THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

Oceanography

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# Economic Considerations in the Design of Ocean Observing Systems

ABSTRACT. Recent work on the potential economic value of improved coastal ocean observing capabilities suggests that aggregate values of better ocean observing system information for all US waters could be in the hundreds of millions of dollars per year. This aggregate value derives from specific information delivered to particular user groups in particular regions; the scale of benefits depends on the economic importance of the user sectors and on their ability to make use of better information about local and regional marine conditions. As we continue to refine these estimates of economic value, information on benefits is becoming sufficiently specific to be useful in the observing system design process. This paper describes a National Oceanographic Partnership Program study on the economics of ocean observing system information, presents a framework for incorporating economic information into observing system design, and sketches the beginning of an application of this process to the northeast region of the United States.

## INTRODUCTION: ECONOMICS OF OCEAN OBSERVING SYSTEMS

Ocean observing systems are networks of sensors for measuring physical, chemical, and biological parameters in the ocean and in the atmosphere above the ocean surface. The sensors are usually deployed on platforms (buoys, towers) and linked to data management facilities. The data may be used directly or may serve as input to models that interpolate present conditions or generate forecasts. Along with other nations, the United States is engaged in a debate over the appropriate public investment in improved ocean observing infrastructure. Two central questions in this debate are: (1) How much, and how fast, should we invest in better ocean observing systems? and (2) What should these observing systems look like? The answers to both questions depend, in part, on how much economic value these improvements are expected to generate.

Ocean observing systems provide information that reduces uncertainty in our knowledge about present and future conditions in the marine environment. This information has economic value primarily because it can contribute to improved decision making by reducing the uncertainty about likely outcomes from using marine resources or responding to threats posed by the marine environment. The value of ocean observing information—what a decision-maker would be willing to pay for the information—depends on how it reduces uncertainty, and on the economic resources at stake in the decision.

This definition of the value of information suggests an approach to estimating the value of ocean observing information. For example, the captain of a container ship heading from Hong Kong to Los Angeles/Long Beach has to make decisions about which route to take—the geographically shortest path, or a longer route that may reduce the likelihood of encountering adverse weather conditions. The choice of route has physical and economic consequences: it determines how long the voyage takes, how much fuel is burned, and how much damage is sustained by ship and cargo from severe wind and wave conditions. The captain's knowledge about marine conditions along potential routes is limited, and the outcome of the routing decision is therefore uncertain. Specifically, without any ocean observing infrastructure, the captain's knowledge is limited to general historical experience of weather patterns, and perhaps recent reports from other vessels crossing the same ocean.

Ocean observing infrastructure can improve this information. By itself, observing infrastructure can provide a better near-real-time "nowcast" of conditions at specific locations (from buoys) and over broad regions (from satellites). When these observations are combined with models, they can produce forecasts of future conditions; these are of particular value in our example, because the voyage will require a number of days. With better nowcast and forecast information, the captain can expect to make better decisions, on average, about the route—decisions that will result, over time, in lower operating expenses and reduced damages and losses. The reduction in costs in this case is a reflection of the value of the information generated by ocean observing.

This paper describes a National Oceanographic Partnership Program (NOPP) project to estimate the magnitude of likely benefits that may accrue from regional observing systems deployed in the coastal waters of the United States, including the Great Lakes, and suggests how economic information might be used in the design of ocean observing systems.

## NOPP PROJECT: COORDINATED REGIONAL STUDIES OF OCEAN OBSERVING SYSTEM BENEFITS

With support from NOPP, a group of researchers from around the country carried out a coordinated series of studies from 2003 to 2005 to estimate potential benefits from improved regional coastal ocean observing systems around the United States. The results of this work are summarized here (for details see Kite-Powell et al., 2005, 2008). In addition to the author, the project team included Charles Colgan (University of Southern Maine), Michael Luger (University of North Carolina, Chapel Hill), Mark Kaiser (Louisiana State University), Thomas Pelsoci (Delta Research, Chicago), Linwood Pendleton (University of California, Los Angeles), Katherine Wellman (Seattle, Washington), and Kenneth Wieand (University of South Florida).

Like NOPP itself, regional ocean observing systems around the United States are partnerships involving federal agencies, such as the National Oceanic and Atmospheric Administration (NOAA), and regional and local entities that implement, support, and use the observing systems and the information they generate. Similarly, this NOPP project brought together researchers from academic institutions and the private sector with representatives of federal, regional, and local organizations to assemble information on the potential use and value of improved observing system information.

