Global Ocean Acidification Observing Network:

Implementation Strategy

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Global Ocean Acidification Observing Network: Implementation Strategy

The GOA-ON Executive Council

Executive Summary:

The Global Ocean Acidification Observing Network (GOA-ON; www.goa-on.org) takes a collaborative international approach to document the status and progress of ocean acidification (OA) in open-ocean, coastal, and estuarine environments, to understand the drivers and impacts of ocean acidification on marine ecosystems, and to support the provision of spatially and temporally resolved biogeochemical data necessary to optimize modelling for ocean acidification.

This Implementation Strategy provides guidance on how to implement the GOA-ON Requirements and Governance Plan, including expanding ocean acidification observations, closing human and technology capacity gaps, connecting scientists regionally and globally, and informing about the impacts of ocean acidification. The aim is to provide guidance that will allow for comparability across the Network, while considering the potentially different requirements and impediments of regions. GOA-ON seeks to increase capacity allowing for synthesis of data for common products.

Further, the intent of this Implementation Strategy is to enable GOA-ON members to apply the vision of GOA-ON locally; however, we recognize that capabilities of members to put all aspects of the GOA-ON Plan into practice will vary. The Implementation Strategy offers practical information prompting members to approach GOA-ON's collective goals. The Implementation Strategy will be updated as information evolves.

GOA-ON Implementation Strategy

GOA-ON Executive Council, release date 15 April, 2019
Version 1.0

Introduction

The Global Ocean Acidification Observing Network (GOA-ON; www.goa-on.org) takes a collaborative international approach to document the status and progress of ocean acidification (OA) in open-ocean, coastal, and estuarine environments, to understand the drivers and impacts of ocean acidification on marine ecosystems, and to support the provision of spatially and temporally resolved biogeochemical data necessary to optimize modelling for ocean acidification. This Implementation Strategy is designed to support GOA-ON members in carrying out the network's goals.

GOA-ON is an international community effort, developed with global participation. The framework for GOA-ON activities, its goals and objectives were defined and published as the "Global Ocean Acidification Observing Network: Requirements and Governance Plan", developed from its first workshop in 2012. Two subsequent workshops and expanded capacity building efforts and outreach have resulted in substantial growth of the network to over 600 members from 94 countries as of March 2019.

GOA-ON has three main goals[1]:

1. **Improve our understanding of global OA conditions:**
    - Determine status and spatial / temporal patterns in carbon chemistry, assessing the generality and specificity of response to increasing carbon dioxide.
    - Document and evaluate variation in carbon chemistry to infer mechanisms (including biological) driving ocean acidification.
    - Quantify rates of change, trends, and identify areas of heightened vulnerability or resilience.
2. **Improve our understanding of ecosystem response to OA:**
    - Track biological responses in concert with physical/chemical changes.
    - Quantify rates of change and identify locations and species of heightened vulnerability or resilience.
3. **Acquire and exchange data and knowledge necessary to optimize modelling for OA and its impacts:**
    - Provide spatially and temporally resolved biological and biogeochemical data for use in parameterizing and validating models.

[1]The GOA-ON Goals are described in detail at: http://goa-on.org/about/goals.php

The activities of the GOA-ON community are directed towards making progress on these three main goals. This Implementation Strategy provides guidance on how to implement the GOA-ON Requirements and Governance Plan, including expanding ocean acidification observations, closing human and technology capacity gaps, connecting scientists regionally and globally, and informing about the impacts of ocean acidification. The aim is to provide guidance that will allow for comparability across the Network, while considering the potentially different requirements and impediments of regions. GOA-ON seeks to increase capacity allowing for synthesis of data for common products.

Further, the intent of this Implementation Strategy is to enable GOA-ON members to apply the vision of GOA-ON locally; however, we recognize that capabilities of members to put all aspects of the GOA-ON Plan into practice will vary. The Implementation Strategy offers practical information prompting members to approach GOA-ON's collective goals. The Implementation Strategy will be updated as information evolves.

The sections of this Implementation Strategy comprise:

1) **Framing the Issu**e: Information useful for articulating why participation in ocean acidification research supported by GOA-ON is important;
2) **Implementing GOA-ON via Regional Hubs and Capacity Building:** How to build observing capacity and improve regional coordination to close currently existing ocean acidification observing and knowledge gaps, including links to regional hubs of activity, and how to find mentorship and training opportunities;
3) **Implementing GOA-ON Goal 1: Measurement Quality:** Information on the measurement data quality goals;
4) **Implementing GOA-ON Goal 2: Biological Needs:** Recommendations on how to implement strategies to understand ecosystem response;
5) **Implementing GOA-ON Goal 3: Data Requirements for Projecting OA and its Impacts:** Insights on how to optimize model forecasting of OA and its impacts;
6) **Implementing GOA-ON's Data Management:** Guidance on data management and communication vision and objectives, including how to submit data and metadata to the GOA-ON data portal;
7) **Synthesis Products and Outreach:** Information on data synthesis products and outreach efforts;

Appendix: A compilation of useful references pertinent to GOA-ON and an acronym glossary.

GOA-ON is currently served by a Distributed Secretariat, with core staff supported by various national and international entities including the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), the International Atomic Energy Agency (IAEA) and the US National Oceanic and Atmospheric Administration (NOAA), and the University of Washington for managing the data portal and website. The role of the Distributed Secretariat is to provide scientific, technical and administrative support for the execution of the GOA-ON, under the guidance of the GOA-ON Executive Council (EC), comprised of international experts and organizational representatives. Close links exist with other organizations, including the U.S. based non-profit The Ocean Foundation.

Section 1: Framing the Issue

Anthropogenic carbon dioxide (CO_2) emissions have led to substantial increases in atmospheric CO_2 concentrations over the last two centuries. The atmospheric concentrations of CO_2 would be even higher, and the effects on climate change still more pronounced, if it were not for the oceans taking up approximately one quarter of the annual emissions of CO_2. However, the CO_2 taken up by the ocean causes changes in seawater carbonate chemistry, including decreases in seawater pH and dissolved carbonate ion concentrations, that are collectively known as 'ocean acidification.' Increased CO_2 concentrations and a lower pH can challenge or promote intrinsic physiological processes in marine organisms. The reduction in carbonate ions can lead to waters with a saturation state value for calcium carbonate (aragonite and calcite forms) that is less than one; these waters have been termed corrosive[2] since dissolution of the calcium carbonate form will be favored. While climate change and ocean acidification are both driven by CO_2 emissions, their impacts are different.

Field and laboratory research have shown that ocean acidification can have a range of adverse impacts on marine plants and animals including corals, fishes, plankton, and shellfish. These impacts could put food security and livelihoods at risk worldwide. Accordingly, quantifying changes to seawater chemistry is necessary to determine where the most dramatic changes may occur, and how local marine resources may be affected.

Ocean acidification conditions vary over a range of spatial scales. Conditions in the open ocean may be different from those closer to shore, which is typically a more dynamic environment. Open-ocean surface water acidification primarily results from the absorption of atmospheric CO_2 and from shoaling of naturally acidified subsurface waters. Coastal acidification is also influenced by upwelling, freshwater input, and riverine output/non-point source runoff. OA also varies by latitude, and while the rate of change is most dramatic at low latitudes, corrosive conditions are more likely to be seen in colder high-latitude waters. These differences in OA

[2] Aragonite saturation values below 1.0 in seawater are often referred to as corrosive conditions, dissolution of pure aragonite and unprotected aragonite shells will begin to occur (Feely, R. A., Byrne, R. H., Acker, J. G., Betzer, P. R., Chen, C. T. A., Gendron, J. F., & Lamb, M. F. (1988). Winter-summer variations of calcite and aragonite saturation in the northeast Pacific. Marine Chemistry, 25(3), 227-241)

conditions are likely to impact resident flora and fauna in different ways, with related geographic variability in impacts on food security and livelihoods.

