ABSTRACT
Establishing the Coastal Module has become the most challenging of the entire process of setting up the Global Ocean Observing System. The complexity of the coast as a social-ecological system demands nurturing a bottom-up process which can enhance capacities of Member States in planning to protect human and ocean ecosystem health and prevent and mitigate losses in the event of natural disasters. Such process must engage policy makers and scientists of coastal states in serious dialogue to agree on key national needs for coastal ocean data and observations. Through the GOOS Regional Alliances, such discourse must continue to determine how a broad collaboration within and between GRAs can leverage expertise and resources, including serious national commitments, to meet these needs. Developing capacities with real investment in personnel and resources may proceed at incremental pace, focusing at one or few variables at a time to build trust and experience in collaboration. Multiplying this grassroots-based scenario across Member States, especially where capacities are weak, will determine the rate at which we all can learn about and adapt to a changing earth.

1. INTRODUCTION
Coastal areas worldwide face many challenges in the 21st century including greater exposure to natural disasters for some, and increased livelihood dependence on degraded ecosystems for many. The need for data and information to address these issues is urgent. Despite the compelling need, many coastal states especially those with developing economies have yet to subscribe to international initiatives aimed at setting up coastal ocean observing systems beyond official paper agreements. This paper aims to examine underlying constraints that prevent meaningful participation, and to explore data and information products that may engender purposeful engagement by coastal developing states. The analysis complements a community white paper by Malone et al. on a strategy to implement the coastal module of the Global Ocean Observing System [1]. In addition, it builds on recommendations proposed by community white papers on storm surges [2], on ecosystem monitoring using chlorophyll [3] and coral reef health [4], and on observations of local sea level changes [5].

2. COASTS ARE SOCIAL-ECOLOGICAL SYSTEMS
Acknowledging that the coast is shaped by interactions between humans and nature provides the basic context for examining the role coastal ocean observing systems may play in informing coastal governance. Culture, government and economy determine how society, organized at different scales, gains access to and use coastal ecosystems (Fig.1) [6, 7, 8]. These interactions make the coast a social-ecological system (SES) and determine complex system attributes [9]. The social-ecological coast is vulnerable to factors such as disease outbreaks, market failure, political instability, climate change and natural disasters. At the same time, the linked system has properties that allow it to withstand exogenous shocks and maintain resilience. Prudent governance protects and enhances these properties to ensure that the integrity of human systems and ecosystems, including livelihoods, are sustained.
Data and information on the states of component systems and the changes they undergo are critical inputs to the decision-making process. However, scientific information is just one of many factors that affects societal choices regarding ecosystems and the goods and services they provide. Power and leadership, voice and representation, and the market economy are palpable forces that can and do override science on the discussion platform [10]. For science to become policy relevant, it must squarely address the questions of decision-makers, imperfect though these answers may be [11]. It should elaborate on the consequences of societal choices, cognizant that uncertainty in predictions might translate to indecisiveness. At the end of the day, a society decides on these issues based on its collective ethic to protect human life and on its shared vision to conserve its natural patrimony including coastal ecosystems [10].

On the coast, jurisdictions and sovereignty play major roles in governance [12]. These provide the nuanced contexts that are unique from state to state for vetting whether or not to participate in internationally coordinated science initiatives such as coastal ocean observing systems (COOS). While observing systems emphasize coordination and broad uniformity and interoperability of protocols for data acquisition, transfer, integration, and product development, among collaborating partners, coastal governing systems at the state to local levels operate as entities independent of other states, and place a premium on sovereignty and uniqueness of circumstance in identifying their perceived needs and solutions. Such difference between the international ocean observing community and a coastal state does shape collective mindsets of scientists and civil servants and explains the orthogonal approaches these two entities have [13]. However, the disparate foci are not immediately obvious to nor appreciated by both groups. The working environments of collaborative global science and that of coastal state governance may be mutually unfamiliar. Without further dialogue, the apparent conflict can erode the potential for a major mechanism like COOS to profoundly make national coastal planning responsive to disasters and ecological change. The discussion below helps to elucidate why such difference in focus can become an initial stumbling block. Understanding these mindsets could in fact pave a sufficiently solid foundation so that the COOS can become a socially accepted mechanism for developing and using data products that are necessary to achieve sustainable coastal futures.

