SCIENCE AND TECHNOLOGY 2013 CONFERENCE

Ocean Acoustic Thermometry using Active Biological Sources recorded at IMS hydrophones
A Proposed Feasibility Study

Ronan Le Bras [(1)], Heidi Kuzma [(2)], and Ronald „Chip“ Brogan [(3)]

[(1)] IMGW University of Vienna, Austria

[(2)] Chatelet Resources, Truckee, CA, USA

[(3)] ENSCO, Inc., Church Falls, VA, USA

universität wien · Chatelet Resources LLC · ENSCO · CTBTO PREPARATORY COMMISSION

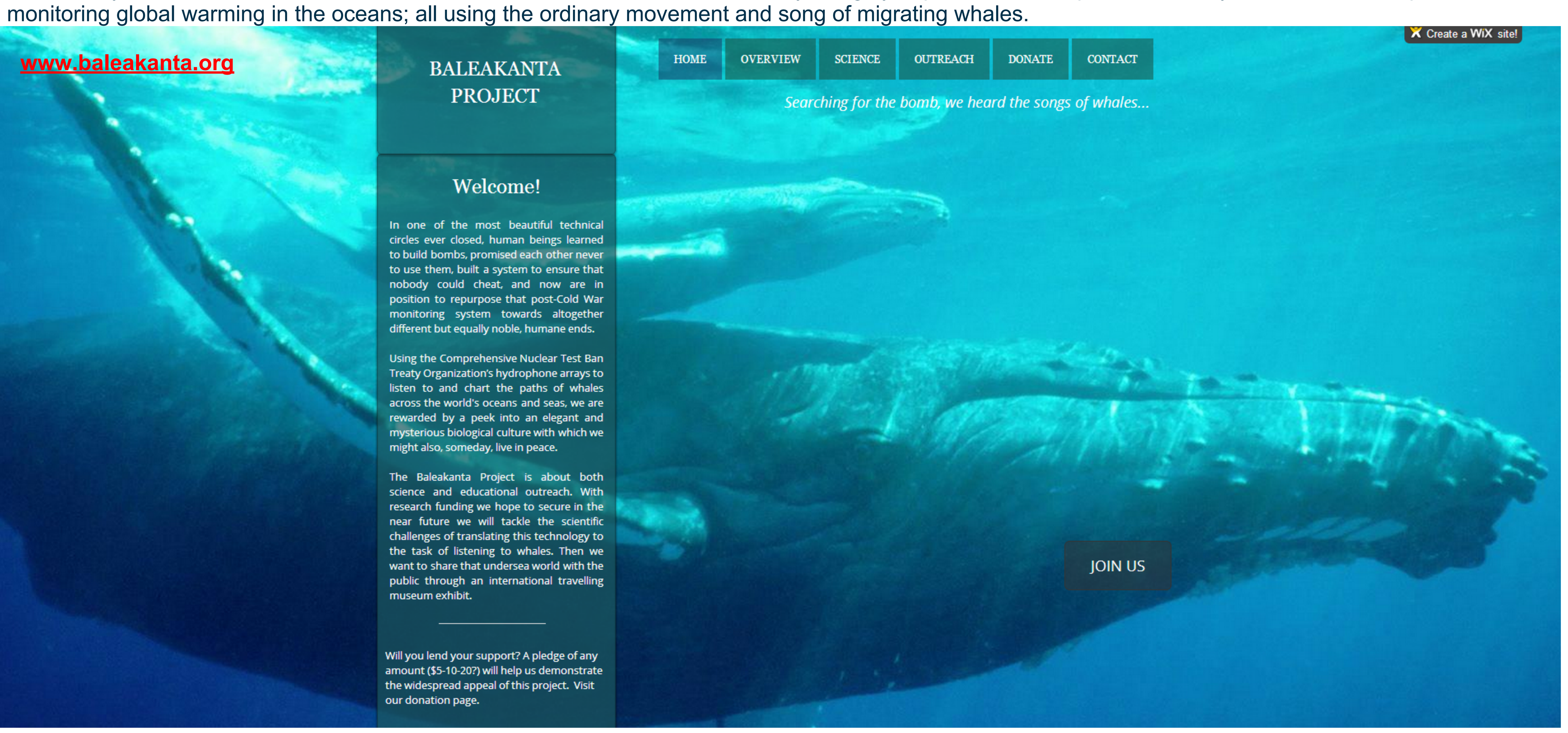
(T2-P54)

