The MOBB experiment: a prototype permanent off-shore ocean bottom broadband station

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There has been increased interest, recently, in the deployment of intermediate to long term broadband seismic arrays on the seafloor, to complement the limited coverage of the earth that can be achieved through land-based installations, at the regional or global scale. Thanks to technological improvements in the last 10 years, this is now within reach (e.g. Purdy, 1995; Suyehiro et al., 1995). In particular, the Sept'02 Ocean Mantle Dynamics (OMD) workshop in Snowbird, Utah (OMD Workshop Committee, 2003) proposed the development of two "leap-frogging arrays" of 30 or so broadband seafloor instruments to fill geophysically important target holes in ocean coverage for deployment periods of 1-2 years. The rationale for an off-shore ("Webfoot") component of the USArray/Earthscope "Bigfoot" array was also highlighted at this meeting, pointing out that the study of the north-American continent should not stop at the sea-shore.

The ocean floor environment is challenging for broadband seismology for several reasons. Broadband seismometers cannot be simply "dropped off" a ship with the expectation that they will produce useable data, particularly on the horizontal components. Several pilot experiments, (OFM, Montagner etal., 1992; Suyehiro et al., 199x; OSN1, 1998; Araki et al., 2002) have addressed the issue of optimal installation of ocean bottom stations, and in particular have carried out comparisons between borehole, sea floor and buried seafloor installations. While a borehole installation is optimal but considerably more expensive and therefore suitable only for permanent deployments, significant noise reduction can be achieved at long periods by burying the instruments under the seafloor (e.g. Collins et al., 1998). As a consequence, one of the recommendations resulting from the OMD workshop is that burial systems should be developed and used in regional deployments arrays of broadband seafloor seismometers. Other technological issues such as power supply and data retrieval for long term operations have received much attention over the years and there are now different possible solutions involving cables or buoys depending on the environment (cite?).

The western margin of North America is an obvious target for extending the land based regional broadband network to the seafloor. It is a complex plate boundary involving, to the north, subduction of the Juan de Fuca/Gorda plates beneath North America, and, to the south of the Mendocino Triple Junction, transcurrent motion between the Pacific and North-American plates along the San Andreas Fault (SAF) system. Tectonics and seismicity do not stop at the continental edge. In northern California, the zone with most abundant seismicity, for example, is associated with the Mendocino Triple Junction, and is mostly off-shore. Much effort has been expended in recent years to deploy networks of seismic stations in the western U.S., and in particular broadband stations, with multiple goals of monitoring the background seismicity, understanding modes of strain release, documenting seismic hazards and providing constraints on crustal and upper-mantle structure. Because there are very few off-shore islands in central and northern California however, practically all stations are located on the continent (except for FARB on the Farallon Islands, Figure 1). As a consequence, the study of plate-boundary processes, as afforded by regional seismological investigations, is heavily skewed on the continental side of the San Andreas system. Offshore seismicity is poorly constrained, both in location and in mechanisms, as is crustal structure at the continental edge.

In April 2002, in a collaboration between the Monterey Bay Aquarium Research Institute (MBARI) and the Berkeley Seismological Laboratory (BSL), we installed a long-term 3 component broadband seismic observatory 40km offshore in Monterey Bay (MOBB: Monterey bay Ocean floor Broad Band project) (cite AGU abstracts). It is the first step towards the future installation of a 10-20 station extension of the land-based broadband network and will serve as a testbed for such future deployments. This project follows the 1997 MOISE experiment (Stakes et al., 1998; Romanowicz et al., 1998; Stutzmann et al., 2001), in which a similar system was installed in a similar location for a period of 3 months. MOISE was a success from the technical point of view: it was the first time that an underwater connection was established between different elements of the seafloor package with the help of a Remotely Operated Vehicle (ROV "Ventana", MBARI). Another lesson learnt with MOISE was the importance of recording auxiliary channels (current speed and direction, pressure) at sampling rates comparable to those of the seismic data, in order to be able to deconvolve correlated noise (e.g. Crawford and Webb, 2000). The MOISE experiment had shown that low frequency noise was strongly correlated with ocean currents and pressure fluctuations, but the sampling rate of auxiliary instruments (current meter, Differential Pressure Gauge - DPG, Cox et al., 2000) were too low for quantitative assessment (Romanowicz et al., 1998; Stutzmann et al., 2001). Also, in the MOISE experiment, the seismic package was not completely buried under the seafloor. With MOBB, we now have the opportunity of documenting these correlations more rigorously, and to propose effective noise reduction procedures.

