UNDERWATER OBSERVATORIES: THE CHALLENGES AND PROMISE OF APPLYING OFF-SHORE CABLE TECHNOLOGY TO LONG-TERM ENVIRONMENTAL STUDIES

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ABSTRACT

Advances in fiber optic cable technology and submarine burial techniques are beginning to move this technology out of the exclusive realm of the large commercial communications firms and into the reach of scientists. Underwater observatories with real time data and virtually unlimited power transmission capabilities (when compared to traditional oceanographic moorings) are beginning to provide scientists with reliable and continuous access to their instruments in littoral waters and even in the open ocean. The Woods Hole Oceanographic Institution is committed to a program that will put this technology within the reach of scientists and students. This paper will examine the feasibility, challenges and benefits of bringing the latest off-shore cable technologies within economic reach of scientific projects through a discussion of trade-offs, risks and new burial methods that have been used in the construction of the Martha's Vineyard Coastal Observatory.

INTRODUCTION

Although scientists have been involved in coastal research for decades there has been a growing focus in this area in recent years. With 50 percent of the earth's population living within a hundred miles of a coast there is increased awareness of severe beach erosion, oil spills and industrial pollution, and impacts of coastal development on near shore fisheries.[1] Episodic events such as tropical storms cause billions of dollars of damage worldwide and are the leading cause of death from natural phenomena. Although we have made some improvements in our ability to predict the path of these storms, we have made little or no improvement in our ability to predict their evolution or intensification. It is difficult to understand the complex and dynamic processes of a winter storm on an exposed coastline by sampling from ships and even relatively long term moored buoy systems. Continuous sampling at permanent installations will, in time, give us the data that will clarify patterns and allow development of predictive models for natural phenomena such as storms, seismic events and toxic alga blooms. Additionally even long-term deployment buoy systems and drifters, have been limited by the amount of on-board power and/or data storage available.

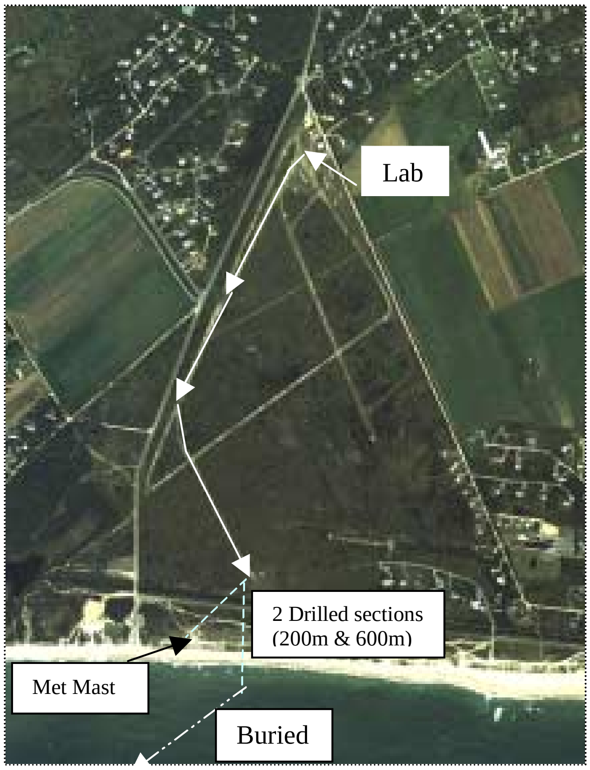

Fig. 1: Aerial View of project site at Katama Air Park showing cable route, lab and met mast sites.

Advances in fiber optic cables as well as the technologies for installing them have moved these high tech and high budget tools into the arena of relatively low budget science. Fiber optic cable capabilities have grown almost geometrically and costs have dropped. Thirty-year-old submarine communications cables are so far behind the state-of-the-art that they are being replaced with fiber and "donated" to science rather than being repaired.[2]

Cabled observatories are opening a new window for all disciplines of ocean research. By providing virtually unlimited power and high-speed wideband real-time data transmission a variety of new research options have now come within economic reach of ocean scientists.