Abstract

The ATOC project (The ATOC Consortium, 1998) had the goal of measuring acoustic velocity in the oceans to assess bulk variations of the ocean temperature with various applications, including long term trend monitoring of Earth climate variation. The method for measuring the velocity variations relied on a few active sources and receivers. Several issues hampered the project, mainly the concern over the consequences of the active source on cetaceans. In conjunction with the work of , we are proposing a roadmap to using the calls of automatically located whales as the active source for monitoring the variation of acoustic propagation. The speed of propagation also corresponds to an integrated measurement of temperature along the paths between the location of the whale and the IMS hydrophones. The general lines of the project are to implement automatic detection and location of the marine mammals, and jointly assess their location and speed of propagation between their location and the IMS hydrophones.

Executive Summary

The CTBTO IDC hydro-acoustic system was designed and implemented to detect clandestine nuclear explosions, yet with some modifications the same technology and sensor network could be purposed to detect large whales, whose acoustic emissions are in the frequency range of the IMS hydrophones. This proposed feasibility study is a first step towards the establishment of such a cetacean-charting system, which, if successful, could be followed by a full-blown operational system. The expected outcome from the study is a prototype which will record whale position at the time of their acoustic emission (“singing”) and provide a time-varying data set of acoustic velocities. The increased information about whale position and variation with time would be of interest to marine biologists, as well as a wider group of people who are simply fascinated by the lives and sounds of these largest of the world’s mammals. In addition to tracking whales, the technology would improve known hydro-acoustic velocity models and serve as an observatory of the variation of oceanic acoustic velocities with time. Since velocity is highly dependent on temperature, the system would be helpful in monitoring global warming in the oceans; all using the ordinary movement and song of migrating whales.



Vision

Out of one of mankind’s greatest scientific understandings, that matter and energy are fundamentally tied together, sprang the most terrifying weapon even invented: the nuclear bomb. Yet, from this horror has sprung what must be surely one of our most noble endeavors – the Comprehensive Test Ban Treaty (CTBT) which is a promise by nations to one another not to test and deploy such weapons against each other. It is a great credit to our world that since the a moratorium in 1992 and inception of the treaty in 1996 only a handful of nuclear tests have been conducted and only by nations who had not then, or still have not signed the treaty. In the first thirteen years of the twenty first century, only three nuclear explosions, all conducted and claimed by the Democratic People’ s Republic of North Korea, have disturbed the nuclear silence. The CTBT is a promise of peace that transcends short-sighted rivalries and disagreements between nations and ought to be lauded as one of the greatest achievements of diplomacy in the late twentieth century.

As far as detecting bombs goes, whale songs are noise on the IMS network. They are often registered in exactly the frequency bands that the network is tuned to record and they can interfere with the location of the hundreds of non-nuclear seismic events (earthquakes) which the network must catalogue each day lest a nuclear event be lost in the earth’s natural rumblings. This “noise” however, contains a rich source of information for marine biologists. A data analysis system could be built which mirrors the International Data Centre (IDC’s) data crunching machinery, but, instead of being focused on locating nuclear events and earthquakes, it could be tuned to understanding biological signals. The result would be a better understanding of whales, their communication, migration patterns and even, perhaps, the personal habits of individual cetaceans. Science wouldn’t stop there, however, because the whale songs provide a predictable set of source signals which could be used to refine our understanding of the propagation of sounds in the oceans (which would feed back into nuclear-event resolution capacity …). And finally, because the migratory patterns of whales are thought to remain constant over long periods, monitoring fluctuations in how the songs are received over decades could contribute to an understanding of how sound transmission in the oceans changes over time. Since transmission speeds and attenuation are thought to be largely a function of temperature, the long-term monitoring of songs could give us insight into how the oceans are changing in response to global warming. (It is notable that an earlier attempt which used man-made noise sources to monitor sound-propagation in the oceans to monitor temperature (the ATOC project) was thwarted to some extent by the activism of people concerned about the health effect of acoustic noise on whales. It is ironic that the whales themselves could provide the signals to study temperature, thus reconciling social differences, advancing science, and benefit both climate scientists and animal enthusiasts with information about both subjects).