3. COASTAL OCEAN OBSERVING SYSTEMS: GOOS Coastal Module

The vision and implementation plan for COOS as a module of the Global Ocean Observing System (GOOS) has been in development since the mid 1990s along with the evolution of various bodies to implement it. The strategic design and its implementation were articulated in 2003 and 2005, resp. [14, 15]. A community white paper in this conference provides an update of the status of the GOOS Coastal module and provides a strategic action plan to further promote its implementation [1]. All the documents to date have envisioned a Global Coastal Network (GCN), the collaboration for which would consist of: (a) a global network of coastal laboratories to document local ecosystem states; (b) the
global network of tide gauges (Global Sea Level Observing System or GLOSS); (c) sensors on at-sea stationary and moving platforms for measuring common variables; (d) ships of opportunity and voluntary observing ships; (e) research vessels and repeat survey programs; (f) land-based platforms with remote sensing capabilities; and (g) satellite and aircraft-based remote sensing assets. However, the set of variables to be monitored by the GCN has yet to be determined by the GOOS.

To organize the needed data collection capacities above, engagement of coastal states are facilitated mainly through the GOOS Regional Alliances (GRAs) where regional priorities are identified so that national and regional information needs critical to coastal planning could be met (Fig. 2). Since 2002, four GRA Fora have been held to facilitate implementation of GCN components and to explore interoperability among observing systems. In addition, the GOOS Regional Council has been established to provide a coordinating body as well as a mechanism for representation of the GRAs at the Intergovernmental Committee for GOOS.

Despite having a community vetted and scientifically robust infrastructure and institutional blueprint to make the GOOS Coastal Module functional, progress has been slow and geographically uneven [1, 13]. Among the GCN components, only the GLOSS is operational globally [13]. The Chlorophyll Global Integrated Network (ChloroGIN), which started as a GOOS/GEO demonstration project in 2006, is expanding successfully and has the potential to become operational with global coverage [3]. GLOSS and ChloroGIN each tracks a single variable that is of immense value to local economies as well as to global science. Taking cue from these two success stories, might it be prudent to reconceptualize the GCN as one to be established over an incremental series of single-variable initiatives, building trust and experience along the way?

Across the GRAs with developing country members, functionality in interfacing with member countries and engaging them in realizing regional and national component systems of the GCN has met with mixed success [16]. While some are successful in developing operational data products like chlorophyll for use in fisheries management (such as ANTARES in South America and the Indian Ocean GOOS) [3], others have yet to develop an implementation plan and identify resources to carry one out (as in IOCARIBE) [17, 18]. Constraints in member state-sourced financial support, inadequate expertise and organizational capacities, and lack of national interest, are recurrent themes for some GRAs. A collective desire among member states to identify and implement an ocean observing system that is mutually beneficial underpins the existence of a functional GRA. Thus, a GRA reflects the collective strengths and weaknesses of its member states. When its leadership is able to build on shared commitments in resources and capacities to meet prioritized needs for ocean observations, the experience could become mutually reinforcing at national and regional scales. It is evident that the need for coastal ocean observation systems be one that is perceived at
the national level to be of extreme benefit and worthy of national commitment in terms of resources including scientific manpower.

