CINTAL - Centro de Investigação Tecnológica do Algarve

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SENSOCEANS'13 sea trial

Data report

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Rep 4/13 - SiPLAB
August/2013

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Projects	SENSOCEAN (PTDC/EEA ELC/104561/2008)
Title	SENSOCEAN'13 sea trial: data report
Authors	P. Felisberto, F. Zabel, O. Rodriguez, P. Santos
Date	August, 2013
Reference	4/13 - SiPLAB
Number of pages	50 (fifty)
Abstract	This internal report describes the SENSOCEAN'13 sea trial
Clearance level	UNCLASSIFIED
Distribution list	SiPLAB, CINTAL
Total number of copies	2 (two)
Acknowledgements	This work was funded by National Funds through FCT-Foundation for Science and Technology under project SENSOCEAN (PTDC/EEA ELC/104561/2008). FCT Fundação para a Ciência e a Tecnologia MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

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Abstract

This report describes the acoustic and other supplementary data gathered during an at sea experiment carried from May 8th to May 15th in front of STARESO (Station the recherches sous-marines et oceanographiques), Bay of la Revellata, Calvi, in the framework of the SENSOCEAN project (PTDC/EEA ELC/104561/2008). The objective of the experiment was to gather a data set for further validation of the models, data processing methods, equipment developed and system integration. To this end several events were considered: fixed and moving configurations, active and passive (acoustic) modes.

Acknowledgments

The authors thank technical and scientific staff at STARESO, for the logistics, at sea operations, meteorological and bathymetric data, Marsensing for the loan of the self-recording hydrophone, Holly Kindsvater from Yale University for the underwater video of the area, and Alberto V. Borges from the Chemical Oceanography Unit, University of Liège, Belgium for the optode array and PAR data. This work was funded by National Funds through FCT- Foundation for Science and Technology under project SENSOCEAN (PTDC/EEA ELC/104561/2008).

Chapter 1

Introduction

The project SENSOCEAN (PTDC/EEA-ELC/104561/2008) aims at developing and testing non intrusive methods using vector sensors for exploration of the ocean environment, in particular the sea bottom. Vector sensors measure the directional particle velocity field, therefore shows an intrinsic spatial filter capability that have been used with advantage in direction of arrival estimation. Under project SENSOCEAN is investigated the usage of the spatial filtering capabilities of vector sensors to "improve" ocean bottom parameter estimation (geoacoustics). The objective is to develop a light system (short array), that should be easy to deploy and operate and could be also installed in small platforms like AUV, ROV or autonomous surface vehicles. Therefore, apart of vector sensors also the frequency band of the probe signals ($\sim$10 kHz) is higher than that used in conventional systems ($< 2kHz$). The research developed so far shown that a short array of vector sensors can be used with advantage to characterize the bottom structure of the (shallow) ocean. In particular it was shown that the vertical particle velocity field is the most relevant. The processing methods developed have been partially evaluated using the MAKAI'05 data set acquired by a 4 element, 30cm aperture vector sensor array. The SENSOCEAN'13 data set described in this report will be used to the final validation of the methods in a challenging coastal environment: the bottom is mainly covered by sea grass, which acoustic characteristics due to the photosyntheses cycle of the plants present diurnal changes; bathymetry is variable in the area of interest.

In particular the SENSOCEAN'13 sea trial will support the following tasks of the project: Task 2.c – validation of the cTRACEO propagation model, Task 3.c – validation of the inversion methods, Task 3.d – test end user services.

This report is organized as follows: in the next chapter the experimental setup is presented and the different events are presented. In chapter 3 the environmental data gathered is discussed, whereas in chapter 4 the acoustic data is shown. Chapter 5 presents some preliminary results. Conclusions are drawn in chapter 6.

Chapter 2

The experimental setup

The at sea operations of SENSOCEAN'13 sea trial took place in front of STARESO (Station the recherches sous-marines et oceanographiques), Bay of Revellata, Calvi, Corsica from 8th to 15th May 2013.

STARESO is a research center of University of Liège (Belgium) located in the Bay of Revellata, Calvi, on the northwest coast of Corsica in the Mediterranean Sea (8°45 E, 42°35 N), Fig. 2.1. Due to the geographic orientation, the Bay of Revellata and the Bay of Calvi are relatively well protected from south-west winds, which are dominant along the year apart of the winter.

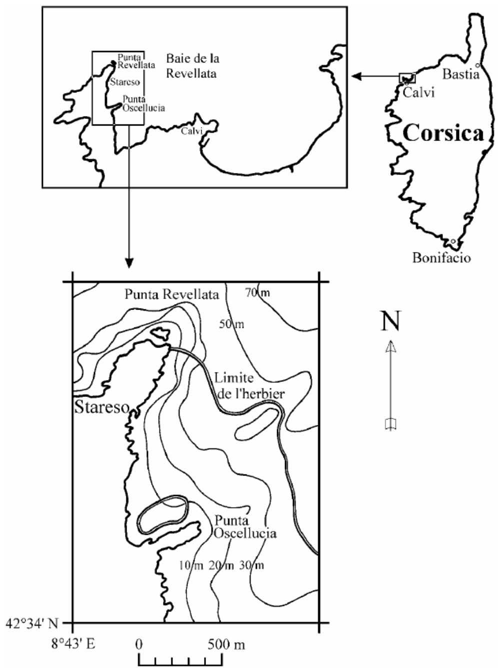


Figure 2.1: Bay of La Revellata map

The station offers to the researchers a direct access to the sea from a small private harbor and a number of facilities like diving, boats, laboratories. The area includes a diversity of sites with different bottom characteristics, including areas densely covered by marine plants, sandy and mud areas at depths ranging from 6 m to 50 m. Since 1970, time series of physical, chemical and biological data have been recorded, thus background information of the area is readily available. The station offers unique conditions to test new equipment and methods, since it allows to in field validation, not possible with computer simulations or even in tank experiments, although in a much more controlled environment then in an open sea experiment.

The acoustic equipment operated during this sea trial was:

- two digitalHyd SR-1, see specifications in appendix A.1, autonomous recorder with a single hydrophone.
- a digitalHyd DA-1, see specifications in appendix A.2, cabled single hydrophone with online streaming and monitoring.
- the Short Hydrophone Array (SHA) and Dedicated Telemetry Unit (DTU), see specifications in appendix A.4, an 8 channel hydrophone array with online streaming and monitoring (Fig 2.2).
- the Portable Acoustic Source Unit (PASU), see specifications in appendix A.3.
- Acoustic sources systems (LUBELL,BATS20)

Figure 2.2: SHA short array of 8 hydrophones

The experiment was conducted in two phases:

- **Phase I** – Fixed geometry: The objectives of this phase is to test acoustic methods for bottom characterization using a controlled sound source (active mode) and characterize the background acoustic noise (passive mode). The source was moored close to the pier at 10 m water depth and the digital hydrophone (DA1) was moored in the harbor in very shallow water (water depth less than 5 m). The source DA1–range is 55 m. A mooring of two self-recording hydrophones and the short hydrophone array mooring were at water depth 10 m at range 120 m and 90 m respectively. The working area and the placement of the acoustic equipment is shown in figure 2.3(a).
- **Phase II** – Variable geometry: The objective of this phase is to acquire acoustic that at sites with different bottom characteristics, evaluate the use of the SHA in mobile platforms. During this phase the source was towed from a boat, transmitting from different locations in the Bay of La Revellata. Figure 2.3(b) shows the boat track during Phase II.

The equipment deployments and the bathymetry of the area are depicted next. The companion Google Earth file *STARESO13.kmz* has information about the location of the various equipments.

(a)

(b)

Figure 2.3: Overview of equipment location (a) with superimposed boat track during Phase II (b).

2.1 DA1 mooring

Figure 2.6 shows the DA1 mooring. DA1 was moored in the STARESO harbor at depth 1.5 m from the bottom.

The DA1 was moored at location labeled *DA1* from May 8th to May 13th 7:00, when DA1 location changed to position labeled *DA1 (DEPLOY2)*. At the initial location the water depth was approximately 2.3 m, whereas in the second location the water depth was approximately 5.8 m.

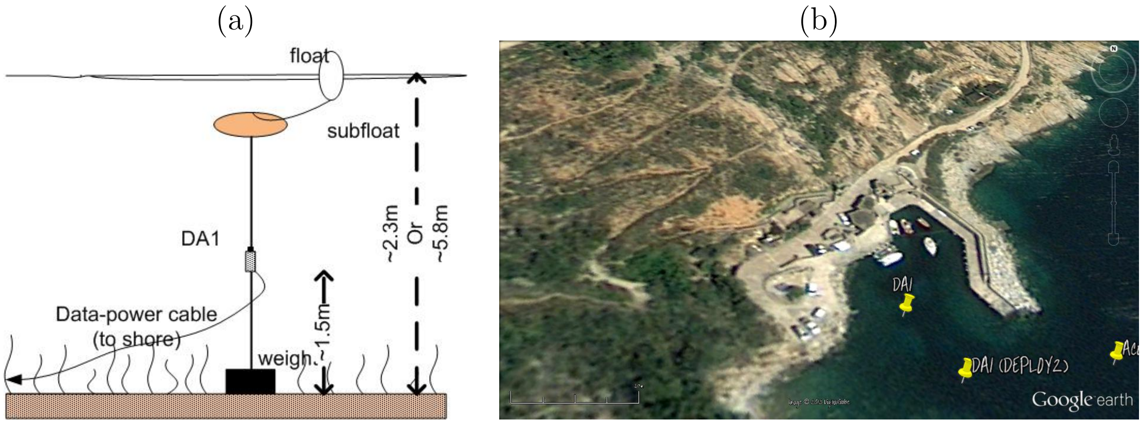


Figure 2.4: DA1 mooring: scheme (a), location (b).

2.2 SHA mooring

Figure 2.5 shows the SHA mooring. SHA was moored at water depth approximately 10 m at depth 4 m from the bottom. The deepest hydrophone is sensor #1 (and the shallowest hydrophone #8).

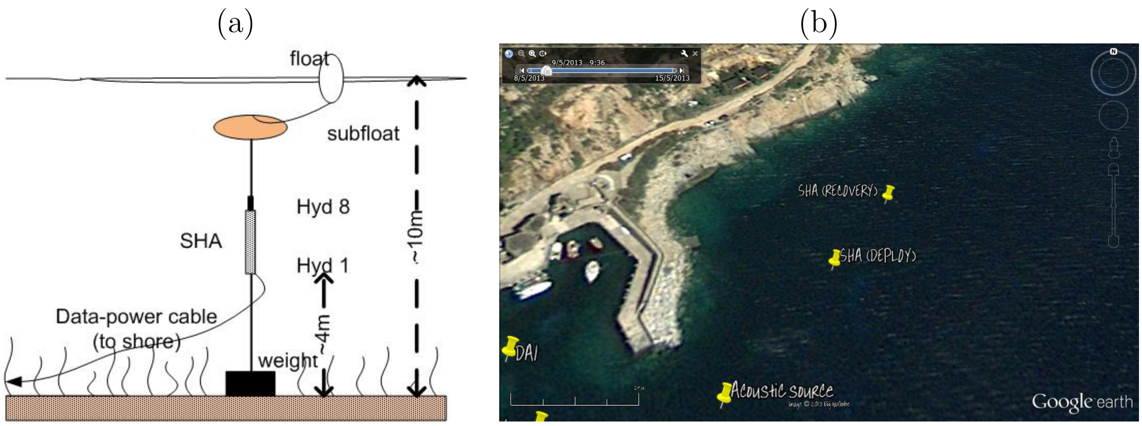


Figure 2.5: DTU mooring: scheme (a), location (b).

The SHA was moored May 9th and recovered May 15th. The SHA was deployed at location labeled *SHA(DEPLOY)* and recovered at location labeled *SHA(RECOVERY)*. Please note that these values are only approximate, which can be affected by relatively large errors (teens of meters). The GPS position indicating the recovery location should be the more precise.

2.3 SR-1 mooring

Figure 2.6 shows the scheme of the SR1 mooring and its location in the experimental area. The SR1 mooring is composed by two SR1 self-recording hydrophones installed 4 and 6 m from the bottom. The SR1 hydrophones were deployed 5 times during the experiment. The deployments were at 10 m water depth, apart of the last (5th deployment) which was at 20 m water depth.

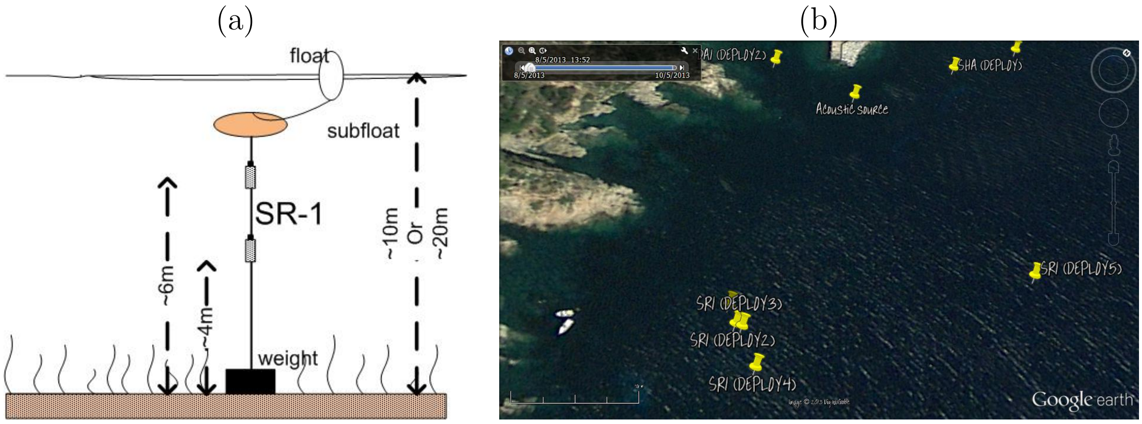


Figure 2.6: SR1 mooring: scheme (a), location (b).