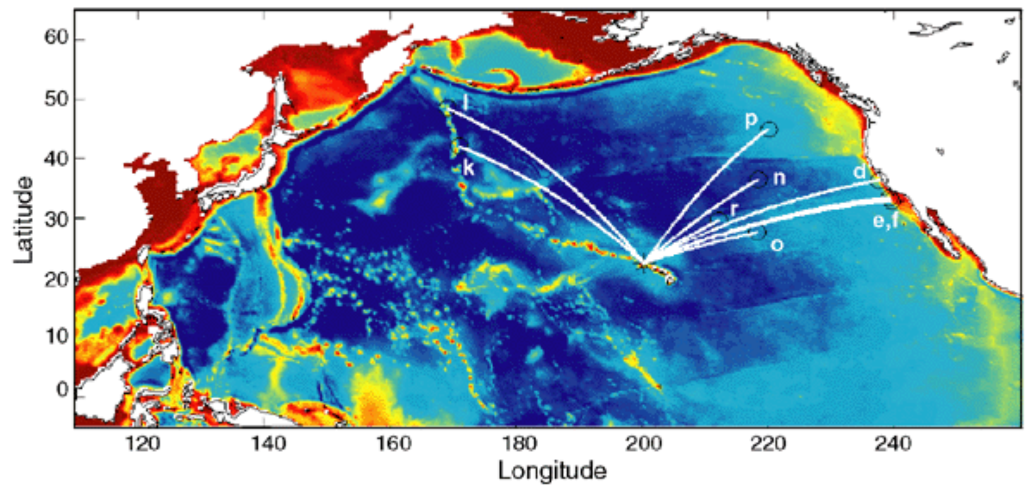
Using the IMS network to listen to whales is a rich project indeed, and especially fitting in what is hoped will become a world of peace and nuclear silence.

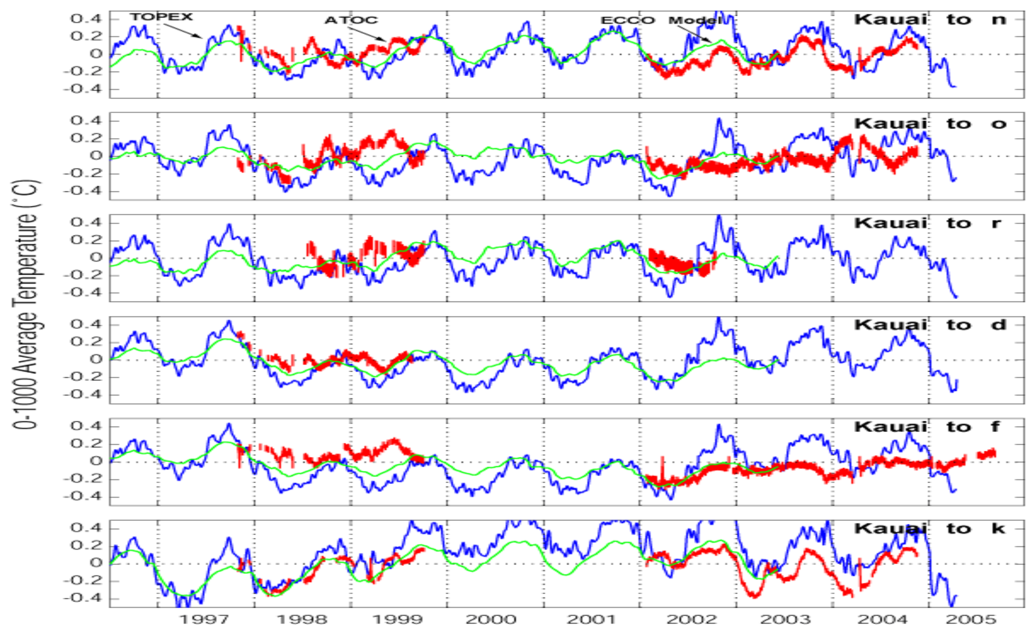
The end goal of this project is to provide a large dataset of marine mammal detections at global IMS hydro-acoustic stations. It is envisioned that this data set would be augmented automatically as new continuous hydro-acoustic data was acquired.