This paper will examine the issues involved in creating a new observatory, principally from the lessons learned at LEO-15[3] and in the recent building of the new observatory at Martha's Vineyard, Massachusetts.

UNDERWATER OBSERVATORIES

The Woods Hole Oceanographic Institution (WHOI) has played a significant role in designing cabled observatories both in littoral waters and the deep ocean. The observatory's underwater node is simply a sophisticated plug strip on a fiber optic extension cord that allows divers to install instruments in a relatively simple operation. Scientists can access their data and instruments in real-time, adjusting sampling parameters based on changing field conditions.

In partnership with scientists at Rutgers University, WHOI engineers designed LEO-15[4] (Long-term Ecosystem Observatory at the 15 meter contour) off the coast of Tuckerton, New Jersey in 1994. Coupled by electro-optic cable to the Rutgers Marine Field Station at the entrance to Little Egg Inlet, two permanent nodes allow scientists from all disciplines to connect instruments and operate experiments remotely over the Internet. Located at 5 and 6 km offshore each node includes an instrumented vertical profiler that can be remotely commanded to rise to the surface then be winched back down into the node. A wide spectrum of biological and physical processes is being studied with a strong focus on ground truthing and improving coastal models.

In 1998, after three years of development, WHOI and University of Hawaii engineers, went a step further and seized the opportunity to use the abandoned AT&T Hawaii-2 telecommunications cable, donated to the IRIS (Incorporated Research Institutions for Seismology) consortium of scientific institutions studying seismic events and processes. Using a research vessel, rather than a cable ship, and the Medea/Jason ROV system, the cable was cut and brought to the surface from 5,000m depth. A commercial cable company spliced the cable to a specially designed termination frame and redeployed it. The ROV then connected the termination to a relatively easy to recover junction box providing power distribution and data telemetry control for six instrument ports. The Hawaii-2 Observatory (H2O) will focus on seismic studies of earthquakes and tsunamis.

A recent entrant in the observatory world is the Martha's Vineyard Coastal Observatory (MVCO). The low profile southern exposure of the Vineyard coast, making it vulnerable to the prevalent southwest winds as well as the sea, gives scientists an excellent opportunity to study dynamic ocean processes and air-sea interaction, especially during severe storms (Fig. 1). With a primary focus on air-sea interaction, core instrumentation will be used to investigate the exchange of momentum, heat, and mass (e.g. moisture and CO_2), using extensive sampling of marine air at a meteorological mast at the shore edge, and ocean surface and subsurface properties from bottom mounted sensors.

The initial plan included the shore-mounted meteorological mast and two offshore nodes, the main node at 15 meters depth and a near shore node at 7meters. The system at present consists of the mast and a main node 1.5km offshore in 12 meters depth. Plans are now under development to install the second, near-shore node next year as well as develop a third node further offshore in 18 meters of water.

PLANNING ISSUES

Beyond the scientific goals the MVCO project faced numerous political and practical planning issues that a scientific research organization is not routinely equipped to handle. In order to develop a plan that could survive the necessary permitting process, a careful evaluation of the sensitive ecological area was undertaken. The design had to minimize environmental impacts at each level. The upland portion is situated on a rare coastal sandplain where a wildlife refuge and grass airstrip share space. The cables would run along the airport taxiways then under protected wetlands and beaches. Installation techniques selected as well as structures erected must be as unobtrusive as possible.

While long-term benefits to science were the initial motivators, more immediate and general benefits to the community at large needed to be included from the outset. Aesthetically the only visible manifestations of the installation include a small cape-style cedar shingled lab on the airfield, a monopole on the beach for the meteorological instruments and a manhole cover on the junction box buried in the airplane parking lot.

Extensive effort was made to educate the community about the project and develop an early collaboration between the scientists and the community. Presentations were made at schools and community meetings in addition to the various hearings before permitting boards. This approach has been successful and even before installation was complete, two research proposals were received from the community to utilize the facility.

SURVEYS

Project planning depended heavily upon the side scan and sub-bottom surveys that were performed offshore. A geotechnical firm was hired to perform a single 14 sample, 50 foot deep boring in the upland plain at the entrance site for the directional drilling. Analysis of the core samples indicated sand and gravel, associated with glacial outwash.

