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Acoustic Maritime Rapid Environmental Assessment during the MREA'04 Sea Trial

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Abstract	This report describes the data acquired with the Acoustic Oceanographic Buoy (AOB) during the MREA'04 sea trial, that took place aboard the R/V ALLIANCE from 29 March - 19 April 2004, in the vicinity of Setúbal, 50 km south from Lisboa, Portugal.
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Foreword and Acknowledgment

This report presents recent developments on the AOB system and the results obtained during its testing in the MREA'04 sea trial. The MREA'04 sea trial took place off the Portuguese coast, approximately 50 km south from Lisbon, in the period 29 March - 19 April, 2004.

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- the NATO Undersea Research Centre for the opportunity for participating in the sea trial
- the scientist in charge Dr. Emanuel Coelho
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- the master and crew of the R/V Alliance
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Abstract

Environmental inversion of acoustic signals for bottom and water column properties is being proposed in the literature as an interesting concept for complementing direct hydrographic and oceanographic measurements for Rapid Environmental Assessment (REA). The acoustic contribution to REA can be cast as the result of the inversion of ocean acoustic properties to be assimilated into ocean circulation models specifically tailored and calibrated to the scale of the area under observation. Traditional ocean tomography systems and methods for their requirements of long and well populated receiving arrays and precise knowledge of the source/receiver geometries are not well adapted to operational Acoustic REA (AREA). The Acoustic Oceanographic Buoy (AOB) was proposed as an innovative concept that responds to the operational requirements of AREA. That concept includes the development of water column and geo-acoustic inversion methods being able to retrieve environmental true properties from signals received on a drifting network of acoustic-oceanographic sensors - the AOBs. An AOB prototype and a preliminary version of the inversion code, was tested at sea during the Maritime Rapid Environmental Assessment 2003 (MREA'03) sea trial and was reported in [1]. On a separate register it should be noted that the characterization of the environment between the source and the receiver also contributes to the identification of the acoustic channel response and therefore provides a basis for fulfilling the objectives of project NUACE[1]. The present report describes the data sets and results gathered during the MREA'04 sea trial that took place from 29 March to 19 April 2004 off the west coast of Portugal, south of Lisboa (Portugal), with the objectives of testing an improved version of the individual AOB and its functionality in a simple network. The acoustic part of the experiment lasted for four days between April 7 and April 10, 2004 and involved the transmission and reception of pre-coded signals along range-dependent and range-independent acoustic tracks.

[1]Non-cooperative Underwater Acoustic Channel Estimation, FCT contract POSI/CPS/47824/2002, initiated in January 2004.

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Chapter 1

Introduction

It is now well accepted in the scientific community that oceanographic and geoacoustic information is of paramount importance for generating stable and accurate acoustic sonar predictions. When that information is used to initialize and calibrate ocean circulation models for reasonably accurate predictions at 24 and 48 hours, sonar predictions can be made ahead of time and in locations to be. One of the main known drawbacks of this scheme is that actual data gathering methodologies are based on heavy spatial and temporal sampling without which prediction accuracy steadly drops. Therefore, there is a generic trend towards using remote observation methods being able to rapidly provide relevant information for model initialization without employing dense traditional ocean sampling - these are called Rapid Environmental Assessment (REA) methods. Such remote methods include, of course, satellite observations, air dropped sensors, autonomous underwater vehicles, etc... Recent work has shown that acoustics itself, by means of ocean acoustic tomography (OAT), can be used as an indirect method for gathering environmental information for ocean circulation model initialization and calibration [2, 3] - this is Acoustic REA (AREA). However, AREA turns out to be a relatively tough process for various reasons: one is that traditional OAT involves heavy equipment both at the source and receiver ends for obtaining a geometry controled experimental setup which is, in many instances, incompatible with the operational requirements of AREA; two, because acoustic data is different in nature and meanning from traditional oceanographic data and may require some type of data assimilation methods and finaly three, because OAT is an along track measurement and therefore the information it provides has a spatial integral interpretation, that is rather different from the very localized measurements obtained by traditional oceanic sampling.

The Acoustic Oceanographic Buoy Joint Research Project (AOB-JRP), initiated in January 2004, is addressing several issues of the operational AREA, mainly those dealing with the development, setup and test at sea of a drifting network of air deployable acoustic buoys as well as related algorithms and methods for on-the-fly AREA.

The first Maritime Rapid Environment Assessment'2003 sea trial (MREA'03) took place from May 26 to June 27, 2003, in the Ligurian Sea, with target areas at North and South of Elba Island. The SiPLAB/CINTAL team was onboard R/V Alliance from 18 to 27 June to proceed with the testing of the first version of the AOB system. Recalling the results obtained, it was shown that it was possible to obtain consistent environmental inversions with the drifting AOB provided that: 1) the frequency band was sufficiently large and in the high range, 2) the number of available hydrophones was large enough to adequatly sample the water column and 3) there was independent environmental information to initialize the system (EOF computation) (see internal report [1] and conference proceedings [4]).

During the MREA'04 sea trial a second AOB test was performed. The AOB was upgraded to 8 hydrophones and a 16 sensor thermistor chain was added. Another objective of the testing was to provide insight into the system setup and integration in a network environment. The transmitted signals included frequency wide multitones and broadband linea frequency modulated (LFM) sweeps for environmental inversion and PSK sequences for underwater communication purposes (NUACE).

This report is organized as follows: chapter 2 gives an overall description of the hardware and software changes introduced in the AOB relative to the version used in 2003; chapter 3 describes the MREA'04 sea trial workframe, ground truth measurements and deployment geometries; chapter 4 shows the acoustic data received on the AOB and the results obtained; finally, conclusions and future developments are drawn in chapter 5. Ocean circulation modeling and data assimilation are to be dealt with in a separate report. An additional DVD contains the various data sets and useful data handling routines.

Chapter 2

The Acoustic Oceanographic Buoy

2.1 AOB hardware

The AOB is a light acoustic receiving device that incorporates last generation technology for acquiring, storing and processing acoustic and non-acoustic signals received in various channels along a vertical line array. The physical characteristics of the AOB, in terms of size, weight and autonomy, will tend to those of a standard sonobuoy, with however the capability of local data storage, processing and online data transmission. Data transmission is ensured by seamless integration into a wireless lan network, which allows for network tomography within ranges up to 10/20 kms. In this second AOB prototype several capabilities were improved relative to the first system tested in 2003 (see figure 2.1). The hydrophone array has been completely rebuilt using a light system composed of

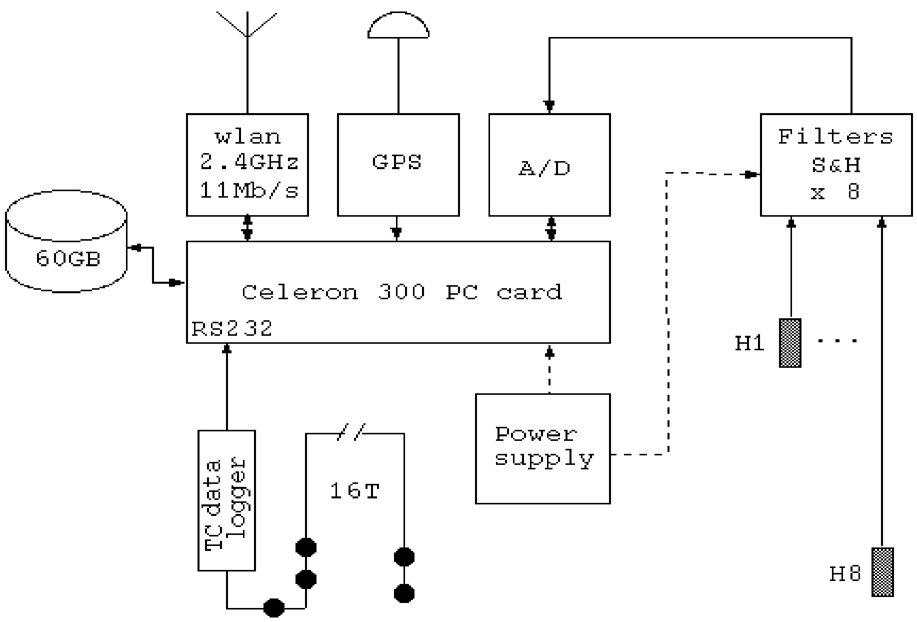

Figure 2.1: *Acoustic Oceanographic Buoy - version 1: block scheme.*

dedicated balanced twisted pairs for each hydrophone and a common power line attached to a 5 mm kevlar rope enveloped in a air fairing sleeve to maintain all wires together. The number of hydrophones has been doubled relative to the previous version and are now 8.

Hydrophone depths are as follows: 10, 15, 55, 60, 65, 70, 75 and 80 m. The hydrophones were manufactured by Sensor Technology (Canada) and their frequency response and overall characteristics are shown in appendix A.

The other subsystem that was added in the actual version of the AOB is the thermistor chain (TC) for online water column temperature monitoring. This subsystem was purchased from RBR Ltd. (Canada) and is mainly composed of a data logger that monitors the 16-sensor-80 m long equispaced TC array. The main characteristics of the TC are shown in appendix B. The TC data logger is interrogated by the AOB's CPU at regular intervals so that synoptic water column temperature measurements are provided to the remote user together with concurrent acoustic data. All the other features of the AOB, such as the Wlan capabilities, on the water ON/OFF circuitry and on board easy battery charge and data transfer were maintained (see report [1] for details).

2.2 AOB software

(a) (b)

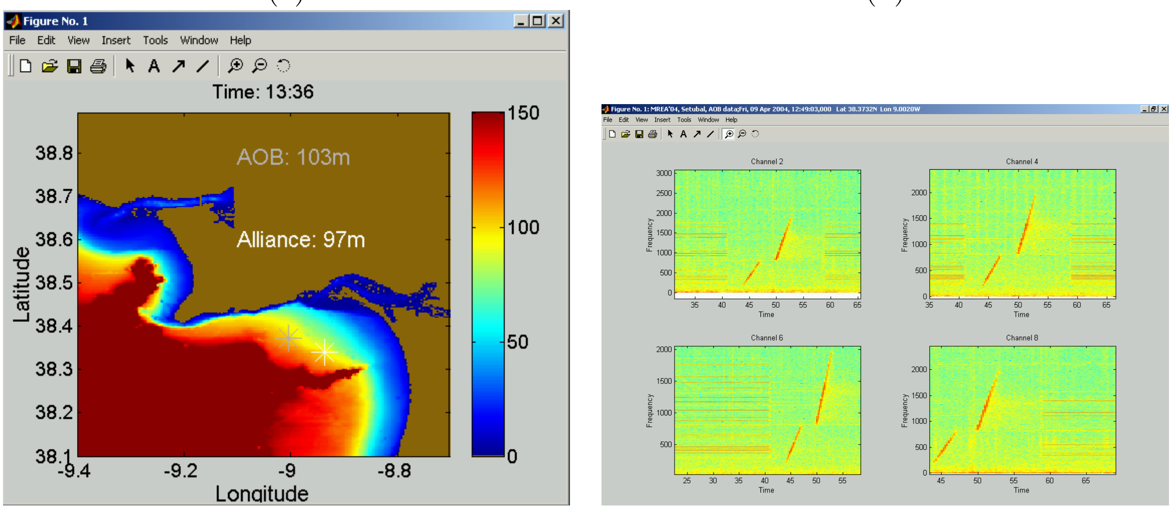

Figure 2.2: *AOB control and monitoring software screeshots: area map with AOB localization (a) and acoustic data monitoring (b).*

An important difference between the MREA'03 and MREA'04 sea trials was on the software being used to control and monitor the AOB and the data being collected. The control and monitor software has now the following characteristics:

1. locates the buoy on a absolute reference bathymetric map of the area under consideration together with the support ship and provides support for more than one buoy (up to eight simultaneous buoys) forming the tomography network.