2.4 Acoustic source mooring

During Phase I the source was moored close to the pier at approximately 10 m water depth. Figure 2.7 shows the mooring scheme (a) and the location of the mooring (b). The source was initially moored at position labeled *Acoustic source* and redeployed after boat tow at position labeled *Acoustic source (2)* at a deeper position. A HOBO data logger recording temperature and depth was installed at the source support (see section 3.3). Although the rope between the source and the weight was 4 m, the depth measured by HOBO data logger (∼9 m) suggests that rope had bent to the bottom.

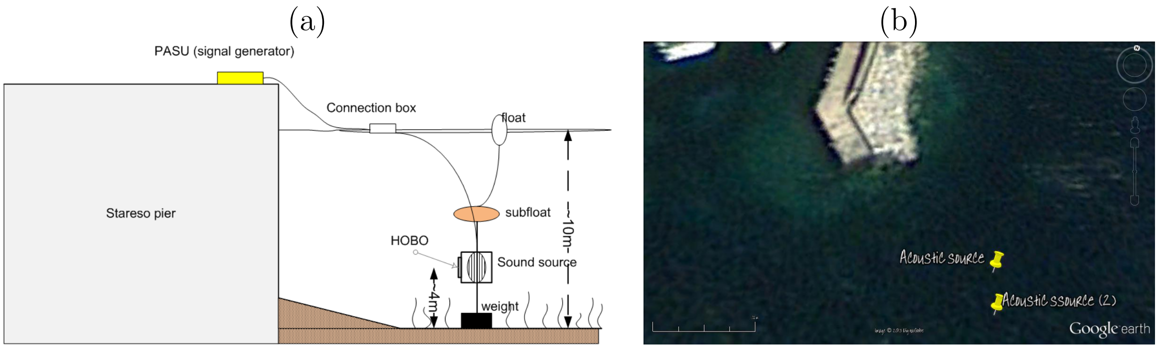


Figure 2.7: Acoustic source mooring (Phase I): scheme (a), location (b).

2.5 Acoustic source tow

During **Phase II** of the experiment the source was towed from 12GMT to 14GMT, May 13th. Fig. 2.8(a). The source was suspended from a buoy at depth 5 m (Fig. 2.8(a)) and towed some 10 m behind the boat (Fig. 2.8(b)). The actual depth is given by the HOBO's pressure data, which is presented in 3.3. The boat's track is shown in Fig. 2.3(b). The boat always turned right on each turn so as not to entangle tow cable.

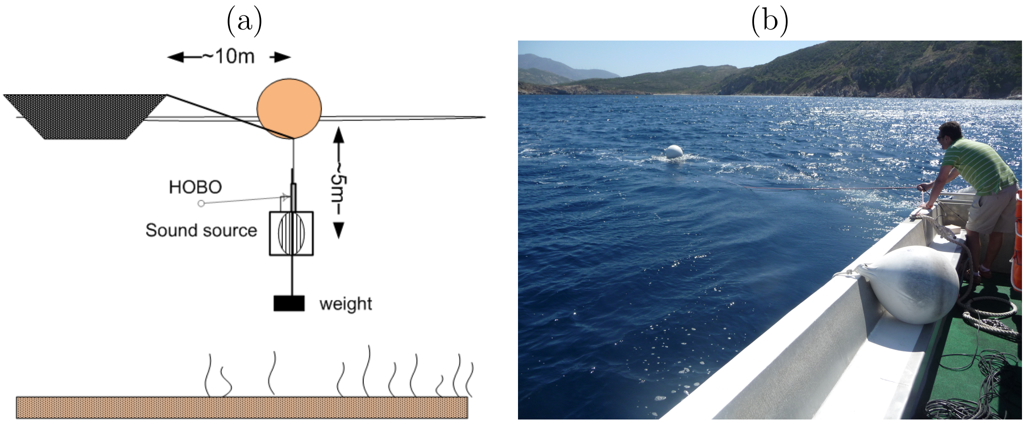


Figure 2.8: Acoustic source tow: scheme (a), picture (b).

2.6 Bathymetry

Bathymetry and bottom data acquired near STARESO by the *Service Hydrographique et Océanographique de la Marine* (SHOM) was provided by STARESO personnel in the form of geographical shapefiles (sets of files with extensions `*.dbf`, `*.shd`, `*.shx`, `*.shp` and `*.prj`), with common files sharing the same name and different extensions. To simplify the manipulation of the data an M-file with the common name was prepared. The common names and a brief description of the corresponding data is presented in Table No.2.1.

Common name	Description
MNTgrd_SHOM	Bathymetry
Bathy_25m_SHOM	Bathymetry contours at 25 m depth
Bathy_5m_SHOM	Bathymetry contours at 5 m depth
Histo_SHOM	Coastline
Habitats_marins_STARESO	Bottom types (STARESO area)
Habitats_baie_calvi_natura_2000	Bottom types (Calvi area)

Table 2.1: Names of M-files prepared for the display of bathymetry and environmental data.

2.6.1 Site bathymetry

Bathymetry data is shown in Fig. 2.9. The data reveals a complex pattern of isobaths, down to a depth around 90 m in the deepest part of the site. GPS positioning of source and receiver over SHOM bathymetry produced a value of bottom depth near 4 m, which is in contradiction with direct measurements, close to 10 m. Corrections are necessary for the calculation of transects between the source and the receiver (SR-1 mooring), and for further refinement of the bathymetry; however, the corrections also reveal that the relative distance between the source and the receiver contains an uncertainty of the order of a few meters.

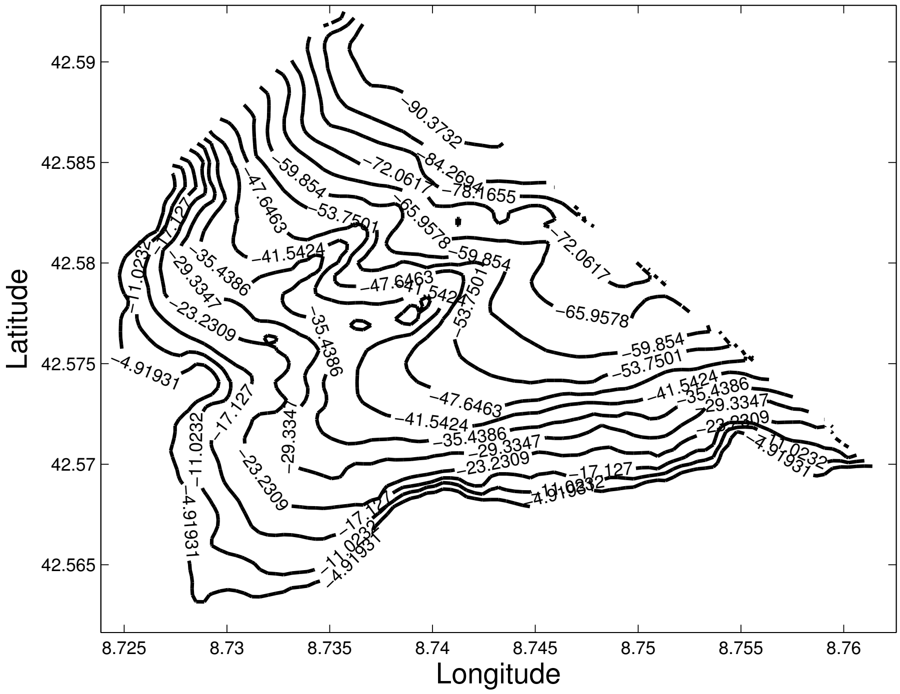


Figure 2.9: SHOM Revellata Bay bathymetry contours.

2.6.2 Site bottom properties

Data provided by STARESO personnel reveal a complex distribution of Posidonia and reef around the source and the receiver (SR-1) (see Fig. 2.10); the data do not contain, however, many rocky formations of smaller scale (which were particularly abundant near the coastline), noticed during the deployment of equipment. Posidonia is also strongly correlated with the distribution of sand banks. Thus, the distribution of Posidonia, reef and rocky formations is representative of the places where the bottom can be expected to be softer or harder.

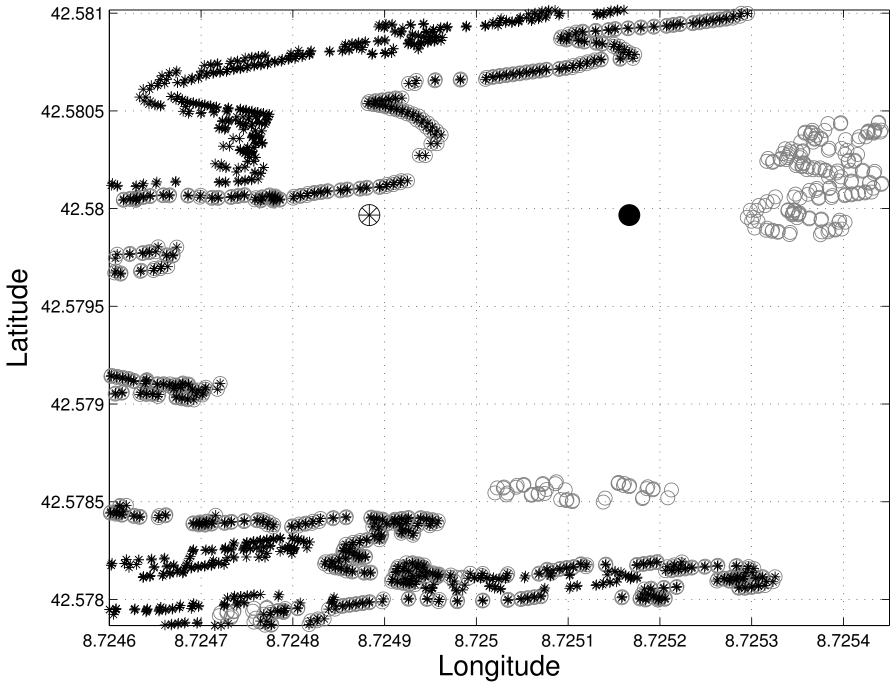


Figure 2.10: STARESO habitat around the source and the receiver (SR-1 mooring): distribution of Posidonia (light circles) and reef (black asterisks); the source position is indicated with an asterisk, the receiver position is indicated with a solid dot.

Chapter 3

Environmental data

This chapter presents atmospheric and underwater environmental data. The atmospheric data was recorded by a meteorological station installed in top of the Hill and by a meteorological station installed in the top of the STARESO building. The underwater data were acquired by a CTD operated from a boat, HOBO temperature/pressure sensor installed at the source, data from the "Optode array" mooring (temperature,salinity, O2, PAR) and few measurements from a multiparameter logger (temperature, currents, presssure, turbidity, O2).

3.1 Atmospheric data

The atmospheric data was measured by an Aanderaa Weather Station (AWS 2700), installed on top of Revellata Cape (45,5787°N, 8.71899°E, alt. 169 m).

Measurements for the last 6 months and detailed description of sensors is available online at *http://www.gitan.ulg.ac.be/race/mat_meteo_6mois.php*. The measured parameters are: Wind speed (average on 20 min), Wind gust (Maximum wind speed over a 2-second period at any time during 20 min), Wind direction (counting clockwise from the North), Air temperature, Air relative humidity, Atmospherical pressure (atmospheric pressure in mb/hPa reduced to sea level obtained by adding 20 mb at the measure taken at the station level $\sim$ 163 m), Solar radiation (direct and scattered solar radiation, as well as thermal radiation from the earth and the atmosphere – λ 300 nm to 60 000 nm). There is a second weather station installed on top of STARESO building. The wind speed is available from this station for the whole month.

Fig. 3.1 shows the air temperature, the wind speed and the solar radiation recorded from 8th to 15th May by the hill station and the wind speed recorded during May by the second weather station. Unfortunately the data recorded by the hill station before 11th May is unreliable.

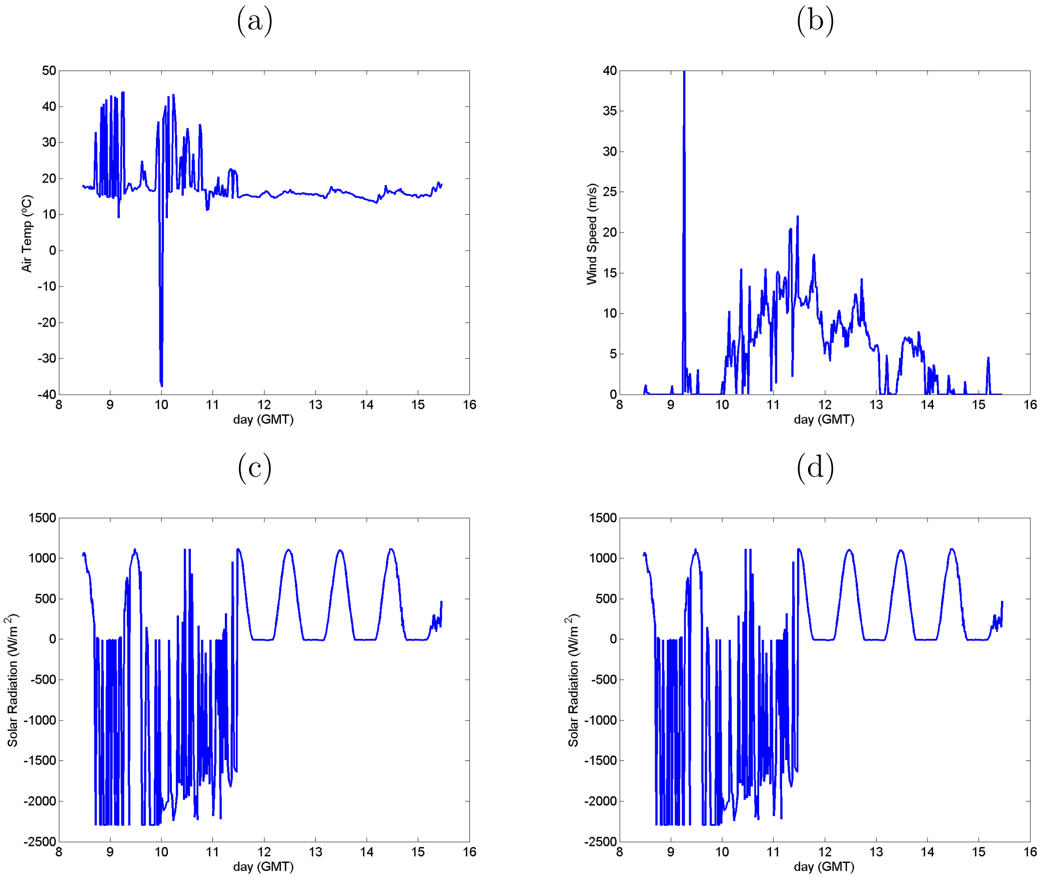


Figure 3.1: Atmospheric data: Air temperature (a), wind speed (b), solar radiation (c), recorded by the meteorological station installed in the La Revellata hill and wind speed (d) recorded by the meteorological station at STARESO building.

