide information on agreed upon data QC protocols, and access to future GOA-ON data synthesis products.

15. GOA-ON Outcomes and Applications

The outcomes from GOA-ON are globally distributed quality-assured data, near-real-time data, and data synthesis products that:

- Facilitate research (new knowledge) on OA and its drivers
- Communicate status of OA and biological response

- Enable forecasting/prediction of OA conditions.

These OA data can be used to provide relevant products to variety of users. Specific applications with information needs relevant to OA are:

- Scientific inquiries
- International policy especially carbon emission policies
- Education and outreach as related to forecasts
- Socio-economic impact forecasts
- Potential fisheries impacts
- Cultural impacts
- Insurance on fisheries yields
- Coral reefs and livelihood, especially developing countries
- Regulatory needs
- International food and economic security
- Shellfish aquaculture (widespread globally) adaptation strategies;
- Shore protection, tsunami protection as related to implications for coral reefs
- Tourism as related to coral reef and marine habitat degradation.

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Commonwealth Office); the NOAA Ocean Acidification Program, the Global Ocean Observing System (GOOS), including the U.S. Integrated Ocean Observing System (IOOS), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO), and the University of Washington.

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Appendix 1. Global OA Observing Network workshop participants

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Alette Yniguez[2] - University of the Philippines, The Philipines

Appendix 2. Schedules of the Seattle and St. Andrews GOA-ON workshops

Appendix 2.1 Seattle Workshop Agenda

Day 1: 26 June 2012

08:15 - 09:00: Workshop Introduction: Welcome, Logistics, and Opening Remarks: Jan Newton (UW-NANOOS, Workshop Leader) and Steve Weisberg (SCCWRP, Workshop Facilitator); Dean Lisa Graumlich, College of the Environment, University of Washington; Clark Mather on behalf of Congressman Norm Dicks, U.S. House of Representatives

09:00 - 10:15: Session A: What is a Global Ocean Acidification Observing Network and why do we need one?

The purpose of this session is to address and discuss the following questions:

1. What has been the activity to date regarding a global ocean acidification observing network and why is one needed?
2. What are the likely benefits to the various stakeholders (academic, governmental, and commercial) that could be provided by global ocean acidification observing network?
3. What kind of ocean acidification observing network is needed to provide such benefits?
4. How can it be coordinated at the international level?

Overview talk: "What are the benefits of a Global Ocean Acidification Observing Network?" by Libby Jewett, NOAA OA Program Director, (9:00 – 9:20) followed by Plenary Discussion (9:20 – 10:15).

10:30 - 12:00 Session B: Network Design: Building from existing programs and assessing strategic needs for new locations

The purpose of this session is to address and discuss the following questions:

1. What are the existing global carbon observing efforts?
2. How do we define Tier 1 and Tier 2 measurements?
3. What are the obvious gaps in existing efforts when viewed as a global ocean acidification observing network?
4. What should a global ocean acidification observing network consist of (survey cruises, moorings, floats, gliders, etc) and where should assets be located?

Overview talk: "What are the possible components of an ocean acidification network based on existing resources?" by Richard Feely, NOAA PMEL, (10:30 – 11:15) followed by Plenary Discussion (11:15 – 12:00).

13:00 - 17:00 Session C: Global Ocean Acidification Observing Network System Design: *1. Definition*

The purpose of this session is to define attributes of the observing network system design.

13:00 Charge to Breakout Groups – Jan Newton/Steve Weisberg

13:30 - 15:00 **Breakout Session I: Defining the Global Ocean Acidification**

Observing Network's System Design

Breakout Group 1: Time Series Measurements and Platform Location Network Design: This group will focus from a temporal and spatial perspective, what scales need to be accounted for in the system design. They will focus on questions 2 & 3. They will also focus on the rationale for the observations in various regions.

Uwe Send, Simone Alin, Maciej Telszewski

Breakout Group 2: Physical/Chemical Measurements Network Design:
This group will focus from a physical/chemical disciplinary perspective, what measurements need to be accounted for in the system design. They will focus on question 1, but also 2 and 3.