2. provides direct access to the status of each buoy on the map by simply positioning the mouse over it; this action automatically directs the directional antenna to the bearing of the requested buoy allowing for grabbing its status like battery charge, data acquisition running, update GPS position, grab acoustic and non-acoustic data.

3. display current acoustic and non-acoustic data; acoustic data can be shown by acoustic channel versus time or as time-frequency plots.

Examples of the various displays provided by this application are shown in figures 2.2(a) and (b). The data inversion procedure used during the MREA'03 sea trial, was based on code previously developed for Blind Ocean Acoustic Tomography (BOAT) [5, 6] with, however, completely different settings for the parameter search bounds and genetic algorithms (GA) conversion parameters, taking into account that source position and local bathymetry was approximately known. It should be remarked that BOAT aims at the inversion of ocean properties and therefore at the identification of the acoustic channel linking the source and receiver, full filing therefore also the aims of project NUACE. As a complement of information and in order to explore a larger frequency band than that normally used in AREA, phase shift keying (PSK) data sequences were also trasmitted and received during the MREA'04 sea trial. This data set are also described here but the detailed processing results are left for a separate report. Unlike in the MREA'03, during the MREA'04 sea trial specific data codes were transmitted and received on the AOB for water column and bottom geo-acoustic inversion, which details and final results are also left for a separate publication.

Chapter 3

The MREA'04 sea trial

3.1 Generalities and sea trial area

The selected area for the MREA'04 is shown in figure 3.1 (a) where the blue box indicates the global model area and the green box denotes the target small scale area. The area covered during the acoustic operation of the AOB (shown in figure 3.1(b)), was situated in the continental shelf to the north of the Setúbal Canyon on water depths varying from 70 to 140 m. During the acoustic trial, the weather was calm with sea state between 1 and 2. Low wind of less than 10-15 knot, generally from the North quadrant, and wave height less than 2 m.

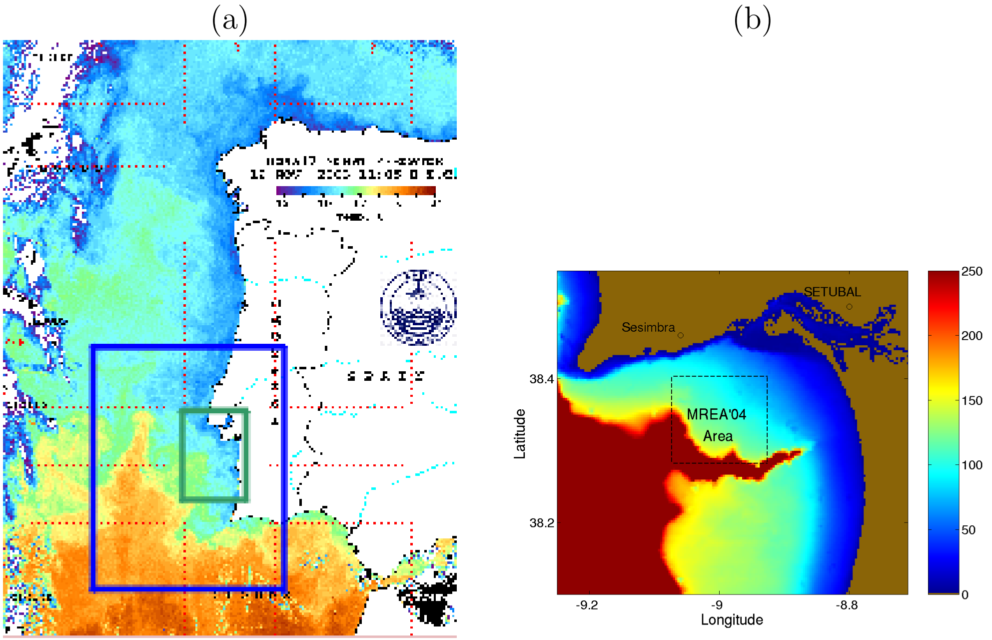

Figure 3.1: *Maritime Rapid Environmental Assessment 2004 work area: global model area (blue) and target area (green) (a) and detailed map of the acoustic activity area (b).*

3.2 Ground truth measurements

Extensive ground truth measurements were performed before, during and after the target week, including CTD, XBT, vessel mounted ADCP, one SEPTR buoy, two bottom mounted ADCPs, two thermistor chains, one meteo buoy and one wave rider buoy. In general most of this information, except for the bottom mounted ADCPs and thermistor chains, was recorded on board or on land stations and transmitted to onboard ship, assimilated and made available through the web. For its relevance to the acoustic data processing, the location of the CTDs collected during the duration of the acoustic trial are shown in figure 3.2. The actual measured CTDs and sound velocity are respectively

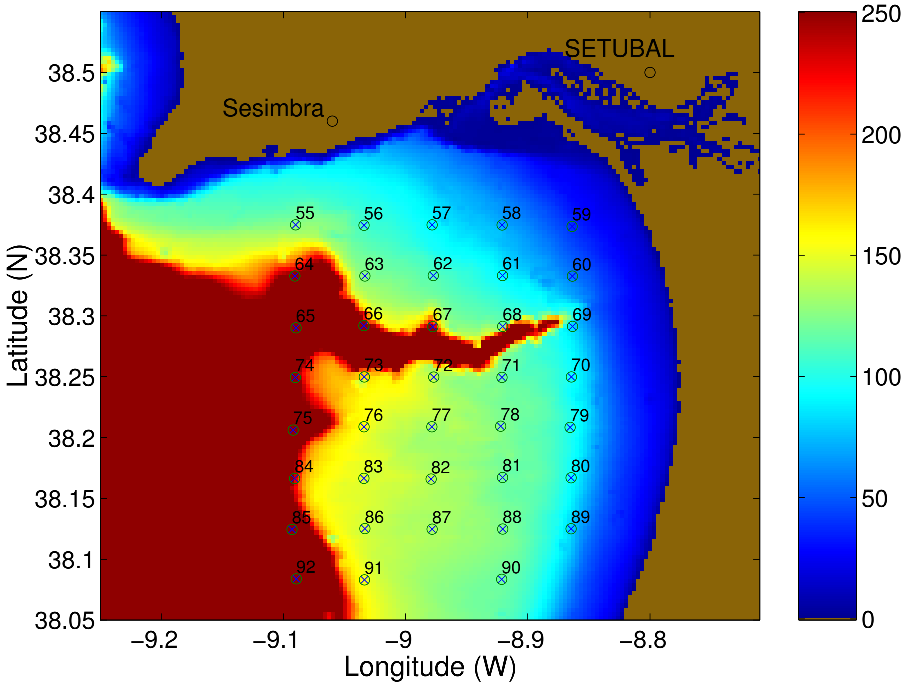

Figure 3.2: *Recorded CTD locations during days 7 to 10 April.*

shown in figure 3.3 (a) and (b), while plot (c) shows the first two Empirical Orthogonal Functions (EOFs) that characterize water column spatial and temporal variability during the MREA04 sea trial according to

$$\hat{T}(z) = \bar{T} + \sum_{i=1}^{N} \alpha_i U_i(z), \qquad 0 \leq z \leq H \tag{3.1}$$

where α_i are the EOF coefficients, $U_i(z)$ the EOF's and H is the water depth, chosen equal to a minimum of 100 m in this example. The first two EOF's shown in figure 3.3 (c) are meant to represent more than 80% of the total energy in the water column.

3.3 Deployment geometries

The initial plan was to collect data from a full network of AOBs in order to be able to test the capacity of the system to provide coverage for an extensive working area as well as its communication capabilities. Since other AOBs were not available at this moment

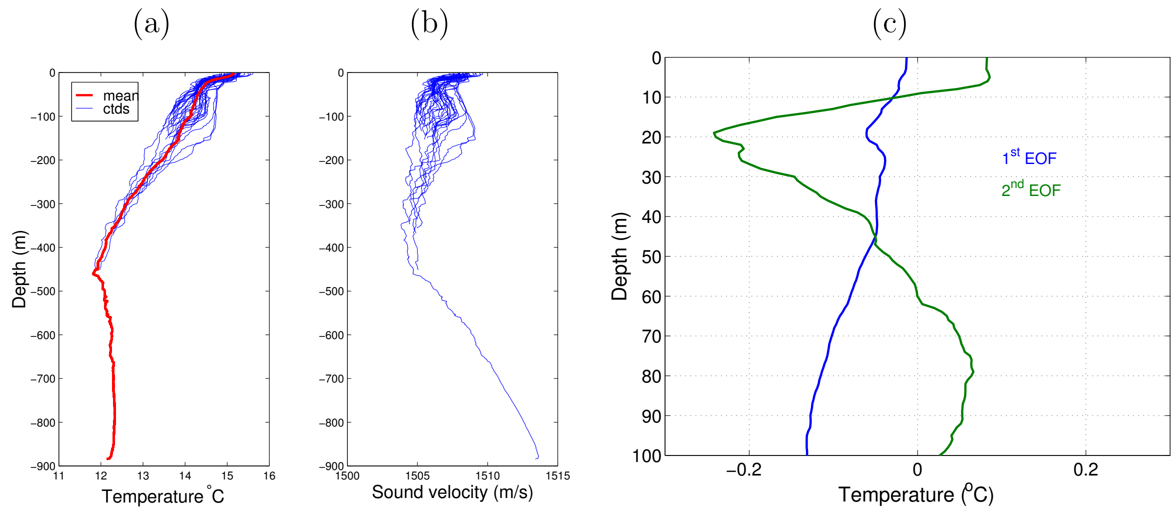

Figure 3.3: *recorded CTD profiles during days 7 to 10 April: temperature (a), sound velocity (b) and first two EOF's (c).*