4. COOSs and National Priorities

What planning needs of a coastal state with a developing economy may be best met by a coastal ocean observing system? A framework that has been extremely useful in planning is the Sustainable Livelihoods Approach (Fig. 3) [7, 8]. It was originally intended to measure the effects of development projects on recipient countries. The framework examines factors relating livelihoods and livelihood assets that include the natural ecosystem-based services, and how these are vulnerable to climate change, natural disasters and market failure, among others. Because the SLA framework explicitly uses key indicators of human wellbeing, ecosystem health and vulnerability, it has become a favoured tool in designing integrated human-environment assessments. Climate change and natural disasters affecting livelihood assets including ecosystem services (natural capital) and societal wellbeing can be made explicitly visible using the SLA Approach. More importantly, the SLA allows for the inputs to be framed across multiple scales of human organization, which is necessary to capture human interests and value systems across scales of human organization [19]. Unlike biological systems for which emergent properties are carried through to higher scales, human values and interests cannot be totally subsumed by higher aggregations because representation is imperfect even among the most democratic institutions [9]. Thus, it is critical that public consultations from local through to national levels become mainstream mechanisms for discourses including those for coastal ocean observing systems to be meaningful and effective. The priority data needs for coastal ocean observations may be defined from local to national levels following this framework. Such data needs may be implemented one or two variable at a time to gain the collective experience in collecting the data and developing the data products for use in integrated coastal planning and smart disaster prevention and mitigation.

Figure 3. The sustainable livelihood approach takes into account vulnerabilities of natural resource-based livelihoods and uses indicators of ecosystem services and of human well being in integrated assessments (modified from 8, 19).

Following the governance principle called subsidiarity, which underscores that matters of governance must occur at the lowest or least centralized competent authority, coastal observation systems must be articulated at appropriate sub-national jurisdictions. At the same time, the support of state leaders is necessary in order to establish functional protocols on data collection to data product delivery. State support is an enabling condition in order for local communities within their coastal states to liaise with international partners who provide remotely sensed data for example, or capacity building resources (expertise, training, grants) through mutually defined governmental agreements.
5. A NEAR-FUTURE VISION OF COOS IN DEVELOPING COASTAL STATES

In envisioning how developing states may engage and participate in developing functional coastal ocean observing systems, this paper briefly describes data products that are essential components of coastal planning to mitigate natural disasters or prevent adverse coastal ecosystem changes. This exercise by no means preempts coastal states from identifying their priorities for observation data and products. The discussion is provided to allow coastal planners to examine a sample of products along a gradient of increasing data support and increasing modelling complexity. They may then determine which ones are achievable given their current resources. In addition, managers and planners may identify data products that may be developed with investments in national capacity building as well as by active participation in a COOS regional network where common needs for data and data products may be met through mobilization and use of pooled resources.

5.1. Vulnerability Maps of Low-Lying Coastal Populations

A distribution map of coastal inhabitants by elevation and distance from the coast is necessary to determine vulnerability of populated areas to coastal flooding due to storm surges, precipitation-induced river flows and to gradual sea level rise, among others. A global coastal population distribution map has been produced by Columbia University’s Centre for International Earth Science Information Network [20] by overlaying three spatially explicit datasets: (a) high-resolution elevation data from the Shuttle Radar Topography Mission (SRTM); (b) national census-based population data; and (c) delineated urban footprint map based on the NOAA night-time light satellite data. All three geographic layers are at 1 km resolution. The maps and spreadsheets are available for download [21]. The distribution of coastal human populations around Manila Bay, Philippines is shown in Fig. 4.

![Figure 4. Population distribution around Manila Bay, Philippines indicating densities inside the 10 m low elevation coastal zone (shades of red), and outside the low lying areas (shades of green) (21).](image)

National and local coastal planners can update the population data and provide additional data layers that will help in multipurpose planning including that for the delivery of emergency services in the event of natural disasters, and those for medium to long-term projections such as the allocation of coastal space for conservation and development. With additional biophysical and climatological data, modelling various scenarios of vulnerability of coastal inhabitants in rural and urban communities to climate and environmental change may be determined at finer resolution. Mitigation of these vulnerabilities may proceed more realistically than without vulnerability maps.
5.2. Seamless Topographic-Bathymetric Mapping

Figure 5. Seamless topographic-bathymetric map of Tampa Bay, Florida (22).

