DEOS MOORED BUOY OBSERVATORY DESIGN STUDY

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Moored ocean buoys are a technically feasible approach for making sustained time series observations in the oceans and will be an important component of any long-term ocean observing system. Because of the broad spectrum of scientific needs identified in DEOS (Dynamics of Earth and Ocean Systems) planning documents, and described in the recent U.S. National Academy of Sciences/National Research Council report “Illuminating the Hidden Planet: The Future of Seafloor Observatory Science,” it is clear that there is no single buoy or mooring design that will meet all of these needs while at the same time minimizing costs. We have, therefore, considered a range of specifications and designs in this study, and evaluated the trade-offs in performance and costs for these different systems. We have found that it is possible to meet the specifications that have

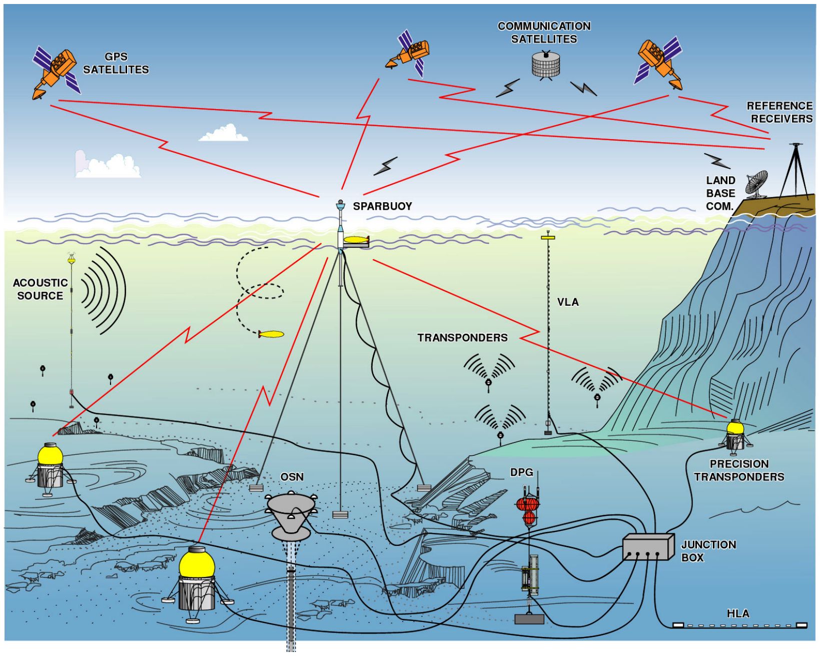

Figure 1 Conceptual diagram of a moored ocean buoy observatory

been proposed in these planning documents by using currently available technologies, although the cost will be significant. The installation of the infrastructure for twenty systems will cost as much as a Class I UNOLS vessel (ca. ~$50M) and the annual maintenance and operating costs of these twenty systems will be the equivalent of operating a pair of major UNOLS ships (ca. ~$10M/yr). However, the establishment of a network of moored ocean buoy observatories will be an important enabling technology that will lead to fundamental new understanding of the oceans and Earth.

The most important specifications driving buoy design decisions are the telemetry rate that the buoy system will support for communication to shore, and the amount of power delivered to the seafloor. The only cost-effective alternative for continuous high-bandwidth communication (64-128 kbps or higher) currently available is a C-Band or Ku-Band satellite system. However, the power requirements for operating these telemetry systems and for the delivery of power to the seafloor lie in the kilowatt range and require a buoy equipped with diesel generators. At present, compact, low-power satellite communications systems that can be powered entirely by solar cells and batteries are limited to modest data rates (<64 kbps) and high tariffs that will limit data transmission to ~5 Mbytes/day. Solar cells can only provide at most a few tens of watts of power to instruments on the seafloor or on a mooring. Diesel generators can provide several hundreds of watts to the seafloor, providing much greater potential for system expandability in the future. Thus, the size and payload capacity of the buoy is strongly dependent on the telemetry rate specified for the system, as well as the power supplied to instruments on the seafloor or on the mooring. The effects are highly nonlinear; that is, reducing power requirements to the seafloor and telemetry rates by a factor of two does not translate into a buoy which is half the size and cost.

We have evaluated both single-point, discus buoy moorings and tri-moored spar buoys for use as ocean observatories. Three specific buoy and mooring designs have been analyzed and are compared on the basis of their costs and capabilities. The primary option investigated was a cable-linked, high-bandwidth observatory employing either a spar or discus buoy that uses an electro-optic cable to connect seafloor and moored instruments to the surface. This system has been designed to deliver 500 W of power to the seafloor and utilizes a C-Band satellite telemetry system that can send ~500 Mbytes of data (or more) each day to shore. We have also evaluated a low-bandwidth discus buoy system that uses acoustic modems to transfer data from instruments on the seafloor or mooring to the buoy, and can deliver about 5 Mbytes/day of data to shore. No power is delivered to the seafloor and solar panels (with batteries) are used to power the satellite telemetry system.