Given the substantial spatiotemporal variability in OA conditions throughout the world's oceans, international collaboration is needed to quantify ocean chemical and biological changes. GOA-ON addresses this need by working towards its three goals. The GOA-ON Executive Council includes representatives from relevant international and intergovernmental bodies, including IOC-UNESCO, the IAEA, the International Ocean Carbon Coordination Project (IOCCP) and the Global Ocean Observing System (GOOS).

Ocean acidification has been recognized by the United Nations as an area in need of immediate action, including in the UN Informal Consultative Process on the Law of the Sea[3], the 2030 Agenda[4] and the UN Framework Convention on Climate Change (Global Climate Observing System)[5]. Within the 2030 Agenda the aim of Sustainable Development Goal (SDG) 14 is to "conserve and sustainably use the oceans, seas, and marine resources". The SDG 14 consists of 10 targets[6]. GOA-ON is particularly involved in supporting countries to achieve Target 14.3, which aims to "minimize and address the impacts of ocean acidification, including through scientific cooperation at all levels." The progress made towards this target by all UN Member States is measured by the corresponding indicator 14.3.1 "Average marine acidity (pH) measured at agreed suite of representative sampling stations". IOC-UNESCO, as the custodian agency for this indicator, was tasked with the development of an indicator methodology[7]. This methodology provides detailed guidance to scientists and countries in terms of what to measure, and how, following best practices guidelines established by the ocean acidification research community. It also provides recommendation on how to report the collected information in a manner that ensures it is transparent, traceable and usable for global comparison of pH measurements. Through this process, GOA-ON directly contributes to the achievement of SDG Target 14.3. The collective expertise of GOA-ON in the areas of science and policy aids the development of a guiding vision for the collection and sharing of ocean chemistry data, which in the future is envisaged to extend to biological data.

Ocean acidification gained further recognition through its adoption as a Global Climate Indicator in 2018. The Global Climate Indicators[8] are a suite of seven parameters, presented to the United

[3] UN Informal Consultative Process on the Law of the Sea: https://undocs.org/A/68/159

[4] Agenda 2030 and the Sustainable Development Goals: https://sustainabledevelopment.un.org/

[5] Global Climate Observing System Global Climate Indicators: https://gcos.wmo.int/en/global-climate-indicators

[6] More information about the Sustainable Development Goals (SDGs) and target 14.3 can be found here: https://sustainabledevelopment.un.org/sdg14;

[7] SDG 14.3.1 Indicator Methodology: http://www.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=21938

[8] For more on the Global Climate Indicators see: https://gcos.wmo.int/en/global-climate-indicators

Nations Framework Convention on Climate Change (UNFCCC), that describe the changing climate, and avoid reducing climate change to a temperature change. The Indicators include key information for the most relevant domains of climate change, such as the atmospheric composition, energy, ocean, water and the cryosphere. The inclusion of ocean acidification in this list sends a strong signal of recognition and the importance of guidance to achieve global alignment in observing ocean acidification, as provided in the SDG Indicator 14.3.1 Methodology.

Section 2: Implementing GOA-ON via Regional Hubs and Capacity Building

The GOA-ON Requirements and Governance Plan defines measurement Levels (1-3) in support of Goal 1, with the aim of increasing both the number of measurement sites and the quality or level of measurements being taken. The Plan identifies severe gaps in the world's collective ability to observe OA and associated biological response. To this end, capacity building is needed on several fronts: physical infrastructure, OA expertise, analytical capabilities, data management and quality assurance/quality control (QA/QC) and demonstrated ability to sustain operations and maintenance.

GOA-ON has embraced two conceptual approaches to enhance global capacity and create communities of practice that are effective regionally. First, the establishment of regional geographical hubs as sub-networks of GOA-ON that are stratified geographically to allow researchers to forge regional collaborations to enhance collective capabilities. Second, GOA-ON is committed to enhancing human and technology capacities. Members of GOA-ON are actively engaging in training and mentorship programmes, supported by a variety of organizations. While the former approach promotes self-organization of the regional hub with the help and support of GOA-ON, the latter is a more targeted effort to build the capacity of individual scientists and regional/local efforts, based on specific requirements and needs.

a) GOA-ON Regional Hubs

GOA-ON has encouraged its member scientists to form geographically explicit hubs to facilitate regional coordination, collaboration, and sharing of OA monitoring expertise. To date, semi-autonomous and autonomous hubs have formed in Africa, Europe, Latin America, Western Pacific, Pacific Islands, North America, and most recently, Mediterranean and Arctic. More information on these regional hubs can be found on the GOA-ON website, under 'Regional Hubs'[9].

GOA-ON members in regions that do not currently have regional hubs are encouraged to start their own, or to join any of the existing hubs that match their needs. The GOA-ON Executive

[9]See Regional Hubs on the website: http://goa-on.org/regional_hubs/index.php

Council welcomes this grassroots, bottom-up approach and each of the current hubs has a representative on the Executive Council.

The unifying theme across the hubs is that they are working under the umbrella of GOA-ON to build collaborations and contributions towards understanding of the threat of OA and ecosystem responses in their regions. There is variability among these entities in both scope and related activities. For example, some hubs are outward facing, with dedicated websites, whereas others are more internally focused on organizing meetings for hub members to enhance collaborations and pool expertise to address regional issues across national boundaries.

Latin American Ocean Acidification Network (LAOCA)
LAOCA includes Latin America and the Caribbean with membership from many countries, including Argentina, Brazil, Chile, Colombia, Peru, Ecuador, Mexico, and Costa Rica. The network was officially launched during an inaugural workshop in December 2015 in Concepcion, Chile. The IAEA OA-ICC, IOC-UNESCO, and IOCCP have provided support for hub activities, including the first science workshop in Buenos Aires, Argentina, in 2017. Since then, several follow-up meetings, trainings, and workshops have taken place with national support. LAOCA secured support from various local, national, regional and international institutions to hold the 2018 Galapagos Ocean Acidification School in August 2018, which convened regional scientists to train using the natural laboratory of the CO_2 vents at Roca Redonda to advance regional capacity for OA research. Additionally, several scientists from Colombia, Ecuador, and Mexico received "GOA-ON in a Box" monitoring equipment and advanced training with support from The Ocean Foundation and other GOA-ON partners in January 2019 to initiate OA observations in the LAOCA region. Major economic drivers in the region include shellfish aquaculture, coral reef management, tourism, and benthic and pelagic fisheries. A wide variety of environments need focus, including the open and coastal ocean, estuaries, upwelling zones, coastal benthic ecosystems, and coral reefs.

Within LAOCA the capacity building needs vary by country. In countries performing ocean acidification observations with existing autonomous sensors or discrete samples (e.g., Brazil, Chile, Argentina, Peru, México, Costa Rica) and biological experiments using CO_2-equilibration systems (e.g., Colombia, Brazil, Ecuador, Chile), there is need for sustained training for comparative and inter-calibration exercises, particularly for those interested in taking CO_2-system measurements at the climate data quality objective. In other countries there is no available infrastructure to perform ocean acidification monitoring (e.g., Ecuador, Panama, Costa Rica), thus, effort is needed for capacity building and acquisition of laboratory materials (e.g., pH meters, titration systems) and field instruments (e.g., pH sensors, CTDO, underway-pCO_2 systems). A key challenge in the coming years will be expanding participation across Latin America – such that all countries with coastal zones are included to improve knowledge across the region.