3.2 CTD data

CTD data (temperature, pressure, conductivity and dissolved oxygen) was acquired by a RBR concerto instrument. During 9th and 10th May 10 CTD profiles were performed close to the moorings. Next days the CTD was moored with SR-1 hydrophones.

Figure 3.2 shows the temperature, sound speed and dissolved oxygen profiles (raw data). It can be seen that the sound speed profiles little varied among days and locations. The sound speed/temperature is virtually constant along the water column. The dissolved O2 increases with depth, what can be ascribed to the O2 production by the seagrasses that cover the sea bottom.

Figure 3.3 shows the data acquired by the CTD fixed at the SR-1 mooring. One can remark that the temperature/sound speed profile varies little among the period.

The dissolved O2 measurements could be affected by a miss operation of O2 sensor (a cap not well fitted).

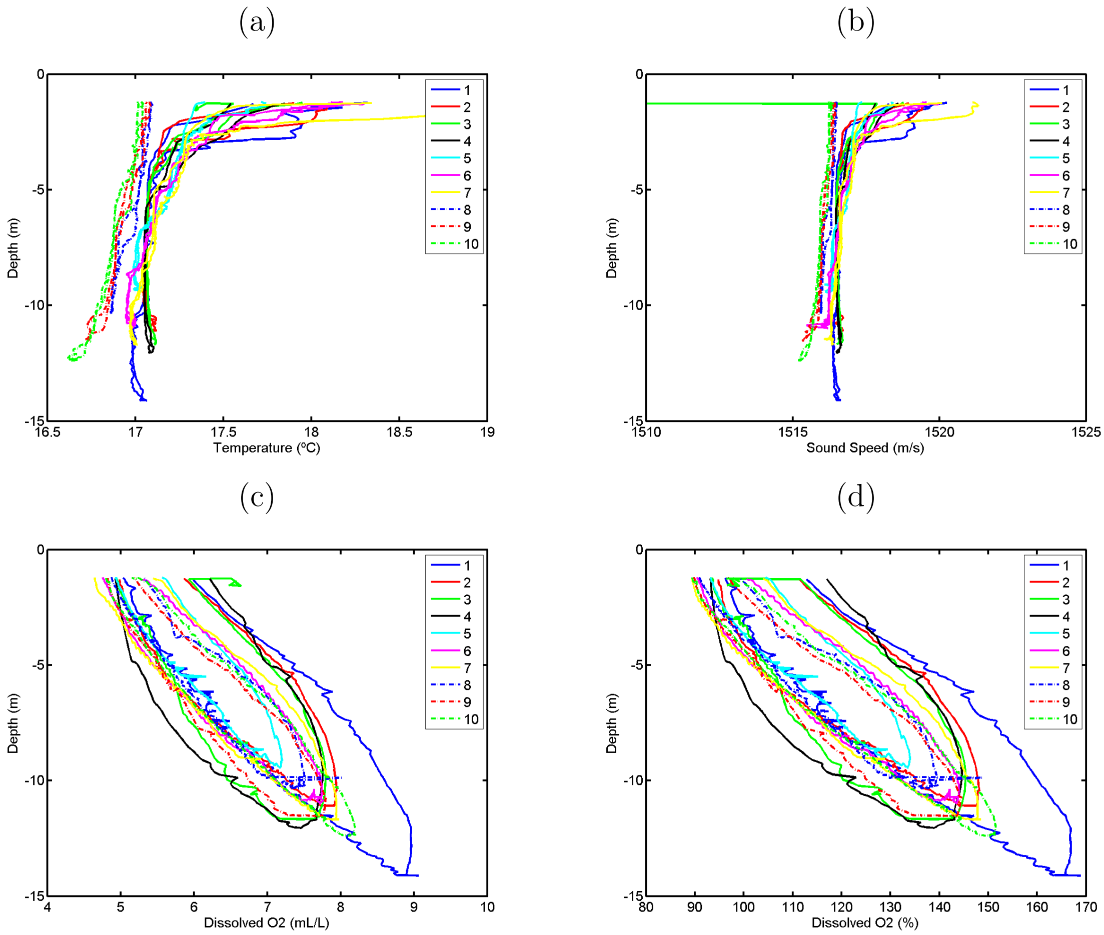


Figure 3.2: CTD profiles measured in the experimental area 9th and 10th May: temperature (a), sound speed (b), and dissolved oxygen (c) and (d) data from CTD. The text label indicates the day-hour (GMT) of a profile. The color legend indicates the CTD number.

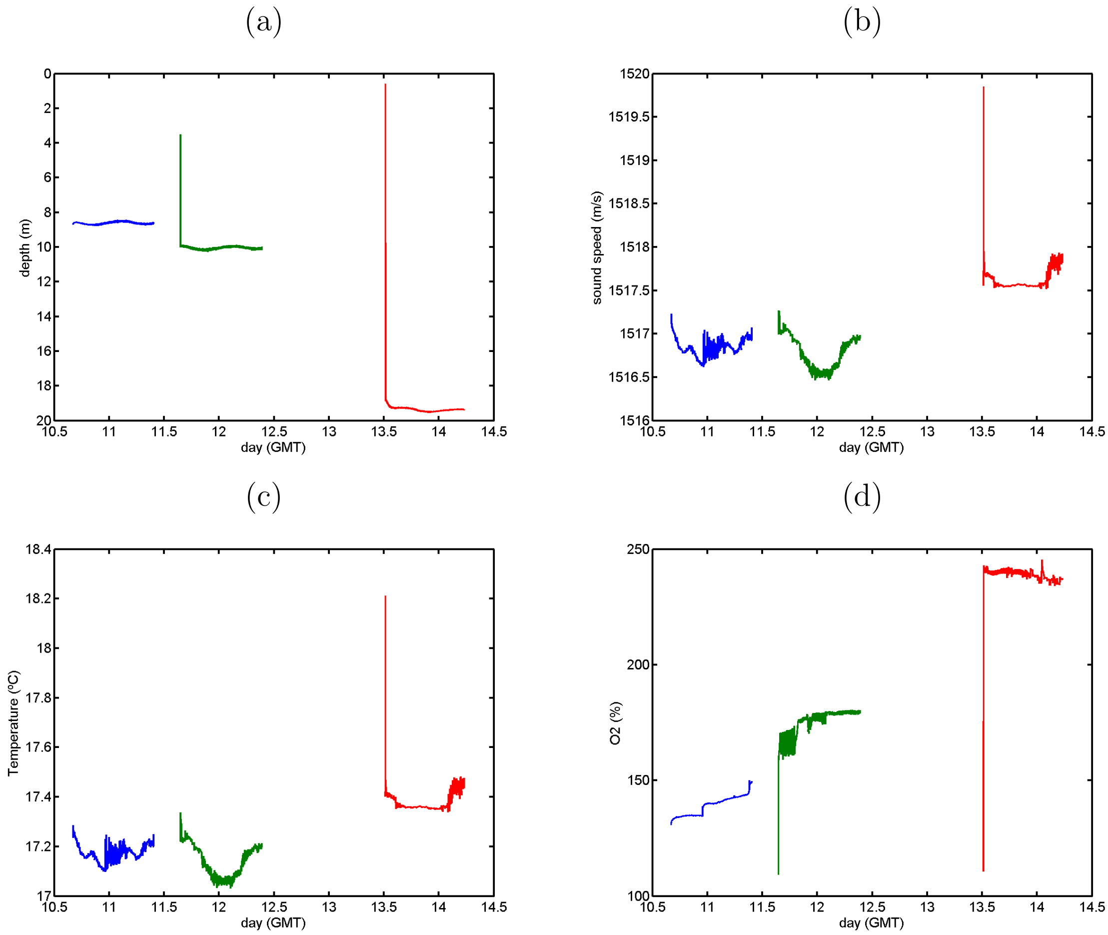


Figure 3.3: CTD measured at SR-1 mooring at a fixed depth: depth (a), temperature (b), sound speed (c) and dissolved oxygen(d).

3.3 Source depth and temperature

A HOBO data logger measuring the pressure and the temperature was installed in the source's support. Figure 3.4 presents the data acquired by the data logger during the 2 periods of **Phase I** (moored source) part of the experiment: (a) and (b) the depth estimated from pressure data, (c) and (d) the temperature.

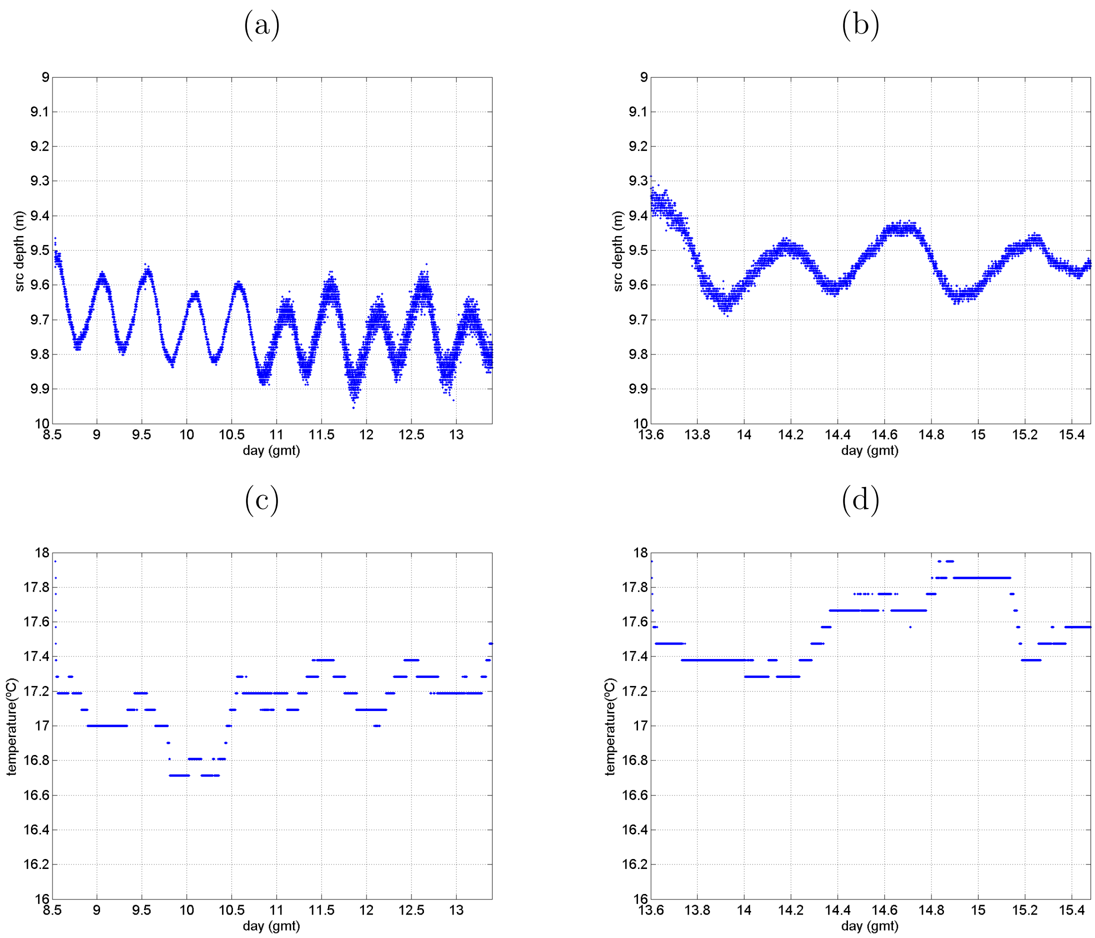


Figure 3.4: Source depth (a) & (b) and temperature (c) & (d) measured by the HOBO device installed at the source during the 2 periods of **Phase I** (moored source) of the experiment

In the depth graph one clearly identify the tidal influence, giving rise to a "sinusoidal" low-frequency variation with a period in line with the tidal period. The maximum peak to peak amplitude is about 30 cm and is stable along the considered periods. The temperature was almost constant around 17°C during both periods.

Figure 3.5 presents the data acquired by the HOBO during the **Phase II** (towed source) part of the experiment: (a) the depth estimated from pressure data and (b) the temperature.

The fluctuation on source depth is due to speed changes and maneuvering of the tow boat. It can be seen that the temperature is virtually constant (17.5 °C) along the boat track.

(a) (b)

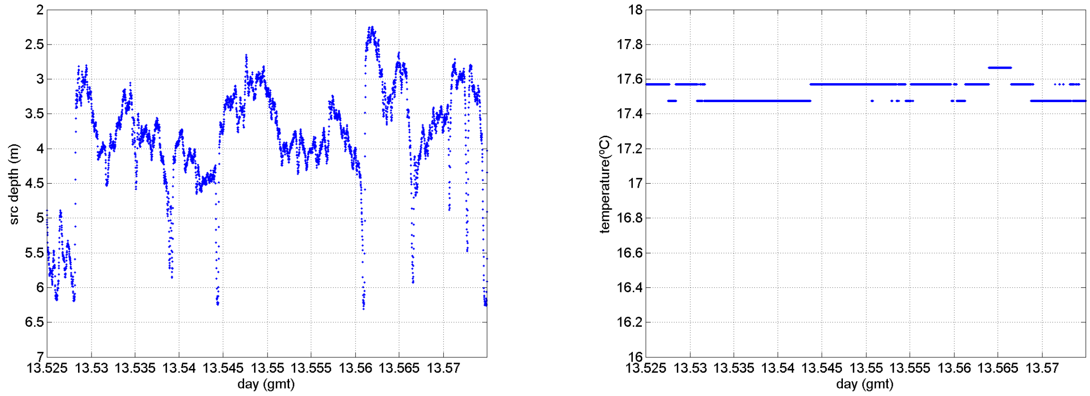


Figure 3.5: Source depth (a) and temperature (b) measured by the HOBO device installed at the source during the **Phase II** (towed source) part of the experiment

3.4 Longterm measurements of photosyntheses related parameters

The data presented in this section is the O2 concentration measured by Optodes and the solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis measured by aPhotosynthetically active radiation (PAR). This data was provided by the Chemical Oceanography Unit, University of Liège, Belgium.

