The Monterey Bay Acoustical Observatory (MBAO)
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A collaborative venture between the
Undersea Warfare Research Center, Naval Postgraduate School (NPS), and
the Monterey Bay Aquarium Research Institute (MBARI)

Introduction and Motivation

The Navy's SOund SUrveilance System (SOSUS) has allowed scientists to study the acoustics of the ocean to both military and societal benefit (Orcutt et al, 2000). However the aging of this 40 year old system has led to a precipitous decline in our national ``acoustical'' presence in the ocean. At the same time increasing hostile submarine threats as well as imminent change in our ocean and planetary climate requires us more than every to maintain persistent ocean acoustical observations.

With this in mind a consortium of scientists and engineers at the Naval Postgraduate School (NPS) Undersea Warfare (USW) Research Center and the Monterey Bay Aquarium Research Institute (MBARI) would like to establish a new, modern SOSUS station termed the Monterey Bay Acoustical Observatory (MBAO). The MBAO would possess state-of-the-art acoustic receiver arrays with both significant vertical and horizontal apertures, and like the original SOSUS sites would be tethered to shore. Using the already operating and successful Monterey Accelerated Research System (MARS) fiber optic cable and junction box (See Figure 1) the MBAO would be provided important power, precise time, and high bandwidth data transfer capability. Scientific activities that could be enabled by the MBAO are:

- *Passive Anti-Submarine Warfare (ASW) studies.* The MBAO will be located at the continental slope near the deep water submarine canyon of the Monterey Bay, thus offering a complex bathymetric environment, similar to tactically relevant regions of the world. Active shipping and fishing in the region as well as significant marine mammal and seismic activity provides a host of factors that require mitigation for successful ASW. Algorithms for detecting transients and tonals can thus be tested with real world data. Numerous shore based AIS receivers around the bay will allow detailed tracking of local ship traffic. Ambient noise data can be used to study the structure of the noise field and determine aspects that could be exploited.
- *Acoustic monitoring of seismic and geological processes.* Acoustic monitoring of water borne seismic signals (T-phases) will complement land-based and seafloor seismic networks (a seismometer is attached to the MARS junction box). These observations will help understand the complex coupling mechanisms involved in seismo-acoustic wave propagation, processes that are important for ASW, nuclear test verification, and seismology (Odom and Stephens, 2004; Fox et al, 2001; Smith et al. 2004). The MBAO will also likely be able to detect and localize intense

gravity flows or landslides into the Monterey canyon and thus increase our understanding of continental margin geology (REFS).

- *Marine mammal abundance and distribution estimates.* The MBAO is located in a region with numerous resident and migrating marine mammals. Marine mammal vocalizations can be used to study the seasonal presence of large whale species and to make estimates of their abundance. Match field processing of the vocalizations can be used to estimate species, ranges and vocalization depth which can provide important behavioral information (Thode et al. 2000; National Research Council 2000, 2003, and 2005; Nieukirk et al. 2004). Investigation of the demodulated vocalizations of marine mammals, especially dolphins can provide important insight into their extremely capable sonar and communications ability; dolphins are some of the best mine detectors available.
- *Wind and rainfall measurements.* The spectral shapes associated with underwater sound generated by wind and rainfall are distinctive, allowing quantitative measurements of wind speed and rainfall rate (Medwin, 1992; Nystuen, 2001).
- *Acoustic Thermometry and Ocean pH.* If acoustic sources could be deployed outside of the Monterey Bay Marine Sanctuary the transmissions received on the MBAO could be used to estimate fluctuations in ocean temperatures in the California Current system (Brink et al, 2000; Collins et al 2002 and 2003). These same transmissions could be used to monitor ocean pH using the variations in received signal strength at different frequencies; the sound attenuation constant in sea water in the hundreds of Hz region is pH dependent (Guoliang and Worcester, 1989; Hester et al 2008; Duda 2009) .

Technical Approach

We propose to deploy an ``L'' shaped array on the MARS node with 1-km vertical and 2-km horizontal apertures (See Figure 2; not created yet). The node will provide 375 or 48 Volt DC power, 100 Mbits/s communications, and 1 μs precise time.

The horizontal array would be cut for low frequency passive ASW. Using a nominal detection frequency of 150 Hz, we propose populating the array with 400 hydrophones at $\lambda/2$ spacing. The vertical array need not be a full array and 50 hydrophones at 20-m spacing would be sufficient for vertical beamforming. Nominal sample rates would be 2000 Hz, yielding a data rate of roughly 3.6 Mbits/sec (to be compared with the available bandwidth of 100 Mbits/s, and assuming a 4 bit word). In addition, the vertical mooring will require precise navigation. Installation of navigation transponders, and appropriate navigation processing and control on the vertical array should enable element localization to 1 m accuracy (Worcester et. al, 1999).