LAOCA POCs: *Michelle I. Graco, Instituto del Mar del Perú (IMARPE), Universidad Peruana Cayetano Heredia (UPCH) (mgraco@imarpe.gob.pe); Jose Martin Hernandez Ayon, Instituto de Investigaciones Oceanológicos, Universidad Autónoma de Baja California, México (jmartin@uabc.edu.mx); Cristian Vargas, Universidad de Concepción, Chile (crvargas@udec.cl)*

OA-Africa

The OA-Africa network formed in 2016 following initial discussions at an IAEA OA-ICC ocean acidification training course in Cape Town, South Africa, in November 2015, and includes over 100 members from across the African continent. The major economic drivers of OA research in Africa are finfish capture and shellfish production, as well as tourism in some countries. Notwithstanding the broad international membership in this hub, OA-related research activities are, at present, limited to a small number of member countries, including Egypt, Mauritius, Mozambique, Namibia, and South Africa. While some national governments support oceanographic research, several OA-Africa members are supported through the IAEA INT7019 project, "Supporting a Global Ocean Acidification Network towards Increased Involvement of Developing States." Other IAEA Technical Cooperation projects build capacity by providing trainings and equipment. The Ocean Foundation has provided 'GOA-ON in a Box' kits and training to three African countries (Mauritius, Mozambique, and South Africa). A project launched in 2018 by the Western Indian Ocean Marine Science Association (WIOMSA) focuses on the establishment of ocean acidification observation and laboratory experiments in the Western Indian Ocean.

Additional funding is required in most countries to facilitate the initiation and maintenance of OA monitoring programs. Requirements are diverse and include equipment, training, and expert exchange. The OA-Africa hosted a side event at the Blue Oceans Conference in Liberia in March 2019 to showcase the OA research and awareness raising efforts being done throughout Africa. Following the conference, the OA-Africa Steering Committee held an in-person meeting to identify priorities and opportunities to advance OA monitoring in Africa.

OA-Africa POCs: *Nayrah Shaltout, National Institute of Oceanography and Fisheries, Egypt, (nshaltout@gmail.com), Sheck Sherif, Queen's University Belfast & Conservation International (CI) (sheck.sherif@gmail.com); Roshan Ramessur, University of Mauritius (ramessur@uom.ac.mu)*

North East Atlantic

The North East Atlantic Hub was established in November 2018 and encompasses countries along the Atlantic coast, including the North and Baltic Seas. The hub currently includes scientists from Portugal, Spain, France, Belgium, the Netherlands, Germany, Denmark, the United Kingdom, Ireland, Iceland, Norway and Sweden. The hub will target ocean acidification chemistry and biology in Open Ocean, deep sea, coastal and shelf sea benthic and pelagic ecosystems.

The marine area of the hub provides the basis for a wide range of goods and services including food, transport, energy and amenities for millions of people. Marine-related industries and services are an important part of the region's economy, with coastal tourism, fishing and shipping among the largest contributors and employers. The intense human activities in the area place considerable pressure on the marine environment. It is therefore of the utmost importance to define the impact of ocean acidification in the region.

The North East Atlantic hub held its first workshop in March 2019. The goals and scope of the regional hub will include facilitating the sharing of information on ocean acidification monitoring, as well as experimental, modelling and Earth observation activities, endorsing community best practices consistent with GOA-ON goals, promoting capacity building and training activities and providing integration across the region.

North East Atlantic Hub POCs: *Helen Findlay (hefi@pml.ac.uk) and Steve Widdicombe (swi@pml.ac.uk), Plymouth Marine Laboratory, UK.*

North America

The North American hub comprises members from Canada, Mexico, and the United States. The hub formed to enhance collaboration on research in ecosystems which cross country boundaries in the region (i.e. the California Current Large Marine Ecosystem, the Northwest Atlantic, the Arctic, and the Gulf of Mexico), to set common standards for OA research in the three countries, and to enhance capacity to serve stakeholder communities who can use information produced by OA research. The stakeholder communities most dependent on ocean acidification observing information in the region are aquaculturists, fishers, scientists, resource managers, and government. Economic drivers include shellfish aquaculture, fisheries, tourism, recreation, and cultural preservation.

The first North American hub network virtual meeting was held in September 2017 and an inaugural in-person workshop was held in October 2018, hosted by the Hakai Institute in Victoria, B.C., Canada. Attendees discussed the development of synthesis products, facilitating data exchanges, improving the observing system, developing uniform Quality Analysis/Quality Control procedures, and developing ocean acidification messages for policymakers and other stakeholders. Members listed several near-term priorities, including streamlining the process of reporting data to national data centres and the GOA-ON data portal, coordination around upcoming research cruises, the development of biological indicators in important species, and strengthening communication between researchers in various sub-disciplines (e.g. chemical observers, experimentalists, modellers, etc.). Needs identified by this hub include workshops to standardize methodologies, capacity building in data management, and development of best practices. Data are typically submitted to data centers and are publicly accessible, but not always easy to find.

North America Hub POCs: *Richard Feely, NOAA, USA (richard.a.feely@noaa.gov); Douglas Wallace, Dalhousie University, Canada (Douglas.Wallace@Dal.Ca); Jose Martin Hernandez-Ayon, Universidad Autonoma de Baja California, Mexico (jmartin@uabc.edu.mx)*

Western Pacific

The conceptualization of a regional network in the Western Pacific and its adjacent regions dates back to 2011 and took shape in 2014. The regional OA network has been developed and advanced by the IOC-UNESCO Sub-Commission for the Western Pacific (WESTPAC) in close cooperation with GOA-ON, mainly through the development of its SEAGOOS programme titled "Monitoring and research the ecological impacts of ocean acidification on coral reef ecosystems."

Given that the Western Pacific is home to the highest marine biodiversity with the largest coral reef coverage in the world, the programme aims to establish ocean acidification monitoring and research networks among individuals, institutions and countries in the region, and advance their capacity for monitoring and researching the ecological impacts on coral reef ecosystems while building on existing coral reef monitoring efforts.

Many countries and institutions take an active part in the development and implementation of the programme. Since early 2015, four regional workshops were conducted, resulting in a set of Standard Operating Procedures for monitoring ocean acidification impacts on coral reef ecosystems, which are applied at more than 20 pilot sites in participating countries. Meanwhile, tailored hands-on trainings were organized targeted at both regional and national level on carbonate chemistry and biological measurements.

IOC WESTPAC has been driving and coordinating the development of the regional hub, through the programme development and with technical assistance by the US National Oceanic and Atmospheric Administration (NOAA) and financial support from its member states and institutions in the region. IOC WESTPAC will continue to advance the regional hub by engaging in ecosystem modelling, conducting lab inter-comparison, data management, and embracing other inter or trans-disciplinary research on OA and its impact on ocean ecosystems.

Western Pacific Hub POCs: *Wenxi Zhu, IOC, (w.zhu@unesco.org); Somkiat Khokiattiwong, Phuket Marine Biological Center, Thailand (skhokiattiwong@gmail.com); Russell Brainard, NOAA, USA (rusty.brainard@noaa.gov); Fei Chai, SIO/SOA, China (fchai@sio.org.cn).*

Pacific Islands and Territories Ocean Acidification (PI-TOA) Network

The PI-TOA regional hub held its inaugural virtual meeting on 14 September 2018 following the Pacific Islands Advanced Ocean Acidification Monitoring Workshop at the University of Hawai'i at Manoa in August 2018. Members elected a steering committee, agreed upon a name for the regional hub, and discussed initial objectives for the network. PI-TOA was formed by scientists from Fiji, Papua New Guinea, Palau, Samoa, Tokelau, Tuvalu, Vanuatu, and New Zealand. Much of the ocean acidification monitoring in the PI-TOA region has been in coral reef ecosystems, as corals play a critical role in sustaining healthy fisheries and supporting local tourism. To date, twenty-two PI-TOA members have received GOA-ON kits and advanced ocean acidification trainings to sustain monitoring in their respective islands and territories. Members plan to use the regional hub as a system of coordination and support as new ocean acidification observing operations are launched in their respective countries. The acronym "PI-TOA" was considered particularly appropriate by the members because "toa" means "warrior" in some Pacific languages.