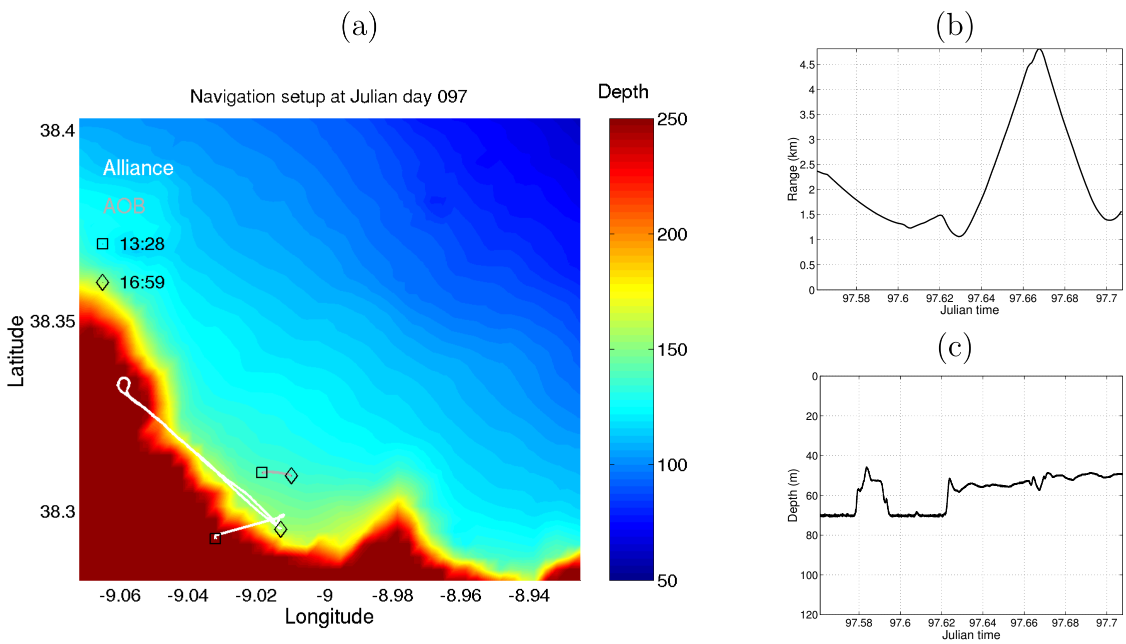

Figure 3.4: *GPS estimated AOB and source ship navigation during the deployment on April 7 at 12:09 UTC by 38.3096N-009.0205W with bathymetry map (a), estimated source range (b) and source depth (c).*

it was decided to use an alternative system formed by a 16-hydrophone vertical line array connected to a surface buoy fitted with a remote data acquisition system on a free drifting configuration. This array belongs to CINTAL and is known as the ULVA/RDAS system (details can be found on [7]). The ULVA/RDAS was deployed various times from the Alliance but unfortunately it refused to work properly, due to various technical problems. Instead, the AOB, was deployed four times on consecutive days from April 7 to 10, 2004, which GPS recordings allowed to draw both the AOB drifting and the Alliance navigation as shown in figures 3.4 to 3.7.

The objective of the acquired data was twofold: 1) to allow channel inversion and characterization using a single buoy with a few hydrophones in an unknown and range-

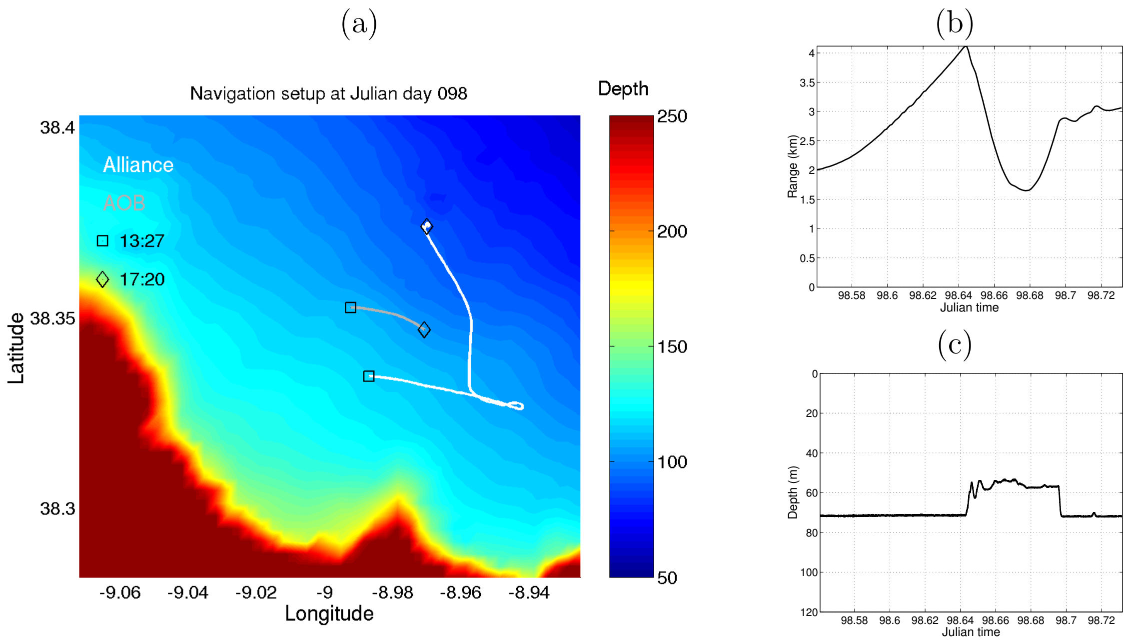

Figure 3.5: *GPS estimated AOB and source ship navigation during the deployment on April 8 at 12:26 UTC by 38.3532N-008.9989W with bathymetry map (a), estimated source range (b) and source depth (c).*

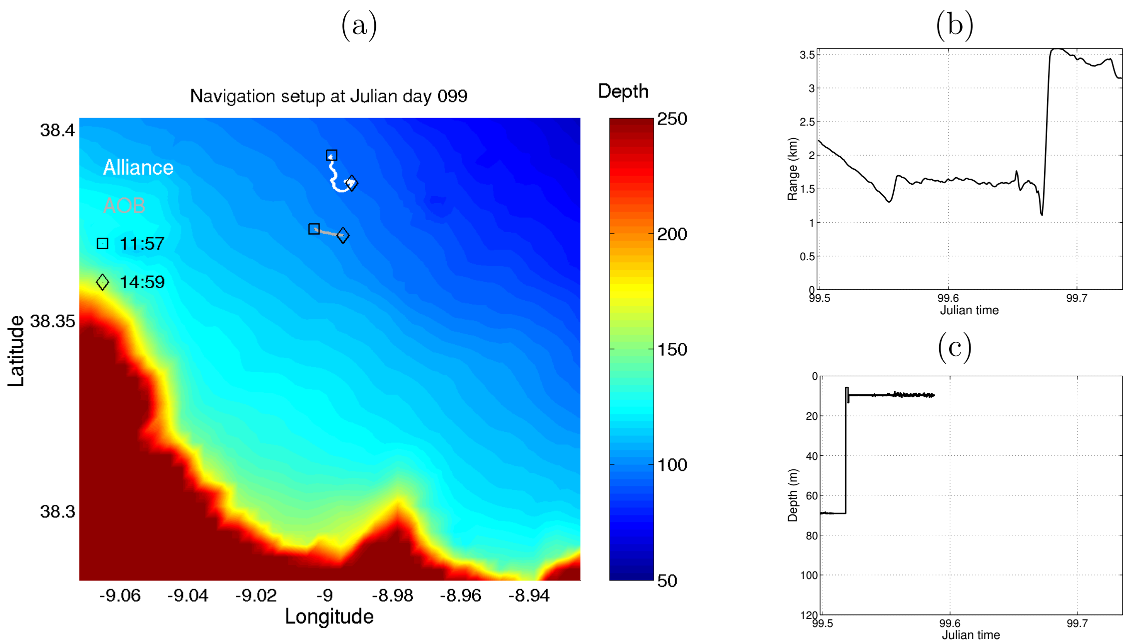

Figure 3.6: *GPS estimated AOB and source ship navigation during the deployment on April 9 at 11:35 GMT by 38.3743N-009.0047W with bathymetry map (a), estimated source range (b) and source depth (c).*

dependent environment and 2) to perform tomographic inversions for both water column and bottom environmental parameters and serve as input to the MREA experiment. Source depth was permanently recorded on board the R/V ALLIANCE, between 60 and 70 m and is shown together with the estimated source range and bathymetric maps. On April 7, the deployment of the AOB ocurred at 12:09 UTC in an area north to the Setúbal

Canyon close to the border of the continental platform with an approximate water depth of 120-130 m. During the deployment the AOB slowly drifted approximately 1 km to the East (see figure 3.4). Source - receiver range varied from 1 up to 5 km on a variable

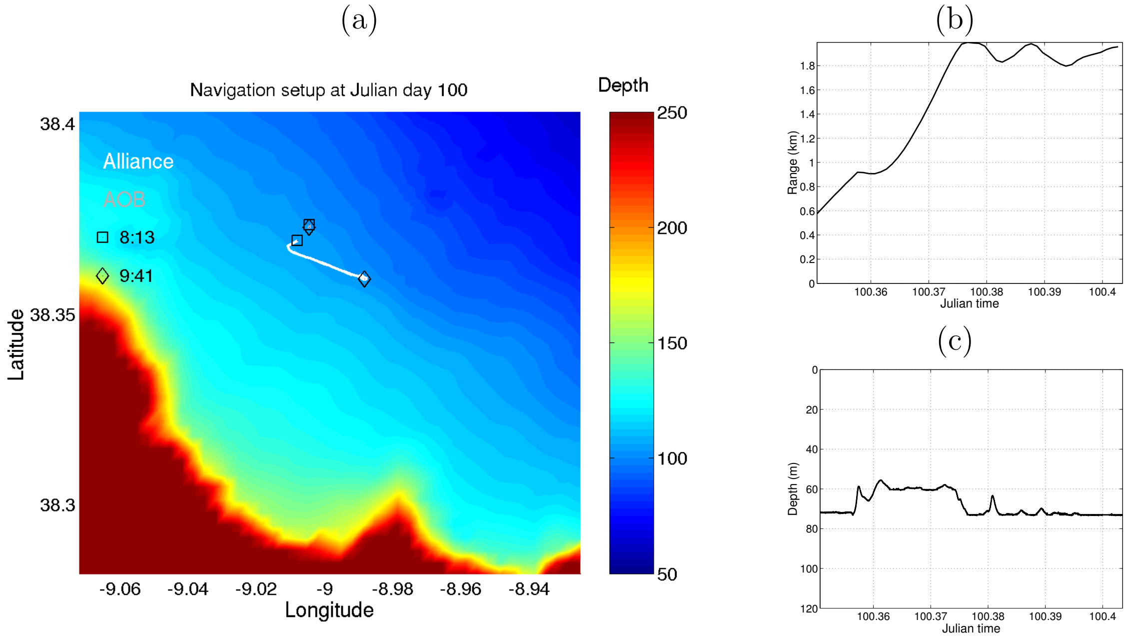

Figure 3.7: *GPS estimated AOB and source ship navigation during the deployment on April 10 (run 1) at 07:55 UTC by 38.3737N-009.0053W with bathymetry map (a), estimated source range (b) and source depth (c).*