An array of 3 Aanderaa O2 optodes (3835) moored at 10 m depth measure the O2 saturation level hourly and the temperature. The optodes are installed at 4.5, 7.0 and 9.5 m depth [1]. Figure 3.6 shows the O2 concentration and the temperature measured during May 2013. The sensor at 4.5 m was malfunctioning.

(a) (b)

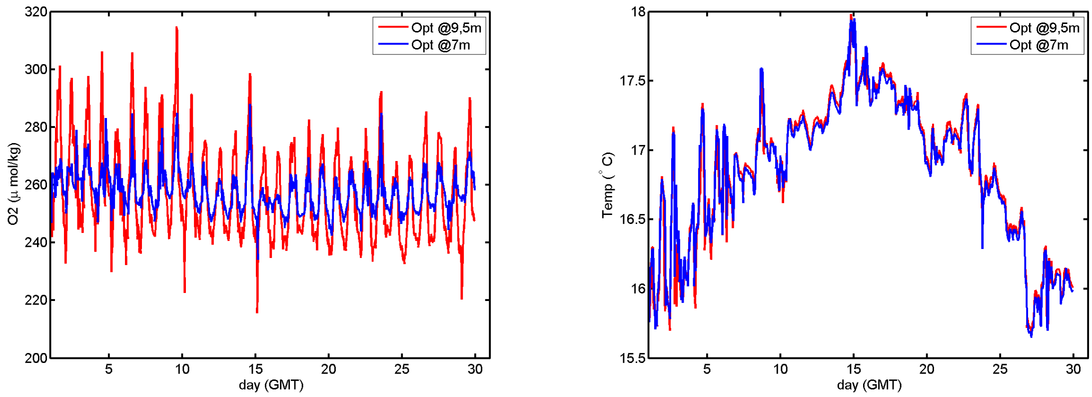


Figure 3.6: O2 concentration (a) and temperature (b) measured at 7 m (blue line) and 9 m (red line)

The O2 concentration is correlated with the diurnal cycle of plants' photosynthesis. The optode at 9 m that is around the plants foliage layer presents the highest values of O2. The temperature during the period of the experiment varied between 17 and 18°C. The temperature was virtually equal at both depths.

In addition to the above measurements a temperature and salinity sonde was installed at 5 m depth (Fig. 3.7), showing that the temperature at this depth is equal to temperature measured at depths 7 and 9 m. It is also shown that the salinity is about 37.8 and its variation is inappreciable.

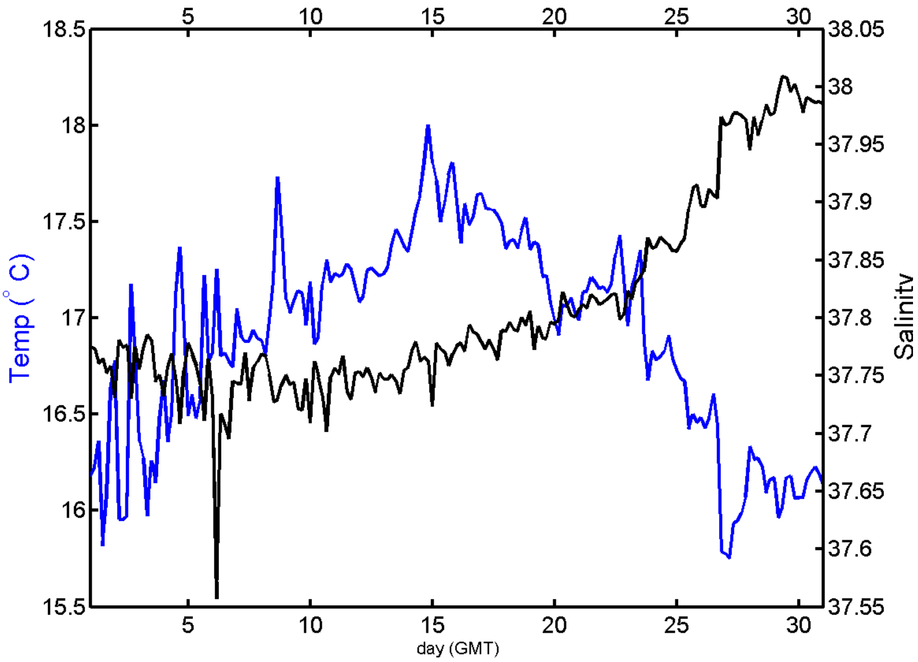


Figure 3.7: Temperature (blue line) and salinity (black line) measured by a sonde installed at 5 m depth

The Photosynthetically active radiation measured during May 2013 data is shown in Fig. 3.8, where one can notice the diurnal cycle of photosynthesis.

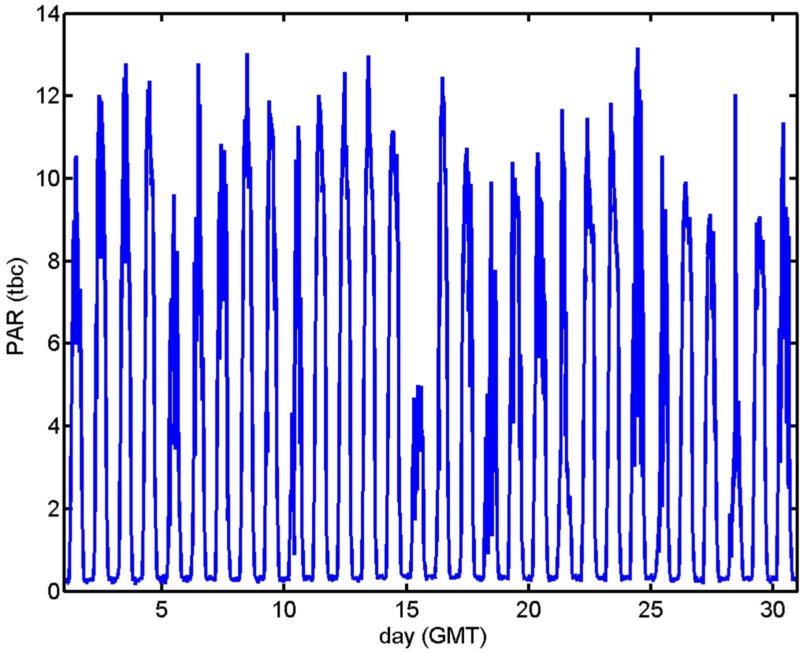


Figure 3.8: Photosynthetically active radiation measured during May 2013

3.5 Multiparameter measurements at 2 m

The STARESO staff using a portable multiparameter device measures at 2 m depth O2 concentration, currents, water temperature and salinity, and turbidity at various locations several times a month. The measurements are performed continuously during a period of approximately 15 min.

Figure 3.9 shows the measurements performed May 3rd and 6th inside STARESO harbor and 14th May near the source and optode mooring. It can be seen that O2 oversaturation has not occurred, the temperature and salinity variability was small. It was impossible to find a common variability pattern of current strength and direction among days.

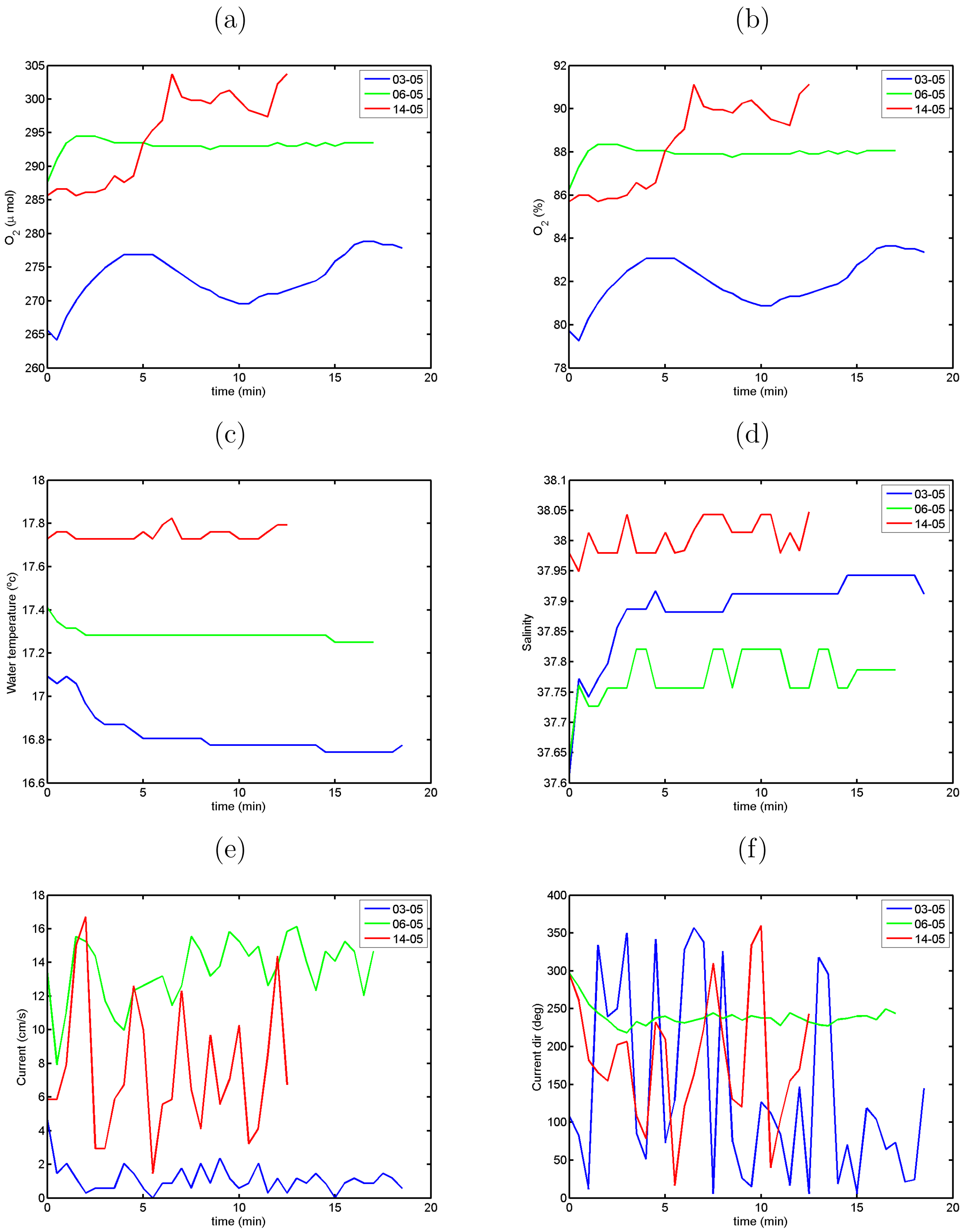


Figure 3.9: Multiparameter measurements at 2 m depth in May 3rd 4:55 (GMT) inside the harbor (blue line), May 6th 4:50 (GMT) inside the harbor (green line) and May 14th 10:40 (GMT) near the source and optode mooring (red line): O2 concentration (a) and (b), water temperature (c), salinity (d), current strength (e) and direction (f).

Chapter 4

Acoustic data

4.1 Emitted signals

During the experiment, probe signals were transmitted from a sound source at 6.5 m depth to the three receiver systems (DA-1 hydrophone, SHA array and SR-1 hydrophones).

The signal sequence described below was transmitted repeatedly every 10 minutes during **Phase I** and continuously during **Phase II**. The source power was set constant during transmissions, but changes could have occurred among source stops. The power settings of the source and the instants of power up and off can be checked in the experiment log book (Appendix B).

4.1.1 Probe signals

The sequence of probe signals, transmitted at rate of 44100 samples per second, were composed by 3 groups of several 3 s long chirps, corresponding to three distinct frequency bands: low frequency band 400-800 Hz, medium frequency band 1500-3500 Hz and high frequency band 6500-8500 Hz. The group of low frequency and the group of high frequency was composed by 12 chirps, the group of middle frequency signals was composed by 10 chirps. The amplitude of the 2 initial chirps was 20 times smaller than the amplitude of the following ones. The groups were separated by 2 s idle, within a group the chirps were 250 ms apart. A 4s long multitone block of was added May 12th, 15:00 (GMT) after LFMs block. The single tone frequencies were: 0.400 kHz, 0.504 kHz, 0.635 kHz, 0.800 kHz, 1.008 kHz, 1.270 kHz, 1.600 kHz, 2.016 kHz, 2.540 kHz, 3.200 kHz, 4.032 kHz, 5.080 kHz, 6.400 kHz, 8.063 kHz, 10.159 kHz.

Fig 4.1 shows the spectrogram of the transmitted probe signal.

A communication signal was added at the end of the sequence.