The ocean-bottom MOBB station currently comprises a three-component broadband seismometer package (Guralp CMG-1), a current-meter, a recording and battery package, and a differential pressure gauge (DPG) with autonomous recording (e.g. Cox et al., 1984). The MOBB deployment took place April 9-11, 2002, with the help of the MBARI ship "Point Lobos", and ROV "Ventana". Prior to the instrumentation deployment, the MBARI team manufactured and deployed a 1181 kg galvanized steel trawl-resistant bottom mount to house the recording and power systems, and installed a 53 cm diameter by 61 cm deep cylindrical PVC caisson to house the seismometer pressure vessel. On the first dive, the seismometer package was lowered into the PVC caisson (Figure 2a), and its connection cable brought to the site of the recording unit. On the second dive, the recording package was emplaced (Figure 2b) in its trawl-resistant mount, and connected to the seismometer package. Tiny (0.8mm) glass beads were poured into the caisson until the seismometer was completely covered, to further isolate it from water circulation. The seismometer package is now buried at least 10cm under the seafloor level. On the third dive, the ROV buried the cable between the seismometer and recording packages, then connected to the seismometer through the recording system, levelled and recentered the seismometer and verified that it was operational. The current-meter was also installed and connected to the recording system. The DPG was installed during a later visit.

The site has been visited every three months since (last on March 24th, 2003). During each dive, the data recording and battery packages are exchanged for new ones, and the seismometers are recentered. Eventually, MOBB will be linked to the planned (and recently funded) MARS (Monterey Accelerated Research System; http://www.mbari.org/mars) cable and will provide real-time, continuous seismic data to be merged with the rest of the northern California real-time seismic system. The data are archived at the Northern California Earthquake Data Center (NCEDC, Romanowicz et al., 1994).

Preliminary analysis of almost a year of data from MOBB indicates that the seismometers have progressively settled. Over the past year, numerous large teleseisms ($M > 6$), including several deep ones have been well recorded, as well as several regional events of magnitude $M > 3.5$. Comparison of teleseismic records with those of nearby land stations shows remarkable consistency at long periods. At shorter periods, signal-generated noise is apparent on MOBB, associated with ringing in the shallow mud layers. This type of observations should be useful in understanding the triggering of submarine landslides in strong motion events, and may be relevant for ocean floor structures such as oil platforms and pipelines. On the other hand, this type of noise may be unavoidable in a shallow buried installation. Our plan is to evaluate it further and investigate ways to suppress it by modelling and post-processing, i.e. designing transfer filters to remove it from future event recordings. Comparison of recordings of regional events that have occurred within 100 miles of MOBB with those of other stations of the BDSN also shows distinct band-limited ringing due to site response (including water reflections). Nevertheless, we have been able to retrieve single station moment tensor solutions for strike-slip events on the San Andreas Fault (Dreger, personal communication) that are consistent with those obtained using other stations of the network. This shows that the MOBB data are well calibrated and have potential for providing valuable constraints in moment tensor studies of events of other types, such as reverse fault events in the Coast Ranges or strike slip events on faults closer to the shore or off-shore.

In Figure 3, we show a comparison of PSD noise spectra at MOBB (vertical component) and 3 land stations of the BDSN network, during a quiet day and a stormy day, as assessed from recordings of a nearby weather buoy. We note that the background noise at MOBB is comparable to other stations at the lowest and highest frequencies shown. The microseismic peak (1-10sec) is noisier, but not dramatically noisier than on the island station FARB, at least on the stormy day. What distinguishes MOBB most from the other stations is the large noise peak between 30 and 200 sec, which we think is related to infragravity waves propagating in Monterey Bay (e.g. Webb, 1997). Interestingly, this peak is also present on the noisy day at FARB, although much less pronounced. Analysis of data from MOISE showed strong correlation of noise in the 20-50sec band with current meter and DPG. We plan to gain quantitative understanding of noise in the long period band in an effort to minimize it by post-processing or future improvements in the installation (when the MARS cable is installed in 1995, there will be an opportunity to move and reinstall MOBB to a location close to the cable).

We plan to evaluate the long term time evolution of background noise, as the system continues to settle and stabilize, and document and understand the shorter term noise fluctuations in relation to tides and currents as recorder by the current-meter as well as the DPG. Since the auxiliary data are sampled at sufficiently high rates (1 sps) compared to what was available for the MOISE experiment, we will be able to investigate ways to reduce the background noise correlated with the pressure and current data at periods longer than 10 sec by designing appropriate filters. If necessary, we will consider experimenting with the addition of a trawl-resistant cover over the seismometer package, to further isolate it from current noise. We will also construct models of the near-surface ground structure and ocean layer response to try and account for the signal generated noise by designing appropriate transfer filters. Availability of reference recordings at nearby land based broadband stations of the BDSN is a crucial asset in this endeavor.