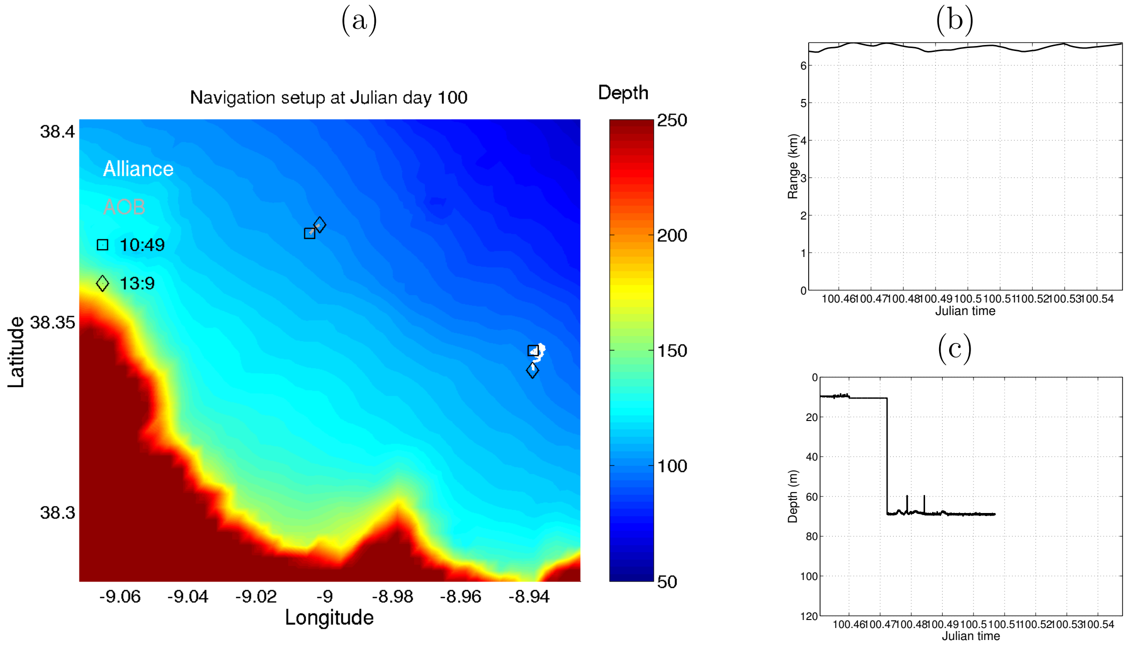

Figure 3.8: *GPS estimated AOB and source ship navigation during the deployment on April 10 (run 2) started at 10:49 UTC with bathymetry map (a), estimated source range (b) and source depth (c).*

water depth area close or over the continental platform border. The second deployment took place on April 8 at 12:26 UTC in a flat area with depths varying between 100 and 110 m. During the 3.5 hours acoustic run the AOB drifted approximately 3 kms to the East, while the NRV ALLIANCE accomplished a complex pattern to the South, East and North relative to the free drifting track of the AOB as shown in figure 3.5. On day April 9, 2004, the AOB was deployed at 11:35 UTC to the South of the source ship at an approximate range of 2.5 km. Along the recording interval the ship was closing range to the AOB down to slightly less than 1 km and then rapidly moved North to approximately 3.5 km from the AOB (figure 3.6). The last day for acoustic data was April 10, 2004, where the AOB was deployed at 7:55 UTC. The acoustic run 1 started at a close range of 0.6 km to the South of the AOB and the source progressively opened range to the South - East along an approximately range independant path up to 2 km (figure 3.7). The broadband source was recovered and the NRV Alliance moved to approximately 6 km range from the AOB along a nearly bathymetric range independant path of 110 m water depth were she made a station (figure 3.8). During this second run of day April 10, the MOD30/40 was lowered at depths of 10 and 70 m, transmitting acoustic signals for bottom inversion.

Chapter 4

Acoustic data

4.1 Emitted signals

4.1.1 Acoustic sources

Acoustic signals were emitted from R/V Alliance mainly using two types of transducers: a broadband sound source covering the band 180 to 5000 Hz for water column inversion and a low frequency MOD30/40 transducer for bottom inversion. The broadband sound source was used on April 7, 8 and run 2 of April 10, while the MOD30/40 transducer was used on April 9 and run 1 of April 10. The broadband sound source was actually composed of two transducers, for the low and high frequency bands, mounted on a single two body. The low frequency transducer was a HX90G (SN51) covering the band 180-600 Hz, while the high-frequency tansducer was an ITC2010 (SN508) roughly covering the band 700-5000 Hz. The transducers were driven by a Instruments Inc. power amplifier. Source level curves of the broadband sound source are shown in figure 4.1(a) while the MOD30/40 frequency response is shown in 4.1(b).

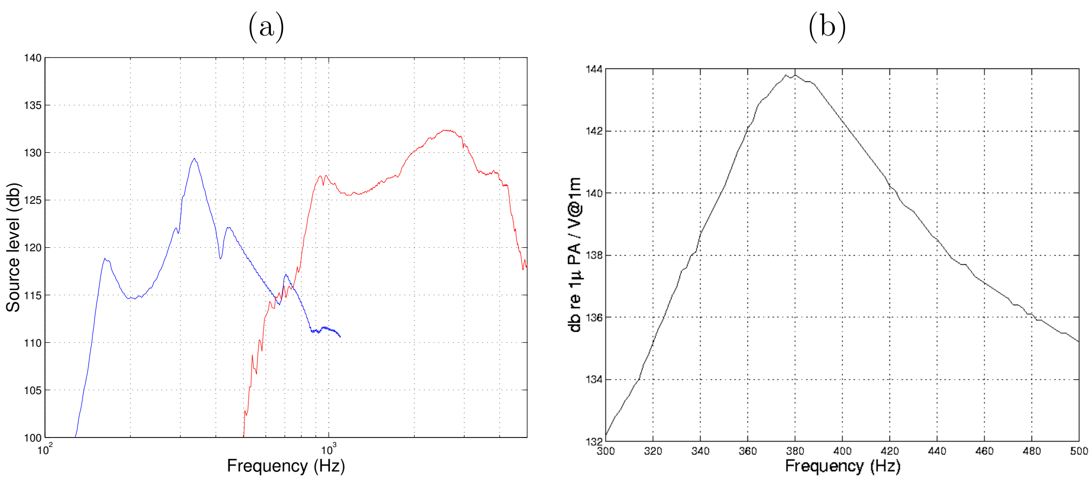

Figure 4.1: *transmitting source frequency response: broadband source (a) and MOD30/40 - SN2 (Seneca Lake, Dec 1990) (b).*

4.1.2 Emitted signals for Acoustic REA

The emitted signals for AREA were a mixture of multitone and linear frequency modulated (LFM) sequences in two frequency bands as shown in figure 4.2. The total sequence duration was 240 seconds, after which it was repeated. The sequence had four signal intervals with a duration of 46 seconds each and 4 intervals of 14 seconds of silence (blue zones in the figure). The signal characteristics are described in table 4.1. The tones

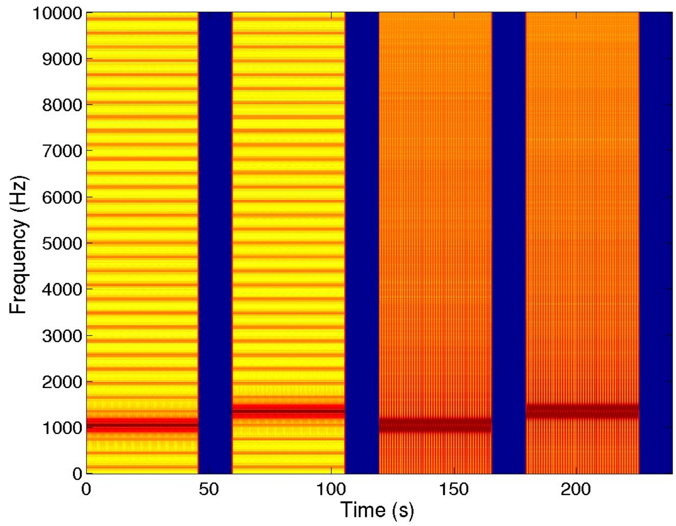

Figure 4.2: *Emitted sequence of tones and LFM's during days April 7 and 8, 2004:*

Code	Type	Duration (s)	Band (kHz)	LFM duration (s)	Fmin - Fmax (kHz)	Freq spacing (Hz)
T2	tones	46	0.9-1.2	-	-	14.3
T1	tones	46	1.2-1.5	-	-	14.3
L2	LFM	46	0.9-1.2	1	0.9-1.2	-
L1	LFM	46	1.2-1.5	1	1.2-1.5	-

Table 4.1: *characteristic parameters of the AREA signals transmitted during days April 7 and 8, 2004. The complete 240 seconds long sequence is shown in figure 4.2.*

packets are formed by 22 equispaced sinusoids on each band, such that frequency spacing between tones is approximately 14.3 Hz. The LFM packets are formed by 46 LFM's of 1 second duration each.

4.1.3 Emitted signals for bottom inversion

During April 9 and run 1 of day 10, a series of acoustic sequences judged more adequate for bottom inversion were transmitted using the MOD30/40 sound source. The emitted sequence (shown in figure 4.3) is composed of a series of 20 tones logaritmically distributed between 200 and 1800 Hz for a duration of 42 seconds. This series of tones is followed by a 6 seconds duration period of silence and then two 2 seconds-long LFM upsweeps, one between 200 and 750 Hz and another between 780 and 1800 Hz. The second LFM sweep is followed by a silence period that ends the sequence, with a total duration of 60 seconds. The sequence is repeated throughout the run.

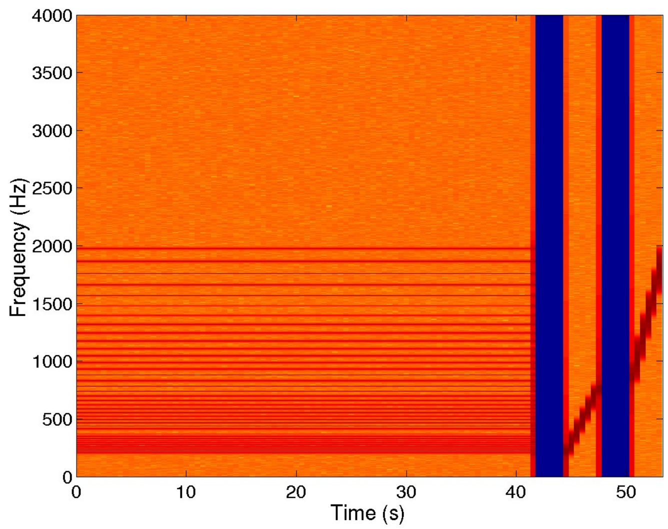

Figure 4.3: *emitted sequence of tones and LFM's during days April 9 and run 1 of April 10, 2004: tones and LFMs.*

4.1.4 Emitted signals for underwater communications

The signals being transmitted with the acoustic sound source during the second deployment of April 10, were computer generated time series of Phase Shift Keying (PSK) modulated binary sequences at various rates and frequency bands. A list of the transmitted codes characteristics is given in table 4.2. Each code is formed by a short time (1 second) duration and double amplitude probe signal followed by a data packet. The used probe signal is the PSK modulation pulse shape shown in figure 4.4(a) to (d). The data packet is formed by each of the codes listed in table 4.2. A full sequence has a total

Code	**Probe signal**			**Data code**			
	Type[1]	Band[2] (Hz)	Duration (second)	Type[3]	Band (kHz)	Bit rate (bps)	Duration (second)
A	rrrc	400	1	PSK2	400	200	20
B	rrrc	800	1	PSK2	800	400	20
C	rrrc	400	1	PSK4	400	400	20
D	rrrc	800	1	PSK4	800	800	20

Table 4.2: *characteristic parameters of the underwater communication code signals transmitted during April 10, 2004 [[1]rrrc=root-root raised cosine pulse shape, [2]with 100% roll-off, [3]PSK = Phase Shift Keying].*

duration of 84 s and is formed as shown in figure 4.5 with four repetitions of each code. Codes A, B, C and D are those shown in table 4.2. The 84 s long data sequences for each code are compiled in a single stream of 336 second and then continuously repeated with a 24 s silence between each repetition (see figure 4.5(c)).