PI-TOA POCs: *Dr. Robert Duncan McIntosh, SPREP, Samoa (robertmc@sprep.org); Dr. Antoine De Ramon N'Yeurt, The University of the South Pacific, Fiji (antoine.nyeurt@usp.ac.fj); Dr. Krishna Kotra, University of the South Pacific, Vanuatu (krishna.kotra@vanuatu.usp.ac.fj); Dr. Kim Currie, NIWA, New Zealand (kim.currie@niwa.ac.nz)*

Mediterranean Ocean Acidification Hub (OA-Med Hub)

The Mediterranean Ocean Acidification Hub is a network that connects Mediterranean scientists who are working and are interested in ocean acidification in the Mediterranean Sea. While in its early formative stage (established early 2019), goals are to: improve the communication between the Mediterranean OA Hub members to better study and understand the ocean acidification and its consequences in the Mediterranean through collaborations and projects; promote community "best practices" consistent with GOA-ON; support the Mediterranean OA community via capacity building and trainings; and to work together as a community to provide OA related messages (social, biological, and physical impacts and implications of ocean acidification) for policy-makers and the public. To date, the OA Mediterranean Hub includes scientists from nine countries in the region: Egypt, France, Greece, Italy, Lebanon, Morocco, Spain, Tunisia, and Turkey.

OA-Med Hub POC: *Abed El Rahman HASSOUN, National Center for Marine Sciences, CNRS-L, Lebanon (abedhassoun@cnrs.edu.lb)*

Arctic

The rate of ocean acidification in the Arctic Ocean is among the fastest currently observed, and several important physiological and geochemical thresholds have already been surpassed in this region. Arctic waters are experiencing changes in the carbonate chemistry that are likely to significantly affect ecological status and entail socio-ecological and economic consequences. An Arctic hub is just beginning to take shape with leadership from scientists in Norway. A major economic driver in the region is the vulnerability of subsistence communities to OA-related ecosystem changes. Foremost in this region is the need for development and maintenance of an internationally coordinated OA monitoring program. While not yet formed, some existing regional partnerships – such as the Arctic Marine Assessment Program (AMAP) and the Sustained Arctic Observing Network (SAON) have OA working groups.

b) Capacity building

GOA-ON is committed to promoting diversity in its membership and in scientific participation across disciplines, countries, socioeconomic status, gender and ethnicity. GOA-ON members are from diverse backgrounds and have a demonstrated commitment to the network's mission. Nevertheless, much of the ongoing OA observation and research efforts are concentrated in a relatively small number of countries, leaving large knowledge and capacity gaps around the world, specifically in the southern hemisphere, Small Islands Developing States (SIDS) and Least Developed Countries (LDCs).

Accordingly, capacity building efforts, particularly in under-resourced areas, are needed to expand the global coverage of OA observations and participation in this scientific endeavour. This capacity building is being undertaken in two main ways: by providing training and field and laboratory equipment, and by the Pier2Peer scientific mentorship program. The latter effort is directed by the GOA-ON Executive Council, and the former is typically organized by GOA-ON working in partnership with other organizations.

<u>Training and equipment provision</u>

Since 2014, many OA training workshops have been held for students and early-career researchers in under-resourced countries. These workshops typically include classroom, laboratory, and networking components, and have provided training in OA monitoring and experimentation. The workshops have been led, organized, and/or funded by a range of organizations and countries, including, *inter alia*, IOC-UNESCO, the IAEA OA-ICC, The Ocean Foundation, NOAA OAP and US Department of State, the Swedish International Development Cooperation Agency (Sida), and Future Earth Coasts. GOA-ON works with these organizations to support the planning and implementation through a range of activities including providing experts for planning and training through its network of members.

In some cases, laboratory equipment and field sensors are provided to workshop participants so that they can directly collect OA data and conduct experiments. For example, two US Department of State-funded projects, ApHrica and Ocean Acidification Monitoring and Mitigation (OAMM), were directed by The Ocean Foundation and have provided pH sensors, alkalinity titration systems, and limited stipendiary support to scientists in three African, seven South Pacific, and six Caribbean countries. These sensor kits, often referred to as "GOA-ON in a Box", allow for the collection of "weather-quality" data, which must be made publicly accessible, likely through submission to a regional ocean data center, and will help expand the global coverage of OA observations. Other countries that are supporting related sensor equipment distribution projects include, among others, New Zealand, Sweden, Germany, and the United Kingdom. In addition, the IAEA, through its Technical Cooperation programme and the Ocean Acidification International Coordination Centre (OA-ICC), has led assessments of equipment and infrastructure gaps and provided scientific technical expertise to scientists in its member countries.

In an effort to standardize the equipment and methodology provided among projects, the IAEA, convened an expert meeting on ocean acidification research methodologies, in October 2016 at the IAEA Environment Laboratories in Monaco. The goal of the meeting was to advance discussions on the development of simplified protocols and ocean acidification "starter kits", in particular for research institutes with limited infrastructure and capacities. Such efforts are valuable; however, they should not discourage would-be funders from providing higher-quality equipment to laboratories with the capacity to collect "climate-quality" data. Indeed, increasing the spatiotemporal range over which "climate-quality" data are collected is a long-term GOA-ON objective.

Given the range of parallel capacity building projects currently underway, continued coordination among projects in terms of target countries and project goals is crucial. Between 2012 and June 2018, nearly 500 participants from developing countries had been involved in ocean acidification capacity building efforts; these include training courses, support to attend regional/international meetings, or receiving GOA-ON kits to measure OA. A continued strongly coordinated capacity building approach, supported by the GOA-ON Distributed Secretariat (established in 2018), ensures that resources are strategically allocated, minimizing spatial or temporal overlap.

Pier2Peer scientific mentorship program

To support diversity of membership, knowledge exchanges, and international collaboration, GOA-ON developed Pier2Peer, a scientific mentorship program that matches senior researchers with early career scientists to provide professional guidance and technical support. The Pier2Peer mentorship program is an integral element of GOA-ON's capacity building activities. It will help enhance global observing capabilities and ultimately diversify and advance the program mission. As of March 2019, 122 pairs have been formed, of which 87 are actively collaborating on activities that range from lab visits to proposal and manuscript writing. As of March 2019, the Pier2Peer program included 120 mentees from 53 countries and 71 mentors representing 20 countries.

GOA-ON provides assistance to Pier2Peer mentors and mentees in a number of ways, including by writing a letter of support noting their contributions, publishing a monthly newsletter sharing details about upcoming workshops, conferences, funding, PhD, and postdoctoral opportunities, and providing an interactive sharing platform for all GOA-ON members to exchange information and questions about OA research in the form of the Ocean Acidification Information Exchange (OAIE). GOA-ON facilitates open and frequent communication between mentors and mentees. There is no specific source of funding for this program; its success relies on the ingenuity and passion of the paired scientists to seek out resources to support their work. The Pier2Peer program has benefitted from scholarship funding coordinated by the Ocean Foundation, originally donated by the Swedish International Development Cooperation Agency, among others. As of March 2019, nine scholarships have been awarded to projects in South Africa, Argentina, Costa Rica, Cote d'Ivoire, Nigeria, the Philippines, Chile, Vanuatu, and Greece.