Andrew Dickson, Burke Hales, Kitack Lee

Breakout Group 3: Biological Measurements Network Design:
This group will focus from a physical/chemical disciplinary perspective, what measurements need to be accounted for in the system design. They will focus on question 1, but also 2 and 3.

Bruce Menge, Rebecca Albright, Joe Salisbury

Questions to be addressed by each group:

1. What minimum physical, chemical and biological parameters (Tier 1 and Tier 2) should be measured for each platform? Where? At what depths?

2. What is the desired spatial and temporal resolution of these measurements?

3. Where are the gaps in present observing systems? Where are the areas of high vulnerability? Where do we need new measurements?

15:30 - 17:00 **Continue Breakout Session C**

Day 2: 27 June 2012

08:30 - 11:30 Session C: Global Ocean Acidification Observing Network System Design: *2. Group Consensus* - Steve Weisberg, Facilitator

The purpose of this session is to hear back from breakout groups re the observing network system design and to reach consensus and/or identify unresolved issues.

08:30 - 10:00 **Breakout Group Reports** (30 min per group)
10:30 - 11:30 **Plenary Discussion** to reach consensus on Observing System Design and/or identify unresolved issues

11:30 - 12:00 Session D: Data Quality Control and Validation for the Global OA Observing Network in the context of International Coordination: *1. Current International Network Coordination*

The purpose of this session is to introduce the current level of international OA network coordination.

Presentation by Richard Feely for Jean-Pierre Gattuso, Chair, SOLAS-IMBER Ocean Acidification Working Group

13:30 - 17:00 <u>Session D</u>: Data Quality Control and Validation for the Global OA Observing Network in the context of International Coordination: *<u>2. Data Quality Control and Validation</u>*

The purpose of this session is to address and discuss the following questions:

1. What are appropriate data quality goals for the proposed measurements?
2. What activities are required to achieve these goals?
3. What should be the network system requirements for data availability and data management? (e.g., data delivery schedule, metadata, data archival centers)
5. What data synthesis efforts are essential to achieve the benefits of the observing system?

Overview talk: "What are the possible guidelines for data quality control and validation?" by Hernan Garcia, NODC, and Emilio Mayorga, NANOOS-IOOS, (13:30 – 14:00) followed by Plenary Discussion (14:00 – 14:30).

14:30 - 15:30 **Breakout Session II. Defining Data Quality Control and Validation for the Global OA Observing Network in the Context of International Coordination**

The purpose of this session is to define data QC and validation attributes of the observing network system design.

14:30 Charge to Breakout Groups – Jan Newton/Steve Weisberg

<u>Breakout Group 1</u>: Cruises and Ships of Opportunity
Benjamin Pfeil, Hernan Garcia, Cathy Cosca

<u>Breakout Group 2</u>: Fixed Platforms (e.g., Moorings & Piers)
Mark Ohman, Adrienne Sutton, Simone Alin

<u>Breakout Group 3</u>: Floats and Gliders
Jeremy Mathis, Libby Jewett, Jenn Bennett

Questions to be addressed by each platform-defined group:

1. What are appropriate data quality goals for the proposed Tier 1 and Tier 2 measurements on each platform?
2. What data quality requirement system is needed to achieve goal?
3. What should be the network system requirements for data availability and data management? (e.g., data delivery schedule, metadata, data archival centers)
4. What are potential data products and strategies for the required data synthesis needed to make the products?

16:00 - 17:00 **Continue Breakout Group Discussions**

Day 3: 28 June 2012

08:00 - 10:15 Session D: Data Quality Control and Validation in context of International Coordination: *3. Group Consensus*

The purpose of this session is to hear back from breakout groups re the data QC and validation needs for the network and to reach consensus and/or identify unresolved issues.

