Research to Operations and Back Again

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***Abstract*- The U.S. Integrated Ocean Observing System (IOOS) is being designed and implemented to provide data and information needed to address seven societal goals related to (1) climate, (2) maritime operations, (3) natural hazards, (4) homeland security, (5) public health, (6) marine ecosystems, and (7) living marine resources. The operational objective is to achieve these goals by providing more timely and accurate assessments of the state of marine systems and predictions of changes in state. Operational capabilities from observations to models are more advanced for those goals that only require physical oceanographic and meteorological observations (goals 1-4) and less advanced for those that also require biological and chemical oceanographic observations (goals 5-7). Thus, building and improving an integrated system that routinely and continuously provides quality controlled data and information in support of decision making for all seven goals will require considerable investment in science and education and timely, effective synergy between advances in science and the development of operational capabilities. A major objective of the IOOS is to facilitate synergy between the development of operational capabilities and advances in scientific understanding of oceanic and coastal environments and their impacts on socio-economic systems.**

To facilitate synergy between research and improvements in operational capabilities, the IOOS includes a spectrum of activities from operational elements to research, pilot, and pre-operational projects. Research and pilot projects represent the research and development end of the IOOS. Transition from a pilot project to pre-operational status is a major step, and it is one that must be undertaken through collaboration between research and operational communities with the support of the organization that will integrate the new capability into to its operational systems.

Describing a rational procedure for linking research and operational activities and developing a more integrated approach to how research and operational data streams are used is one thing. Implementing them is another. Needed now are government policies and procedures for doing so – from adopting standards and protocols required for interoperability to the formulation of budgets for operational activities in concert with budgets for research intended to improve operational capabilities.

I. INTRODUCTION

The U.S. Integrated Ocean Observing System (IOOS) is being designed and implemented to provide data and information needed to address seven societal goals: (1) improving climate predictions; (2) improving the safety and efficiency of maritime operations; (3) improving prediction and mitigation of natural hazards; (4) improving homeland security; (5) reducing public health risks; (6) sustaining and restoring healthy marine and estuarine ecosystems; and (7) sustaining and restoring living marine resources. As discussed in *The First U.S. Integrated Ocean Observing System (IOOS) Development Plan*[1], the IOOS efficiently links observations to applications through integrated data management and modeling (Figure 1). The observing subsystem is a multi-scale system that incorporates two interdependent components, a global ocean component with an emphasis on ocean-basin scale observations[2] and a coastal component that focuses on the Nation's Exclusive Economic Zone (EEZ), Territorial Waters, Great Lakes and estuaries.

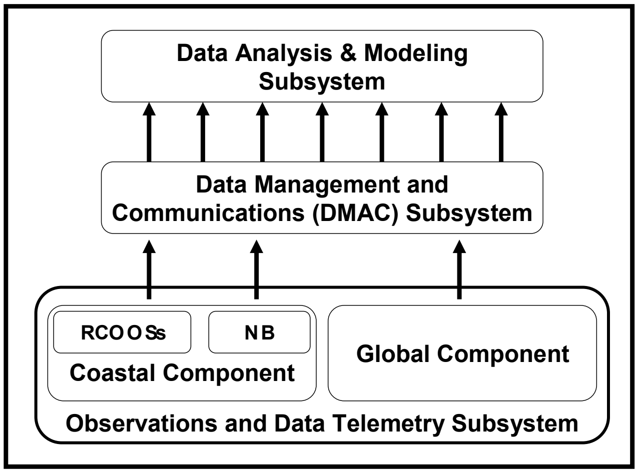

Figure 1. The IOOS is a multiscale system of systems consisting of three efficiently linked subsystems for (1) observations and data telemetry, (2) data management and communications (DMAC), and (3) data analysis and modeling. The observing subsystem consists of global and coastal components with the latter broken down into a National Backbone (NB) for the Nation's EEZ and Regional Coastal Ocean Observing Systems (RCOOSs) to address regional and local needs. The integrating engines are the DMAC and modeling subsystems. The NB provides data and information required by federal agencies and most, if not all, Regional Associations. RCOOSs contribute to the NB and are tailored to the data and information needs of each region.

