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Jean-François d'Eu, Jean-Yves Royer, Julie Perrot. Long-term autonomous hydrophones for large-scale hydroacoustic monitoring of the oceans. Yeosu 2012, May 2012, Yeosu, North Korea. pp.1-6, 10.1109/OCEANS-Yeosu.2012.6263519 . insu-00817948

# Long-term autonomous hydrophones for large-scale hydroacoustic monitoring of the oceans

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*Abstract*—**We have developed a set of long-term autonomous hydrophones dedicated to long-term monitoring of low-frequency sounds in the ocean (<120Hz). Deploying arrays of such hydrophones (at least 4 instruments) proves a very efficient approach to monitor acoustic events of geological origin (earthquakes, icequakes), sea state or large baleen whales, over large and remote areas of the world ocean (up to 1000 km between instruments or more). Such approach takes advantage of the high sensitivity of hydrophones and of the long-range acoustic properties of the water column. Our instrument have been designed to be deployed for more than one year, continuously recording the ocean sounds at 240Hz with high dynamic 24-bit resolution.**

***Keywords-component: hydrophone, seismology, bioacoustics.***

## I. INTRODUCTION

Observing the marine domain is a formidable task due to the immensity of the sea and to the variety of natural or biological events that take place in this environment. Local studies and observations give important information for specific small-scale events, but it is also of great importance to observe large portions of the ocean for understanding large scale and long-term variations. Particularly, unpredictable events such as seismic activity or marine mammals' migrations need to be monitored at the scale of whole oceans for global processes to be understood.

The ocean being an excellent sound waveguide, underwater acoustics proved very helpful for monitoring this environment [1, 2]. Therefore, recording the sounds of the ocean for long periods of time at chosen frequencies can provide loads of useful information on the marine environment and life.

This is the reason why we developed a new set of long-term low-frequency hydrophones, to be deployed in the oceans for monitoring acoustic signals on large scales.

## II. THE NEED FOR PASSIVE ACOUSTIC MONITORING

Passive acoustic observations are of great interest for a variety of applications, all sources of noise being a signal for a different scientific purpose, from geosciences, to biology and oceanography, and in particular for evaluating the evolution and impact of anthropogenic noises.

### *A. Monitoring ocean seismicity at a broad scale*

Seismicity in the ocean is usually recorded with the help of seismometers, such as Ocean Bottom Seismometers (OBS), placed in the proximity of active areas. Due to the rapid attenuation of seismic waves in the crust, this approach is very efficient to monitor limited areas (e.g. 50 x 50 km), for instance for studying a small portion of an active spreading oceanic ridge. However, to understand processes taking place on a regional scale, for example to monitor the low-level seismicity along a large section of mid-ocean ridges (e.g. [2, 3]), would require to deploy hundreds of OBS's. For the same reason, remote oceanic areas still remain poorly covered by land-based seismological networks, where they only detect events of magnitude larger than 4 or 5, which are not representative of the actual background seismicity. Passive hydroacoustic recording is thus an interesting option to overcome this limitation.

### *B. Detecting and monitoring large marine mammals*

Detecting and monitoring large marine mammals is a similar issue. Marine mammals spend most of their time diving, making visual observation from ships difficult and hardly representative of their actual presence and abundance. In remote and inaccessible areas, such as the Southern Ocean, this approach is even more difficult and ocean-wide, there are still very large gaps of pertinent observation. Acoustic signals from marine mammals allow to discriminate different species and sub-species, and in some cases to count their calls and use this information as a proxy or index of their presence and abundance (e.g. [4]). Moreover, it is interesting to retrieve seasonal information on the presence of the cetaceans along certain paths, as they migrate through the year. Only long-term acoustic recording would provide such information.

### *C. Recording background noise*

Finally, passive-acoustic recordings are a necessary tool to evaluate the overall background noise in the ocean. Indeed, passive acoustic instruments record all kind of sounds, from marine life to seismic events, but also iceberg cracks (e.g. [5]), and noise related to the sea state (e.g. [6]), and human activities, from surface ships to seismic exploration. Such data can therefore be of interest for a large scientific community.