With in the horizontal aperture there should be 4, 4-hydrophone``high frequency'' subarrays designed for marine mammal and rain and wind recordings using sampling frequencies of upto 400 kHz. These 4 subarrays would generate data at a rate of roughly 25.6 Mbits/s. All hydrophones on both the horizontal and vertical apertures should be broadband and capable of recording signals from 1 Hz to 400 kHz (i.e. seismic to odontocete (toothed whale) frequencies).

To get the array into as deep water as possible we propose to utilize two 4-km Electro-optical-mechanical (EOM) extensions from the junction box. These small diameter extension cables will be unspoiled by an ROV and will be connected to the MARS node and the hydrophone array interface using underwater mateable connectors. These extensions would nominally place the array at 1200-m water depth, compared to the 900-m of the MARS junction box.

An interface between the acoustic arrays and the MARS junction box will likely be required to convert the analogue electrical signals from the array into optical signals for the long cable runs.

The nominal MBAO data rate would be 29.2 Mbits/s or 2523 Gbits/day, and would require an intelligent data management system (this data rate is comparable to those required for video). We will examine the The ROADNet (Real-time Observatoies, Applications, and Data management network; http://roadnet.ucsd.edu) architecture which is located at the San Diego Supercomputer Center (SDSC), as a framework for developing a Data Management and Archiving System (DMAS) for MBAO. We will also examine results from the LOOKING (Laboratory for the Ocean Observatory Knowledge Integration Grid) project, which is the National Science Foundations (NSF's) effort to develop DMAS strategies for ocean observatories. MBARI is a partner in LOOKING, and will be a critical partner in the development of a DMAS for MBAO.

Future Expansion of MBAO

Presently there is significant interest to try and extend the MARS cable into the deep ocean (3000-m or deeper) so as to obtain oceanographic observations in this very difficult to access region. In addition the use of AUVs to enhance the spatial extent of the MBAO is an important future capability that is being considered. While these efforts should not impact the present effort to instrument the current MARS node, they raises some interesting opportunities for expanding the MBAO. A few of these opportunities are:

- *Study of Reliable Acoustic Path (RAP) propagation*. Vertical arrays moored below the surface conjugate depth suffer considerably less noise contamination than arrays at shallower depths. These arrays can thus potentially localize and identify low intensity sources of sound in the upper ocean very effectively. For the deep waters west of the Monterey Bay the conjugate depth is between 2500 and 3000m (See Figure 3).
- *Study of mobile and distributed systems.* AUV's with extreme depth capability allowing them to voyage below the surface conjugate depth could act as mobile RAP receivers, utilizing horizontal arrays or vector sensors for upper ocean source localization.
- *Acoustics of complex canyon and ridge systems.* AUV's can be used to study the concentration or dissipation of acoustic fields near canyons and ridges.

Education and Outreach

The educational and outreach impact of real time ocean acoustic data, accessible from the web, is likely to be extremely large given the intense public interest in ocean sound and its impacts on the ocean environment. Presently there are two web sites which address ocean sound and they have proven to be enormously popular. One site, The Discovery of Sound in the Sea (DOSITS; http://omp.gso.uri.edu/dosits/dosits.html) was funded by the Office of Naval Research (ONR) and has targeted K-12 education. Launched in 2002 it presently receives over 3 million hits per year, and this rate has been growing. The second site, Ocean Explorer/Explorations/Sound in the Sea, was developed by NOAA and provided live access to a 4 element hydrophone array located just North of Monterey Bay (http://oceanexplorer.noaa.gov/explorations/sound01/sound01.html). This website was one of NOAA's most popular sites receiving over 1 million hits per year until a fault in the cable leading out to the hydrophones ended the data acquisition.

As part of MBAO it is proposed to establish a web presence to serve both the educational and research communities. These efforts would build upon the successful DOSITs and NOAA sites, and would also incorporate data distribution strategies from such programs as ARGO, and TOPEX/POISIDON.

Workplan

It is envisioned that NPS and MBARI would partner in the oversight of the acoustic array fabrication, likely to be contracted to General Dynamics. MBARI would take the lead in:

1. Engineering the interfaces between the acoustic array and the MARS node.
2. Engineering the navigation system for the vertical array and providing 4 bottom transponders.
3. Installation of the array using MBARI ships and the ROV.

NPS would take the lead in the following aspects of the MBAO:

1. Formulation of a data security procedure, and the placement of infrastructure to support that procedure.
2. Establishment of an MBAO data and archive center.
3. Maintenance of a web page for research, education, and outreach.

Budget

More to come…..