The global ocean component and the National Backbone (NB) represent the suite of operational observing subsystem elements that support the following functions:

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[1] www.ocean.us/documents/docs/IOOSPlan_6-20-05_lowres.pdf
[2] http://ioc.unesco.org/goos/docs/GOOS_066_act_pl.htm

- Monitor core variables[3] in the nation’s EEZ and Great Lakes using both remote sensing and *in situ* measurements;
- Make *in situ* measurements at a network of sentinel sites using federally approved methods;
- Transmit Data Management and Communications (DMAC)-compliant data on core variables to national data assembly centers continuously, routinely and reliably (real-time or delayed mode as needed); and
- Link larger scale changes occurring in the ocean and on land to changes occurring within coastal regions.

The operational objective is to address the seven societal goals by providing more timely and accurate assessments of the states of marine and estuarine systems and predictions of state changes. Operational capabilities from observations to models are more advanced for those goals that require physical oceanographic and meteorological observations only (goals 1-4) and less advanced for those that require biological and chemical oceanographic observations in addition to physical and meteorological observations (goals 5-7). Thus, building and improving an integrated system that routinely and continuously provides quality controlled data and information in support of decision making for all seven goals will require considerable investment in science and education and effective synergy between advances in science and the development of operational capabilities.

Today there are unacceptable lags between advances in science and applications of new technologies and knowledge to achieve societal goals. Thus, a major objective of IOOS implementation is to enable more effective synergy between the development of operational capabilities and advances in scientific understanding of oceanic and coastal environments and their impacts on socio-economic systems. Enabling timely and effective synergy between advances in science and improving IOOS operational capabilities requires a managed process that selectively uses new technologies (*in situ* biological sensors; gliders; high frequency radar; high resolution, satellite-based remote sensing of ocean color, etc.) and scientific knowledge (numerical models of ecosystem dynamics, algorithms for translating ocean color into phytoplankton biomass, etc.) to enhance and supplement all operational aspect of the IOOS from observations and data telemetry to data management and models. Achieving synergy, the subject of this contribution, is a major challenge and is inherently difficult.

II. THE EVOLUTION OF AN INTEGRATED SYSTEM

To enable synergy between advances in science and technology and the development of operational capabilities, the IOOS encompasses a continuum of mutually dependent activities from research to operational modes, where “operational” is used here to indicate the routine, sustained and timely provision of data and data-products of known quality to user groups. In terms of integration across all seven IOOS societal goals, operational capabilities are most developed for the natural hazards and marine services goals and least developed for the goals of ecosystem-based, adaptive management for public health, environmental protection and resource management. Thus, strong Earth and ocean science research programs are critical to increasing our understanding of Earth systems and expanding IOOS operational capabilities in this context.

Expanding IOOS operational capabilities will also enable strong Earth and ocean science. Enabling timely positive feedbacks between advances in science and improving IOOS capabilities requires a managed process that selectively uses new technologies and scientific knowledge to enhance and supplement all three subsystems of the IOOS (Figure 2).

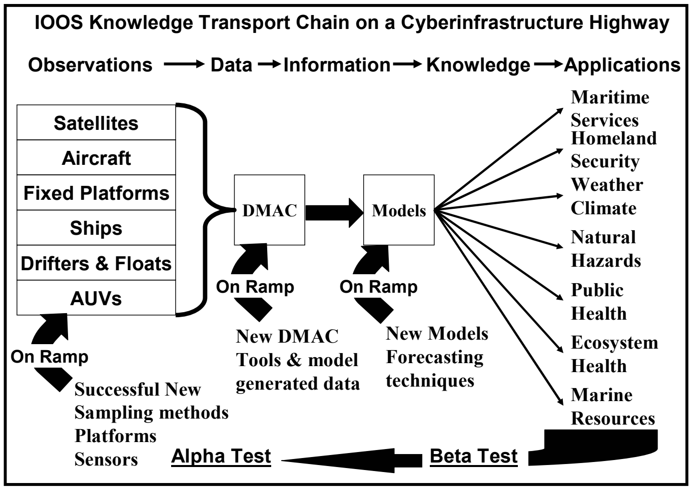

Figure 2. “On Ramp” model for improving IOOS capabilities over time with Alpha testing of technologies (performance-based metrics of *in situ* biological sensors and platforms, high resolution satellite-based remote sensing of ocean color, etc.) and models (numerical ecosystem models, algorithms for estimating phytoplankton biomass from ocean color) before moving into the On Ramp and Beta feedback on user satisfaction with the data and information generated by the IOOS (societal performance metrics).