These capacity-building efforts continue to have the potential to be transformative for both the spatiotemporal scale at which OA research is conducted and for the individuals involved. However, without clear metrics for what constitutes success, the impact and value of these efforts will not be quantifiable. While individual capacity building projects may have their own timelines and goals to assist with streamlining and coordinating efforts, GOA-ON, through the Executive Council and advice from the broader network membership, will be developing overall capacity building objectives and outcome-oriented metrics by which success will be judged. For example, the amount of quality-controlled data collected, countries involved, regions covered, and papers published because of Pier2Peer collaborations, etc. These overarching objectives will help partners of GOA-ON to align their own efforts.

Section 3: Implementing GOA-ON Goal 1: Measurement Quality

Goal 1 of GOA-ON is to ensure that measurements are of appropriate quality and are comparable across sites. The measurement quality goals may differ from site to site. In order to achieve measurements of high quality the sampling strategies and observations will need to be adapted to the conditions at each sampling site. It is advised to establish new ocean acidification observation sites at locations providing ocean services or marine products, which are potentially vulnerable to ocean acidification. When establishing new ocean acidification observations, it is recommended to add these at sites where long-term water quality monitoring is being carried out to provide context and enable the efficient use of existing infrastructure. For the development of sampling strategies, the expected outcome of the observations, local constraints and opportunities, data needs, and methodology and instrumentation available should be considered. The outcomes of ocean acidification observations will likely be to evaluate the impacts of ocean acidification and to improve predictions. Constraints with regard to scientific infrastructure, financial resources, human capacities and site accessibility are important factors to consider. Data needs will vary according to the natural variations in ocean chemistry and the driving forces behind it (such as tides, seasons, upwelling, freshwater runoff), which will determine the number, times and places for sampling. The methodology and instrumentation required are further described in the SDG 14.3.1 Indicator Methodology[10], which provides guidance on sampling strategy, standard operating procedures, and data and metadata requirements.

The GOA-ON Requirements and Governance Plan, defines two data quality objectives: climate and weather. Based on propagation of measurement uncertainty, what these two terms imply with respect to OA measurements is updated here (Table 1):

The **climate quality objective** requires that a change in the dissolved carbonate ion concentration to be estimated at a particular site with a relative standard uncertainty of 1%. The carbonate ion concentration is calculated from two of the four carbonate system parameters (pH, partial pressure of carbon dioxide (pCO_2), total alkalinity (TA, also known as AT), and total dissolved inorganic carbon (DIC, also known as CT)). The climate quality objective implies an uncertainty of approximately 0.003 in pH; of 2 µmol kg^{-1} in measurements of AT and CT; and a relative uncertainty of about 0.5% in the pCO_2. Such precision is only currently achievable by a limited number of laboratories and is not typically achievable for all parameters by even the best autonomous sensors.

The **weather quality objective** 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 AT and CT; and a relative uncertainty of about 2.5% in pCO_2. Such precision should be achievable in competent laboratories and is also achievable with the best autonomous sensors.

***Table 1**: Recommended measurement uncertainties for climate and weather quality objectives*

Parameter	Climate Uncertainty	Weather Uncertainty
TCO_2	2 µmol/kg	10 µmol/kg
TA	2 µmol/kg	10 µmol/kg
pCO_2	2 µatm	10 µatm
pH	0.003	0.02
Aragonite Saturation	0.04	0.2
Calcite Saturation	0.06	0.3

[10]For the full text of the SDG Methodology see: http://goa-on.org/resources/sdg_14.3.1_indicator.php

Observations provided through GOA-ON, its members, and associated programs need to report corresponding values for the uncertainty parameters, regardless of data quality objective, with observations calibrated using community-accepted reference materials.

From the GOA-ON Governance Plan, the following five parameters were considered to be the minimum suite of Goal 1 Level 1 measurements for all marine environments:

- Carbon-system constraint based on at least two parameters, achievable in a number of ways, including through combinations of direct measurements and well-constrained estimates using parametrizations, where appropriate.
- Temperature
- Salinity
- Pressure (water depth at which measurement is made)
- Oxygen concentration

In addition, two further parameters of fluorescence and irradiance are considered desirable if the platform is appropriate and sensors available: Fluorescence and irradiance are included because biological processes (primarily photosynthesis/respiration) may affect the chemical status of OA and its attribution to underlying mechanisms. Recipients of the GOA-ON in a box kit, and indeed most countries that are in the early stages of developing their OA observation programme, often do not meet the Goal 1 Level 1 requirements, because they do not measure oxygen, nor fluorescence or irradiance.

Section 4: Implementing GOA-ON Goal 2: Biological Needs

The second goal of GOA-ON calls for a greater understanding of biological impacts and strong coordination of this research. In 2015, GOA-ON established a biological working group to focus on recommendations relevant to achieving GOA-ON's Goal 2. The biological working group has three objectives: to inform the chemical monitoring program about the biological needs (Task 1), to evaluate the needs and requirements of a biological monitoring program (Task 2), and to develop a theoretical framework linking chemical changes to biological response (Task 3). Herein, we will publish additional guidance from the outcomes of this working group, with links to products from the tasks upon publication.

a) Chemical monitoring needed for biology

In order to determine the effect of OA on biology / organisms it is necessary to monitor OA at the temporal and spatial scales relevant to the organisms in question. Marine organisms are often living in highly fluctuating environmental conditions and experience an even wider variability through migrations, changes of environment at different life-history stages or manipulation of their niche. The time scales at which ocean acidification impacts the organisms need to be understood and monitored for, this can include variability around the "ocean weather", on timescales of hours and days. We need to better capture all the aspects of this variability; for example, predicting organism sensitivity and identifying relevant future scenarios important for determining appropriate laboratory treatments require capturing the yearly pH regime experienced by an organism, including extremes, such as the minimum value experienced.

b) Approaches to GOA-ON biological measurements

OA will non-uniformly affect marine ecosystems in ways that are not yet understood. Beyond the established OA impacts on biocalcification, changes in pH, pCO_2 and other carbonate chemistry parameters also can influence nutrient chemistry, biological uptake efficiencies, and metabolic processes in ways that may enhance or degrade different components of marine ecosystems. Developing a coherent understanding of OA impacts depends upon applying a uniform set of assessment criteria that are specific to OA yet still functional across coastal and oceanic systems globally. Using emerging and established principles describing the physiological and ecological responses of biological systems, GOA-ON recommends a strategic approach that enables direct comparison of the impacts of OA across different ecosystems. GOA-ON presents five fundamental hypotheses as a guiding framework that can be tested in all marine ecosystems. These hypotheses address whether OA 1) leads to increased autotrophic production, 2) reduces heterotrophic production, 3) causes fundamental changes in community structure and biodiversity, 4) changes the ratio of inorganic to organic carbon in pelagic and benthic systems, and 5) leads to altered rates of species and community adaptation. We present explicit sampling strategies that start with fundamental observations but can be expanded to encompass greater detail and expertise. This approach maximizes the potential for data collections from both under- and well-developed observational platforms so that these hypotheses can be tested in the global context. The target ecosystem processes and strategies selected here serve both as sentinels of early change, as well as necessary continuing observational metrics to quantify the effects of OA on marine ecosystems in the future oceans.

Section 5: Implementing GOA-ON Goal 3: Data Requirements for Projecting OA and its Impacts

The GOA-ON Goal 3 – to acquire and exchange data and knowledge necessary to optimize modelling of ocean acidification and its impacts – has two main objectives:

- 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.

Models require information relevant to the model scale (grid-size, temporal resolution). This information can be acquired through either high-density measurements or interpolation based (optimally) on using scaled algorithms (e.g. estimating TA from parameterizations using salinity and temperature). Where observations are limited in spatial or temporal scales, models can be used to identify the optimal spatial and temporal scales of observations for a stated organism, ecosystem, or industrial activity.