08:00 - 09:30 Breakout Group Reports (30 min per group)

09:30 - 10:15 Plenary Discussion to reach consensus on Data QC/V in context of International Coordination and/or identify unresolved issues

10:45 - 12:00 Session E: International Data Integration and Network Coordination

Plenary Discussion on the International Coordination for Data and Network Integration – Steve Weisberg, Facilitator

The purpose of this session is to identify if we have consensus on data sharing and what roadblocks inhibit data integration and network coordination.

Presentation by Jan Newton of the "Declaration of Interdependence" from the Consortium for the Integrated Management of Ocean Acidification Data (CIMOAD)

Group poll: Do we have consensus to share data?

Identify roadblocks inhibiting data integration and network coordination on an international scale (take individual participant contributions)

1. What are ideas to overcome identified roadblocks?
2. How will we ensure that the discrete observing efforts become a network?
3. Should there be an official structure or a more organic collective?
4. What actions are needed to better integrate and coordinate the observation network?
5. What actions are needed to better integrate and coordinate data access?

13:00 - 15:30 Session F. Future Planning

The purpose of this session is to identify if we have consensus on vision for network and what next steps are.

1. Looking at the current/planned observing system vs. the vision for the system we have identified here to address gaps, do we a consensus view?
2. What tasks should be done first to move this effort forward?
3. What infrastructure will be needed to achieve this?
4. What has not been resolved and how shall this be addressed?
5. What is an appropriate timeline, with milestone steps, for implementation of the network?
6. How should we define the network association and what is the most efficient way to integrate efforts in the future? (e.g., regular meetings, website, steering committee, etc.)

16:00 - 17:00 Workshop Summary: Recap Action Items and Identify Points of Contact for follow-up

Appendix 2.2 St. Andrews Workshop Agenda

Day 1: 24 July, 2013 **Joint session of UKOA ASM and GOA-ON workshop**

13.30 **Ocean acidification research in a wider context**

Chair: Carol Turley

1. From national to international, from science to policy (*Phil Williamson*)
2. Awareness and action on ocean acidification (*Jane Lubchenco*)
3. Environmental protection in the North Atlantic (*Darius Campbell, Executive Secretary, OSPAR Commission*)
4. Framework for ocean observing and ship-based time series aiding the design of a global OA observing network (*Maciej Telszewski*)
5. Update on the OA International Coordination Center (*Lina Hansson*)
6. Promoting technological advances: the X-Prize (*Paul Bunge*)

Discussion

15.20 **The development of a global ocean acidification observing network**

Chair: Bronte Tilbrook

1. Why we need a global OA network (*Wendy Watson-Wright, Executive Secretary IOC/UNESCO*)
2. Where we are now: outcomes from Seattle 2012 *(Jan Newton)*
3. An introduction to the global OA observing asset map (*Cathy Cosca)*

Discussion: where we want to be

16.30 **Global observing of ocean acidification and ecological response**

Chair: Arthur Chen

1. Observing OA in regional seas: a modeller's perspective (*Jerry Blackford*)
2. OA processes and impacts in US coastal waters (*Richard Feely*)
3. Observing OA in upwelling regions off South America (*Rodrigo Torres & Nelson Lagos*)
4. Observing OA and its impacts in the Pacific-Arctic (*Jeremy Mathis*)
5. Observing OA and its impacts in the Southern Ocean (*Pedro Monteiro*)

Discussion

18.00 Session ends

Day 2: 25 July 2013 **GOA-ON Workshop**

08.40 **Aims and objectives of the workshop – and the network**

Chair: Libby Jewett

1. Goals for the meeting (*Jeremy Mathis and Phil Williamson*)
   Discussion: Defining how the network will operate – and what it will deliver

09.30 **Best practice for analytical chemistry** (Goal 1, Level 1)

1. Review best practices for OA chemistry ('weather' v 'climate') as decided at Seattle (*Andrew Dickson*)
2. Comparison of carbonate chemistry software packages – and implications for GOA-ON (*Jim Orr*)

Discussion

10.00 **Short presentations on physico-chemical variability (and how it may be affected by biology) in specific environments**

Chair: Maciej Telszewski

What are the key science issues relevant to establishing long-term observing programmes?