A 200 kHz side scan was used to survey for obstacles along the cable path. The area had once been part of a military practice range and at least one former bunker was known to be offshore east of the site. Sand waves on much of the side scan record supported the expectation of sand along the offshore cable path.

A sub-bottom analysis was performed using an Edgetech towfish with a chirp sub-bottom profiler, which reinforced the conclusion that the cable route was principally sand, mud and gravel to a depth greater than the intended 6-foot burial depth. Due to budget constraints it was decided not to perform offshore core samples or penetration tests.

PERMITTING

Both the upland and marine segments of the project required multiple layers of permitting from local, state and federal agencies. For example the laboratory was built on leased land on a private grass-strip airport owned by the Town of Edgartown and operated by an appointed Commission. However the land is also a rare coastal sand plain wildlife refuge overseen jointly by the Conservation Commission and a private nature conservancy. The beach approach crossed a barrier beach and dune area of a State Park, then entered the airport after crossing a major road and a herring run. The offshore burial is near a popular fishing ground and busy boating area. The upland trenching area was a potential spiritual site of the Wampanoag Tribe.

Under the State (MEPA) and Federal (NEPA) Environmental Protection Acts almost every permitting agency is a conduit to a group of "commenting" agencies, all of which need to review the application before the permitting agency can act. In Massachusetts the US Army Corps of Engineers and the Coastal Zone Management offices are pivotal points for coordinating multi-agency interactions. Wandering through the maze of permitting is comparable to blundering into a minefield if you don't take the time to read the originals of the critical legislation. Consultants are costly, unreliable and tend to have specialty focus (i.e. environmental) where to some extent a generalist is needed to pull in the historic, archeological and aesthetic issues. For instance the NEPA (National Environmental Preservation Act) mandates conformance with the National Historic Preservation Act, which in turn mandates participation of local tribal councils.

Allowing adequate time for the legally required posting and appeal periods is critical as well as understanding that all the permits cannot be applied for in parallel as certain ones must be in hand as a prerequisite to other applications. Maintaining communications, gaining local knowledge, and establishing a local presence are vital to meeting schedules.

Fig. 2 Two horizontal crossings (626m and 205m) were drilled from one entrance pit.

DIRECTIONAL DRILLING

Surface trenching was allowed only along the existing taxiways of the airport. Despite the cost, the far superior method of handling both the beach approach and crossing the herring run and dunes was directional drilling. The lack of surface impact on these features was a significant factor in expediting the permitting.

Two horizontal crossings (Fig. 1) were undertaken from a single entrance pit at the beach parking area of the airport. A maximum running depth of about 12 meters was used. The first run was approximately 200 meters SW with next to the lifeguard building. The second bore ran south 600 meters and punched out in about 7 meters water depth, beyond the shore break. The drill pipe was left in place as the cable conduit. Two cables were pulled back from the met mast (one for science and a power cable for the lifeguard building). A messenger line was installed in the offshore conduit. The tillings indicated that the geology was sand and gravel as expected. The complete operation, including the extensive logistics involved to get the rigs by ferryboat on and off the island, was completed in a week.

CABLE

The MVCO cable consists of 10 single mode optical fibers in a central loose-tube with a polyurethane jacket, surrounded by 3 twisted pair of high voltage power conductors, protected by a cross-laid double stainless steel armor in a polyethylene outer jacket. Total cable diameter is .84” diameter; weight in air is 722lb/100ft with 2.9 specific gravity and 7,000-pound maximum load. At the offshore node the system will deliver single phase 60Hz AC, making 4 kW available to the scientist.[5] The high voltage power is subdivided by the node’s transformer to 240 VAC so that each of the twenty instrument ports has its own AC/DC converter supporting isolated 12 and 24V power supplies. The data telemetry system provides for three transmission options: RS-232, RS-422 or 10-base-T Ethernet. The initial system that has been installed only uses one third of the potential power and two of the available fibers

Fig. 3 Cable laying configuration on F/V Nobska shows conversion of fishing net drum pedestal for cable, cable tensioning engine at stern with arch easing cable beneath A-frame. Power system for cable engine sits next to fish hatch in foreground.