However, models need much more than hydrographic and biogeochemical data. The requirement to capture function, productivity, and biodiversity characteristics including ecosystem phenology requires improved biological information to better represent (at least) functional group processes. The "roughness" of the model biological representations will dictate if this information is needed down to the cellular or process level. With expensive computational requirements, it will be important to constrain, and thus maximize, relevance at the scale of the processes in focus. This could be over spatial, depth or timescales that are relevant for, for example, life stage development, pre-harvesting growth period, and ecosystem boundary research.

Model projections, in turn, need to be relevant to the scale of the organism. Earth System Models are typically too coarse resolution to deliver ecosystem relevant information at the basin to local scale. However, their information is necessary to inform global steering of energy, salt, nutrients and carbon through boundaries of, ideally, nested regional models.

Use of global models to inform local models is sub-optimal. To be useful, it is required to develop a series of nested models down to the level of interest. In coastal regions the coupling of land and benthic models may also be appropriate. Prior to each downscaling, it is required to assess the performance of the donor model against relevant datasets; primarily at the boundaries of interest to the acceptor model. Offset between the observations and the model data should inform adjustments to the boundary information transferred to the higher resolution model. Boundary adjustments can be of the delta-change form using either absolute or percentage errors. The latter is used to avoid negative values.

Section 6: Implementing GOA-ON's Data Management

It is essential that data are made broadly, easily, and rapidly accessible to researchers and the interested public. GOA-ON supports and aims to provide FAIR (Findable, Accessible, Interoperable, Reusable) data[11]. Free and open access to information is a significant driver of scientific progress, and accessible data serves the interest of securing scientific reproducibility and credibility. Data describing the marine carbonate system, required for studies of ocean acidification and the carbon cycle and budget are available at present but are difficult to access. This is due partly to the complexity of the variables (the carbonate system is described by several actual variables and their combinations) and partly to the lack of interoperability between the various national and international data centers, observing networks, data products, and programs involved in the field. Carbonate system data are archived and served by various national and

[11]The FAIR data principles can be found here: https://www.nature.com/articles/sdata201618

international data centers, which are heterogeneous and independent, have different mandates, and are based on different approaches for data storage and retrieval. As a result, it has been challenging for users to get a complete overview available ocean acidification data.

a) GOA-ON data portal and asset inventory

The GOA-ON Data Portal (http://portal.goa-on.org) aims to overcome many of these issues by offering easy access to data and metadata from participating platforms. It contains information and links to the original data sources, while providing maps of the ocean observing assets submitted by GOA-ON members. It is not intended to be an archive, as that should be provided by the data originator. Rather, it aids discovery of data, with metadata information, and links to the data providers and to the data if available. The data on the GOA-ON portal include information from various marine biogeochemistry networks (VOS/SOOP, OceanSites, GO-SHIP, US IOOS, etc.), voluntary observing ships, time series stations, and world ocean data centers as well as mapped data synthesis products from SOCAT and GLODAP.

The data portal gives access to the **GOA-ON asset inventory** of metadata for such networks, platforms, and sensors used for observing carbonate chemistry. This inventory contains detailed metadata that provide common vocabularies, contact and acknowledgment information, and links to data sources. The inventory can be searched interactively by region, platform type and variables via a set of "Filters." Platforms can be added or modified by filling out the on-line GOA-ON Platform Survey form. For a subset of in situ fixed-location platforms (moorings, fixed ocean and coastal time series, etc.), the data portal also provides time series visualization and direct access to near real-time or delayed mode data.

The capability to provide visualization and direct access to time series data at fixed-location platforms (moorings, fixed ocean and coastal time series, etc.) involves the integration of well-organized and freely distributed data made available by data centers or other data providers. This capacity builds on the metadata provided for the GOA-ON asset inventory, but requires additional metadata, information, and capabilities for data provision, including file formats, available data delivery mechanisms, and detailed data encoding documentation. The GOA-ON Data Portal provides user-friendly and consistent access to such time series data. To be considered for integration, time series data should be made available using data distribution tools, protocols, and standards that are widely accepted internationally and clearly documented, such as netCDF files following the CF (Climate & Forecast) conventions and distributed via the OPeNDAP protocol.

For inclusion, datasets must include at least one carbonate system variable, but other important ancillary variables such as temperature and salinity should also be made available via the same data access mechanism. Both near-real-time and delayed-mode long time series may be integrated into the Data Portal. Priority will be given to data distribution points that provide access to multiple platforms via a single, common mechanism, including common conventions.

Requests for time series data integration can be made through the Comments box when filling out the on-line GOA-ON Platform Survey form. For questions regarding the portal and data integration, contact Emilio Mayorga, University of Washington, USA (*mayorga@apl.washington.edu*).

b) OA-ICC Portal for Ocean Acidification Biological Response Data

Studies investigating the effects of ocean acidification on marine organisms and communities are increasing every year. However, results are not easily comparable since the carbonate chemistry and ancillary data are not always reported in similar units and scales and calculated using similar sets of constants. In response to this problem, a portal for accessing biological response data[12] was developed by the OA-ICC in collaboration with Xiamen University, China and the Laboratoire d'Océanographie de Villefranche, France. Through this portal, users are able to access data sets used in biological response studies based on a set of filters.

c) Data reporting and repositories

The capacity to store OA data sets varies among institutions and countries. While in some countries National Oceanographic Data centres (NODCs) hold the majority of OA data and metadata sets, regional and international data centres are acting as relevant data repositories in other parts of the world, e.g. ICOS, SeadataNet.

GOA-ON and the SDG 14.3.1 indicator methodology encourage open access to data. More detail on different ways of data storage and reporting mechanisms to enable global comparability and data products can be found in the Guide to Best Practices for Ocean Acidification Research and Data Reporting (see Appendix), the US NOAA OAP Metadata Template (Appendix) and the SDG 14.3.1 Indicator Methodology [13]. A newly developed 14.3.1 Ocean Acidification Data portal, to be launched in 2019, will be a further step in achieving the full implementation of the 14.3.1 methodology by increasing countries' capacity to share related data sets.

Section 7: Synthesis products and outreach

Sustained observations and modelling of ocean acidification are vital to better inform policymakers and marine industries on OA and associated biological impacts, and to evaluate adaptation and mitigation strategies. How OA is modulated at small or regional scales, the relationship of changing ocean conditions to biological impacts including the consequences for

[12] The OA-ICC portal for ocean acidification biological response data can be found here: http://oa-icc.ipsl.fr/

[13] The full text for the Methodology can be found here: http://goa-on.org/resources/sdg_14.3.1_indicator.php

biology as OA variability exceeds the natural background variability, and the linkage to policy actions will rely on a robust GOA-ON. The growing GOA-ON network, data management, and the capacity building activities outlined above provide the framework to deliver data and synthesis products. Evolving aspects of GOA-ON include:

a) Detecting long-term OA trends against background variability

In order to delineate the anthropogenic CO_2 signal and determine the multi-decadal trends in time series data, a community-wide practices need to be developed and agreed upon. A workshop is planned to develop a strategy for uniform analysis of cruise and time series data, especially from coastal areas. The workshop will involve international experts working together with regional scientists to develop and agree upon a common set of approaches for analyzing data. NOAA Pacific Marine Environmental Laboratory (PMEL) and the University of Washington will be hosting the workshop during 2019; results will be used to update this section.

b) OA as a climate indicator

In 2018, the Global Climate Observing System included OA as one of seven global climate indicators. The World Meteorological Organization to the Conference of Parties submits annual reports on the indicators for the United Nations Framework Convention on Climate Change (Global Climate Observing System)[14] and GOA-ON is tasked with providing annual updates of the indicator. The assessment for 2018 is based on data from Northern Hemisphere time-series sites (https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate) due to a limited number of sites with 20+ years of high quality data. As longer records from the expanding number of time series sites become available, the geographic coverage of the indicator will be increased.