In order to have more accurate projections of the extent of water movement from the coastal ocean to the coastal zone and its impacts under various climate change scenarios, it is critical to define the width of the shoreline. To discriminate the shoreline, it is critical that bathymetric data for the coastal basin and topographic data for the adjacent land be seamlessly merged. Bathymetric and topographic data would need to use a common vertical reference datum. For countries with the technology, mapping using Light Detection And Ranging (LIDAR) techniques allows for highly resolved topographic-bathymetric mapping of the coastal zone (Fig. 5) [22].

It is worth noting here that although shoreline detection has been done globally through products such as the World Vector Shoreline, the current resolution at 250 m is too coarse for coastal planning use. Presently, the US National Geospatial-Intelligence Agency is engaged in refining a Prototype Global Shoreline Data that is based on satellite derived High Water Line data (orthorectified NASA, 2000 era, LANDSAT GeoCover) [23]. At its current state of development, the Global Shoreline Data set has not been tide coordinated, even with an improved resolution of 50 m.

For areas where limited resources prohibit the use of the airborne LIDAR technology, a coastal mapping strategy may be implemented to resolve the coastline and to merge basin bathymetry and adjacent land topography. The strategy components include: (a) establishing real-time tidal measuring stations, (b) developing hydrodynamic models with tidal components, and (c) designing protocols to merge offshore bathymetric and onshore topographic datasets. Expertise in coastal physical oceanography is needed to develop tidal models and to integrate elevation and bathymetric data. Member countries may use Global elevation datasets such as that produced by the SRTM and which are currently available at 20 m horizontal and 16 m vertical accuracy. These may be further validated with finer resolution data where available. Digitizing historical nautical chart soundings in comparison with contemporaneous in situ depth measurements yields bathymetric data where LIDAR mapping is not possible. COOS GRAs may encourage national representatives to assess data and expertise availability for coastal mapping, and examine realistic mechanisms to support this.

5.3. Modelling Coastal Physical Processes to address risks to natural disasters

With maps indicating the location by elevation of coastal inhabitants, the dynamic location of the shoreline, and the geomorphology of coastal basins and adjacent land areas, scenario models of natural disasters may be implemented. These can include models of coastal flooding resulting from storm surges and from extreme disasters such as tsunamis for tectonically active areas. Such models are essential to increasing preparedness and planning efficient mitigation and emergency protocols.
As an example, this paper examined current modelling initiatives on storm surges and tsunami run-ups in the Philippines, a coastal state that is highly vulnerable to natural disasters including cyclones, earthquakes and volcanic eruptions. Drews created a 2009 coastal storm surge model for Manila Bay using a Regional Ocean Modeling System (ROMS), a modern Ocean General Circulation Model that can be configured at local to basin scale \[24\]. However, the model did not include tidal forcing which is the major driving force in the circulation of Manila Bay \[25\]. In addition, the model was not parameterized using real wind field data and instead assimilated an idealized hurricane wind field based on Hurricane Katrina 2005 parameters, which was not necessarily appropriate for mean tropical cyclone wind fields for the area.

In the meantime, physical and geological oceanographers in the Philippines have empirical and modelled data on wind, bathymetry and tidal and wind-induced circulation of Manila Bay, but have not assimilated these data into a coastal storm surge model because of lack of access to or resources in programming and computing capability to implement ocean general circulation models. ROMS is fairly new and has been in development only since 2002. Storm surge models have been developed for Manila Bay as early as 1984 using shallow water hydrodynamic equations. Since then, these have progressed from one (wind-driven barotropic component) to two dimensions (wind and tides), and with the inclusion of non-linear advection. Villanoy et al. has developed a circulation model for Manila Bay using the three-dimensional Princeton Ocean Model in order to explain Pyrodinium bloom dynamics as below \[26\].