4.1.2 Communication signals

The communication signals which were transmitted during this sea-trial are FSK signals based on the JANUS[1] protocol. The JANUS toolkit release v3.0.0 was used for the

[1] http://www.januswiki.org

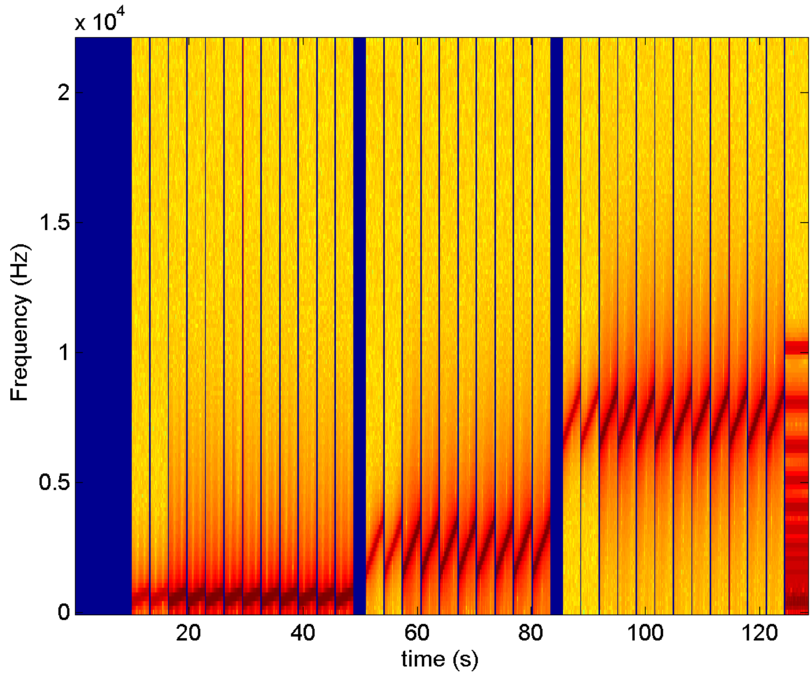


Figure 4.1: Probe signal sequence acquired by an hydrophone

signal generation. A total of 3 center frequencies (6kHz, 11kHz and 18kHz) where defined and transmited sequentially from separate wav files (figure 4.2) using the Lubell LL916C acoustic source. Each signal contained a simple payload with the following text **JANUS Test 11kHz** where the frequency value was substituted by the respective center frequency. Commands to generate these signals can be seen in table 4.1.

janus-tx –pset-center-freq 6000 –stream-fs 44100 –stream-driver wav –wut –packet-payload "JANUS Test 6kHz"
janus-tx –pset-center-freq 11000 –stream-fs 44100 –stream-driver wav –wut –packet-payload "JANUS Test 11kHz"
janus-tx –pset-center-freq 18000 –stream-fs 44100 –stream-driver wav –wut –packet-payload "JANUS Test 18kHz"

Table 4.1: JANUS TX comands

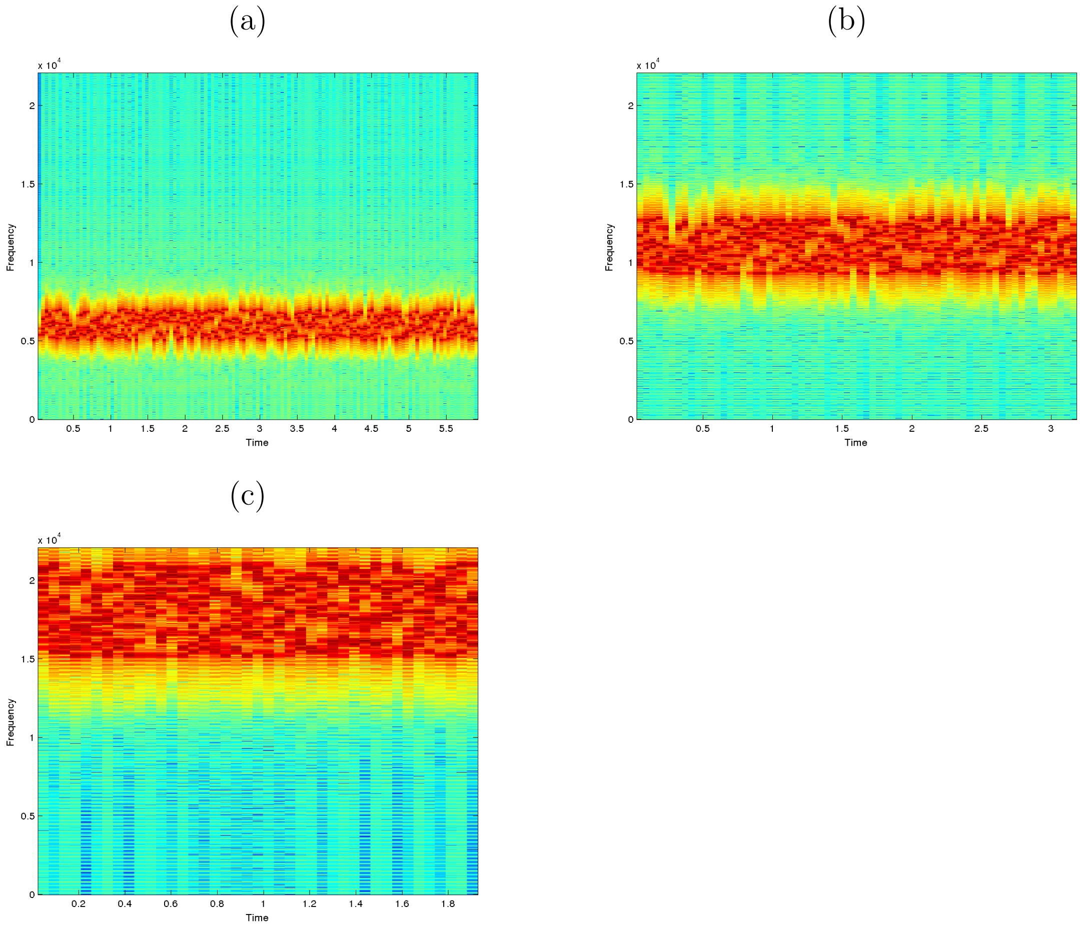


Figure 4.2: Transmitted signals, center frequency 6kHz (a), 11kHz (b) and 18kHz (c)

4.2 Received signals

The signal recorded by SHA and DA1 were continually recorded. The SR-1 hydrophones acquired 3 min of signal every 10 min. The data was stored in "WAV" format with the following sampling parameters

- SHA - 8 channels, 24 bits at sampling frequency 52734Hz, some initial data were acquired at 128kHz, the system gain was changed from 1x to 4x at May 11th 2pm (GMT);
- DA1 - 1 channel, 24 bits at sampling frequency 101562Hz
- SR-1 - 1 channel, 24 bits at sampling frequency 50781Hz

Figure 4.3 shows the monitor and acquisition program displaying in real-time the raw SHA and DA1 data and its basic signal analysis.

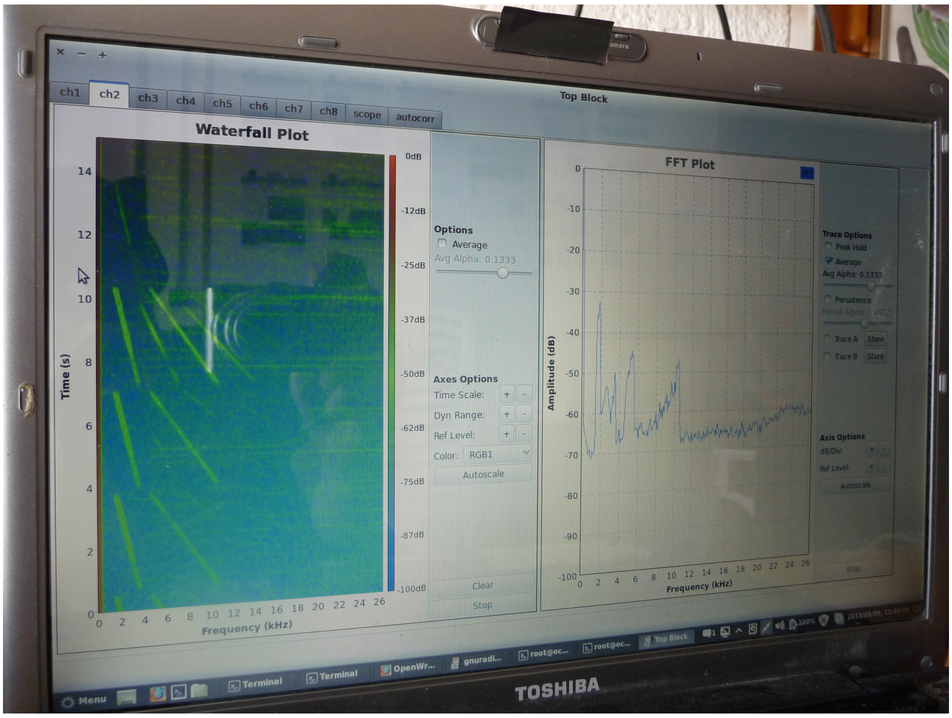
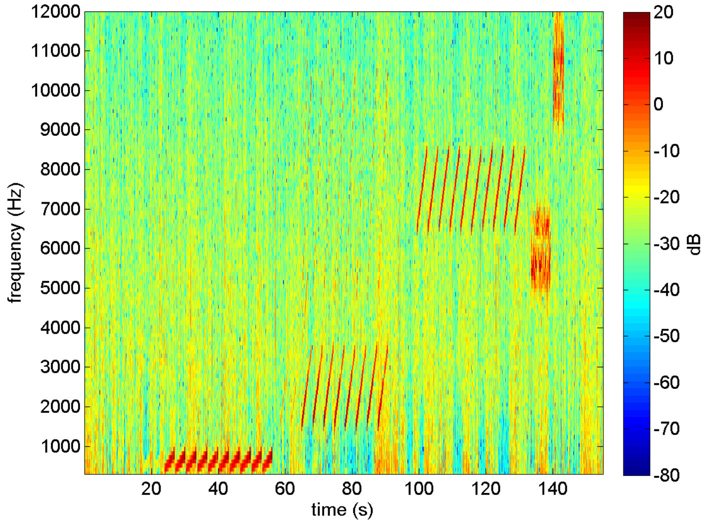


Figure 4.3: Real time display of SHA and DA1 data.

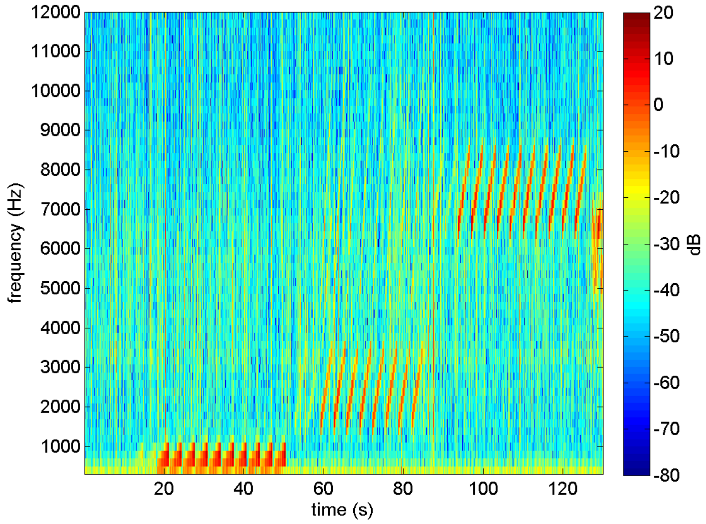
The file name of the SHA and DA1 systems have the format "DATA_DTU_*DDDHHMMSS*" and "DATA_DA1_*DDDHHMMSS*" respectively, where *DDD* is the julian day (May 9th is julian day 129), *HH* is the hour, *MM* is the minute and *HH* is the second when the file was closed (GMT time). The file name of the SR-1 hydrophone is sequential, the date of modification of the "WAV" file is the system time (GMT) when the file was closed (end of the acquisition). The "WAV" files were 3 min long.

Figure 4.4 shows the spectrogram of data snapshots received in the various systems. Please note that the gain of DA1 and SHA changed few time along the experiment. Please check the Experiment log book for details (Appendix B) for details. Apart of emitted signals and environmental noise, during the experiment occurred events like ship cruising the area, which are registered (not exhaustively) registered in the Experiment log book (Appendix B).

(a)



(b)



(c)

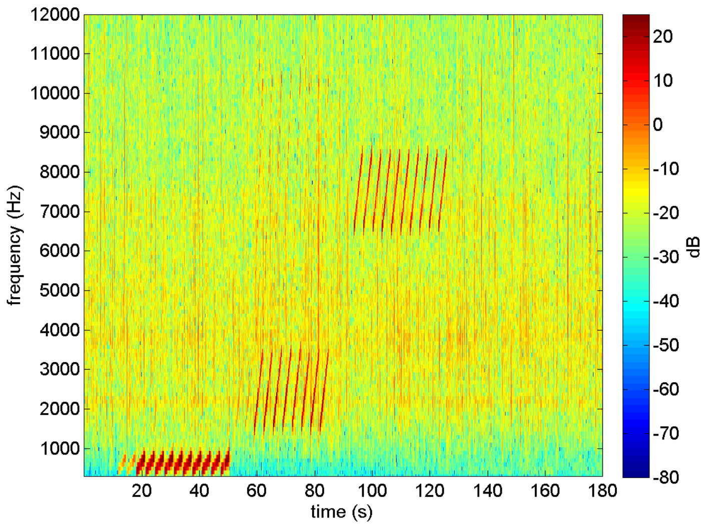


Figure 4.4: Sepctrogram of signal received at DTU (a), DA1 (b), and SR1 (c).

Chapter 5

Preliminary data analysis

The preliminary data analysis comprises the estimation of impulse responses using LFMs to get insight about the variability of the various acoustic channels (source-DTU, source-DA1, source-SR1), estimation the time variability of the noise power spectrum, pressure and particle velocity beamformer for bottom characterization and 3D propagation effects modeling.

5.1 Impulse responses

The impulse responses were computed by pulse compression, crosscorrelation between the received signal and the emitted signal, without considering the transfer function of the emitting system. The signals were downsampled before pulse compression. The instantaneous envelopes of pulse compressed signals of a group were averaged after alignment by the maximum of crosscorrelation. The two low amplitude signals at the beginning of each block were discarded.

Figure 5.1 presents the impulse responses estimated from the signals acquired in SR1 hydrophone installed 6 m from the sea bottom from May 11th afternoon to May 13th noon. The logarithmic scale used emphasizes latter arrivals.