References

http://aog.ucsd.edu/thermometry/index.htm (last accessed May 2013)
http://staff.washington.edu/dushaw/atoc.html (last accessed June 2013)
The ATOC Consortium, 1998, Ocean climate change: Comparison of acoustic tomography, satellite altimetry, and modeling, Science, 281, 1327–1332
Brown, D., Cerranna, L., Prior, M., Mialle, P. and Le Bras, R. The IDC Seismic, Hydroacoustic and Infrasound Global Low and High Noise Models.
Santos P., Rodriguez O.C., Felisberto P., and Jesus S.M. Geoacoustic inversion with a vector sensor array. J. Acoust. Soc. Am, 5(128), 2652-2663, November 2010.
Rodriguez, O., C., Traceo user manual, 2011. http://www.siplab.fct.ualg.pt/models/traceo/manual.pdf. (last accessed 5/2013)

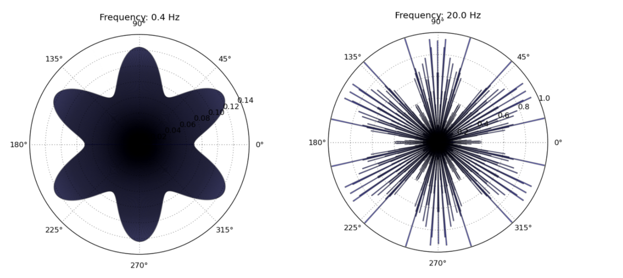
ATOC project background





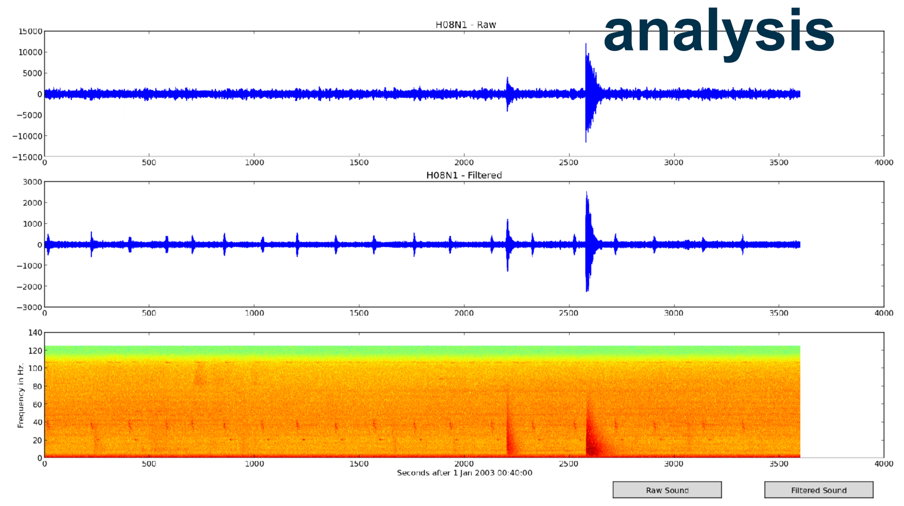
The ATOC project has been monitoring ocean temperatures using acoustic velocity recordings between a fixed source and fixed hydrophones (see map above)

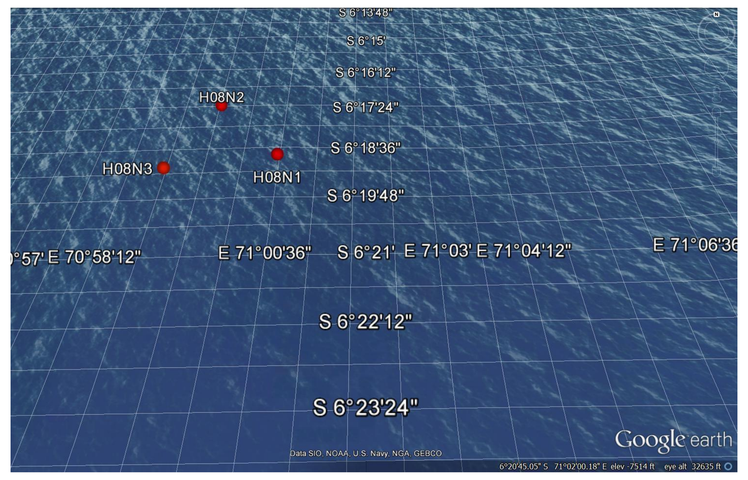
Blue -> Topex-Poseidon (modified satellite data)
Green -> ECCO model
Red -> ATOC measurements



Theoretical array responses for 0.4Hz and 20Hz for an equilateral hydrophone triplet 2km on the side for water velocity of 1.5km/s.