## III. PRINCIPLES OF PASSIVE ACOUSTIC MONITORING

### A. *Long-Range Ocean Sound Propagation*

The purpose is to record sounds of the ocean that can be listened at great distance. This is possible thanks to the occurence of a low-sound-velocity layer in the ocean, called the SOFAR channel (Sound Fixing and Ranging channel [7]). Due to the combined effects of increasing pressure and temperature changes at depth, the sound velocity varies with depth and pass through a minimum (Figure 1). This minimum is located at about 1000m depth at mid-latitudes and varies with the temperature gradient, to be for example shallower towards the high latitudes.

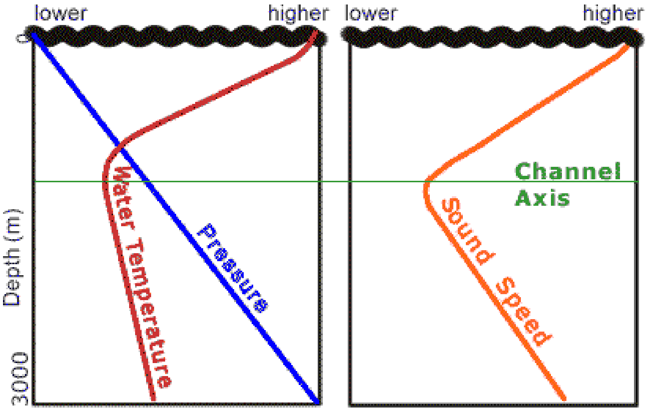

**Figure 1 The SOFAR Channel in the ocean derives from conjugate variations of pressure and temperature at depth. Its depth is mainly dependant on the temperature profile.**

This low sound-velocity layer acts as a wave-guide, allowing sounds to propagate over long distances with little attenuation.

Thus, a microphone located in the SOFAR channel will record short- to long-range signals. Moreover, since their attenuation is reduced, low-intensity signals will also be detected, allowing for a large variety of signals to be recorded and analyzed. To place an acoustic recorder in the SOFAR channel, one can use a mooring line anchored to the sea-bottom, with a buoy pulling the line (Figure 2). Keeping the buoy underwater limits the transmission of noise from the surface and avoids breakage due to rough sea states. An acoustic release placed above the anchor allows recovering the instrument after the experiment.

### B. *Event Localization*

Localizing the source of an acoustic event requires a simultaneous recording of this event with an array of hydrophones. Theoretically, a minimum of 3 instruments is needed. Experience shows that 4 are actually required to limit, through redundancy, data-losses due to a malfunctioning instrument and to compute uncertainties in the location and time-origin of the event. In addition, to survey large areas (e.g. 1000 x 1000 km) and to limit the effects of acoustic shadows due to submarine reliefs interrupting the SOFAR channel, a typical array will comprise 5 or more instruments. Figure 3 shows an example of acoustic events located from a 3-hydrophone array in the Indian Ocean [8]. Several experiences have shown that location uncertainties are in the order of 2-3 km inside the array and increase away from the array (e.g. [9,10]).