BURIAL: PLOWING VS TRENCHING

Since the sub-bottom profiles along the planned cable route were consistent with sand and gravel, a jet trenching technique was selected rather than the traditional cable[6] plow that was used at Rutgers. This would offer a substantial cost savings (40%), largely in marine staging and mobilization costs. Additionally, the work site is extremely exposed to the prevalent winds and nearly always has a significant shore break and frequent high surf conditions. This limits suitable working conditions and made stand-down cost also a significant consideration. The ability to use smaller vessels and fewer personnel reduced the risk of running up a large over-run due to bad weather.

The critical issue appeared to be whether this jet trenching method could provide the desired 6-foot burial depth. Although 3 foot was more customary, the equipment was capable of reaching the 6 feet assuming the strata were as predicted. This method of jet trenching has long enjoyed wide acceptance in northern Europe but is a relatively new approach on our East Coast.

A two-phase operation was planned, with the cable being laid by one vessel then trenched from a second. Using local vessels would provide additional savings. The surface trencher and divers could operate from the 45 ft. research vessel Asterias rather than necessitating the use of a large cable-laying vessel or barge and tug operation. The cable was laid by a local fishing trawler, F/V Nobska, using a cable engine to control cable tension and assure a flat, unlooped “lay.” A vessel with a bow thruster helped ensure an accurate track along the intended path and to maintain a shallow angle of descent to avoid undue stresses on the cable.

The diver-managed system can operate off a relatively small boat; in this case a 45-foot coastal research vessel with a lifting boom. The burial rate varied from about 400 meters per hour in light cobble to 600 meters in sand. Patches of unexpected peat and clay, not discerned on the sub- bottom survey, were found under .5m of sand waves approximately 2500 m along the planned route. This required extensive modification of the trencher to increase jetting force, accompanied by hand jetting as well as a shallow (1M) burial. Budget considerations required a reevaluation of the plan based on the new knowledge of the bottom strata. A new node position 2.8 rather than 4.4 km along the route was selected, which placed the node 1.5km offshore. This would allow the node pedestal to be jetted in at a confirmed sandy area.

Fig. 4 Trencher aboard F/V Nobska

PEDESTAL INSTALLATION

The node design consists of three parts: a permanent pedestal, transformer bay and an instrument package that can be unbolted by divers and brought to the surface for periodic maintenance. The two part pedestal, a 12-foot long, one-foot diameter stainless steel tube, will be jetted into the sand so that the 4’x4’x1’ transformer bay bolted on top is about 18” above the sand (Fig. 5). This section will include the power transformer, in an oil compensated housing, and the cable tray where the last hundred feet of cable will be coiled.

The upper section, approximately 4-foot square by 3 feet high, will contain the electronics bottle, the panel of underwater-mateable connectors for guest instruments in addition to the core sensors and closed foam floatation. Adding floatation to make the instrument package neutral or slightly positive eases handling by the divers when the unit is taken aboard a vessel for routine maintenance then re-installed.

PLATFORM POTENTIALS

Looking to the future, there is no limit to the potential contribution that long-term observatories can make to our understanding of both of complex dynamic processes and sudden episodic events. It is also apparent that the economic viability of both fiber optics and burial techniques for coastal cables are coming within the reach of relatively low budget science. But perhaps more importantly, as the large commercial users upgrade to higher performance fiber, more opportunities to access existing cables, such as the telecommunications cable used for H2O, will become available to the scientific community.

Coastal observatories such as LEO-15 and the US Army Corps of Engineering's Field Research Facility in Duck, NC, are making significant contributions to our understanding of near shore processes. Investigations at these observatories and ultimately MVCO are expected to help engineers and planners who have long been concerned with coastal protection, particularly in heavily populated areas where wave attack, set-up and shoreline erosion threaten coastal structures. These observatories are also expected to help geologists understand how the astonishing variety of coastal geological features form or evolve in response to near shore processes. Finally, coastal meteorologists are only now beginning to investigate physical processes that are unique to the coastal environment. These observatories can be used as focal points for experiments that investigate air-sea interactions in the coastal environment that will improve marine forecasts and severe storm and surf warnings.