Ultimately, we hope that the data provided by MOBB will 1) complement the land based network, in particular in the joint UC Berkeley/USGS Menlo-Park real-time earthquake notification program for northern California, as well as for regional structure studies and 2) help design best installation and data processing procedures for temporary and permanent off-shore seafloor broadband stations. system.

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References

Araki, E., M. Shinohara, S. Sacks, A. Linde, T. Kanazawa and K. Suyehiro (2002) Improvement of seismic observation in the ocean by use of ocean boreholes, Bull. Seism. Soc. Am. COMPLETE REFERENCE

Collins, J.; Vernon, F; Orcutt, J; Stephen, R.; Peal, K.; Hildebrand, J.; and F. Spiess, 1998, Relative Performance of the borehole, surficially-buried, and seafloor broadband seismographs on the Ocean Seismic Network Pilot Experiment: Frequency-domain results, EOS Trans (abstr), 79, 661.

Cox, C., T. Deaton and S. Webb (1984) A deep-sea differential pressure gauge, *J. Atm. Ocean. Tech.*, 1, 237-245.

Crawford, W. C. and S. C. Webb (2000) Identifying and removing tilt noise from low-frequency (< 0.1 Hz) seafloor vertical seismic data, *Bull. Seism. Soc. Am*, 90, 952-963.

Montagner, J.P., J. F. Karczewski, B. Romanowicz, S. Bouaricha, P. Lognonne, G. Roult, E. Stutzmann, J.L. Thirot, J Brion, B. Dole, D. Fouassier, J-C Koenig, J.C. Savary, L. Floury, J. Dupond, A. Echardour and H. Floc'h, (1994) " The french pilot experiment OFM-SISMOBS: first scientific results on noise level and event detection", Phys. Earth and Planet Inter., 84, 321-336.

OMD Workshop Committee (2003) Ocean Mantle Dynamics Implementation Plan, Report of a Community Workshop, SNowbird, Utah, 18-20 September 2002.

OSN1 reference

Purdy, M., editor: " Broadband Seismology in the Oceans: towards a five year plan", report of Ocean Seismic Network workshop published by Joint Oceanographic Institutions, 1995.

Romanowicz, B., D. Neuhauser, B. Bogaert and D.Oppenheimer (1994) Accessing Northern California Earthquake Data Via Internet, EOS Trans A.G.U., 75, 258-261.

Romanowicz, B., D. Stakes, J. P. Montagner, P. Tarits, R. Uhrhammer. M. Begnaud, E. Stutzmann, M. Pasyanos, J.F. Karczewski, S. Etchemendy (1999) MOISE: Ta pilot experiment towards long term Sea-floor geophysical observatories, Earth Planets Space, 50,927-937.

Stakes, D., B. Romanowicz, J.P. Montagner, P. Tarits, J.F. Karczewski, S. Etchemendy, D. Neuhauser, P. McGill, J-C. Koenig, J.Savary, M. Begnaud and M. Pasyanos, MOISE: Monterey Bay Ocean Bottom International Seismic Experiment, EOS Trans., A.G.U., 79, 301-309, 1998.

Stutzmann, E., J.P. Montagner et al. (2001) MOISE: a prototype mutliparameter ocean-bottom station, *Bull. Seism. Soc. Am.*, 81, 885-902.

Suyehiro, K., J.P. Montagner, A. M. Dziewonski and B. Romanowicz, The International Ocean Network Structure, Proceedings ION/ODP International Workshop, " Multidisciplinary observatories on the deep seafloor", Marseille, 61-72, 1995.

Suyehiro, K. et al. (japan stations)

Webb, S. C., Broadband seismology and noise under the ocean, Rev. Geophys. Space Phys., 36, 105-142, 1997.