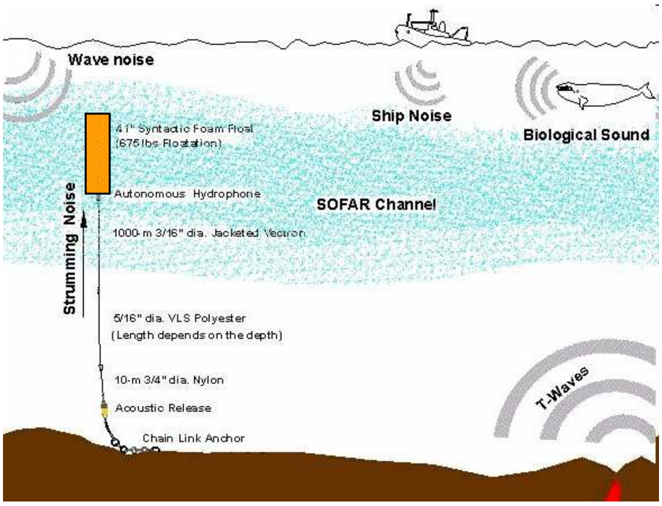

**Figure 2 Deployment of a hydrophone in the SOFAR channel and sound sources in the ocean (courtesy NOAA-PMEL)**

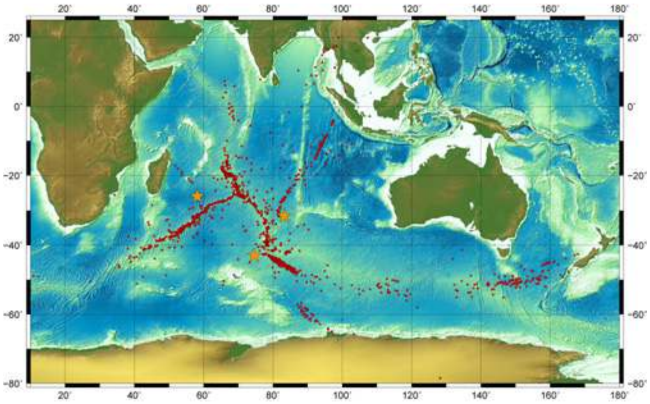

**Figure 3 Acoustic events (red dots) due to earthquakes and icequakes in the Indian Ocean, located with a 3-hydrophone array (orange stars; 2006-08 DEFLO experiment [8]).**

For sounds of lesser intensities, like in marine mammals studies, the size of the array must be reduced to few tenth of kilometers [3]. An experiment is underway in the Southern Indian Ocean to test such arrays. The location of the instruments must also be carefully chosen on whale migration routes.

## IV. INSTRUMENT DESCRIPTION

### A. *Mooring line*

As shown in picture 4, the instrument is housed inside the buoy. It simplifies the mooring deployment and recovery, and protects the instrument itself. The hydrophone sensor is fixed to and protected by the buoy metallic frame. This disposition showed not to be generating particular noise on the data.

The buoy is made of syntactic foam to resist pressure up to 2000m water depth. The instruments are moored in the SOFAR channel axis at depth usually less than 1500m below the sea-surface. The length of the mooring line is thus adjusted according to the depth of the seafloor and to the depth of the SOFAR axis in the area. The depth of the SOFAR channel can be measured by launching an expendable bathythermograph (XBT) from the ship prior to the deployment.

**Figure 4 The hydrophone instrument is housed inside the buoy just before deployment. The sensor is attached to the buoy frame and plugged into the instrument.**

The whole line is held by a 400kg disposable anchor. An acoustic release system (we use IXSEA RT2500) is placed just above the anchor. The recovery of the line relies upon their autonomy, typically up to 2 years with alkaline batteries.

### *B. Instrument Housing*

In order to survive long-term immersion, the instrument is contained in a 90cm-long solid titanium tube (Figure 5). Inside the instrument, an aluminum frame attached to the tube end cap holds the electronic board and the batteries. The battery volume is important to allow for long-term deployments. Two Subconn wetmate connectors make the link to the outside world, one for the hydrophone sensor, one for a communication cable to configure and start the acquisition system (Figure 6).

### *C. Hydrophone Sensor*

The sensor is of course a key component of the instrument. The underwater microphone is a piezoelectric ceramic sensor, molded in polyurethane to guarantee underwater resistance. We use HTI-90-U sensors (Figure 6), with a custom preamplifier in the sensor itself. The preamplifier has a gain of 22dB for an average sensitivity of the sensor of -163.5dB re 1V/µPa. The preamplifier power consumption is only 2.3mW. The bandwidth of this sensor is wide and flat from 2Hz to 2kHz. At low frequencies (< 2 Hz), the transfer function is dominated by the AC-coupling capacitor, necessary for these sensors, and by a high pass filter included in the preamplifier for sensor noise reasons at low frequencies. The AC-coupling capacitor is rather large, 22µF. The high-pass filter starts to cut the signals from 0.2Hz to 2Hz.