The project team surveyed ocean industries and marine activities in nine regions (Pacific Northwest, California, Gulf of Mexico, Florida, southern Atlantic coast, mid-Atlantic coast, New England/Gulf of Maine, Alaska, Hawaii, and the Great Lakes) to identify the levels of economic values that might be affected by the availability of improved and expanded information from ocean observing systems. Rough estimates of the potential value of ocean observing system information initially were made by assuming that small increments (typically on the order of 1%) of the total value generated by underlying activities could be realized as possible benefits. The research team then developed more formal models of the relationship between ocean observing information and decision making in a selected set of user sectors and regions.[1]

The detailed information needed to develop precise estimates of the economic benefits of ocean observing systems was, for the most part, unavailable at the time the NOPP project was carried out. Both the development of the observing systems themselves and the economic information needed to estimate their benefits remain incomplete in 2009. In light of this limitation, the NOPP project team was able to characterize only the order of magnitude of benefits that may be expected from a fully implemented network of regional ocean observing systems. The findings suggest that annual benefits to users from the deployment of ocean observing systems are likely to run in the multiple hundreds of millions of dollars per year (see Table 1).

These potential benefits must be considered in light of the cost of ocean observing systems. The cost depends

[1] These models are described in a series of papers. Wieand (2008) discusses potential benefits from ocean observing system information to recreational fishing in the Gulf of Mexico. Wellman and Hartley (2008) describe potential benefits to the commercial fishing industry in Alaskan waters. Pendleton (2008) models economic benefits associated with improved beach closure management in California. Kaiser and Pulsipher (2007) describe the role of ocean observing and forecasting in offshore energy production in the Gulf of Mexico. In related papers by researchers not directly connected to the NOPP project, Dumas and Whitehead (2008) estimate ocean observing system benefits in a number of user sectors for the southeast Atlantic coast region, and Richert et al. (2008) provide an overview of costs and benefits of the Gulf of Maine Ocean Observing System.

Table 1: Order of magnitude estimates of OOS benefits by major user sectors

| | | Order of Magnitude of Possible Annual Benefits (millions of dollars) | Regions with Greatest Benefits* |
|---|---|---|---|
| **Recreational Activities** | Recreational Fishing | 100s | Great Lakes, Gulf of Mexico |
| | Recreational Boating | 100s | Great Lakes, Gulf of Mexico, Atlantic |
| | Beaches/Shore Recreation | 100s | Florida, California |
| **Transportation** | Transportation (Freight) | 10s | Florida, Mid Atlantic |
| | Transportation (Cruise Ships) | 10s | Florida |
| **Health and Safety** | Search and Rescue | 10s | All |
| | Oil Spills | 10s | All |
| | Tropical Storm Prediction | 10s | Atlantic, Gulf of Mexico |
| **Energy** | Electricity Load Planning | 10s to 100s | Great Lakes, California, Atlantic |
| | Ocean Structures | 10s | Gulf of Mexico |
| **Commercial Fishing** | Commercial Fishing | 100s | Alaska, New England |

*As used here, "Florida" includes both east and west coasts of the state; "Gulf of Mexico" excludes the west coast of Florida.
Source: Kite-Powell et al. (2008)

on the final design and configuration of the systems, which are not yet known. Based on extrapolations from established regional systems, such as the Gulf of Maine Ocean Observing System (GoMOOS; http://www.gomoos.org/), we estimate that providing ocean observing system coverage along all US coasts may require several hundreds of millions of dollars in up-front investment, and about $100M per year for annual operations and maintenance. This sum suggests that, over time, the benefits from carefully managed investment in such systems are likely to exceed the costs. This finding is consistent with previous conclusions about the economic benefits of such systems (see Adams et al., 2000).

In conducting the analysis for this project, the project team made no attempt to evaluate the benefits of specific technologies, instruments, platforms, or communication channels. We assumed that economically relevant data would be available in an integrated form and timely manner to users irrespective of observation technology or data dissemination means. In general, the project team assumed that the sort of data and information streams that are already being delivered by existing ocean observing system organizations would be widely and effectively used. We made no specific assumptions about improvements in data other than that development of the observing technologies and systems would permit a substantial increase in the amount, quality, and usability of information delivered to users. The estimates we developed are thus potential benefits from systems already being established and expanded, not from the observing technologies, platforms, and data distribution systems in place in 2005.

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## THE SYSTEM DESIGN PERSPECTIVE

Estimates of the potential value of improved ocean observing information have been useful to broad, high-level decisions about investing in ocean observing systems (see following section). But what should be the role of economic information in the design of these systems? The fact that the benefits from the systems as a whole may exceed the costs under certain circumstances does not mean that benefits will exceed costs for every individual local or regional application or observing parameter. The configuration of observing systems in each region ideally should take into account the priorities of local and regional user groups, as well as the economic implications of these priorities.