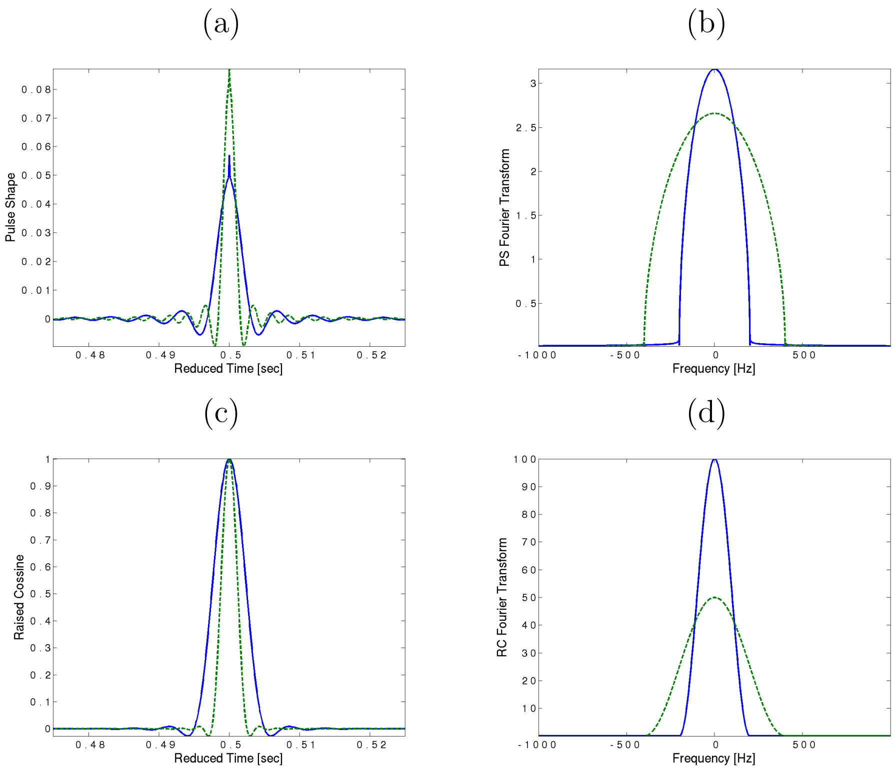

Figure 4.4: *pulse shape used as probe signal: root-root raised cosine (a) and its spectrum (b), raised cosine (c) and its spectrum (d); continuous line is for 200 symbols per second while dashed line is for 400 symbols per second.*

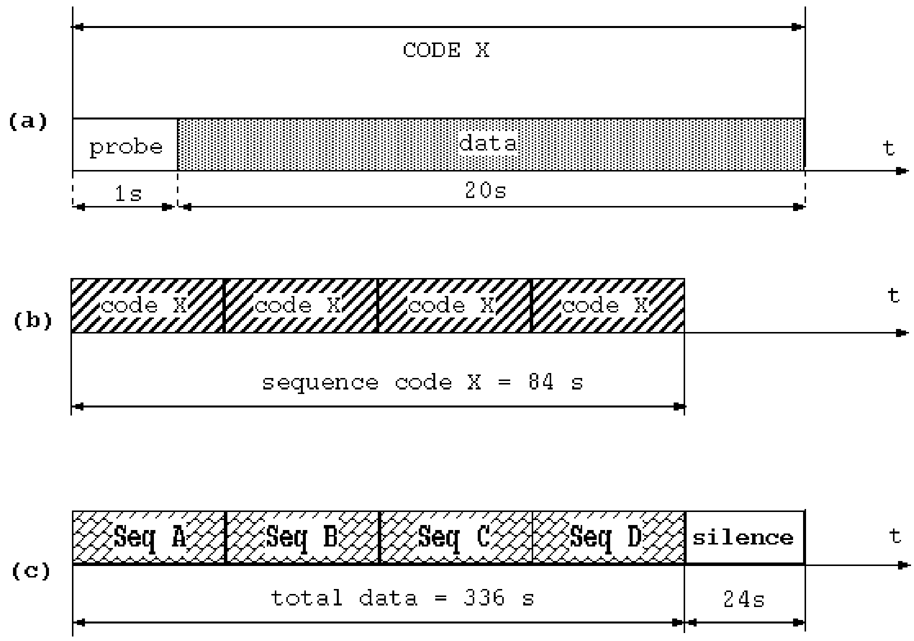

Figure 4.5: *transmitted data: probe signal for code X (a), 84 s code X sequence (b) and four codes A, B, C and D total data packet (c).*

The binary data is a stream of 0s and 1s with duration of 20 seconds at symbol rates of 200 or 400 symb/s. The data stream is formed as a random sequence of symbols that is different for each code. PSK modulations used are binary (PSK2) and quadrature

(PSK4), therefore the base bit/rate is doubled for PSK4. Carrier frequency is 3.6 kHz and bandwidths are variable depending on symbol rate. The transducer frequency response around 3.6 kHz shows a relatively wide bandwidth reaching 1.5 kHz with an attenuation smaller than 3 dB. Spectograms of the transmitted signal sequences are shown in figure 4.6.

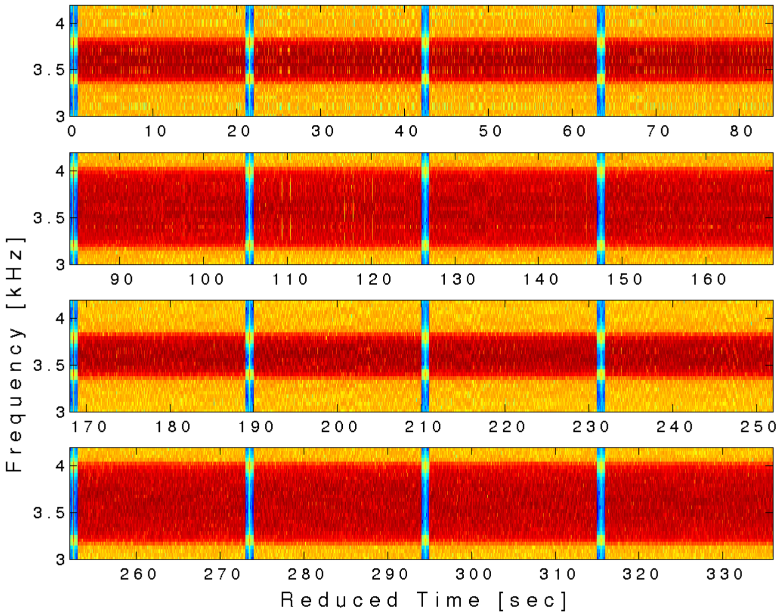

Figure 4.6: *spectograms of the transmitted signals: four distinct codes A, B, C, D (from top to bottom), repeated four times each, with 1 second probe-signal and 20 seconds of data, giving a total duration of 84 seconds. The 336 second long stream of data is then continuously repeated with a silence of 24 seconds between each repetition. The signals are transmitted with a carrier frequency of 3600 Hz.*

4.2 Received signals

4.2.1 Received signals for acoustic REA and bottom inversion

The received signals for AREA and bottom inversion were a mixture of multitone and linear frequency modulated (LFM) sequences in two frequency bands as shown in figure 4.7 (a) for water column inversion and in 4.7 (b) for geo-acoustic inversion. An example of a spectogram of the signals received on hydrophones 2, 4, 6 and 8 during day April 9, is shown in figure 4.8.

4.2.2 Received signals for underwater communications

An example of a spectogram of the signal received on hydrophone 6 during day April 10, at 09:28:05 GMT is shown in figure 4.9. Since emitter and receiver were not synchronized the codes in this figure are in the order D(end) - silence - A - B - C - D.

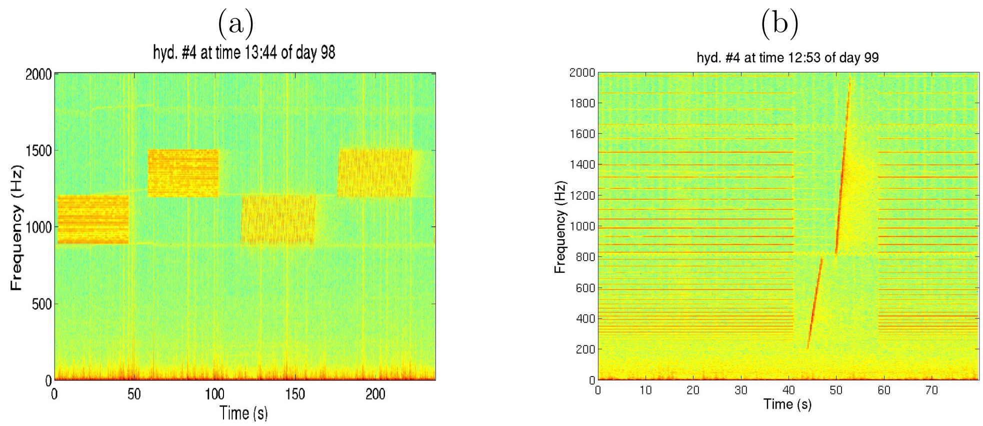

Figure 4.7: *Received signals on hydrophone 4 at 60 m depth, multitones and LFM's: in frequency bands between 900 and 1500 Hz on day April 8, 2004 at 13:44 UTC (a) and in frequency band 200 - 1800 Hz on day April 9, 2004 at 12:53 UTC (b).*