- Shelf seas: from sea surface to sediment (*Kim Currie)*
- Riverine influences on coastal systems (*Joe Salisbury*)
- Polar-specific issues (*Liqi Chen*)
- Tropical-specific issues (*Moacyr Araujo*)

Discussion

Short presentations on ecosystem response to OA in specific habitats and environments

Chair: Mark Ohman

11.15 What are the key science issues relevant to establishing long-term observing programmes?

- Pelagic ecosystems in shelf seas (*Ulf Riebesell*)
- Warm water corals (*Rusty Brainard*)
- Cold water corals (*Murray Roberts*)
- Other coastal benthic and intertidal habitats (*Steve Widdicombe*)

Discussion

12:15 **Charge to the breakout groups** *(Libby Jewett)*

Tropical regional seas (excl coral reef habitats)	**Temperate regional seas** (excl cold-water coral habitats)	**Polar regional seas**	**Warm and cold -water corals**	**Nearshore, intertidal & estuarine habitats**
Leaders: Eric de Carlo Rodrigo Kerr	***Leaders: Bruce Menge Kirsten Isensee***	***Leaders: Richard Bellerby Jeremy Mathis***	***Leaders: Dwight Gledhill Andreas Andersson***	***Leaders: Sam Dupont Terrie Klinger***

14.00 **Breakout session #2**

Discussion on how to observe relevant variability – continued, with same breakout groups (but opportunity for some individuals to change groups). Overall goal: to fine-tune the recommendations for the Ecosystem Response part of the network, developing the optimal observing system for the various ecosystem types, with variables appropriate for model testing and development. Issues requiring attention include:

- What suite of chemical and biological measurements comprise the essential (Level 1) and desirable (Level 2) at the regional level (maximising congruence with Seattle report)?
- What spatial and temporal coverage is essential/desirable for these measurements?
- Are there regionally-specific 'hot spots' (high rate of change or potential for high impacts) for prioritising national and international effort?

Break-out leaders as identified above

Tropical regional seas (excl coral reef habitats)	**Temperate regional seas** (excl cold-water coral habitats)	**Polar regional seas**	**Warm and cold -water corals**	**Nearshore, intertidal & estuarine habitats**

15.15 Time for breakout leaders to put together their reports. Opportunity for poster-viewing and other informal discussions.

15.45 **Data sharing and management**

Chair: Jim Orr

Introductory presentation: "The vision for GOA-ON data management" (*Hernan Garcia & Alex Kozyr*). Discussions on:

1. Specific issues for shelf seas/coastal regions, and integrating chemistry and biology – building on decisions at Seattle
2. Use of the GOA-ON map as a starting point – scope for including links to databases and datasets
3. Importance of metadata
4. Lessons learnt from SOCAT, ICES and EPOCA *(to include inputs from Dorothee Bakker, Evin McGovern and Lina Hansson)*
5. Linkages to other relevant data management activities , via IOCCP and GOOS

17:30 – POSTER SESSION

Day 3: 26 July, 2013 **GOA-ON workshop**

09:00 **Summary of workshop progress and outcomes. Consensus on how to observe chemistry and biology in shelf seas and coastal regions, across full climatic range**

Chair: Jan Newton

Two slides from each of yesterday's break out groups (summarizing main outcomes), presented by breakout leaders.

Discussion

10.45 **Consensus on how to observe chemistry and biology in shelf seas and coastal regions – continued**

Chair: Jeremy Mathis

1. What measurements
2. How frequently
3. Spatial distribution
4. How precise do we need the data to be, given the high level of variability
5. What technology advancements need to be made? For example, how can gliders contribute and how can we promote that?