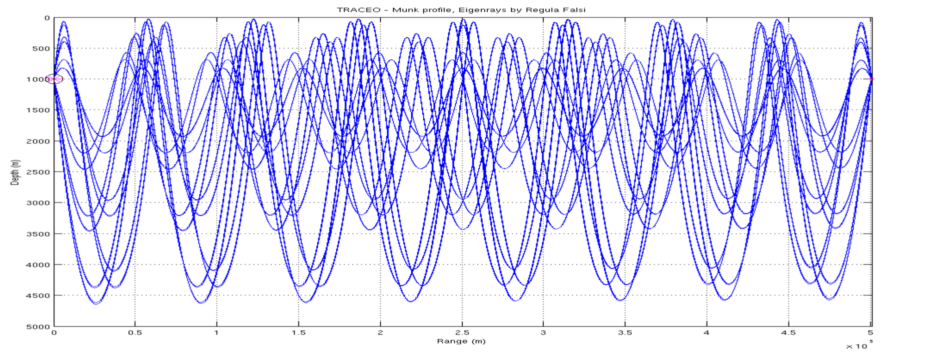
Initial data analysis



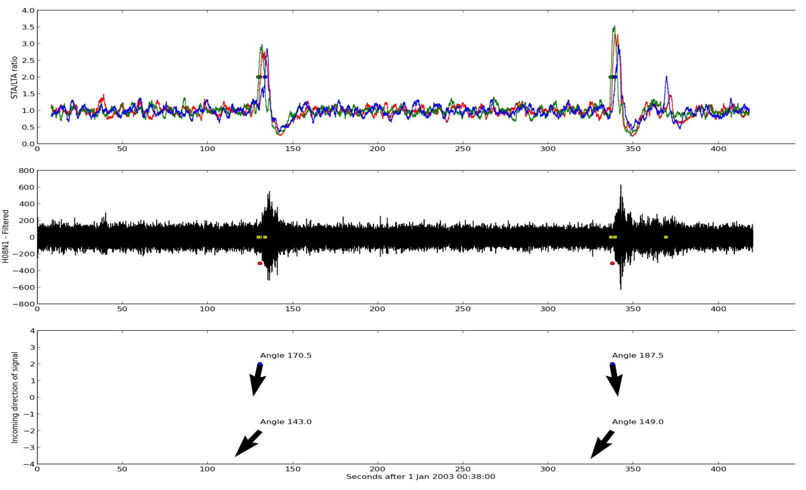


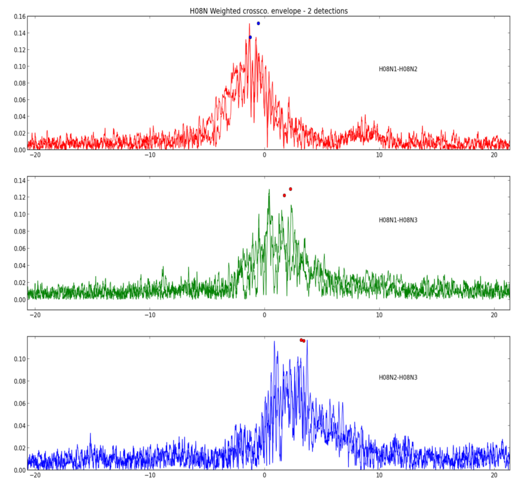
One hour of data at hydrophone H08N1, on January 1, 2003, starting at 00:40:00. The top trace is the raw data, the second is the data filtered between 10 and 60 Hz, enhancing the whale calls which are dominant in that frequency band. The spectrogram for the whole hour is shown below and the calls are very clear in this image. There are two distinct frequency ranges for the calls. The dominant one is centered around 40 Hz and the second one is centered around 20 Hz. This second call usually follows-- but not systematically-- the higher frequency one. One could speculate that this either represents the call of a single animal or that an animal is responding with a lower frequency call to the first call. The large signals during the second half of the hour are likely T phases generated by earthquakes.
The map to the right shows the location of the three hydrophones forming the H0N triplet near the Chagos archipelago in the Indian Ocean. The red dots are the location of the hydrophones. The water depth is respectively 2308m for H08N1, 2373m for H08N2, and 2342m for H08N3. The hydrophones are placed at the depth of the SOFAR channel.