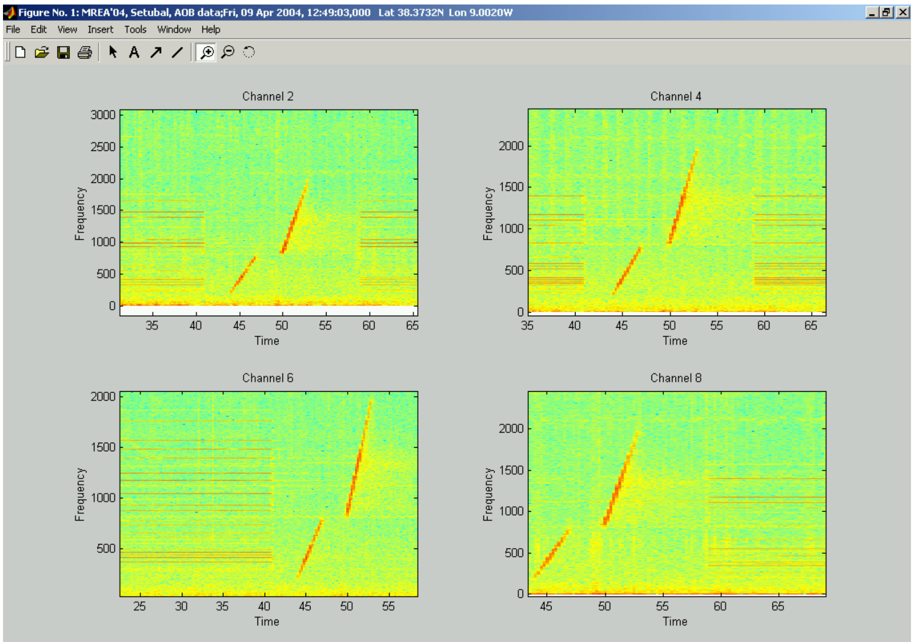

Figure 4.8: *AOB received signals during day April 9, 2004 as seen on the monitoring screen aboard R/V Alliance.*

4.3 Channel variability

A common preliminary processing consists in matched filtering the incoming data with the emitted signal so as to obtain an estimate of the channel acoustic response. This processing is also known as time-compression. In fact the channel response estimate is as good as the frequency band of the emitted signal is large and the arrival times are resolvable. The obtained matched-filter output is known as the arrival pattern estimate. Of course the channel response (or arrival pattern) varies in time due to the medium variability and in space due to the experimental geometry. During the MREA04 both the emitting source and the receiving array were moving along time - so time and space variability effects are mixed in the estimated response. Figures 4.10 and 4.11 show the correlations of the transmitted signals with the incoming data LFM pings on band 1.2-1.5

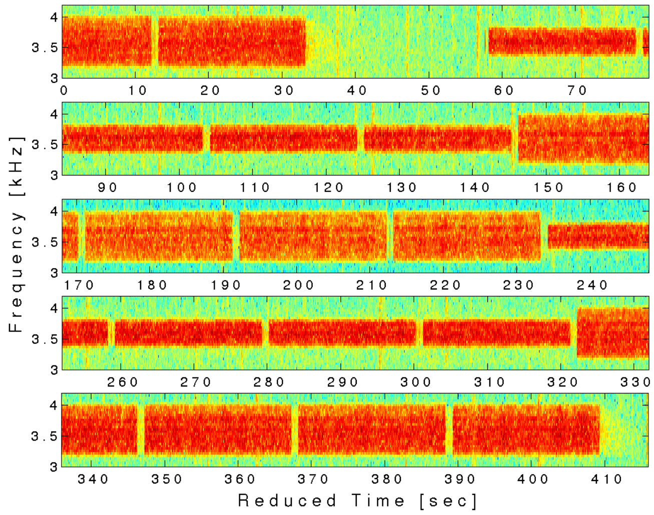

Figure 4.9: *AOB received underwater communication signals during day April 10, 2004 on hydrophone 6 at 9:28:05 : in the upper subplot the 24 second silence that mark the beginning of a new transmitted signal and then four times code A, four times code B, four times code C and four times code D with one second of separation between them where the appropriate probe signal is transmitted.*

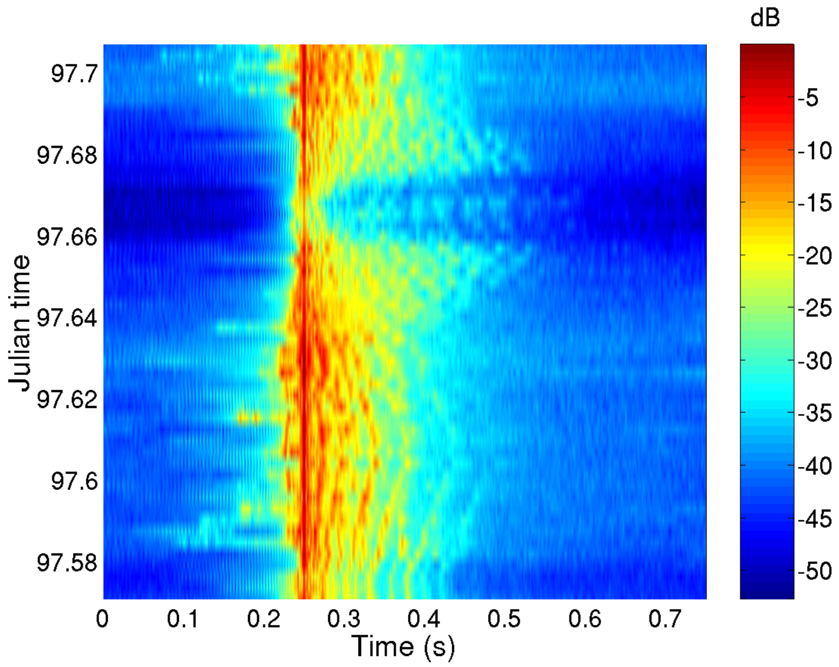

Figure 4.10: *time compression of the LFM signals in the 1.2 - 1.5 kHz band received on hydrophone 4 at nominal depth of 60 m during day April 7, 2004.*

kHz, received on hydrophone 4 (60 m nominal depth) during the run of days April 7 and 8, respectively. The multipath structure can be clearly correlated with the source - receiver variable range with increasing and decreasing number of visible arrivals from 2 up to 7 arrival packets, generally accompained by a pre-peak faster than water arrivals at close ranges.

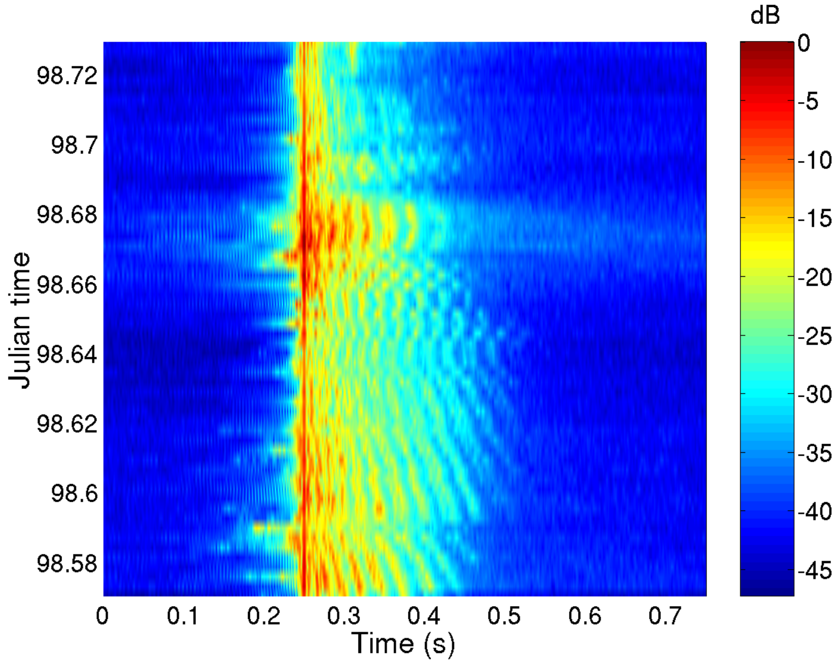

Figure 4.11: *time compression of the LFM signals in the 1.2 - 1.5 kHz band received on hydrophone 4 at nominal depth of 60 m during day April 8, 2004.*

4.4 Underwater communications

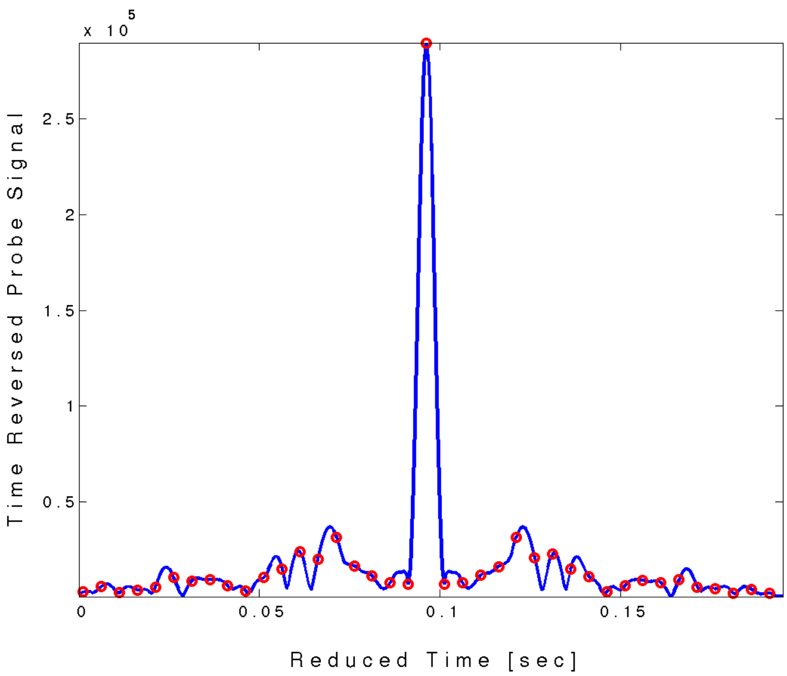

Figure 4.12: *self virtual time reversing of the received base band probe signal. Red dots represent the symbol rate.*

During April 10, 2004 a series of communication codes were transmitted to probe the underwater acoustic channel capabilities for data communication. The scope of the processing is to use the virtual time reversal concept as presented in [8, 9]. Very simply speaking, the idea is to use the received probe signal as an image of the signal pulse shape convolved with the channel impulse response to match-filter the received data sequence that follows the probe signal. In doing this, there is the hope that the acoustic channel is sufficiently stable to hold during the data sequence duration, which is 20 seconds in our case. The ideal (no channel or geometric variability) virtual time reversal response of the whole array mainly depends on the number of hydrophones and their localization on the water column. Figure 4.12 shows an estimate of the ideal virtual time reversal response for the array configuration used during the MREA'04 data set of day April 10. The red dots represent the symbol rate, so one can see that the virtual time reversal impulse response main lobe is narrower than a symbol interval resulting therefore on a ISI less output data stream. In order to obtain an idea of the channel time variability that