The technologies comprising ocean observing systems include a wide array of instruments and platforms. The "platforms," broadly, include moored and unmoored buoys and drifters, radar stations, satellites, fixed marine platforms, dedicated manned and unmanned vehicles, and platforms and vessels of opportunity. Satellites, moored buoys, and radar make up much of the current generation of improvements in ocean observing systems. The data output from instruments deployed on these platforms consists of a wide array of parameters, including wind speed and direction, current speed and direction, wave height and periodicity, air and water temperature at varying heights and depths, chemical parameters such as salinity, biological constituents (such as chlorophyll *a*), visibility, and ice, among others.

Data derived from these observations are distributed directly and indirectly through a variety of channels. They may be fed to modeling and forecasting centers operated by the federal government, universities, or private organizations for incorporation into nowcast and forecast products that are distributed widely through public and private channels including television, newspapers, radio, or the Internet. Data may also be delivered directly to subscribers via the Internet or by telephone.

Fundamentally, observing system design decisions deal with choices about which data to collect, using what sensors on which platforms, when and how often to measure each parameter, what technologies to employ to transmit and manage the data, and what models to build in order to generate which end-user products. The vision for integrated ocean observing infrastructure for the nation, as articulated by the agencies supporting system development, is that these systems should be designed to "provide data in forms and at rates required by decision makers to address seven societal goals." Those goals are: (1) improve predictions of climate change and weather and their effects on coastal communities and the nation, (2) improve the safety and efficiency of maritime operations, (3) mitigate the effects of natural hazards more effectively, (4) improve national and homeland security, (5) reduce public health risks, (6) protect and restore healthy coastal ecosystems more effectively, and (7) enable the sustained use of ocean and coastal resources (see http://www.ocean.us/what_is_ioos). A process that seeks to design a regional observing system so as to meet an economic criterion, such as maximizing value generated in support of these goals subject to an overall budget constraint, or maximizing the rate of return on investment in the observing system, must build economic considerations into the design process from the outset.

## A FRAMEWORK FOR USING ECONOMIC INFORMATION IN OCEAN OBSERVING SYSTEM DESIGN

The framework for the integration of economic considerations into the design of ocean observing systems and products begins with a conceptual view of the observing system as a collection of platforms and associated data links (V) and sensors (S) that generate data streams (D), a data processing/modeling/dissemination infrastructure (M) that produces products (P) that are delivered to users (A):

$$V \,\&\, S \rightarrow D \rightarrow M \rightarrow P \rightarrow A.$$

The economic value (B) generated by an observing system is a function of the information products (P) the system generates and the applications or user sectors (A) in which these products are used. Cost (C) associated with the observing system is a function primarily of the infrastructure and its operation and maintenance:

$$B = f(P, A) \quad C = g(V, S, M).$$

An economic criterion for observing system design is to make choices about V, S, and M so as to maximize the net benefits generated by the system, possibly subject to constraints on budgets and the range of permissible or required applications:

$$\max\,(B - C)\;[\text{s.t. } C < C_{max}].$$

In addition to information about the benefits of products to users, this formulation requires information on the cost of obtaining observing system data via different combinations of platforms and sensors. There are several potential sources of economies in the design of the observing system, including: (1) platforms (V) that can support multiple sensors (S), (2) data streams (D) that can support multiple models (M), (3) models (M) that can support multiple products (P), and (4) multiple applications (A) that benefit from a single product (P).

Within the observing system design process of determining what data to collect and what time intervals and in what locations, observing system simulation experiments (OSSEs) can serve as an internal optimization procedure that sheds light on the effect of different data streams on the characteristics (quality) of the final information product. OSSEs thus represent an internal optimization process within the larger economic question of what products to deliver.

Using this kind of economic analysis to inform observing system design questions is useful because it forces a focus on net benefits and makes explicit the economics of synergies, or economies of scale and scope, within the observing system. It can also help estimate the potential value of a hypothetical new sensor or platform, which would change design options and possibly the optimal system design.

## TOWARD AN APPLICATION

The results of studies such as those described above indicate, not surprisingly, that ocean observing systems often will have the largest benefits where the information from such systems is used by the largest possible groups, or when they significantly affect outcomes, such as human lives, that carry a large unit price. In our NOPP study, recreational activities are consistently the highest generators of benefits because of the very large number of people who use beaches, boat on the Great Lakes or in the coastal ocean, or engage in marine recreational fishing. Although the per-user benefits are smaller than those realized by, for example, commercial fishermen or maritime vessels, the large number of recreational users drives the overall magnitude of potential benefits to substantial sums. These results have influenced decisions regarding state funding for ocean observing system development in Massachusetts and the Northeast (see Kite-Powell, 2007) and are increasingly used by governing bodies of regional observing system associations in setting priorities for data and products.