References

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Figures

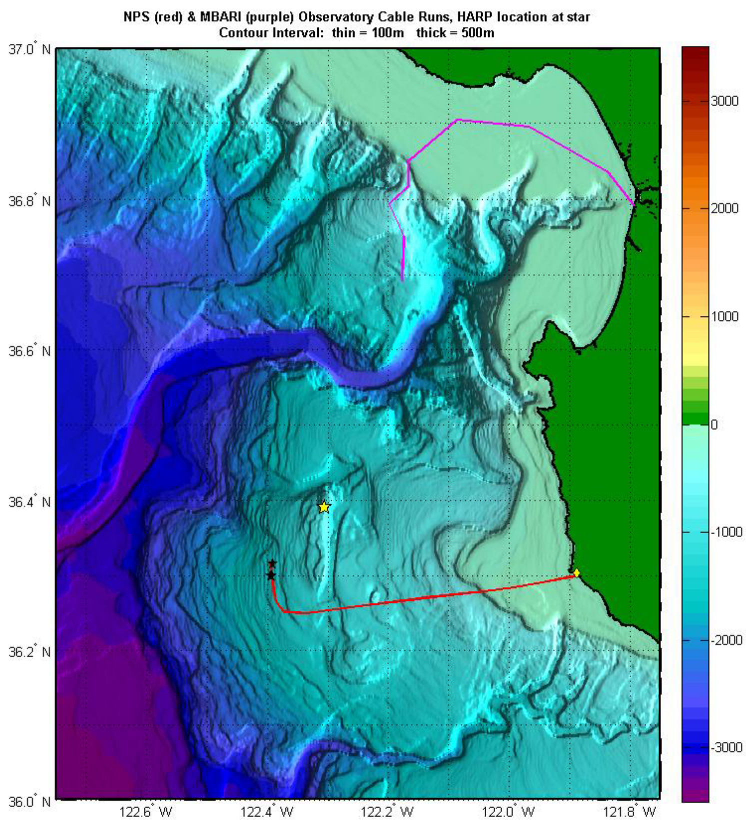

Figure 1: Location of the MARS cable (purple), and the damaged Pt. Sur SOSUS cable (red). The end of the MARS cable is located at approximately 900-m water depth, where a junction box provides 8 ports for power, communication and precise time.

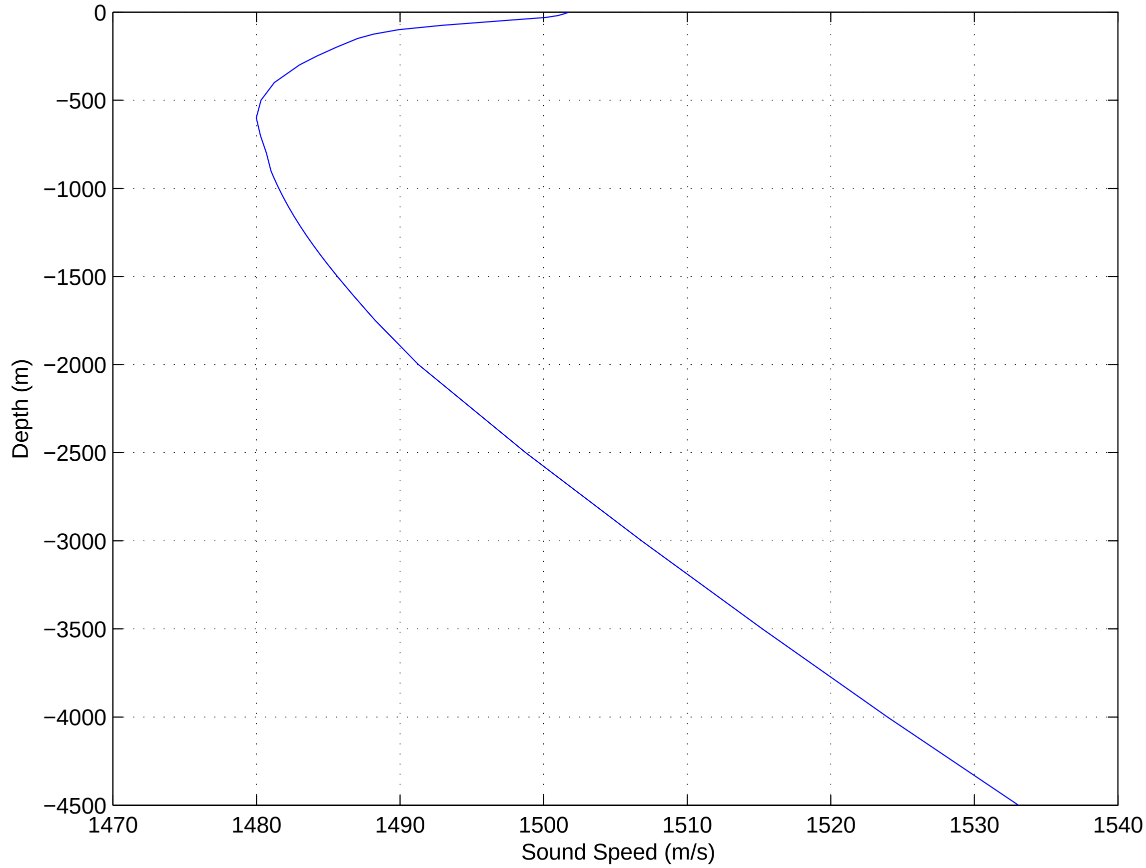

Figure 3: A World Ocean Atlas annual mean sound speed profile from the deep water West of the Monterey Bay.