The next major observatory, already well along in the planning phase, is NEPTUNE[7], (North East Pacific Time-series Networked Experiments). To be located on the Juan de Fuca Plate at the US-Canadian border, the site is ideal for studying all the important plate tectonic processes as well as coastal ecosystems, fisheries issues, and the physical and meteorological properties of ocean dynamics. An expandable network of fiber-optic cables will stretch 1200 km along the coast and over 500 km west into the Pacific will link junction boxes that can support a wide variety of scientific instrumentation.

CONCLUSION: LESSONS LEARNED

It is critical to the permitting process to develop a sound ecological approach and a realistic estimate of the amount of time required for each permit. There are public agencies, such as CZM (Coastal Zone Management) that have staff whose principal function is to help people coordinate and expedite the multi-agency permitting process. Finding these people is a key to success.

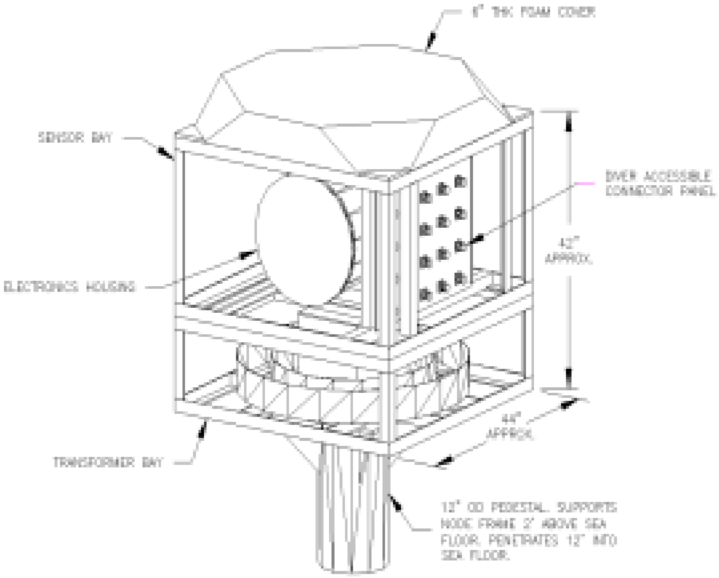

Fig. 5 The upper section of the underwater node can be floated to the surface and recovered for maintenance. Excess cable is coiled in the permanent lower section. Instruments can be mounted on the frame or on fixtures nearby.

Comprehensive project planning is vital to success, particularly when the budget is limited. A ground truth survey of any remote sensing analysis is critical. Offshore core samples or a diver inspection with a hand-jet and probe along the cable path would have prevented costly choices on this project. Overall surveys will more than pay for themselves: they increase the knowledge base which minimizes risks.

Trenching vs. plowing will remain a key issue especially where cost is a factor. Enormous savings can be achieved if mobilization and stand-down costs can be minimized and lighter equipment on smaller vessels is a key. This technology works very well in the specific environment it was designed for, sand and mud, but it has limitations that should be understood at the start. Both the hardness factor and plasticity of the sediment need to be known, along the entire cable path.

Directional drilling for shore approaches in non-industrial or eco-sensitive areas is the clear winner in terms of expediting the permitting process. The cost alone serves as a demonstration of good intent and the state and federal agencies have become sufficiently familiar with the technique to accept it. The risks are relatively low if good surveys are done and most of the experienced vendors are able to handle even an inadvertent return efficiently to avoid significant clean-up costs. If the geology is pliant, 5k PSI or less, the costs can be kept reasonable. Where strata harder than 10k PSI are apparent a horizontal crossing may not be cost effective and, again, the preliminary surveys are critical to determining these risks.

Advances in cable and installation techniques are putting cabled observatories within economic reach of relatively low budget science and careful planning, rather than the cost of the technology will be the critical element to making it happen.

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