Figure 7 shows the response, in gain and phase, of the preamplifier and high-pass filter from 10mHz to 10kHz. The filters mostly affect very low frequencies (< 1 Hz), but have little or no effects for recording seismic activity or bioacoustics sounds (> 4 Hz). Thus, for very low frequency noises, the data must be recalibrated prior to their interpretation.

**Figure 5 Titanium cylinder housing the batteries, electronic board and data storage (hard disk drive)**

**Figure 6 Hydrophone electronic board and sensor.**

### D. *Electronics and Data-logging*

The acquisition system consists of one unique board, connected to the batteries, sensor, communication connectors, and hard disk drive to store the data, and that ensures the data-logging (Figures 6 and 8).

An accurate logging of the time is a key issue for the data analyses, particularly when dealing with an array of hydrophones and with long-term deployments. Localization of a specific event is indeed derived from the time of arrival of this event on each instrument. Therefore, the data-logging algorithm is centered on the clocking system.

The links between the different electronic components are summarized in the block diagram in figure 8.

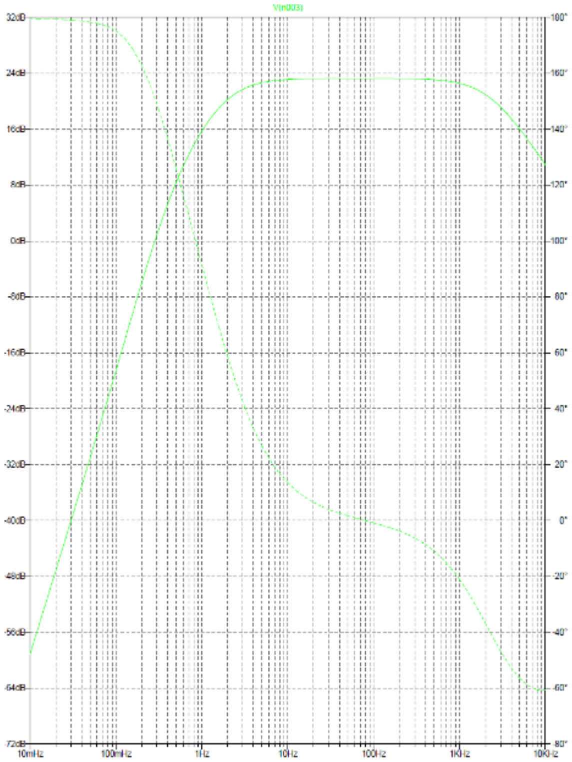

**Figure 7 Theoretical response curve of the preamplifier in the hydrophone sensor (gain is the solid line in dB, phase is the dashed line in degrees).**

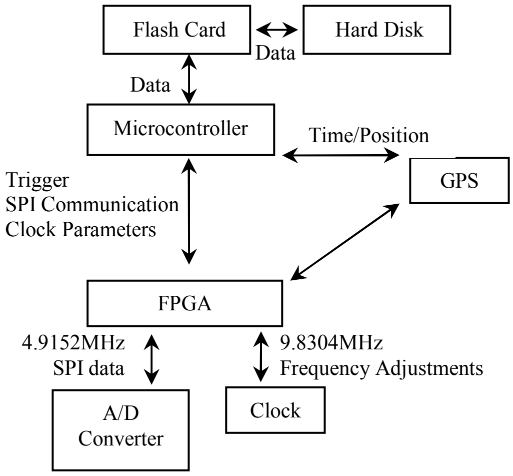

**Figure 8 Block diagram of the acquisition system.**

#### 1) *Timing and FPGA*

The clocking system is embedded in a small FPGA (Field Programmable Gate Array). The FPGA is connected to the main clock, a precise TCXO (Temperature controlled oscillator) at 9.8304MHz with a frequency adjustment feature, to the 24-bit analog to digital converter, and to the microcontroller. Its role is to send a trigger signal to the microcontroller (a Persistor CF2), derived from the main clock and synchronized on the GPS PPS (Pulse Per Second) at startup. The FPGA is also generating the clocking frequency at 4.9152MHz to the analog to digital converter from the main clock.