13.00 **Discussion on what do we mean by a "network"? Are there examples of observing networks that we can use as a model? What are the optimal governance arrangements?**

Chair: Libby Jewett

Contributions by Maciej Telszewski and Phil Williamson – plus wide input from participants

13.45 **Regional coverage and capacity building. Can we identify specific regions (currently under-observed but potentially subject to rapid change) which this global OA community will target for improved coverage in the next 2-3 years? How will additional partnerships be created, expertise developed and national funding secured to help fill gaps in the map?**

Chair: Phil Williamson

Contributions by Jim Orr (re role of OA-ICC and iOA-RUG), plus wide input from participants

14.30 **Next steps/ synthesis products:** Jeremy Mathis and Phil Williamson

15.15-~16.40 ***Workshop Organizing Committee meeting:*** *implementing the agreed actions*

Appendix 3. An excerpt from the "Interagency Ocean Acidification Data Management Plan" produced by NOAA, US IOOS, and NODC.

"**Declaration of Interdependence of Ocean Acidification Data Management Activities in the U.S.**"

Whereas Ocean Acidification (OA) is one of the most significant threats to the ocean ecosystem with strong implications for economic, cultural, and natural resources of the world;

Whereas our understanding of OA and our ability to: 1. inform decision makers of status, trends, and impacts, and 2. research mitigation/adaptation strategies, requires access to data from observations, experiments, and model results spanning physical, chemical and biological research;

Whereas the various agencies, research programs and Principal Investigators that collect the data essential to understanding OA often pursue disparate, uncoordinated data management strategies that collectively impede effective use of this data for synthesis maps and other data products;

Whereas an easily accessible and sustainable data management framework is required that:
i) provides unified access to OA data for humans and machines; ii) ensures data are version-controlled and citable through globally unique identifiers; iii) documents and communicates understood measures of data and metadata quality; iv) is easy to use for submission, discovery, retrieval, and access to the data through a small number of standardized programming interfaces;

Whereas urgency requires that short-term actions be taken to improve data integration, while building towards higher levels of success, and noting that immediate value can be found in the creation of a cross-agency data discovery catalog of past and present OA-related data sets of a defined quality, including lists of parameters, access to detailed documentation, and access to data via file transfer services and programming interfaces;

Whereas this integration will also benefit other users of data for a diverse array of investigations;

Therefore, be it resolved that the 31 participants of an OA Data Management workshop in Seattle, WA on 13-15 March 2012 established themselves as the Consortium for the Integrated Management of Ocean Acidification Data (CIMOAD) and identified three necessary steps forward to achieve this vision:

1. The endorsement of agency program directors and managers for collective use of machine-to-machine cataloging and data retrieval protocols (including THREDDS/OPeNDAP) by each agency data center to provide synergistic, consolidated mechanisms for scientists to locate and acquire oceanographic data;

2. The commitment of the scientific community to establish best practices for OA data collection and metadata production, and the leadership to provide a means of gaining this consensus; and

3. The endorsement of agency program directors and managers to direct data managers to collaborate to develop the system articulated above and contribute to a single national web portal to provide an access point and visualization products for OA.

We, the undersigned, request your attention to this matter and commitment to bringing this vision to reality in the next five years for the benefit of our nation and contribution to the global understanding.

Signatories to the Declaration of Interdependence of Ocean Acidification Data Management Activities:

1. Alexander Kozyr, Oak Ridge National Lab, CDIAC
2. Burke Hales, Oregon State U
3. Chris Sabine, NOAA PMEL
4. Cyndy Chandler, WHOI & NSF BCO-DMO
5. David Kline, UCSD
6. Emilio Mayorga, UW & NANOOS-IOOS
7. Hernan Garcia, NOAA NODC
8. Jan Newton, UW & NANOOS-IOOS
9. Jon Hare, NOAA NMFS NEFSC
10. Kevin O'Brien, NOAA PMEL
11. Kimberly Yates, USGS
12. Krisa Arzayus, NOAA OAR NODC
13. Libby Jewett, NOAA OAP
14. Libe Washburn, UCSB
15. Liqing Jiang, NOAA OAP
16. Michael Vardaro, OSU & OOI
17. Mike McCann, MBARI
18. Paul McElhany, NOAA NMFS NWFSC
19. Peter Griffith, NASA
20. Philip Goldstein, OBIS-USA
21. Richard Feely, NOAA PMEL
22. Roy Mendelssohn, NOAA SWFSC
23. Samantha Siedlecki, UW & JISAO
24. Sean Place, U South Carolina
25. Simone Alin, NOAA PMEL
26. Steve Hankin, NOAA PMEL
27. Tom Hurst, NOAA NMFS AFSC
28. Uwe Send, UCSD SIO
29. Sarah Cooley (via phone), WHOI and OCB
30. Derrick Snowden (via phone), NOAA IOOS
31. Jean-Pierre Gattuso (via phone) OAICC