The observed behavior corroborates previous measurements in the area with a similar source-SR1 setup [2]. In low and medium frequency signals, figure 5.1 (a) and (b) respectively, one can see a remarkable difference between the time spread of the impulse responses during the daylight (shorter) and night period (longer). The oxygen produced during the daylight period give rise to higher attenuation, thus latter arrivals, which suffer large number of bounces "can not be seen" in the impulse responses. Also, arrival patterns show a higher variability during the daylight period than during the night, what can be explained by the fact that the oxygen production and the dissolution of oxygen in water varies along the day (mainly with irradiance) but it is not a linear and smooth process. At sunrise (daytime ∼5:00) there is an abrupt change in the arrival structure. At the sunset the change is smoother.

Figure 5.2 shows the impulse responses between the source and SHA (channel 8) for low frequency signals (a) and high frequency signals (b).

It can be seen that the impulse responses estimated from low frequency signals show a similar variability pattern that of observed in Fig. 5.2, however not so marked, what can be explained by the shorter distance between the source and the receiver. At shorter distance

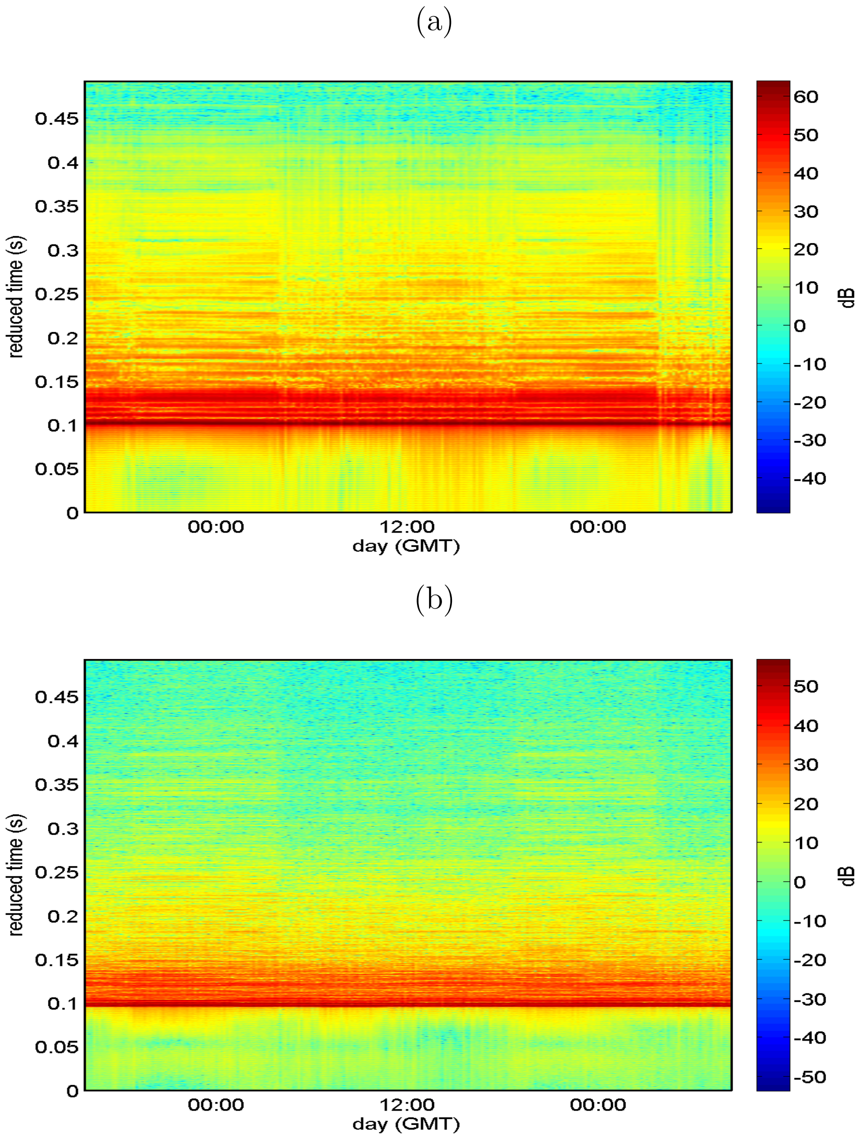


Figure 5.1: Impulse responses estimated from low frequency LFM (a), medium frequency LFM (b) acquired in SR1 hydrophone (6 m from the bottom) May 11th.

the number of rays that connect the source and the receiver as well the number of bottom bounces are smaller, thus the "oxygen-photosynthesis" signature in the impulse responses is not so visible. Moreover at shorter distances, most likely there is a direct path between the source and the receiver. This energy (ray) does not interacts at all with the bottom, thus suffer inappreciable attenuation when compared with bottom reflected energy and smears the (visible) effect on latter arrival. It could explain why in the medium (Fig. 5.2(b)) and high frequency (not shown) signals the "oxygen-photosynthesis" signature is not visible. In order to extract the "oxygen-photosynthesis" signature from this shorter range signals more complex estimation methods and analysis should be applied. Also, the usage of the vertical particle velocity estimated using the SHA could filter out the influence of the direct energy (traveling horizontally), and thus enhance the contribution of bottom bounced energy (see 5.1).

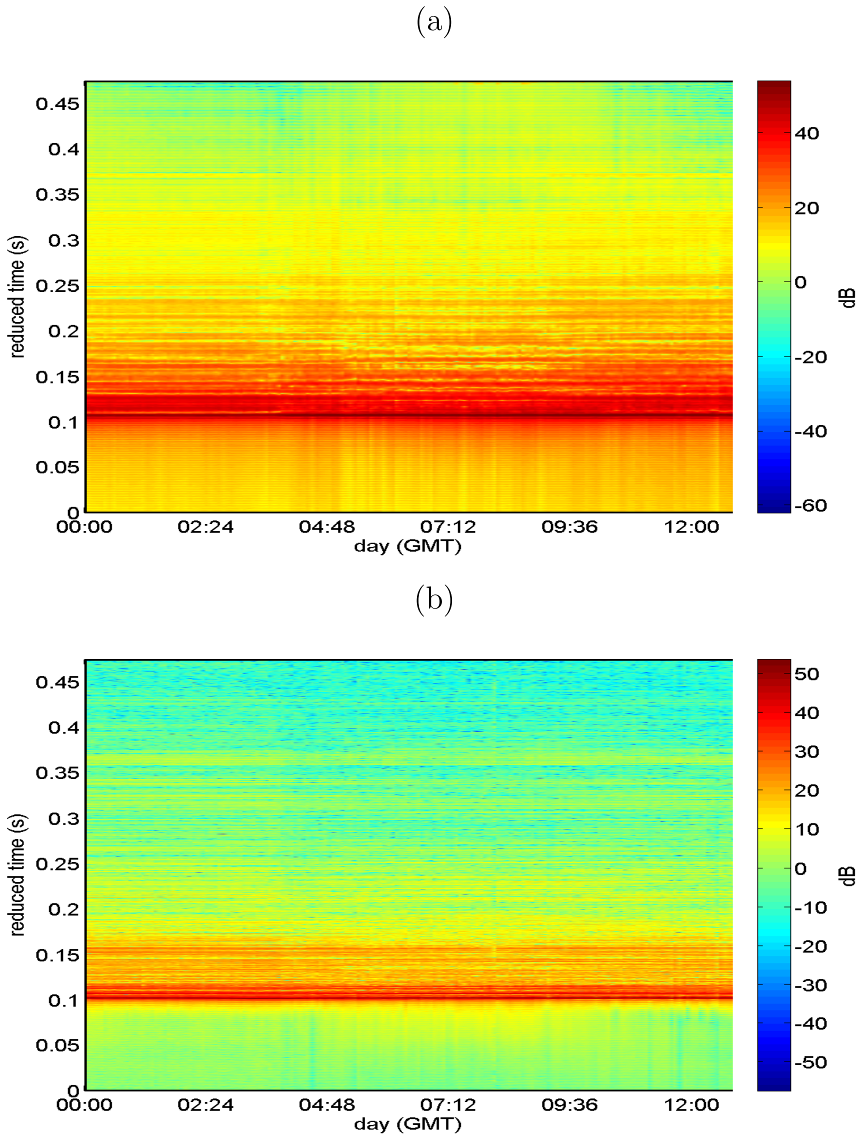


Figure 5.2: Impulse responses estimated from low frequency LFM (a), medium frequency LFM (b) acquired in channel 8 of SHA May 11th.

5.2 Power spectral density of environmental noise

Figure 5.3 shows the power spectral density of noise estimated hourly May 14th between midnight and midday at DA-1 (a) and at channel 8 of DTU (b). During this period the power source was off. The power spectral density was estimated by the hour using the Welch's method, after down sampling to approximately 5 kHz a DA-1 or a SHA 3-min long data snapshot, and applying a high pass filter (cutoff frequency 50 Hz). It was checked that the snapshots of data were not contaminated by other readily identifiable source of noise like boats passing in the area.

It was noticed in both hydrophones (DA1 and SHA channel 8) for frequencies above 2 kHz and in SHA also for low frequencies that the noise power is higher during the night period and decreases significantly after sunrise (∼5:00 GMT) most likely due to photosynthesis. The beginning of photosynthesis is correlated with the increase of dissolved O2 (Fig. 5.4(a)) and particularly with the increase of PAR(Fig. 5.4(b)). Moreover, it can be seen that wind speed has not visible influence on the described behavior, the values are

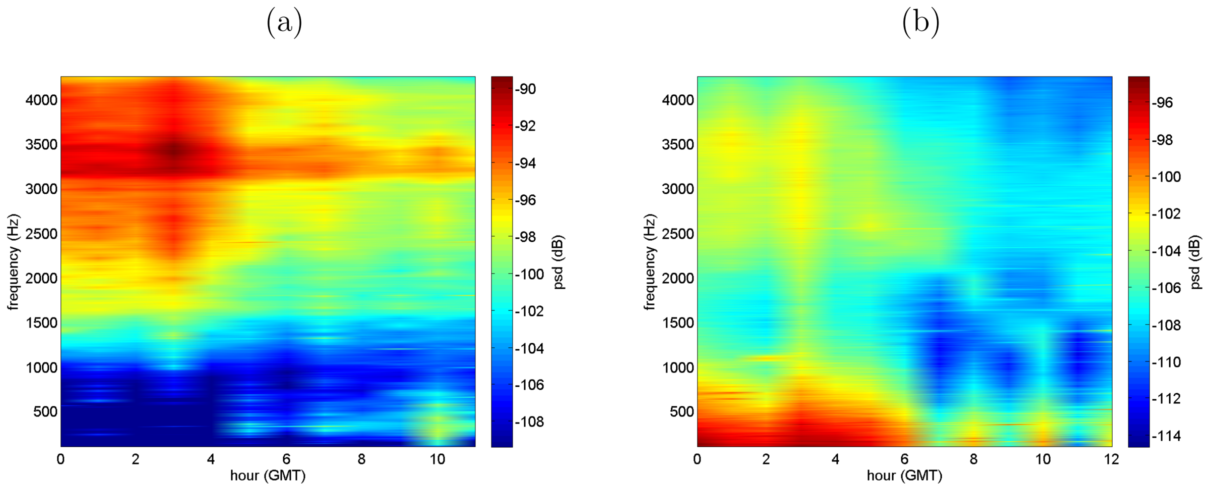


Figure 5.3: Power spectral density of environmental noise observed May 14th from 0:00 to 12:00 (GMT): at DA-1 (a), at SHA channel 8 (b).

small and vary little among the period (Fig. 5.4(c)). The peak observed at 8:00 (GMT) has not a visible power spectral density plots.

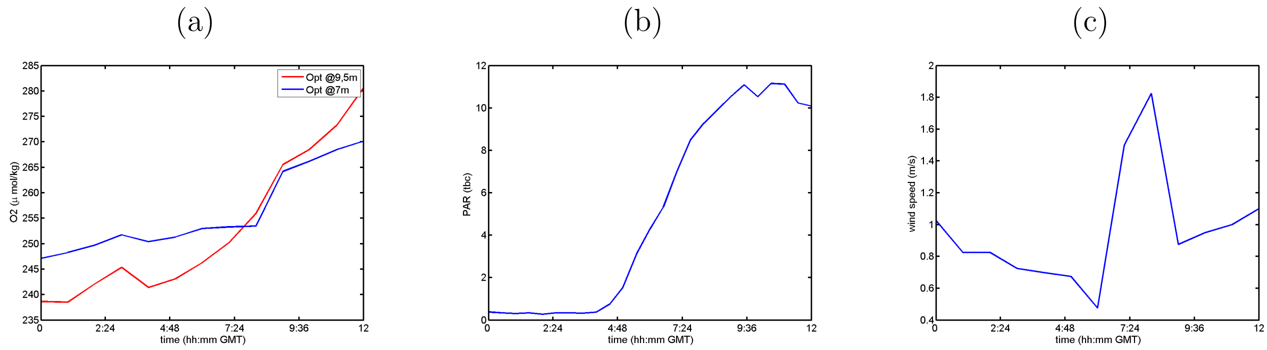


Figure 5.4: Environmental data observed May 14th from 0:00 to 12:00 (GMT): dissolved O2 (a), PAR (b), wind speed (c).

The difference at low frequencies between DA1 and SHA is likely due to the fact that DA1 is moored at very shallow water, thus low frequencies (below the cutoff frequency of the waveguide) are highly attenuated. These results suggest that environmental noise power varies with the photosynthesis activity of the plants covering the sea bottom. Thus the photosynthesis activity (O2 production) can be potentially assessed using passive methods. To this further research includes the usage off the full SHA array to determine the directivity of the noise field, and how it varies along the diurnal period.

5.3 Short horizontal array beamforming

The data processed herein were obtained using the SHA array presented in Fig. 2.2. The SHA is a 8 hydrophone array composed by 4 pair of close located hydrophones. The distance between hydrophones in a pair is 2 cm, the pairs are 10 cm apart. The hydrophone

1 was at 4 meters from bottom and hydrophone 8 was at 4.30 meters from bottom and source range around 90 m (2.2).