c) UN Sustainable Development Goal 14 and the Decade of Ocean Sustainability

GOA-ON is a vital contributor of indicator data for the SDG14.3 target and the SDG process is an important link between science and policy makers of UN member countries. Individuals, organisations and governments make voluntary commitments[15] to SDG14.3 and these are used to track progress on delivery to the target, surveys of commitments provide information on impediments (resources, infrastructure, equipment and capability) and also provide information on regional gaps and opportunities in observing. GOA-ON and the IAEA OA-ICC are co-focal points for the UN SDG Community of Ocean Action on Ocean Acidification, a group effort to follow up on the more than 240 Voluntary Commitments addressing OA submitted to date. GOA-ON has registered a Voluntary Commitment, titled “Enhancing global ocean acidification

[14] United Nations Framework Convention on Climate Change (Global Climate Observing System) https://gcos.wmo.int/en/global-climate-indicators

[15] Voluntary commitments can be found here: https://oceanconference.un.org/commitments/

monitoring and research" (#OceanAction16542)[16], with the Communities for Ocean Action on Ocean Acidification. GOA-ON regional hubs and members need to be encouraged to submit voluntary commitments to SDG14.3 for both the UN Oceans Conference in 2020 and for the planning for the UN Decade of Ocean Science for Sustainable Development (2021-2030).

d) Integration with other observing networks to enable synthesized results

Other stressors in the marine environment including warming, deoxygenation and pollution have potential to modify the impact of ocean acidification on marine ecosystems. GOA-ON will engage with other networks to maximize the efficiency of the networks and to develop synthesized information on the cumulative impacts of changing conditions on individuals and food webs. This integrated approach is important for determining if there are biological thresholds for organism and ecosystems.

[16] More on the GOA-ON Voluntary Commitment :https://oceanconference.un.org/commitments/?id=16542

Appendix

a) Reference Materials

Global Ocean Acidification Observing Network: Requirements and Governance Plan
The Global Ocean Acidification Observing Network (GOA-ON) Requirements and Governance Plan provides both broad concepts and key critical details on how to meet GOA-ON's high level goals to improve our understanding of global ocean acidification conditions; to improve the understanding of ecosystem response to ocean acidification; and to acquire and exchange the data and knowledge necessary to optimize the modelling of ocean acidification and its impacts.
http://goa-on.org/documents/general/GOA-ON_2nd_edition_final.pdf

Framework for Ocean Observing
The Framework for Ocean Observing (FOO) was developed at the 2009 edition of the decadal conference series OceanObs. The FOO is used by the Global Ocean Observing System (GOOS) to guide global ocean observation efforts. It articulates the need for ocean observing, data acquisition and management standards, essential ocean variables, etc.
http://www.oceanobs09.net/foo/FOO_Report.pdf

Global Ocean Observing System (GOOS) Essential Ocean Variables (EOVs)
GOOS is an international framework that coordinates ocean observations aiming to meet three critical themes: climate, ocean health, and real-time services. The EOVs are divided into physical, biogeochemical, and biological/ecological groupings:
http://www.goosocean.org/index.php?option=com_content&view=article&id=14&Itemid=114

Guide to Best Practices for Ocean Acidification Research and Data Reporting
This book of guidelines and standards for ocean acidification research was developed by the European Project on Ocean Acidification (EPOCA), IOC-UNESCO, and other partners. The addendum provides useful information and links to complementary resources for users of the guide, including technical guides and papers that were published after the 2010 guide.
2010 Original: https://www.iaea.org/sites/default/files/18/06/oa-guide-to-best-practices.pdf2015
Addendum: http://www.ioccp.org/images/08dataANDinfo/addendum_oa_guide_october-2015.pdf

Guide to Best Practices for Ocean CO_2 Measurements
This PICES Special Publication and IOCCP Report by Dickson, Sabine, and Christian contains the definitive standard operating procedures for the process of measuring and recording the four major carbon system parameters needed for ocean acidification observation.
http://cdiac.ess-dive.lbl.gov/ftp/oceans/Handbook_2007/Guide_all_in_one.pdf

Sustainable Development Goal (SDG) 14.3.1 Indicator Methodology, Metadata and Data Files

The Methodology for the Sustainable Development Goal (SDG) 14.3.1 Indicator, which calls for the "Average marine acidity (pH) measured at agreed suite of representative sampling stations" provides the necessary guidance on how to conduct ocean acidification observations, what to measure and how, providing standard operating procedures and methods approved by the ocean acidification community. The Methodology, along with the associated data and metadata files, provides support on what kinds of data to collect, and how to submit, towards the SDG 14.3.1 Indicator to enable the collection and comparison of ocean acidification data worldwide. The SDG 14.3.1 Indicator is under the custodianship of the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

http://goa-on.org/resources/sdg_14.3.1_indicator.php

How to Document Ocean Acidification Data: ASLO e-Lecture by Jiang et al.

This e-Lecture provided by the Association for the Sciences of Limnology and Oceanography provides an overview of the methods of data collection, types of data, and standards for documenting metadata.

http://www.ioccp.org/images/05OceanAcidification/JiangLQ16_ASLO-eLectures-How-to-manage-OA-data.pdf

Metadata Template and Instructions

This template and associated instructions provides a guide for the type of information that should be recorded in association with carbonate parameter data.

ftp://ftp.library.noaa.gov/noaa_documents.lib/NESDIS/NODC/OA_metadata/

Ocean Acidification Education Tools from NOAA/PMEL

The OA Educational Tools from NOAA/PMEL include visualizations/animations and lectures that are useful for teaching the basics of OA to students, stakeholders, and the general public.

https://www.pmel.noaa.gov/co2/story/OA+Educational+Tools

Ocean Acidification Short Course Materials

This is a collection of videos of lectures on ocean acidification by experts, and includes other reference materials used in the course. This page includes instructions on how to obtain the open source Microsoft Excel program CO2SYS and the R software package *seacarb*, as well as instructions on their use.

http://www.whoi.edu/page.do?pid=33598

Ocean Acidification Summaries for Policymakers

These summaries from IOC-UNESCO and the InterAcademy Panel on International Issues provides relevant information on how ocean acidification affects ecosystems and the

communities that depend on them. It includes evidence for OA's acceleration and potential impacts in accessible terms.
http://www.ioc-unesco.org/index.php?option=com_content&view=article&id=148&Itemid=76

b) Data Platforms

Biological and Chemical Oceanographic Data Management Office (BCO-DMO)
The BCO-DMO database stores oceanographic data from a variety of programs, including several significant datasets from Arctic programs.
https://www.bco-dmo.org/

Global Ocean Data Analysis Project (GLODAP) Database
GLODAP is oceanographic database representing coordinated efforts to bring together global synthesis products. It stores data from a variety of cruises between 1972 and 1999.
https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0001644

Ocean Carbon Data System (OCADS) (formerly CDIAC-Oceans)
OCADS is a data management project run by the US NOAA National Centers for Environmental Information. It hosts data from 1993-present including discrete and underway measurements from a variety of platforms. OCADS includes data from the World Ocean Circulation Experiment (WOCE), the CLIVAR/GO-SHIP Repeat Hydrography Program, the SOCCOM Cruises, and data synthesis products from GLODAP, CARINA, and PACIFICA. It also stores data from the Global Time-Series and Mooring Project.
https://www.nodc.noaa.gov/ocads/