Appendix 4. Global OA Observing Network Executive Council (as of October 2015)

Co-chairs:
Libby Jewett (US - NOAA)
Bronte Tilbrook (Australia – CSIRO)

Science Members:
Richard Bellerby (PR China - East China Normal University and Norway - NIVA)
Fei Chai (US - University of Maine)
Chen-Tung Arthur Chen (Taiwan - National Sun Yet-Sen University)
Minhan Dai (PR China - Xiamen University)
Sam Dupont (Sweden - University of Gothenberg)
Richard Feely (US - NOAA)
Kitack Lee (South Korea - POSTECH)
Jeremy Mathis (US - NOAA)
Pedro Monteiro (South Africa - CSIR)
Jan Newton (US - University of Washington/IOOS)
Benjamin Pfeil (Norway - University of Bergen)
Christian Vargas (Chile - Universidad de Concepcion)
Phillip Williamson (UK – UKOA/NERC)

Program Representative Members:
Albert Fischer (GOOS/IOC-UNESCO)
David Osborn (IAEA/OA International Coordination Centre)
Maciej Telszewski (IOCCP)
Henrik Enevoldsen (IOC-UNESCO)

Technical Architect:
Cathy Cosca (NOAA)

Support:
Kirsten Isensee (IOC-UNESCO)
Lina Hansson (OA International Coordination Centre/IAEA)

For information, write: info@goa-on.org

Appendix 5. List of Abbreviations

ADCP	Acoustic Doppler current profiler
BATS	Bermuda Atlantic Time-Series
C	Carbon
$CaCO_3$	Calcium carbonate
CDOM	Colored dissolved organic matter
CLIVAR	Climate Variability and Predictability Study
CO_2	Carbon dioxide
CRMs	Community reference materials
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DON	Dissolved organic nitrogen
GOA-ON	Global Ocean Acidification Observing System
GO-SHIP	Global Ocean Ship-based Hydrographic Investigation Program
GOOS	Global Ocean Observing System
HABS	Harmful algal blooms
HPLC	High-performance liquid chromatography
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Sea
IGMETS	International Group for Marine Ecological Time Series
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IOC	Intergovernmental Oceanographic Commission
IOCCP	International Ocean Carbon Coordination Project
IOOS	Integrated Ocean Observing System
N	Nitrogen
NCC	Net community calcification
NCM	Net community metabolism
NCP	Net community production
NEC	net ecosystem calcification
NEP	net ecosystem production
NOAA	National Oceanographic and Atmospheric Administration
NPP	net primary production
NRT	Near real-time (data)
OA	Ocean acidification
OA-ICC	Ocean Acidification International Coordination Centre
OSPAR	Commission for the Protection of the Marine Environment of the North-East Atlantic
OSSE	Observing System Simulation Experiments
P	Phosphorus
PAR	Photosynthetically Active Radiation
pH	pH is the negative log of the hydrogen ion concentration in solution
PIC	Particulate inorganic carbon
POC	Particulate organic carbon
POP	Particulate organic phosphorus

SOCAT	Surface Ocean CO_2 Atlas
SOLAS	Surface Ocean-Lower Atmosphere Study
SOOP	Ship of Opportunity Program
SOPs	Standard operating procedures
TEP	Transparent exopolymeric particles
TSS	Total suspended solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
UK	United Kingdom
UKOA	United Kingdom Ocean Acidification Research Programme
USA	United States of America
VOS	Volunteer observing ship

GOA-ON

Global Ocean Acidification
Observing Network

GOA-ON

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www.goa-on.org

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