The data was processed using the four even hydrophones (hydrophone 2, 4, 6 and 8) for pressure outputs and using the four pairs of hydrophones for vertical particle velocity v_z outputs, which was obtained from the difference between hydrophones in a pair.

The vertical beam response experimental data results were calculated for frequencies between 6500 and 8500 Hz and for three days of SHA data acquisition: May 10th (Julian day 130), May 11th (Julian day 131) and May 12th (Julian day 132). The vertical beam response for each frequency is shown in Fig. 5.5 for a snapshot of data acquired on May 12th. The results for pressure (even hydrophones) are shown in Fig. 5.5 (a), while (b) presents the vertical particle velocity v_z results.

One can observe from Fig. 5.5 that almost of the energy reaches the array from two arrival angles, one around 10^o (energy reaching the array directly) and other around -40^o (energy reaching the array from bottom reflection). From this figure and due to the small range between the source and the array (90 m), one can observe two paths: the direct path and one bottom reflected path. Comparing Fig. 5.5 (a) and (b), the vertical beam response obtained from v_z (b) reveals with good resolution the two rays paths, in particular the bottom reflected ray that has poor resolution when obtained with the pressure outputs (a).

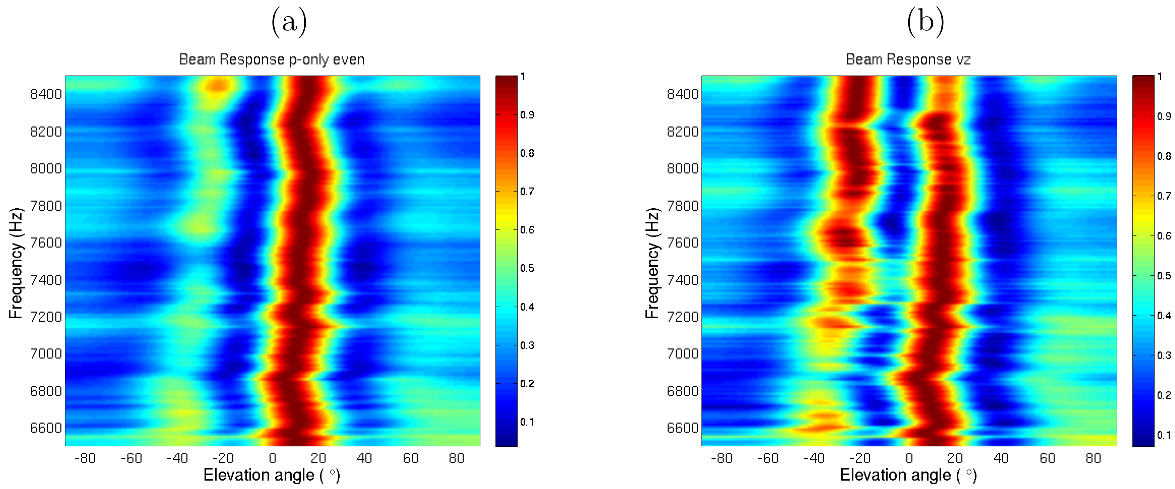


Figure 5.5: The experimental data normalized beam response obtained with four hydrophones (pressure outputs) (a) and four vertical particle velocity outputs (difference between hydrophones in a pair) (b) for frequencies between 6500 and 8500 Hz on May 12th.

The bottom reflection loss at 6.5-8.5 kHz frequency band, deduced from the ratio between the down (energy from surface) and up (energy from bottom reflection) beam response is presented in Fig. 5.6 (a) considering the pressure outputs and (b) the v_z outputs. A first analysis of this figure reveals that both pressure and v_z outputs present one lobe at equal grazing angle. One can concluded that the energy, at 6.5-8.5 kHz frequency band, is all attenuated at the first sediment. Further analysis of these data will performed in near future.

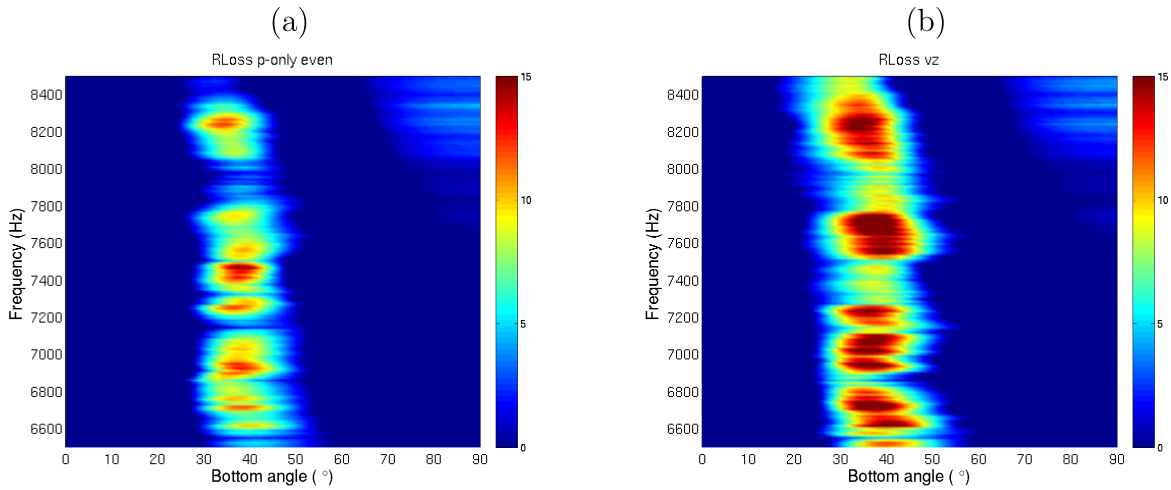


Figure 5.6: The bottom reflection loss at 6.5-8.5 kHz band deduced from the down-up ratio of the experimental beam response on May 12th.

5.4 Impulse response modeling

This section compares the source-SR1 measured impulse responses with 2 and 3D modeled impulse responses. Impulse responses (IRs) for the low frequency band from a set of fourteen minutes transmissions are shown in Fig. 5.7; the IRs reveal a stable structure of arrivals packed in two groups, with a first group between 0.07 and 0.1 s and a second group between 0.1 and 0.12 s. Beyond 0.12 s arrival amplitudes quickly fade out, which is believed to happen because of strong signal attenuation after multiple bottom reflections. Two-dimensional or three-dimensional modeling of the acoustic data is presented in the following sections.

5.4.1 Two-dimensional modelling

Eigenrays, calculated with the TRACEO ray tracing model[1], are shown in Fig. 5.8; the calculation points to an almost flat transect, with later rays propagating at very steep angles.

5.4.2 Three-dimensional modelling

Bathymetry data for the Stareso bay shows that the given configuration of source and receiver can be approximated as an scenario with cross-slope transmissions in an uplsope waveguide; such configuration can induce horizontal ray bending and out-of-plane propagation. Eigenrays calculated with the TRACEO3D ray tracing model (under current development at SiPLAB) are shown in Fig. 5.9; amplitudes were calculated considering that rays with travel times below 0.1 s propagate over a sandy bottom, while the remaining rays propagate over basalt (the acoustic properties are shown in Table 5.1, values are taken from the available literature).

The IR calculated from TRACEO3D is shown in Fig. 5.10 next to the real low-frequency

[1] http://www.siplab.fct.ualg.pt/models.shtml (Last viewed 09/10/2013).

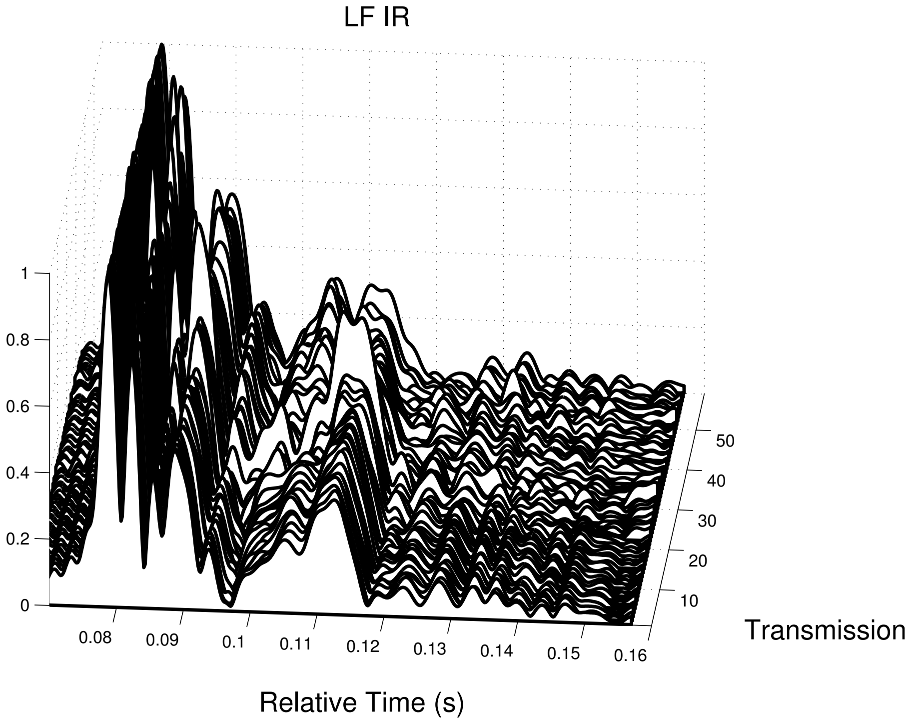


Figure 5.7: Low frequency band averaged impulse responses along transmissions.

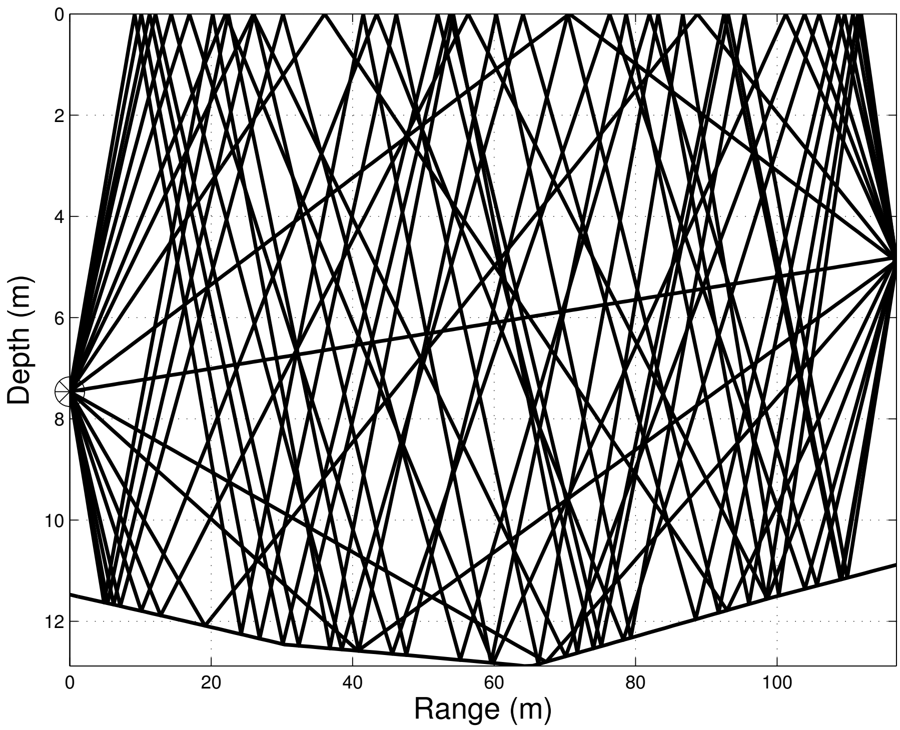


Figure 5.8: Eigenray calculations with TRACEO, the source position is indicated with an asterisk.

IR; the predicted temporal distribution of arrivals seems to last longer than observed. However, the fading of amplitudes is consistent with observations. TRACEO predictions for a sandy bottom (see Fig. 5.10, second from bottom) reveals only a fast vanishing of ampltidues due to bottom reflections; TRACEO prediction for basalt (see Fig. 5.10,

Table 5.1: Bottom properties.

Parameter	Units	Sand	Basalt
Density	kg/m^3	2.0	2.7
Compressional speed	m/s	1800	5250
Shear speed	m/s	600	2500
Compressional attenuation	dB/λ	0.1	0.1
Shear attenuation	dB/λ	2.0	0.2

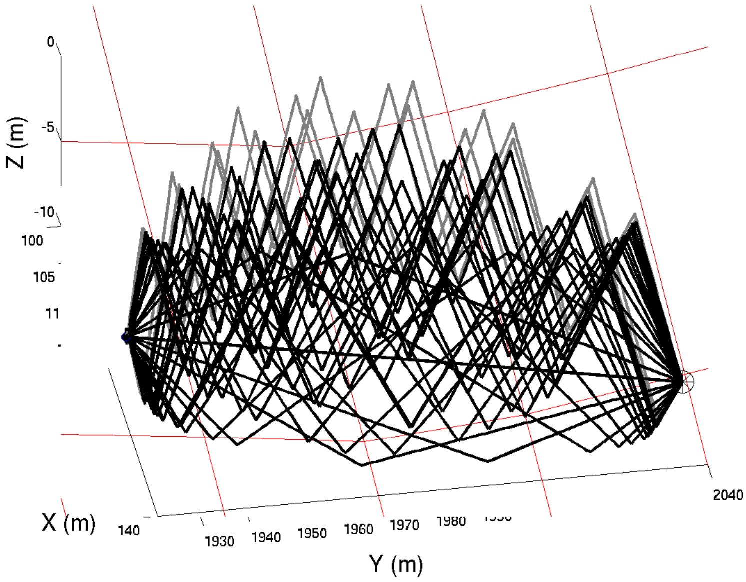


Figure 5.9: Eigenray calculations with TRACEO3D; ligther rays are those propagating over a harder bottom (the source position is indicated with an asterisk).

bottom) reveals amplitudes more intense than observed.