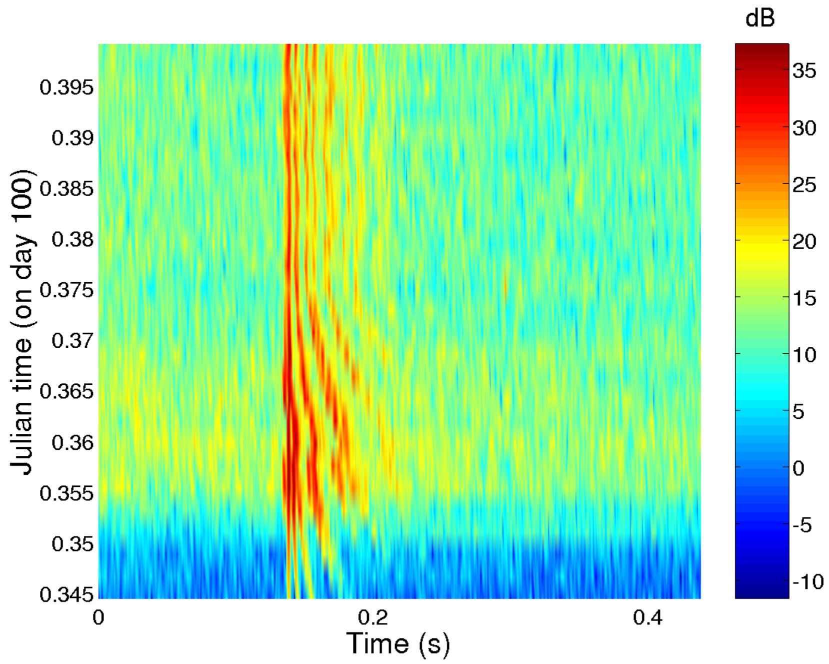

Figure 4.13: *pulse compression of the 1 s duration-800 Hz bandwidth probe signals along the PSK transmissions of run 2 on day April 10, 2004, received on hydrophone 4 at nominal depth of 60 m.*

the virtual time reversal (or equivalently any channel equalizer) has to cope with, the 1 s duration probe signal before each data packet was pulse compressed with the transmitted replica. The results obtained along the data set of run 2 of April 10, 2004, using the 800 Hz probe of hydrophone 4 (60 m depth), are shown in figure 4.13. The multipath structure can be clearly associated with the relative source -re ceiver movement along time by close observation of figure 3.8. However, one thing is to account for time variability and another is to cope with spatial variability, which is the main goal behind virtual retrofocusing for underwater communications. Figure 4.14(a) to (h) shows the module of the baseband channel impulse response estimate for hydrophones 1 (shallowest) to 8 (deepest), respectively. A strong multipath can be noticed, that spans up to 22 symbols and a strong variability between the channels that is evident in the top hydrophones 10 and 15 meters depth and in the bottom hydrophones 55, 60, 65, 70, 75, 80 meters depth. It is remarkable to see how that strong spatial variability is perfectly accounted for to form the ideal response of previous figure 4.12.

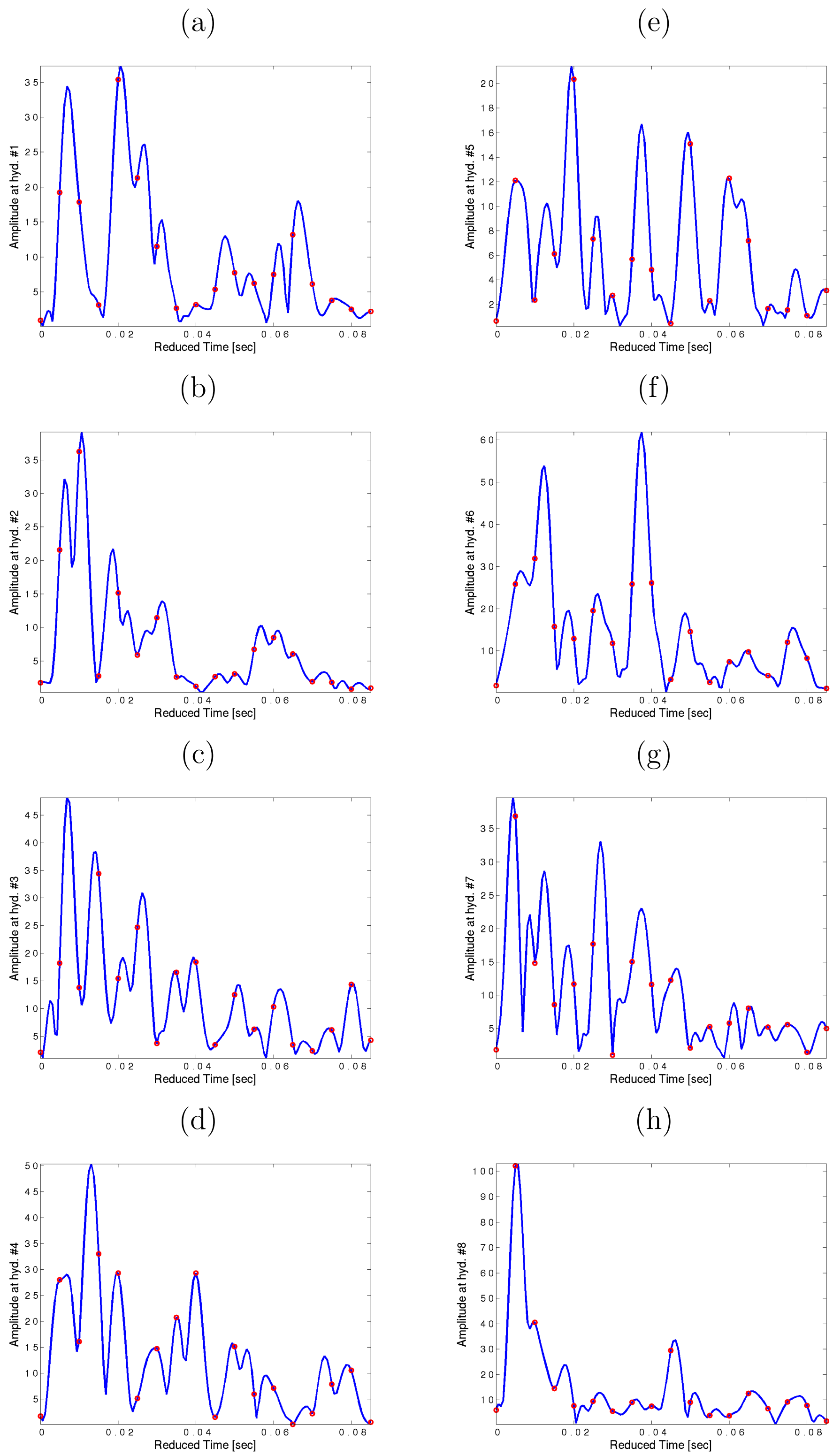

Figure 4.14: *base band channel impulse response estimation by pulse compression for each hydrophone (a) to (h) for hydrophones 1 (shallowest) to 8 (deepest), respectively; red 'o' represent the same response sampled at the symbol rate.*

Chapter 5

Conclusions and future developments

The Maritime Rapid Environmental Assessment 2004 (MREA'04) sea trial is the second in a series of experiments aiming at proving the concept of bringing together the expertise of various fields for a rapid and consistent estimation of a shallow water area. Contributions from ocean circulation modelling, remote sensing, direct CTD, wave height and sea current measurements and acoustics are assimilated into a single web based framework for easy data exchange and manipulation, aiming at a final as accurate as possible 24 and 48 hours forecast of environmental conditions in the area. This report mainly describes the acoustic testing data set gathered during the MREA'04 effort. The acoustic data set can be divided in three subsets: 1) the water column REA subset, 2) the geoacoustic REA subset and 3) the underwater communications subset.

This report describes the experimental setup for whole the acoustic part of the MREA'04 and gives data processing details for subsets 1) and 3), while for subset 2) details are under the responsability of J.-P. Hermand and Mathias Meyer from ULB (to be made available in a separate report). Preliminary results show that the AOB is a reliable system for underwater acoustic data gathering, giving low-noise highly accurate recordings at all times and in a wide frequency band.

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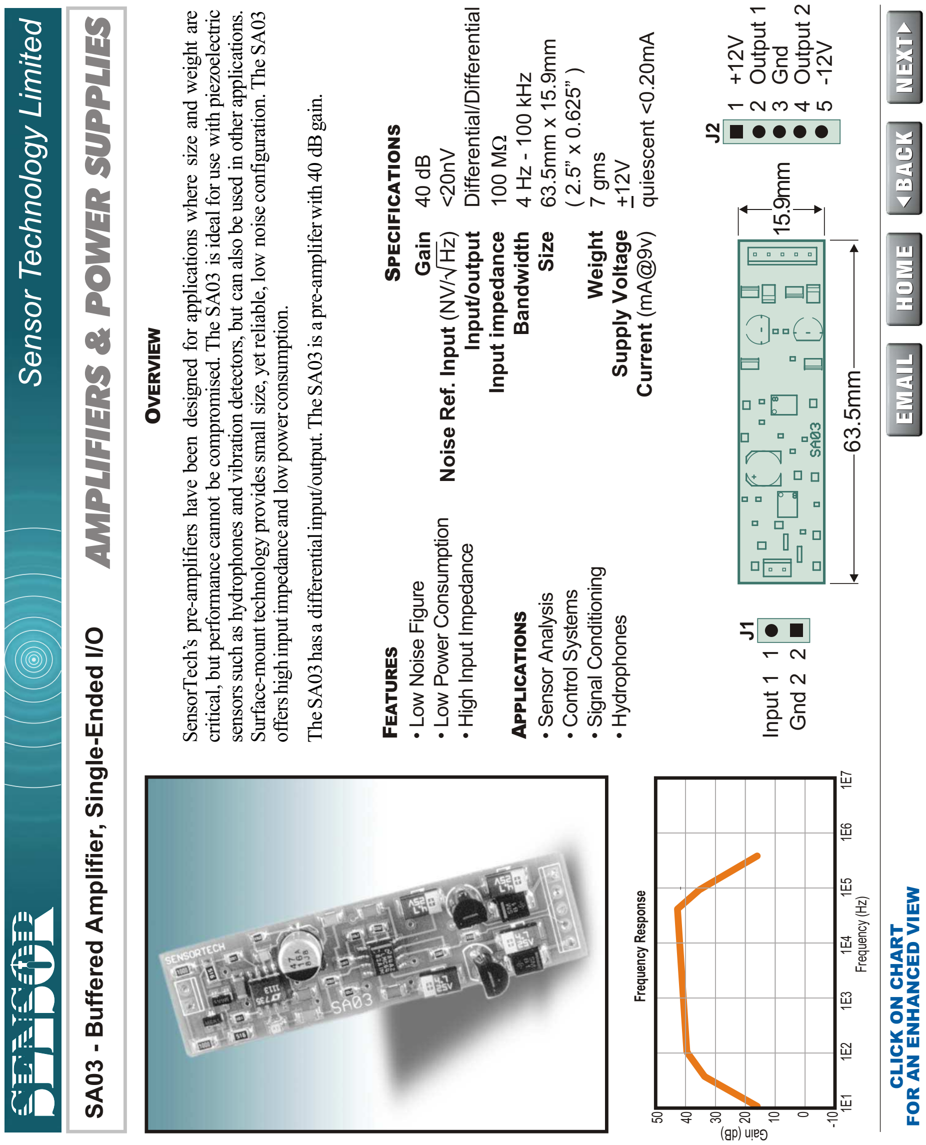
Appendix A

Hydrophone characteristics



SENSOR

Sensor Technology Limited

SA03 - Buffered Amplifier, Single-Ended I/O

AMPLIFIERS & POWER SUPPLIES

OVERVIEW

SensorTech's pre-amplifiers have been designed for applications where size and weight are critical, but performance cannot be compromised. The SA03 is ideal for use with piezoelectric sensors such as hydrophones and vibration detectors, but can also be used in other applications. Surface-mount technology provides small size, yet reliable, low noise configuration. The SA03 offers high input impedance and low power consumption.