Using new technologies and knowledge developed through research to improve operational capabilities is a big step and is inherently difficult. In addition to cooperation and good will on the part of the research and operational communities involved, it will require ongoing guidance from both data-providers and users and advanced planning and budgeting for transitioning research capabilities to an operational mode. Steps for selectively incorporating new knowledge and technology into an operational mode and for promoting synergy between research and operational oceanography are described in the *First IOOS Development Plan*. The next step is for Ocean.US to work with its federal partners to formulate and implement policies and procedures that enable this process as conceptualized in Figure 2.

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[3] www.ocean.us/NB_Component

Policies and procedures for migrating new technologies and knowledge into an operational mode must consider the two dimensions of involving both data suppliers and users in IOOS development (Figure 3). On the supply side, Advanced Very High Resolution Radiometer (AVHRR) is an operational sensor for measuring sea surface temperature (SST). The data streams used to routinely produce maps of SST are sustained, continuous and guaranteed – the "user" dimension. AVHRR data, along with data on SST from other remote and *in situ* sensors, are being used in an experimental mode to improve the resolution and, therefore, the usefulness of SST maps.[4] The development of a sensor for measuring sea surface salinity (SSS) from space is a research priority. Altimetry (Ocean Surface Topography Mission, OSTM) is used to estimate changes in sea surface height (SSH) for detecting and predicting trends in sea level related to global warming. Although these are research missions that have a finite life time with data provided on an "as able" basis, maps of SSH are provided in an operational mode. QuikSCAT (scatterometer for estimating ocean surface vector winds) and sensors for measuring ocean color and estimating sea surface chlorophyll-*a* concentration[5]also fall into this category. Jason 3 and the Visible Infrared Imager/Radiometer Suite (VIIRS) are planned to be operational missions for SSH and ocean color, respectively.

Integrating data streams from research projects and sustained operational sensors to serve "blended" products operationally will become especially important as long term time series observations become priorities for advancing the Earth sciences. Thus, procedures will be needed to establish standards and protocols for intercalibration and validation required to blend data from different measurement systems (remote and *in situ*). Two research programs, the Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS)[6] project completed in 2001 and the Global Ocean Data Assimilation Experiment (GODAE) high-resolution sea surface temperature (GHRSST)[4] pilot project currently ongoing provide prototypes for the effort that will be needed to integrate data from different sensors. Both studies illustrate the non-trivial technical difficulties of combining data from different measurement systems (SIMBIOS: ocean color from an array of satellite-based sensors; GHRSST: sea surface temperature (SST) from satellites and *in situ* measurements) for routine provision of accurate, more highly resolved sea surface chlorophyll-*a* (SIMBIOS) and SST time series (GHRSST) products. These, and programs like them, will be needed to sustain and improve IOOS capabilities to serve the data and information needed to address all seven IOOS societal goals.

		Supply	
		Research	**Operational**
Use	**Research**	**• Aquarius (SSS) (Planned)**	**• Global High–Res SST**
	Operational	**• OSTM (SSH) • QuikSCAT (Wind) • SeaWiFS, MODIS (SS Chl)**	**• AVHRR (SST) • Jason-3 (planned) • VIIRS (planned)**

Figure 3. An example of the two dimensions of operational capability as illustrated by satellite-based, remote sensing where supply refers to the provision of data and use refers to provision of products and services.

Policies and procedures for migrating new technologies and knowledge into an operational mode must also consider gaps between current capabilities and observing subsystem requirements detailed in action and implementation plans for the global ocean-climate component of the IOOS[7] and for the coastal modules of the Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS).[8] Gaps fall into one or more of the following categories:

- "Sustainability" challenges focused on maintaining existing observation capabilities;
- "Resolution" challenges that target requirements for increasing time, space and spectral resolution;
- "Synoptic" challenges of measuring geophysical and biogeochemical variables at the same times and places;
- "Knowledge" challenges that require research and development; and
- "Resilience" challenges that require the hardening of sensors and systems against natural forces and vandals.