If we consider, for example, a regional observing system for the marine waters of the northeastern United States, the estimates of potential annual benefits range from $24M per year for improved search and rescue results to the order of $1M per year for applications such as harmful algal bloom predictions or recreational boating (see Table 2). A project is currently underway, with funding from NOAA, to refine these estimates of potential benefits and validate them in practice as a regional observing system is built for the Northeast. This project builds on the results of the NOPP project described above and came about largely as a consequence of the NOPP initiative; similar projects have been funded in other regions. In New England, the effort to build a regional system is organized under the umbrella of the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS; www.neracoos.org).

The detailed application of the economic design approach described above to the Northeast regional system is a work in progress, and it is too early to report any definitive results. However, it seems likely, assuming that the distribution of estimated potential value from uses of ocean observing information in Table 2 holds up under further study, that an economic design criterion will favor the inclusion of observations and models that support a better understanding of surface currents in particular, and regional ocean circulation in general, as a priority item in the design of the system. Surface current nowcasts and forecasts are crucial to most of the applications of interest to

Table 2: Potential benefits from the Northeast regional ocean observing system

| User sector | Information to users | Requires observation and modeling of: | Potential annual value (approximate) |
|---|---|---|---|
| Recreational fishing | water temperature, currents | temperature, currents | $11 million |
| Recreational boating | visibility, wind, waves, currents | visibility, wind, waves, currents | $1 million |
| Commercial maritime | wind, waves, currents | wind, waves, currents | $1 million |
| Search and rescue | surface currents | surface currents | $24 million |
| Commercial fishing | biological community structure, now and forecast; circulation and environmental parameters, now and forecast | biological community structure (sampling, visual observation) | $4 million |
| Shellfish farmers and harvesters | harmful algal bloom forecast | algal bloom cysts, currents, temperature, nutrients | $1 million |
| Emergency management | coastal flooding forecast | winds, water levels | $2 million |

Sources: Estimated values are from Kite-Powell et al. (2008), except as follows: harmful algal bloom forecast (Jin and Hoagland, 2008); coastal flooding forecast: preliminary estimate from work by the author.

ocean observing system users in New England, and are clear examples of a single data stream (current measurements in a few key locations) feeding into multiple products and applications. These include, notably, the search and rescue operational planning task, where the likelihood of a successful rescue following an accident that leaves a boater or fisherman in the water depends critically on how well the search effort is targeted, taking into account drift due to surface current and wind (O'Donnell et al., 2005).

The complete application of the economic design framework to the Northeast regional observing system will require more detailed specification of products and applications and their economic benefits, and annualized cost estimates for different combinations of platforms and sensors, as well as data transmission and management components, and modeling activities. We expect to carry out this work in collaboration with NERACOOS, and to report results within the next 24 months.

## CONCLUSIONS

The development of estimates of the economic value derived from ocean observing information by different user groups in different geographic regions is useful and interesting. Although the information available to date is not perfect, progress has been made in recent years in understanding how to estimate such values, and on the scale of benefits likely to be realized. The results suggest that the economic value delivered by properly designed ocean observing systems is likely to exceed their costs, and that targeted public investment in observing systems is justified. NOPP and NOAA are to be commended for investing in research to improve our understanding of these questions.

Without a clear framework for, and commitment to, the integration of economic information into the design of ocean observing systems at an early stage, this information is of limited value. This paper has described a general framework for the integration of economic information into the design of an observing system. The complete development of this approach, and its application to the regional observing system being designed for New England waters, is underway now through a NOAA-funded project that will generate not only results specific to the northeast region of the United States, but also generic tools that can be applied in other regions. This follow-on effort was greatly facilitated and informed by work carried out with seed funding and start-up support provided by NOPP.

## ACKNOWLEDGEMENTS

I am grateful for the contributions of the NOPP project team (Charles Colgan, Kenneth Wieand, Katherine Wellman, Marcus Hartley, Linwood Pendleton, Mark Kaiser, Alan Pulsipher) to the work reported on here, and to Rodney Weiher for his long-standing support of social science in the service of oceanography. This work was supported by NOPP, NOAA's Integrated Ocean Observing System Program, and the Marine Policy Center of the Woods Hole Oceanographic Institution. Three anonymous reviewers and Ben Chicoski provided helpful suggestions on the manuscript.

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