Therefore, timing of the data acquisition is only driven by the main oscillator, resulting in a determinist pacing of the communication between the converter and the datalogger trigger. This prevents clocking drifts that can result in crashes during long-term experiments and help optimizing power consumption.

Moreover, the main clock can have its frequency adjusted, at startup, as close as possible to the GPS clock, typically achieving an accuracy of 5E-8. Once the instrument is deployed, its frequency is expected to remain stable, as temperature is stable at SOFAR channel depth and power voltage drift and vibrations are reduced to the minimum. At recovery, the clock drift is checked again against the GPS clock. We measured drifts in the order of a few seconds (1 to 5) over 12 to 14 months of deployment.

#### 2) *Microcontroller*

The microcontroller, a persistor CF2, has the task to communicate with the users at startup and recovery of the instrument, perform the configuration of the converter and clocks, and mainly to record the data. Data is first saved in a fast memory buffer, and then transferred to the flash card once the buffer is full. When the buffer on the flash card is full, the hard disk is started and a file is created with data flushed from the flash card. This procedure allows saving power avoiding frequent startups of the hard disk. Up to 160GB of data can be stored in the instrument.

### *3) Data Converter*

Data conversion is performed by a high precision 24-bit sigma delta converter. It is paced by the same clock than the data logging trigger, to ensure ab perfect synchronization between the converter and the data logger during long-term experiments. The output rate of the converter is set to 240Hz, to detect seismic activity or to monitor low-frequency call of some species of large baleen whales. Sampling rate can be increased to extend the frequency range of detection, to the expense of power consumption, i.e. shorter autonomy.

### *4) Power*

The instrument is powered from battery blocks of lithium elements at 7.2V. Although expensive, these elements are very reliable and have a controlled discharge rate. Blocks of 350Ah are parallelized to extend battery life. Alkaline batteries can also be used if necessary, although their actual autonomy has not been fully tested yet.

The overall instrument requires less than 50mA to run permanently at 240Hz. Drastic reduction of the power consumption is in progress.

## V. DATA EXAMPLES

Figure 9 shows one example of data recorded by one of our instrument near the mid-atlantic ridge axis, about 400km south of the Acores archipelago. It shows a series of events during a seismic crisis close to the "lucky-strike" hydrothermal site. The greyscale spectrogram outlines the power and frequency content of the seismic events. The crisis took place close to the instrument, so some of the strongest events slightly saturated the preamplifiers.

Data on the other instruments in the area are now being processed. Assigning events on each instrument will allow localizing the events, then understanding the distribution in space and time of the events to contribute understanding the processes taking place in this region for the short and long term evolution of the ridge.

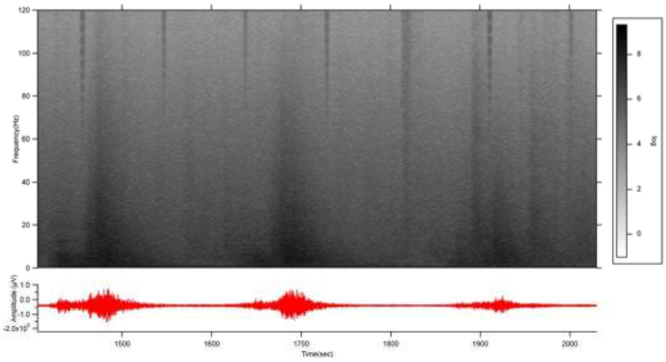

**Figure 10 Subset of figure 9 showing 3 seismic events, and regular seismic exploration shots every 100 seconds**

Figure 10 shows a subset of the same data, with 3 earthquakes and a series of seismic exploration shot every 100 seconds. Acoustic waves generated by earthquakes have much higher energy and lower frequencies (<40Hz) and broader signals than the seismic shots (>60Hz).