In terms of enhancing operational capabilities of the IOOS, *sustainability* challenges are concerned with both continuity of funding over time and transitioning observing subsystem capabilities from research to operational modes. R*esolution* challenges range from increasing the spectral and spatial resolution of ocean color observations from space to blending data from *in situ* and remote sensing for improved temporal and spatial resolution (e.g., the Global Ocean Data Assimilation Experiment's (GODAE) High Resolution Sea Surface Temperature (GHRSST) pilot project[3]). S*ynoptic* sampling challenges include the need for concurrent measurements of geophysical and biogeochemical variables in time-space as well as the need for multipurpose platforms for more cost-effective operations (e.g., more effective use of

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[4] http://ghrsst-pp.metoffice.com/documents/GHRSST-PP-Strategy-v1.5.pdf

[5] Sea-viewing Wide Field of view Sensor (SeaWiFS) and the MODerate resolution Imaging Spectroradiometer (MODIS).

[6] http://www.ioccg.org/reports/simbios/simbios.html>

[7] http://ioc.unesco.org/goos/docs/GOOS_066_act_pl.htm; www.wmo.ch/web/gcos/gcoshome.html

[8] www.eohandbook.com/gosp/Coastal.html; http://unesdoc.unesco.org/images/0014/001412/141242E.pdf

ship-time). *Knowledge* challenges range from advances in technology (e.g., satellite-based remote sensing of sea surface salinity) to more accurate algorithms for estimating concentrations of chlorophyll-*a* and other phytoplankton pigments in turbid coastal waters. *Resilience* challenges include not only sensors but also power systems, platforms, and systems for data collection, analysis and transmission.

Cross-cutting all of these challenges is the issue of increased capacity and infrastructure. For example, as more platforms are added to the National Backbone and Regional Coastal Ocean Observing Systems (RCOOSs), additional ships and technicians will be needed to install and maintain them. Similarly, as the volume of data increases, more transmission, analysis and dissemination capability will be needed. Thus, as the enhancement of IOOS is undertaken, planning for increased infrastructure and support capability must be included.

III. CONCLUSIONS

Achieving synergy between research and the development of operational capabilities will require (1) ongoing guidance from data-suppliers and -users, (2) cooperation and goodwill on the part of the research and operational communities involved, and (3) harmonization of federal planning and budgeting processes to provide funding for both research and sustained observations for the public good. Participation in IOOS development must catalyze interactions among research and operational communities to enable their respective organizations (e.g., research institutions and operational centers) to learn from each other (new knowledge and technologies, operational requirements, “best practices”, adopting common standards and protocols, exchanging model code, comparative evaluations of model performance and predictive skill, etc.)

Improvements in operational IOOS capabilities will be driven by the needs of user groups for data and information (“pull”) and by advances in both understanding and new technologies driven by scientific inquiry and national priorities (“push”). To facilitate synergy between research and improvements in operational capabilities, the IOOS includes a spectrum of activities from operational elements to mission-driven research, pilot, and pre-operational projects. Research and pilot projects represent the research and development end of the IOOS. Transition from a pilot project to pre-operational status is a major step, and it is one that must be undertaken through collaboration between research and operational communities with the support of the organization (federal agency, RA, private company, etc.) that will integrate the new capability into the IOOS.

The process of linking research and operational activities has two dimensions, one for the provision of data (supply) and one for the transformation of data into derived products for applied purposes (use). Thus, operational products are currently being served using research data, operational data or both. Integrating data streams from research programs and sustained operational sensors to serve “blended” products operationally will become especially important as long term time series observations become priorities for advancing the Earth sciences (e.g., the NSF ORION and OOI programs). As long-term time series observations continue to be implemented for the purposes of basic research, functional distinctions between research and operational activities will become increasingly vague.

Describing a rational procedure for linking research and operational activities and developing a more integrated approach to how research and operational data streams are used is one thing. Implementing them is another. Needed now are government policies and procedures for doing so – from adopting standards and protocols required for interoperability to the formulation of budgets for operational activities in concert with budgets for research intended to improve operational capabilities.

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