The SA03 has a differential input/output. The SA03 is a pre-amplifier with 40 dB gain.

FEATURES

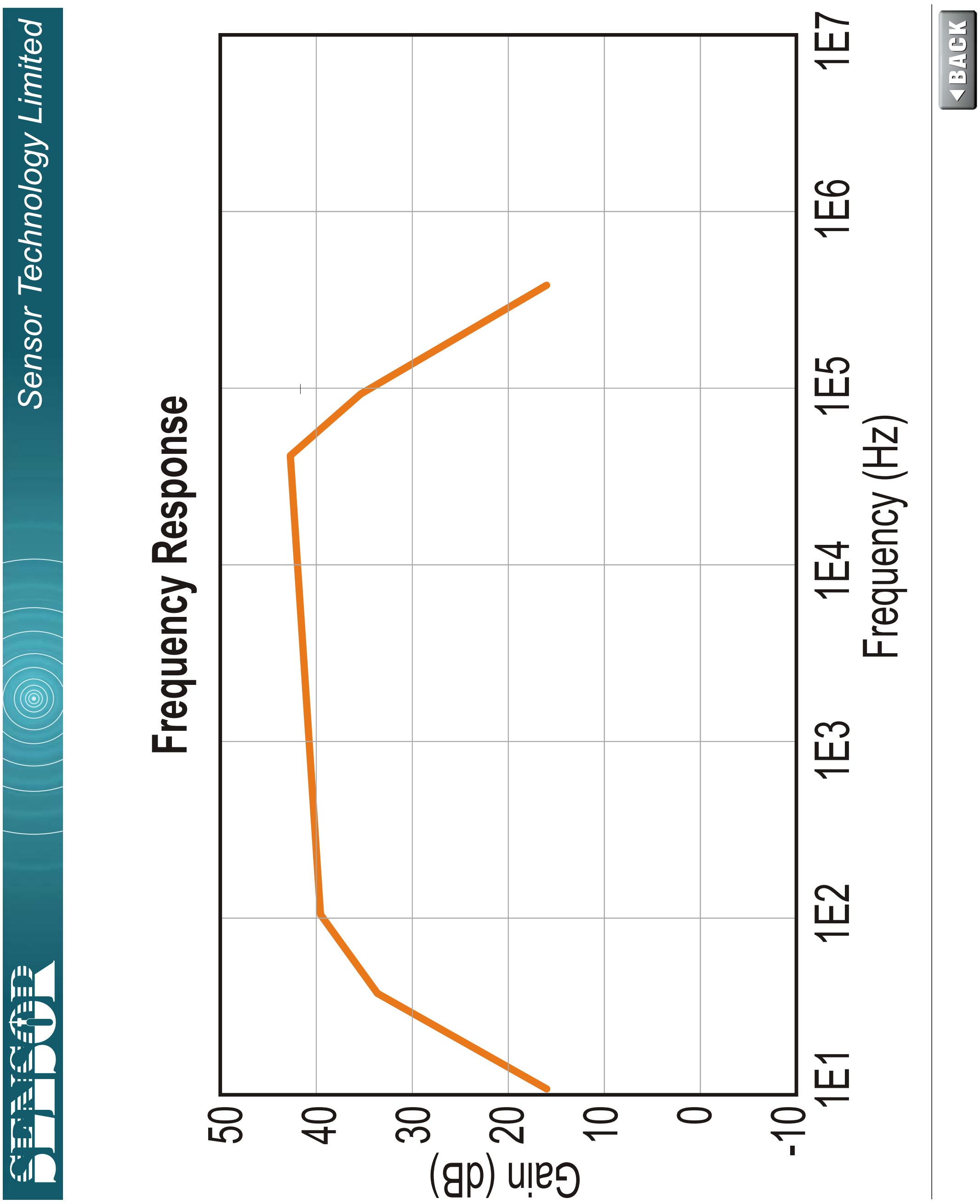
- Low Noise Figure
- Low Power Consumption
- High Input Impedance

APPLICATIONS

- Sensor Analysis
- Control Systems
- Signal Conditioning
- Hydrophones

SPECIFICATIONS

Gain	40 dB
Noise Ref. Input (NV/√Hz)	<20nV
Input/output	Differential/Differential
Input impedance	100 MΩ
Bandwidth	4 Hz - 100 kHz
Size	63.5mm x 15.9mm (2.5" x 0.625")
Weight	7 gms
Supply Voltage	±12V
Current (mA@9v)	quiescent <0.20mA



Sensor Technology Limited
Frequency Response
Gain (dB)
50
40
30
20
10
0
-10
1E1
1E2
1E3
1E4
1E5
1E6
1E7
Frequency (Hz)
BACK

SENSOR Sensor Technology Limited

SQ26 Hydrophone Specifications

HYDROPHONES

Overview

The SQ26 is a general-purpose low-cost hydrophone. It has good sensitivity, wide bandwidth and good stability. Custom configurations of these hydrophones are also available. For additional data on frequency response or outline drawings, please call our customer support. All parameters measured after hydrophones have been subjected to pressures of 70 bar. The polyurethane-encapsulated hydrophone will withstand continuous immersion in isoparaffinic hydrocarbon fluids and sea water.

Specifications

Voltage sensitivity	-193.5 ± 1.0 dBV re 1 Pa @ 20 °C, 20 V/bar
Charge sensitivity	24 nC/bar
Capacitance	1.4 nF ± 10 % @ 20 °C
Sensitivity variation with temperature	less than 1 dB loss from 0 to 35 °C
Capacitance variation with temperature	0.33% increase per °C
Capacitance variation with depth	7% loss per 1,000 m
Operating depth	down to 1,000 m
Frequency response	flat from 1 Hz to 28,000 Hz
Acceleration sensitivity	< 0.2 mbar/g when properly mounted
Storage and operating temperature	-30 to +60 °C
Diameter	25.4 mm (1.0”)
Length	25.4 mm (1.0”) max
Mass	16 grams
Electrical leads	two red and black stranded, 28AWG 15 cm (6”) long, Hytrel-insulated leads
Electrical insulation	> 500 M Ohms
Water blocked leads	Yes

Features

- Low cost
- Rugged
- Good depth capability

Applications

- General-purpose research
- Towed arrays

EMAIL HOME BACK NEXT

Appendix B

Thermistor chain main charateristics

RBR Richard Brancker Research Ltd.

NEW! Life-time Warranty

Model XR-420 T8, T16, or T24 Multi-channel Temperature Loggers

The XR-420 T8, T16 and T24 are a series of multi-channel temperature data recorders designed to operate with arrays of thermistors. The XR-420 can include up to three eight-channel modules. Any combination of thermistors up to 24 can be readily made using the eight channel modules. Each set of eight channels is connected by a nine-way underwater connector. The thermistor array may be deployed under water, in the ground, in concrete, permafrost or in ice.

The thermistor arrays are made to order, and may be any practical length. We have made them to be deployed in sea or lake water, as well as underground, in concrete, in permafrost or in ice. They have been used to measure internal waves and for cryospheric studies. The array may be mounted in-line on a cable, or embedded into a rugged PVC tube for ground temperature measurements. With extra pressure housings they may be used at depths up to 4,000m. The data logger has an extended operational temperature range of -20°C to +35°C.

The standard thermistor used in the strings is the Thermometrics P Series, chosen for stability. Other thermistors have been supplied, and the particular model is selected according to the temperature range anticipated. The thermistor strings are calibrated to ±0.005ºC. The calibration section on the services page of our web site gives further details of the methods we use and the expected performance.

4MB of nonvolatile flash memory is provided. This ensures data retention even when the batteries run out. This provides sufficient memory for 1,200,000 readings, which can be logged on one set of high-powered 3V lithium batteries. The batteries are common camera batteries (CR123A), which are readily available. Power consumption can vary significantly depending on the sampling rate, and operating temperature. A fresh set of batteries will usually permit collection of a full complement of readings over periods exceeding one year.

The accuracy of the real time clock is ±30 seconds/year.

For more detailed information, please visit our web site: www.brancker.com

Specifications

Body Size	230mm (T8), 310mm (T16-24) x 64mm OD	**Temperature:**	
Depth Rating	740m (plastic) 8,500m (titanium)	Standard Range	-5°C to +35°C*
Power	x4 3V CR123A lithium batteries	* Extended temperature ranges available	
Memory	4MB flash	Logger Operating Temperature	-20°C to +35°C
Communications	RS-232	Accuracy	Typically ±0.005°C – depends on sensor array
Download Speed	19.2 - 57.6 Kbaud (auto-selected)	Resolution	<0.00005°C for 40°C range
Clock Accuracy	±30 seconds/year	Time Constant	Depends on probe construction

Richard Brancker Research Ltd. 27 Monk Street, Ottawa, Ontario K1S 3Y7 CANADA
(613) 233-1621 fax (613) 233-4100 info@brancker.com www.brancker.com

16/10/02

Appendix C

MREA'04 DVD-ROM list

The acoustic data gathered with the Acoustic-Oceanographic buoy as well as file logs and auxiliary reading files are contained in seven DVD-ROMs, attached to the back cover of this report. Tables C.1 to C.7 list and describe all DVD-ROM files and directories.

Table C.1: *DVD ROM April, 7 2004 reference MREA04-01-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	Noise	array data - noise only	12:55:51-13:27:26
	T2T1L2L1	array data	13:28:46 - 16:59:26
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 7	18:17 - 23:57
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 7	

Table C.2: *DVD ROM April, 8 2004 reference MREA04-02-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	T2T1L2L1	array data	13:27:59 - 17:20:57
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 8	00:21 - 10:19
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 8	

Table C.3: *DVD ROM April, 8 2004 reference MREA04-03-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	T2T1L2L1	array data	17:22:17 - 17:34:17
	Noise	array data - noise only	13:08:47 - 13:26:39
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 8	00:21 - 10:19
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 8	

Table C.4: *DVD ROM April, 9 2004 reference MREA04-04-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	Compo3	array data	11:57:03 - 14:59:53
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 9	00:34 - 10:32
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 9	

Table C.5: *DVD ROM April, 9 2004 reference MREA04-05-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	Compo3	array data	15:01:13 - 17:39:53
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 9	00:34 - 10:32
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 9	

Table C.6: *DVD ROM April, 10 2004 reference MREA04-06-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	PSK	array data	08:13:25 - 09:41:25
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 9	00:06 - 06:11
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 10	

Table C.7: *DVD ROM April, 10 2004 reference MREA04-07-SiPLAB*

Dir name	**sub-dir**	**Content**	**Time(start-end)**
AcousticData	Noise	array data - noise only	10:34:45 - 12:16:05
	Compo3	array data	10:49:25 - 13:09:29
	Software	m-file to read data	
Auxiliary	EmittedSignal	computer generated emitted signals (mat files - 16bits)	
	Log	log of acoustic emissions	
NonAcousticData	Bathymetry	bathymetry files of the area	
	CTD	ctd files of April 9	00:06 - 06:11
	Navigation	ship and source navigation	
	SourceDepth	source depth readings April 10	