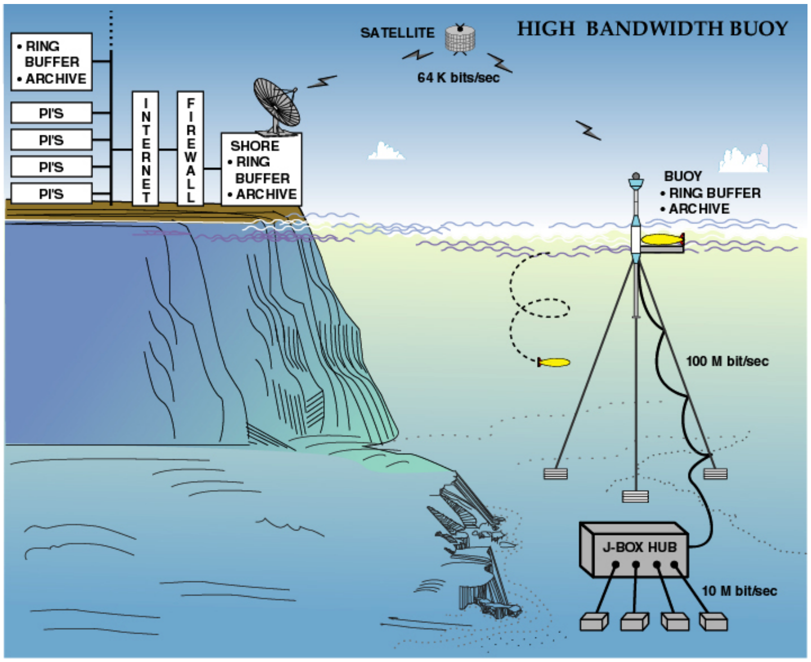

Figure 2 High-Bandwidth, Cable-Linked Moored Buoy Observatory with a fiber optic connection from the buoy to the seafloor and nearly continuous 64 kbps two-way communication between the buoy and the shore via satellite.

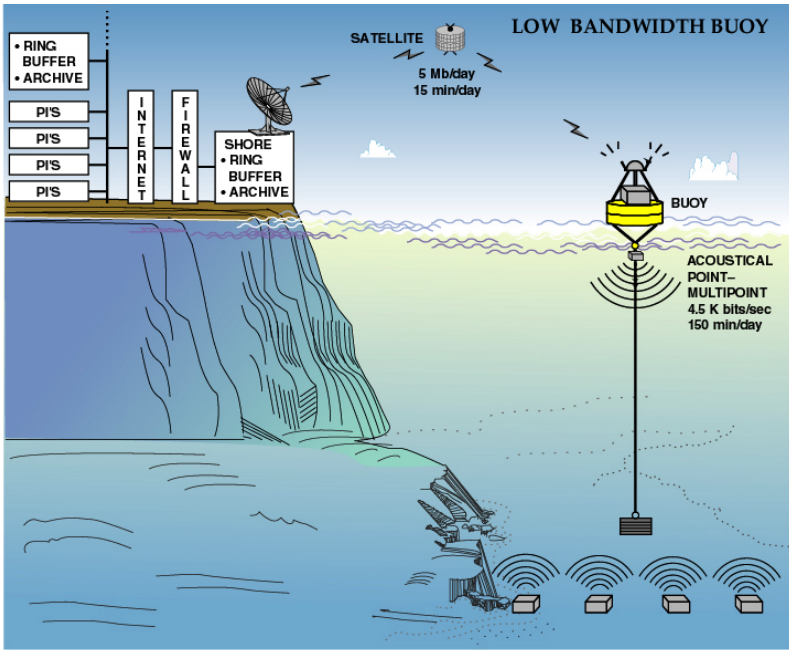

Figure 3 Low-Bandwidth, Cable-Linked Moored Buoy Observatory. Uses acoustic communication to link instruments on the seafloor or the mooring with the buoy and delivers ~5 Mbyte to shore via a solar-powered, low-power satellite telemetry system.

The acoustically-linked approach has the advantage of lower cost and less complicated logistics at the expense of lower data rates, and inability to provide power to the seafloor. The cabled buoy systems are more expensive to build, install and operate, but offer much higher data rates and can provide significant power to operate seafloor instruments. Costs for the two approaches averaged over the ten year operational life of the systems differ by about a factor of 2 to 3, while data rates differ by a factor of more than 100. Cable-linked, moored buoy systems will be well-suited to applications which require high-bandwidth and for which observations over a long time period (a decade or more) are needed. Acoustically-linked moored buoy systems will be the preferred solution when power does not need to be supplied to sensors, the data telemetry requirements are modest, and systems need to be relocatable or deployed rapidly in response to transient events. It is likely that a mix of capabilities will best meet broad observatory needs.