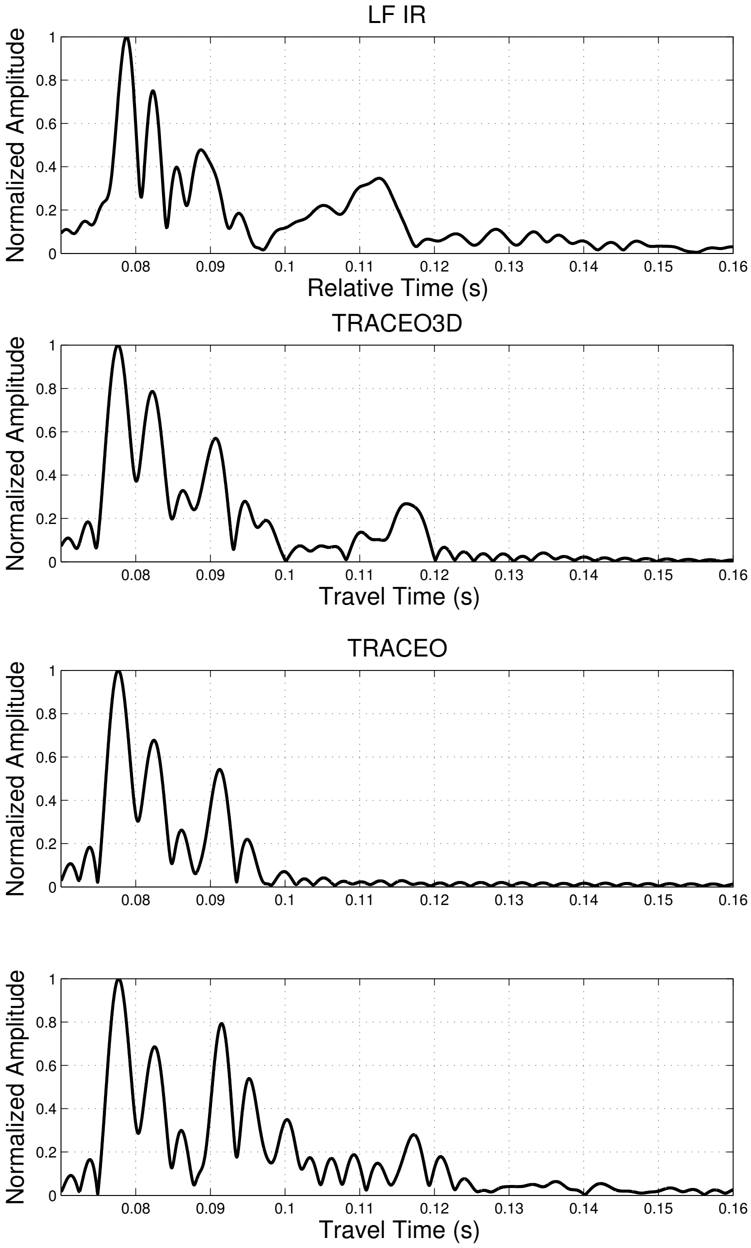


Figure 5.10: Comparison between experimental and modelled impulse responses: experimental impulse response (top); TRACEO3D prediction (second from top); corresponding TRACEO predictions for a sandy bottom (second from bottom) and for basalt (bottom).

Chapter 6

Conclusions

This report describes the SENSOCEAN'13 experiment carried out in the framework of the SENSOCEAN project, which main objective was to develop and test an vector sensor array system to estimate the sea bottom properties. The area of the experiment is characterized by a complex bottom with large areas covered by seagrasses, giving rise to diurnal variability due to the oxygen produced by the photosynthesis process. This variability was observed in the preliminary data analysis and it was shown that the vertical particle velocity estimated using the new developed short horizontal array emphasizes the bottom reflected energy, thus it has potential to filter out the direct energy (which not interacts with the bottom) and it allows to improve the bottom characterization. The variability of the environmental noise power observed suggests that is correlated with the photosynthesis process, what can be potentially used to passively estimate the O2 production. The impulse responses also suggested that 3D propagation effects are relevant when acoustic signals are transmitted close to the cliffs. Preliminary results show that impulse responses modeled by the 3D extensions of the newly developed ray code cTraceo are in better agreement with measured impulse responses than its 2D counterpart.

Bibliography

[1] W. Champenois and A. Borges, "Seasonal and inter-annual variations of community metabolism rates of a posidonia oceanica seagrass meadow," *Limnology and Oceanography*, vol. 57, no. 1, pp. 347–361, 2012.

[2] S. Mazzuca, M. Bjork, S. Beer, P. Felisberto, S. Gobert, G. Procaccini, J. Runcie, J. Silva, A. V. Borges, C. Brunet, P. Buapet, W. Champenois, M. M. Costa, D. D'Esposito, M. Gullström, P. Lejeune, G. Lepoint, I. Olivé, L. Rasmunsson, J. Richir, M. Ruocco, I. A. Serra, A. Spadafora, and R. Santos, "Establishing research strategies, methodologies and technologies to link genomics and proteomics to seagrass productivity, community metabolism and ecosystem carbon fluxes," *Frontiers in Plant Science*, vol. 4, no. 38, 2013.

Appendix A

Equipment Specifications

A.1 digitalHyd SR-1

Description	Specification
Diameter	5cm
Length (including Transducer)	32.5cm
Maximum Operating Depth	100m
Acquisition Sample Rate	50781 Hz and 101562 Hz
Real Sample Rate	50781.25 Hz and 101562.50 Hz
Programmable Gains	1x, 2x, 4x, 8x, 16x, 32x, 64x
18650 battery specs	2400mAh, 3.7VDC
Continuous Acquisition Autonomy (1 battery)	11 Hours
Standby Autonomy (1 battery)	about 14 days
Power Supply Voltage	3.0V-5.0V (DC)
Standby Current	4mA @ 3.3VDC
Acquisition Current	200mA @ 3.3VDC
Maximum Storage Device Capacity	128GBytes
Diameter 4PACK battery extension	8cm
Length 4PACK battery extension	45cm (incl. Transducer)
4PACK Battery Capacity	15000mAh, 3.7VDC
Continuous Acquisition Autonomy (5 batteries)	75 Hours
Standby Autonomy (5 batteries)	estimated 90 days

Table A.1: digitalHyd SR-1 Technical Summary

A.2 digitalHyd DA-1

Description	Specification
Diameter	4cm
Length (including Transducer)	20cm
Maximum Operating Depth	100m
Acquisition Sample Rate	50781 Hz and 101562 Hz
Real Sample Rate	50781.25 Hz and 101562.50 Hz
Programmable Gains	1x, 2x, 4x, 8x, 16x, 32x, 64x
Continuous Acquisition Autonomy	Unlimited - Cabled
Power Supply Voltage	12V (DC)
Maximum Storage Device Capacity	Unlimited - Cabled

Table A.2: digitalHyd DA-1 Technical Summary

A.3 Portable Acoustic Source Unit (PASU)

Table A.3: System Specifications

Item	Description
Power Supply	25,9 V Li-Ion Battery or external 12V power supply
Autonomy	7 hours with battery/infinite when external power supply connected
Maximum Safe Output Voltage	20 Vrms
Maximum Input Voltage (MIC)	400 mVrms
Maximum Input Voltage (AUX)	500 mVrms
Frequency Response	200Hz - 21KHz (-3dB)
Total Weight of Case	10kg
Box Dimension	45.9 x 32.7 x 17.1 (cm)
Acoustic Source Unit	Lubell LL916C
Max SPL Output Level	180dB re 1uPa @1m, 1kHz, 20 Vrms

A.4 Short Hydrophone Array and Dedicated Telemetry Unit

Type	High-frequency bottom moored acoustic vertical array.
Total maximum aperture	30 cm
Total Nr. of sections	1 (50cm)
Acoustic and Non-Acoustic section	1
Nr. of acoustic channels	8
Hydrophone Frequency range	100Hz -100 kHz
Sampling frequency	10, 52, 105 or 128 kHz
D/A conversion	24 bits
Total bit rate (max)	26 Mbit/s (8 channels)
Temperature sensors	1
Temperature sensor range	-5^{o}C to +35^{o}C
Temperature sensor accuracy	$\pm$ 0.1^{o}C
Array Weight (air/water)	2Kg/$\sim$1kg
Autonomy (min/max)	infinite if shore connected
Processor & Comm	
Processor	Analog Devices Blackfin BF518 (400MHz)
Data storage	infinite if shore connected
Ethernet	Cable - CAT5e
Throughput (Real)	0 - 90MBit/s
Communication range	100m cabled, extendable
System weight (+cables)	2kg (+8kg)
System Dimensions	
DTU	10cm diameter, 30cm length
SHA	10cm diameter, 50cm length

Appendix B

Experiment Log Book

```
All times in GMT

DATA/DTU - all data from DTU, sampling at start was 128kHz@24bits... During
experiment sampling was 52734Hz@24bits.  - 8 channel array

DATA/DA1 - all data from DA-1, sampling at 101562Hz@24bits, PGA gain was 1x
throughout the complete experiment.

DATA/SR-1 - data from the SR-1's, sampled at 50781Hz@24bits, duty cycle was
3minutes acquisition every 10 minutes.



---------------
2013/05/08

- Prepared Source with rope + weight 4 meters from bottom, hobo attached.

- DTU / SHA Array with hydrophone 1 at 4 meters from bottom, hydrophone 8 was top
at the top (4m + ~30cm).

- SR-1 attached 4meters from bottom and 6 meters from bottom.

12:30GMT
- started SR-1 Top 6m
- started SR-1 Bottom 4m

Fonte deployed @ ~8m ?
Hydrophone deployed @ ~10m

DA-1 deployed in STARESO port

19:40 started TX (test)
19:55 started TX - staresosequence of LFMs

---------------
2013/05/09

DTU deployed ~@11m depth, PGA gain 1x
```

```
CTD's
1 - on top of sandbank located between 12m and 15m depth
2 - next to DTU/SHA
3 - next to Source
4 - next to SR-1's

13:22 - DTU tested with PGA gain 2x
14:20 - SR-1 recovery
15:30 - mota de agua ao pe de SR-1
15:51 - Kayak next to SR-1
18:25 - Barco a sair do porto de STARESO

---------------
2013/05/10

03:15 GMT - Removed PASU charger
- DTU only with PASU battery
- Noise level better
- 2x12V@7Ah battery charged

03:30 GMT
- changed to 2x12V@7Ah battery
- First Light of Day

12:46/47 - High Speed Ferry
16:00 - SR-1 recovery
16:10 - Started DTU with CABLE
16:15 - SR-1 deploy with CTD @3m from bottom
17:10 - PASU from battery to external 12V DC/DC, started charger of PASU
~21:00 - New battery for DTU

---------------
2013/05/11

13:57 GMT, tested gain 2,4,8 on DTU
14:15 - fixed gain at 4x on DTU
14:55 - SR-1 recovery
15:05 - in lab with SR-1
15:34 - SR-1 redeployed
16:48 - removed 50Ah battery from DTU, attached 7Ah
16:49 - started DTU ACQ, gain 4x
21:03 - removed 7Ah battery from DTU, attached 50Ah
21:05:53 - started DTU ACQ

---------------
2013/05/12

06:27 - DA-1 reset in middle of sequence, DATA_DA1_132062734.WAV
11:33 - stopped DA-1, last file DATA_DA1_132113034.WAV
11:35 - started DA-1, DATA_DA1_132113506.WAV
14:28:00 - OFF DTU, battery change
14:29:39 - ON DTU, with 7Ah battery
15:00 - Source OFF, tried to recover with kayak, not possible.
Added TONES
19:30 - DTU failed - low battery ?,
19:35 - attached 50Ah battery

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```

```
2013/05/13

Measured water depth of DA-1
Mooring 1 - 2.3meters
Mooring 2 - 5.80meters (check Filme)

07:00 - DA-1 turned OFF, DA-1 pulled to new position
08:04 - started DA-1 ACQ
08:30 - Barco ao pe da fone / DA-1, barco ao pe de DTU, barco buscar SR-1's

Download dados SR-1's

6meters - OK - Data from 11/05 15:20 up-to 13/05 08:45
4meters - NOTOK - Data from 11/05 15:20 up-to 13/05 01:25 -  low battery ? memory card

09:42 - 2 Barcos a passar ao pe do DA-1
09:45 - 2 RHIB parados e a abalar p/ CALVI
09:54 - Mota de agua a passar, no entanto nao se viu na DA-1
10:10 - Source stopped, out of water, measured with 3meter cable above bottom, check H
12GMT - 14GMT - reboque fonte, check GPS track, fixed at 5m water depth, hobo was plac
12:46 - High Speed Boat
14:30 - Source restarted
14:30 - Boat in STARESO port.
14:37 - Boat leaving
14:37 - Stopped DA-1 (battery)
14:39 - Started DA-1
15:30 - Happag-LLoyd Cruise Ship leaving CALVI
15:50 - Boat ariving in STARESO
16:58 - DTU OFF (battery change)
16:59:30 - DTU ON
20:28:00 - DTU OFF (battery)
20:31:00 - DTU ON

PASU Failed during the night @ ~23:00GMT

---------------
2013/05/14

PASU OFF, Military operations and training near and in STARESO.

07:30 - Barco commandos por cima da DA-1
07:41 - STARESO RHIB leaving
08:10 - Heli near DTU
08:46 - Boat passing outside
09:13/14 - DA-1 stopped, restarted
15:10 - PASU started, added 3.25A PTC Fuse to DC/DC
15:33 - Musica Grandola
15:40 - PASU back to Normal TX (LFM's + Comms + Tones)

---------------
2013/05/15

05:05 - DA-1 OFF, battery failed
09:00 - DA-1 recovered for packing.

12:00 - 13:50 Recovery of all equipment

SR-1 6m - DATA from 13/05 12:00 up-to 14/05 22:23 - Low battery LED was on
```

SR-1 4m - DATA from 13/05 11:00 up-to 15/05 10:50 - Low battery LED was on