Surface Ocean CO_2 Atlas (SOCAT)
SOCAT focuses on synthesizing high quality surface ocean fCO_2 observations. The latest version of SOCAT includes data from 1957 to 2017.
https://www.socat.info/

c) International Programs

Intergovernmental Oceanographic Commission (IOC) of UNESCO
IOC-UNESCO promotes international cooperation and coordinates programmes in marine research, services, observation systems, hazard mitigation, and capacity development in order to understand and effectively manage the resources of the ocean and coastal areas. IOC-UNESCO is the custodian agency for SDG Target 14.3.
http://www.unesco.org/new/en/natural-sciences/ioc-oceans/

Global Ocean Observing System (GOOS)

GOOS is an international framework that coordinates ocean observations aiming to meet three critical themes: climate, ocean health, and real-time services. It has received mandates from the UNFCCC, the UN CBD, and the IOC/WMO. Their website provides a variety of resources including webinars and reference documents. GOOS expert panels agreed on variables that facilitate coordinate ocean observation efforts that cover the most useful ocean environmental characteristics that are also relatively cost effective to obtain.

http://www.goosocean.org/

The Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP)

GO-SHIP is a globally coordinated network of physical oceanographers, marine biogeochemists, and other users and collectors of hydrographic data with the goal of creating a synthesized network of hydrographic observation sections. The GO-SHIP website has a data directory, detailed data standards, a hydro manual, and various manuals and implementation plans.

http://www.go-ship.org/index.html

IAEA Ocean Acidification International Coordination Center (IAEA OA-ICC)

The IAEA OA-ICC fosters global collaboration and capacity building for OA, bringing together researchers, policy-makers, educators, and other stakeholders. The OA-ICC runs capacity development workshops and their website hosts some data and a variety of educational resources on OA.

https://www.iaea.org/ocean-acidification/page.php?page=2181

International Ocean Carbon Coordination Project (IOCCP)

The IOCCP works to develop global cohesion on ocean carbon research by fostering communication, international agreements on technical standards and methods, and stakeholder advocacy. It is co-sponsored by the Scientific Committee on Oceanic Research and IOC-UNESCO. The IOCCP runs technical training workshops and hosts a variety of resources on its website.

http://www.ioccp.org

OceanObs'09 and OceanObs'19

The OceanObs'09 website provides a number of useful resources emanating from the last meeting in the decadal conference series on coordinating and standardizing global ocean observation, including the Framework for Ocean Observing, plenary papers, and a number of influential community white papers. The OceanObs'19 gives information for the upcoming meeting.

http://www.oceanobs09.net/
http://www.oceanobs19.net/

d) Regional Hubs

All Regional Hubs can be found on the GOA-ON website: http://goa-on.org/regional_hubs/index.php

Latin American Ocean Acidification Network (LAOCA)
The LAOCA network coordinates Latin American participants in ocean acidification research active in the GOA-ON network. Its website hosts a forum for members and resources from its first symposium in Buenos Aires, Argentina, in October 2017. LAOCA consists of 36 members from 8 Latin American countries.
http://laoca.cl/en/

Mediterranean Ocean Acidification Hub (OA-Med Hub)
The Mediterranean Ocean Acidification Hub is a network that connects Mediterranean scientists who are working and are interested in ocean acidification in the Mediterranean Sea. To date, the OA Mediterranean Hub includes 40 scientists from nine countries in the region: Egypt, France, Greece, Italy, Lebanon, Morocco, Spain, Tunisia, and Turkey.
http://goa-on.org/regional_hubs/mediterranean/about/introduction.php

Ocean Acidification Africa Network (OA-Africa)
The OA-Africa Network that coordinates African OA research and promotes awareness of OA and its impacts. The network has held four workshops and works to integrate OA research in Africa with GOA-ON goals. Its website hosts reference resources, event information, and a forum for members. OA-Africa consists of over 100 scientists from 17 African nations as of Spring 2018.
https://www.oa-africa.net/

The IOC Sub-Commission for the Western Pacific (WESTPAC)
WETPAC is an organization of 22 member states in East Asia, Southeast Asia, the South Pacific, and the eastern Indian Ocean that develops and coordinates regional marine science and ocean observations. WESTPAC has held several training workshops on ocean acidification.
http://iocwestpac.org

The North East Atlantic Hub
The North East Atlantic Ocean Acidification Hub is being established to serve European countries that are conducting monitoring, and other OA activities, within the NE Atlantic region. Countries within the region known to be engaged in OA research and/or with data submitted to the GOA-ON data portal: Belgium, Denmark, Faroe Islands, France, Germany, Iceland, Ireland, Netherlands, Norway, Poland, Portugal, Spain, Sweden, UK.
https://www.pml.ac.uk/Research/Projects/North_East_Atlantic_hub_of_the_Global_Ocean_Acidif

North American Hub

The North American Ocean Acidification Hub is being established to serve the countries of Canada, United States, and Mexico. The Global Ocean Acidification Observing Network (GOA-ON) has encouraged grass-roots formation of regional hubs to foster communities of practice for the efficient collection of comparable and geographically distributed data to assess ocean acidification and its effects and to support adaptation tools like model forecasts.
http://goa-on.org/regional_hubs/north_america/about/introduction.php

PI-TOA (Pacific Islands & Territories Ocean Acidification) Network

The PI-TOA network works collectively to better understand and combat the impacts of ocean acidification in the region. In recent years, there have been several ocean acidification trainings and "GOA-ON in a Box" kit recipients in the Pacific Islands and Territories. As capacity for ocean acidification monitoring increases in the region, there is an increasing need for collaboration and communication among the various islands and territories.
http://goa-on.org/regional_hubs/pitoa/about/introduction.php

e) Acronym Glossary

CARINA	Carbon Dioxide in the Atlantic Ocean data synthesis project
CF Conventions	Climate & Forecast Conventions
CLIVAR	Climate and Ocean: Variability, Predictability, and Change
DIC	Total dissolved inorganic carbon
EC	Executive council
ERDDAP	United States Environmental Research Division’s Data Access Program
ERSEM	European Regional Seas Ecosystem Model
fCO_2	Fugacity of carbon dioxide
GLODAP	Global Ocean Data Analysis Project for Carbon
GOA-ON	Global Ocean Acidification Observing Network
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Program
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Sea
IOC-UNESCO	Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization
IOCCP	International Ocean Carbon Coordination Project

LAOCA	Latin American Ocean Acidification Network
NIWA	National Institute of Water and Atmospheric Research, New Zealand
NOAA	United States National Oceanic and Atmospheric Administration
OA	Ocean acidification
OA-ICC	IAEA Ocean Acidification International Coordination Center
OCADS	Ocean Carbon Data System
OGC SOS	Open Geospatial Consortium Sensor Observation Service
OPenDAP	Open-source Project for a Network Data Access Protocol
OSPAR Convention	Convention for the Protection of the Marine Environment of the North-East Atlantic
PACIFICA	Pacific Ocean Interior Carbon data project
pCO_2	Partial pressure of carbon dioxide
pH	Potential of hydrogen
PICES	North Pacific Marine Science Organization
PMEL	United States Pacific Marine Environmental Laboratory
PML	Plymouth Marine Laboratory, United Kingdom
QA/QC	Quality assurance/quality control
SDG	Sustainable Development Goal
SGOA	ICES-OSPAR Study Group on Ocean Acidification
SOCAT	Surface Ocean CO_2 Atlas
SOCCOM	Southern Ocean Carbon and Climate Observations and Modeling
SOOP	Ship of opportunity
TA	Total alkalinity
THREDDS	Thematic Real-time Environmental Distributed Data Services
UN	United Nations
US IOOS	United States Integrated Ocean Observing System
VOS	Voluntary observing ships
WESTPAC	Western Pacific