Gaussian ray tracing in a standard ocean, using the Munk depth profile for the acoustic velocity. The depth of the source and receiver are at 1000m, which corresponds roughly to the axis of the SOFAR channel. The computation and graphics are made using the Traceo software (Rodriguez, 2011, Santos et al., 2010)



The bottom shows the three STA/LTA traces, the trace at H08N1 and the directions derived from the initial picks (SNR of 2 on the STA/LTA) at the bottom and the peak of cross-correlation envelope directions.





Focusing on the two first detections for the hour of data, this is a presentation of the cross-correlations of 50 s. segments around the initial picks.

The figure shows the two superimposed envelopes of the cross-correlations and the pick of the maxima.

Background

The IMS hydro-acoustic array is a sparse array of hydrophone triplets placed at SOFAR channel depth (around 1000 m). The network is very sparse, (three stations in the Indian Ocean, two in the Pacific Ocean, and a single one in the Atlantic Ocean), but also very sensitive, and hydro acoustic signals travel enormous distances through the water. The stations are installed as triplets of hydrophones placed at SOFAR channel depth. The triplet configuration allows for the determination of a direction of propagation of a signal and enhances the detection and location capabilities of the station. The ability to chart directionality is a strong asset for the identification of individual whales since the direction of propagation may indicate songs coming from different individuals.

The current IMS hydro-acoustic processing system distinguishes between three types of signals which are distinguished during the *station processing* stage of the IDC’s automatic processing system: :

- *T phases*, which are emitted by undersea or near-shore earthquakes, couple into the ocean and are efficiently propagated into the SOFAR channel.
- *H phases*, which are emitted by in-water explosions and propagate into the SOFAR channel.
- *Noise phases* which include everything else, a variety of signals from various sources, including whales.

Signals from different stations are processed together to form discrete “events” (nuclear blasts and earthquakes). One of the problems of hydro-acoustic monitoring is that continents and islands can block the propagation acoustic signals; the processing operation to form multi-station events takes this blocking factor into account.

A similar system can developed which would take advantage of the current network and processing to identify and locate whale calls instead of earthquakes. Since it is believed that individual whale calls are unique, it might be possible to identify individual whales, although the complex propagation characteristics of the ocean will make this a technical challenge. The gathered data can then be used by both scientists studying the cetaceans and physical oceanographers studying various aspects of the physical properties of the oceans, including their propagation characteristics.

The commonalities between nuclear bomb detection and cetacean detection make it relatively simple to build on the IDC processing system to produce a new system that will detect and accumulate a wealth of data on the location of the cetaceans and the propagation characteristics between their locations and fixed sensors. Such a project would leverage the huge body of knowledge acquired by CTBTO in processing hydro-acoustic data. Through improved acoustic propagation knowledge, the project would benefit the core mission of the CTBTO which is to detect and locate potential explosions.

The whale project, however, is not exactly the same as nuclear monitoring. For one thing, whale songs can last for hours during which time the animal is moving (earthquakes or explosions happen in one place). Although whale songs are commonly heard in IMS data, there is not a perfect overlap between the frequency bands they occur in and the principal band of the IMS system which means that the entire signal is not being heard. And although earthquakes do, in some sense, have individual characters in that the signals emitted are dependent on their source mechanics and signals registered have to do with the geology along the propagation path between source and receiver and so are somewhat direction and distance dependent. But registering earthquakes it is far cry from listening to the calls of individual whales. Telling whales apart is a difficult problem, akin to that of speaker identification in audio signal processing. Solving this problem might make an interesting and popular contest for machine learning researchers and could be made public as a challenge, for instance, on the Kaggle website.

Disclaimer

The views expressed in this paper are those of the authors and do not necessarily reflect the views of their employers or of the CTBTO.