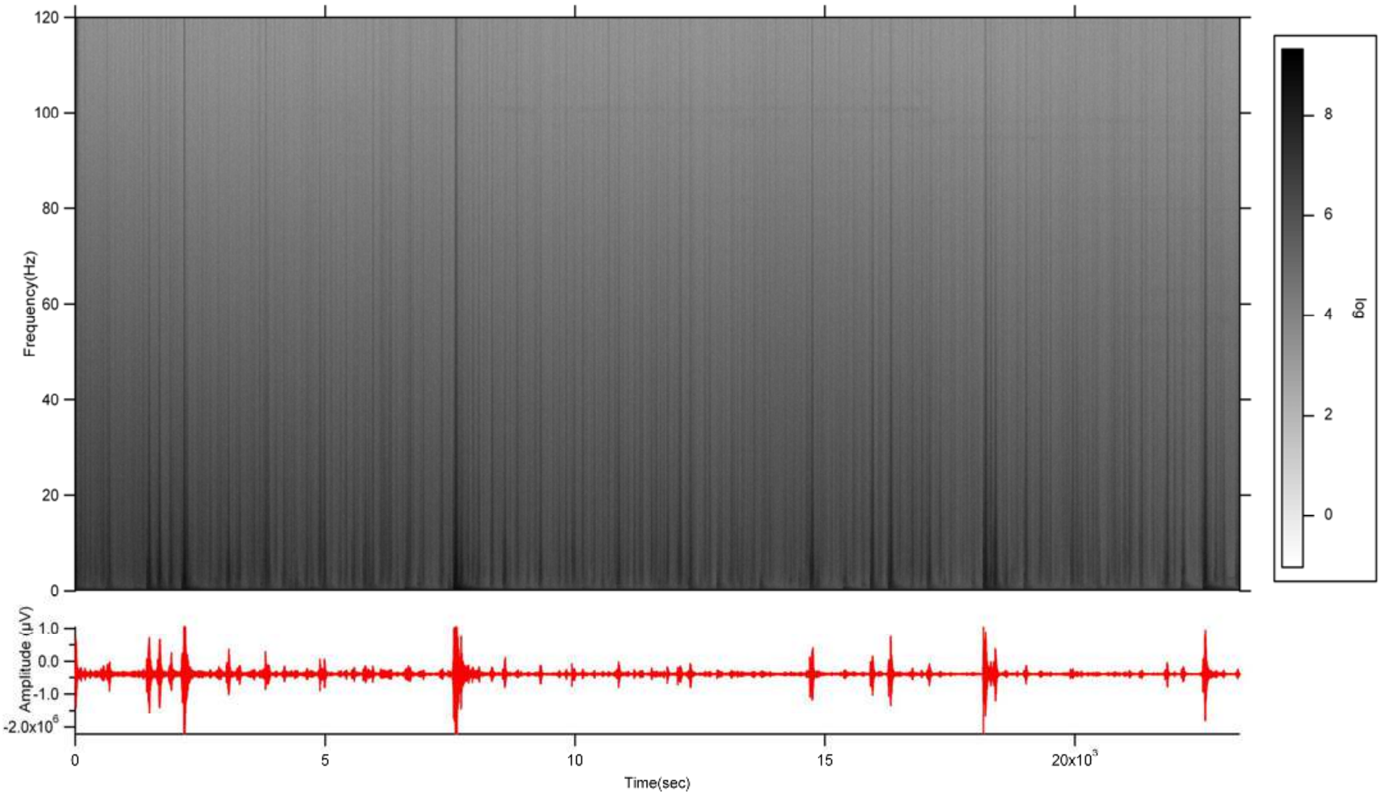

**Figure 9 Record example of 6.5 hours of data, collected south of Acores islands near the mid-Atlantic ridge. Time series is in red, spectrogram in greyscale.**

## VI. CONCLUSIONS

We have developed a new park of autonomous instruments for long-term monitoring of the low frequency noise in the ocean. We now have 15 instruments available, 5 under construction. Instruments have been and are deployed in 2 main zones, one in the South Atlantic Ocean, and the other one in the south Indian Ocean. The data already collected is now under analysis by multiple groups depending on the scientific targets, which makes autonomous hydrophone a useful and multisubject tool for ocean sciences.

## ACKNOWLEDGMENT

The development of our hydrophones has been funded by *Région Bretagne*, CNRS (INSU) and the European Union though the *Contract project between the French State and the Brittany Region* (CPER 2007-2013).

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