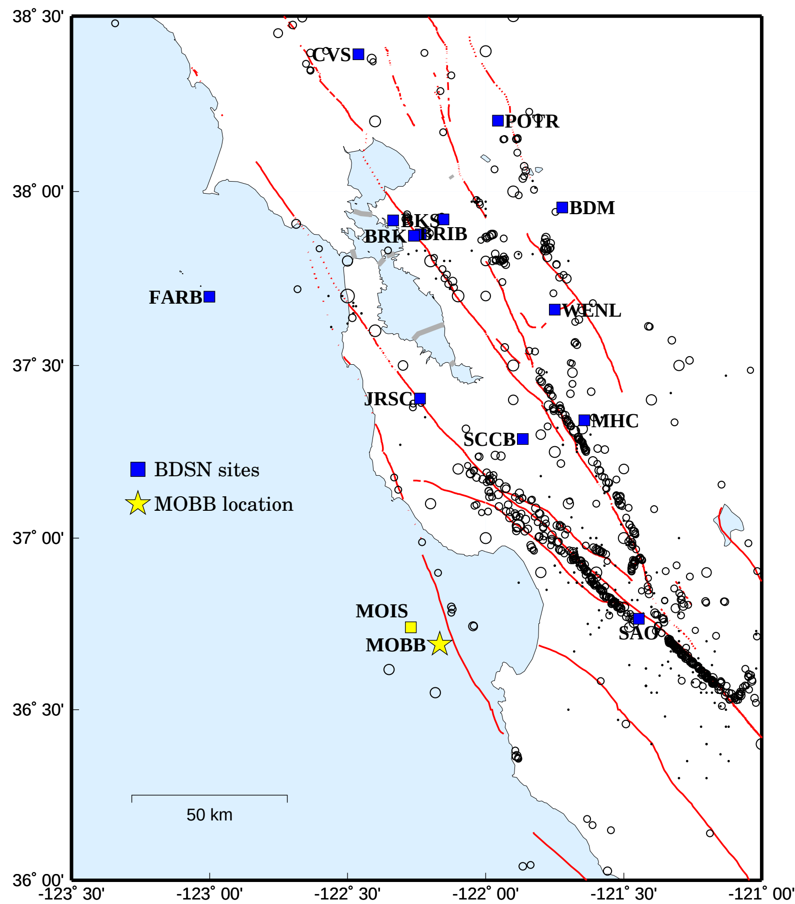

Figure 1: Location of the MOBB site (star) with respect to nearby broadband stations of the Berkeley Digital Seismic Network. The site of the temporary MOIS deployment, in summer of 1997 is also indicated. The background seismicity is from the CNSS catalog and covers the time period 1950-2002.

Figure 2: left: Installation of the seismometer package inside the PVC caisson. This was later completely covered by glass beads. Right: Trawl-resistant enclosure for the recording and battery packages. This snapshot was taken as the ROV Ventana was bringing the cable from the seismometer package in order to connect it onto the recording package. The first time such a remote underwater connection was attempted during the MOISE experiment, it took 2.5 hours to succeed and led to a redesign of the geometry of the instrument packages. The ROV operators are now able to do this routinely in less than 5-10mn.

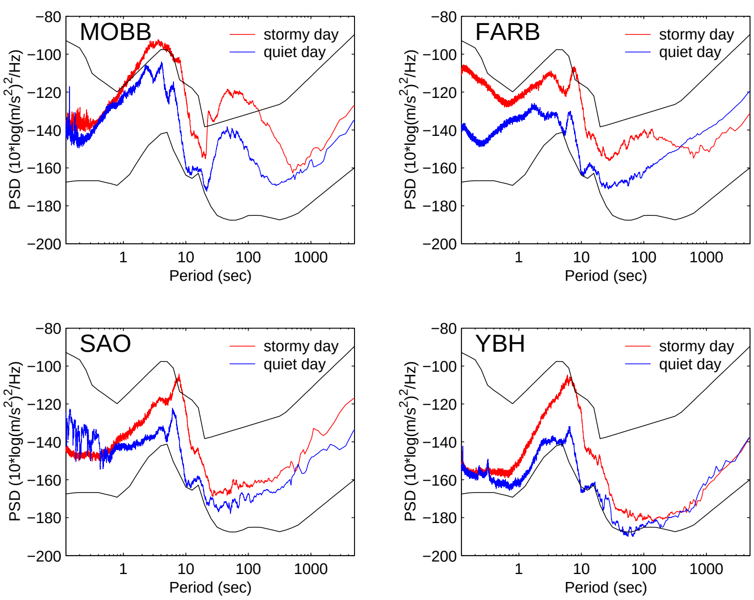

Figure 3: Observed background noise PSD at MOBB, FARB, SAO, and YBH. Shown are the Z-components on a stormy (red; Dec.16,2002) and on a quiet day (blue; May 23,2002). The USGS high- and low-noise models for land stations are shown in black. Increased noise level for periods between 20 and 500 sec, due to ocean currents and infragravity waves, is observed at MOBB, as well as at the island station FARB. The noise level at MOBB between 30 and 100 sec on a quiet day is comparable to the noise level at the island station FARB on a stormy day. The noise level at MOBB between 10 and 20 sec is comparable to the land station YBH, one of the quietest stations of the BDSN. See Figure 1 for FARB and SAO locations. Station YBH is 560 km north of MOBB.