For high-bandwidth applications both discus (single-point mooring) and spar buoys (tri-moors) are suitable. The discus approach is less expensive initially and simpler to install. For the MOMAR and NAZCA sites a discus system costs ~$1.9-2.3M/node to build and install (including ship time) versus ~$3.2-5.2M/node for the spar. However, a spar buoy with a 3-point mooring may be more reliable in terms of satellite telemetry. Amortized over the 10-year operational life of the systems the cost to build, install, operate and maintain a spar system are only about 15-20% higher than for a discus buoy. The appropriate choice of approach will depend on anticipated weather conditions, location (latitude, water depth), required system lifetime, the power and telemetry requirements of the sensors, and the need for continuous real-time data. The greater the water depth, the larger the cost differential between the discus and spar options. The spar buoy system provides a more stable platform for telemetry, making it the preferred system for high-latitude, bad-weather sites. At lower latitude, better weather sites, a discus system may be a cost-effective solution for observatories requiring high-bandwidth. The decision on whether a spar or discus approach is preferred for a specific high-bandwidth application must be addressed by a careful, site-specific and application-specific analysis.

Assuming the costs given for the MOMAR and NAZCA sites are representative of the average costs for establishing observatories at DEOS sites, an array of 20 nodes including 10 high-bandwidth spar systems (for high latitude sites), 5 high-bandwidth discus buoy systems (for lower latitude sites) and 5 low-bandwidth systems (for applications with modest data telemetry requirements or the need to be relocatable) could be built and installed for a cost of ~$38M. Annual maintenance and operations costs would be ~$500K node for the high-bandwidth systems and ~$200K/node for the low-bandwidth systems or ~$7M/yr for 20 buoys. If all twenty nodes were high-bandwidth systems an initial investment of ~$33M (discus design) to ~$54M (spar design) would be required and annual operating and maintenance costs would be ~$10M/yr. None of these figures include ship costs; these costs are difficult to estimate accurately without knowing specific deployment sites. As a rule of thumb, total costs will approximately double if ship costs are included. These cost estimates also do not include scientific instrumentation or labor associated with the scientific use of the observatories; in the case of the low-bandwidth system each instrument builder will have to supply power and on-board data storage, and in most cases the instruments will have to be recovered and serviced annually. These are infrastructure costs, though some of the cruise costs would likely be shared between the science users and the infrastructure providers. We anticipate that the scientific uses and instrumentation will evolve rapidly over the initial decade of the program.

There are several important remaining questions regarding the design and development of moored buoy ocean observatories that should be addressed through a series of engineering studies or prototype testing. These include:

- The reliability of the acoustic communication system in the low-bandwidth system in deep water. What average data rates can be achieved and what environmental factors determine acoustic link performance? Does the large watch circle of a discus buoy on a single-point mooring present problems for directional acoustic telemetry?
- The effectiveness of discus and spar buoys as platforms for Inmarsat B (low-bandwidth) and C-Band (high-bandwidth) satellite telemetry systems. Up to what sea states will these systems operate reliably in practice? How sensitive is performance to buoy/mooring design?
- The expected operational lifetime of the electro-optic cables for single-point and three-point moorings. How do factors such as sea state, currents and mooring design affect cable reliability?
- The service interval required for diesel-powered buoys with C-Band telemetry systems. Is a maintenance interval of ~12 months realistic?

In view of the engineering issues discussed above and the substantial resource commitment necessary to build and operate a global network of ocean observatories, we recommend a carefully phased program to develop the infrastructure needed to begin operating buoy-based observatories. The goal of this program will be to build, install and operate both a prototype high-bandwidth, cable-linked observatory and a low-bandwidth, acoustically-linked observatory. When completed, these two systems will demonstrate the full range of solutions that are available for buoy-based ocean observatories. We recommend that the high-bandwidth prototype be based on the tri-moored spar design, which we believe is the more conservative approach based on its inherently lower dynamics. The low-bandwidth prototype should be implemented using the acoustic link technology combined with the single-point discus mooring configuration to optimize the system for remote applications and to minimize overall costs. While it is possible to design and construct these systems, the long-term reliability, over year-long periods, of the communications and power systems will have to be evaluated through experience. This two system approach will result in tested designs that are suitable for use in most of the envisioned applications at deep ocean sites.

The full copy of the DEOS Buoy Design Report is available on-line at http://obslab.whoi.edu/buoy.html