In the case of tsunami modelling, local bathymetry is crucial in determining the extent to which earthquake-induced wave front amplitude is reduced by bay mouth restriction and by wave breakage. The tsunami simulation models usually subsume four sequential processes: (a) seabed displacement to simulate earthquake in a subduction zone; (b) initial wave generated by seabed displacement; (c) wave propagation using a dispersive oceanic wave model; and (d) wave amplification at shoreline. The last component requires detailed local basin scale studies on coastal processes including tidal circulation. For modelled tsunamis generated at the Manila Trench and entering Manila Bay, Løvholt et al. could not provide meaningful estimates of run-up times and amplitude using public domain bathymetric data from GEBCO1 \[27\].

The scenario above describing the constraints that face developing country scientists and their developed country counterparts is fairly typical. Such constraints may be strategically addressed by COOS GRAs by facilitating workshops through which scientists can come together to assimilate existing data such as those shown in Fig. 6, enabling developing country expertise to develop scenario models for coastal storm and tsunami surges. The high potential to develop such data products in collaborative fashion is sufficiently appealing to engage the support of coastal states in implementing regionally coordinated efforts.

5.4. Modeling Coastal Ecosystem Change

The occurrence of harmful algal blooms in eutrophied coastal waters has spurred modelling in developing coastal states where fisheries-based food consumption is high. To continue with the example of Manila Bay, Villanoy et al. modelled the bloom dynamics of *Pyrodinium bahamense* var. *compressum*, a toxin-bearing dinoflagellate \[26\]. The distributions of *Pyrodinium* cells in the water column and of cysts in the sediments in relation to wind forcing, water circulation, and sediment dispersal, were examined. The authors employed a number of models to simulate wind-forced and tidally driven water circulation, wave influenced sediment resuspension and transport of *Pyrodinium* cysts. Modeled simulations indicate that
maximum bottom currents achievable during spring tides and under constant wind forcing are sufficient to stimulate bloom formations when cell survival is allowed over a 15-day period and with a doubling time of 3 days. The simulations appeared to explain the timing of observed blooms in 1998 (Fig. 7).

When in-country competence is advanced to develop coupled biophysical models, the need to obtain data on input parameters in real time is much more obvious. In developed countries, the concept of coastal observatories within a broad framework of ocean observing systems, with both in situ automated instrumentation and access to operational satellite-based data products, has become the approach [30]. In the US, the infrastructure to develop ocean observing systems including coastal ocean observatories, has been in development in the last two decades [30, 31]. The initial investment in physical outlay and organizational structure is high, but is more cost-effective than traditional field campaigns with limited spatial and temporal coverage.

Figure 6. Merging data from multiple sources to develop vulnerability maps such as tsunami impact models for Manila Bay, Philippines: A. SRTM elevation map of areas around the bay (28); B. Bathymetry (29); C. Low elevation coastal population (21); D. Tsunami run up model constrained by lack of local bathymetric data (27).

Figure 7. Modelling harmful algal blooms in Manila Bay (26).

For developing countries, the cost of setting up similar coastal observatories will remain prohibitive despite an increasing clamor for the knowledge they can generate in assisting countries to better cope with natural disasters and climate and human induced changes in coastal ecosystems. The model of a coastal observatory for developing countries may be modified to mean sustained field observations using existing resources. The key element is that funding for thematic ocean observations may have to transition from project support with finite longevity to core institutional support with sustained government provision. As knowledge products meet societal demands to enhance preparedness and mitigate losses from natural disasters and ecosystem changes, incremental investments toward acquiring automated sensors attached to mooring and surface buoy systems with cabled telemetry systems featuring low-cost, low power acoustic transmitters, is no longer a remote possibility.

Developed countries located adjacent to developing country clusters such as Japan in Asia-Pacific, the US and Canada in the
Americas and Caribbean, and the EU in Africa may have to expand their distributed cyber-infrastructure to regional scales in active anticipation of and support for increased capabilities among their developing country neighbors to engage in operational oceanography. The US and Canada are pioneering this initiative for regional scale ocean observations [30]. In particular NEPTUNE Canada has launched the world’s first regional-scale underwater ocean observatory with an 800 km cabled ocean observing system on the Juan de Fuca tectonic plate. The system is accessible through the worldwide web, engaging multiple audiences including the public and policy makers while scientists in their laboratories conduct their experiments and data analysis from remote [32].

6. THE ROLE OF GOOS REGIONAL ALLIANCES

Figure 8. The functional relationships of Coastal States and the GOOS Regional Alliances (GRAs) in developing observation-based data products for the use of the former in coastal planning to sustain coastal livelihoods and ecosystems.

The growing awareness among developing coastal nations to increase knowledge about the ocean domain for their own survival, and the deepening realization among developed littoral states to foster international collaboration to facilitate this process is central to how GRAs may envision their role (Fig. 8).

An appreciation from multiple views that ocean observing systems can enhance a coastal nation’s capacity to minimize and mitigate what may otherwise be catastrophic consequences of natural and human-induced ecological disasters is a necessary precondition for a functional GRA. Furthermore, investments to enhance this process is money well spent compared to disaster aid which is expensive, highly inefficient and insufficient to meet rebuilding needs in the aftermath of a catastrophe.

The voices of Member States, the GRAs as well as the assessments provided by experts in the GOOS structure contained in the IOC Reports of Governing and Major Subsidiary Bodies, as well as the IOC Reports of Meetings of Experts and Equivalent Bodies were reviewed for this section, with a focus on the most recent reports which reviewed the status of the GRAS [33, 34, 35].

6.1. GRAs as platforms for multilateral strategic needs assessment

For coastal nations that are already aware of their needs for coastal ocean observations, GRAs can serve as platforms for identifying strategic and common needs, perhaps at an incremental pace of one parameter/sensor at a time, as discussed in section 3.0. Such needs from member countries must be coupled with formal statements of their willingness to invest in capacity and institutional building that must accompany the acquisition of hardware and satellite data. The active participation of scientists from member countries in such assessments is fundamental, as keeping the process transparent and fostering ownership of the assessment process and its outcomes underpin the sustained engagement of participants.
6.2. GRAs as facilitators to leverage multilateral support

Identified strategic needs that when fulfilled serve as bases for countrywide action programs and for regional (multilateral) cooperation warrant support from international donors including the Global Environment Facility (GEF) of the World Bank. The GRAs can facilitate a process that will translate the identified needs into fundable action programs, underscoring in-country investments to match requests for international support. The GEF portfolio has included the assessments of international (transboundary) waters, as well as large marine ecosystems. It seems very logical to include coastal ocean observing systems as a necessary component in such regional ocean assessments. A process-based articulation of such need awaits bottom-up proposal development that the GRAs are in a position to facilitate, and provides an excellent opportunity for GEF to be involved.

6.3. GRAs as hubs of regional operational oceanography

With definite targets identified and financial support leveraged to meet these goals, one can envision GRAs to become hubs of scientific activity in operational physical and ecological oceanography, generating data products and knowledge at scales appropriate for coastal ocean planning by member states. As the latter gains incremental experience in multilateral scientific cooperation and in using the products these create to enhance societal benefits at local and national scales, one can envision that the GRAs can become sustainable institutions. The process would need to start soon, but not without the momentum that needs to be seeded at national scale.

7. CONCLUSION

Coastal ocean observing systems are scientific tools that can revolutionize oceanography and coastal planning in the 21st century in a profound way. To build them, coastal states need to share a vision to monitor their oceans in real time so they can better respond to planetary changes that often entail loss of lives and livelihoods. Collaboration to realize this vision has had a rough journey, but the potential that it will flourish with purpose remains high. The stakes are just too great, otherwise.

8. REFERENCES


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