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Universidade do Algarve

EDELWEIS 2014

Acoustic Oceanographic Buoy Data

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Abstract	This report describes the data acquired with two Acoustic Oceanographic Buoys (AOB21 and AOB22) during the EDELWEIS'14 sea trial, that took place aboard the R/V NEREIS from August 4 -11, 2014, off the west and south coast of Zakynthos I., Greece.
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Foreword and Acknowledgment

This report presents preliminary results obtained during the EDELWEIS'14 sea trial and provides the data acquired with two Acoustic Oceanographic Buoy (AOB) systems. The EDELWEIS'14 sea trial took place in the Ionian Sea, to the west and south of the Island of Zakynthos, Greece, along the Hellenic Trench, and in the period between August 4 and August 11, 2014.

The authors of this report would like to thank:

- all the personnel involved and in particular Sylvia Frey and R/V Nereis crew,
- the scientist in charge Alexandros Frantzis,
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- Manolis Sifalakis for his suggestions and comments included in this report,
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Abstract

The long term goal of this initiative is to contribute to the conservation of sperm whales by means of developing an effective detection and localization system, which should be able to feed alert information into navigation systems for ship - whale collisions avoidance. The EDELWEISS'14 sea trial, which was an initial step toward this goal, aimed at acquiring (a) acoustic data from a pinger (serving as an emulation of a sperm whale) in configurations compatible with sperm whale behavior, and (b) actual sperm whale vocalization acoustic recordings, in order to test and validate source localization algorithms.

Weather conditions in the area limited the period and coverage zone for effective work as well as the number and duration of acoustic deployments. After several long runs, up and down along the west coast of Zakynthos Island no sperm whales could be detected and therefore activities concentrated on simulating sperm whale dives using the acoustic pinger. Receptions were made with two Acoustic Oceanographic Buoys (AOBs) during three days, from which data sets were collected and are described in this report. The data show well defined received pings for relatively long periods of time and encompassing a variety of geometries both in terms of source - receiver distance and source depth over deep water (1000 m or more) areas. Although some technical problems arose in the GPS of one of the AOBs and synchronization problems in the other buoy, the data show the potential for further processing and algorithm testing as long as no precise localization is required.

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Chapter 1

Introduction

Among the existing panoply of instrumentation for cetacean research, acoustic systems play a particular role due to their capacity for distant vocalization detection, localization and, in some cases, animal identification. Depending on cetacean size, sound level and propagation conditions, detection ranges up to 10 - 15 miles are possible in practice. Animal localization is difficult with simple towed systems with a single or only a few hydrophones, and identification is seldom achievable for social groups where individual sounds frequently overlap. The capacity of these simple systems is very similar to those of early sonars and their performance very much depends on the capacity and training of the listener who, in many cases, may give an estimate of animal range, its approximate bearing and, in cases, an estimate of the number of animals in the group.

Sperm whales normally gather in social communities of 10 to 15 individuals along feeding areas as for example those frequently found along the Hellenic Mediterranean Trench, off the coast of Zakynthos I., in Greece. Since that area is also a busy cargo shipping route, collisions between ships and animals is often unavoidable, with disastrous effects for the latter. The EDELWEIS initiative is an international effort[1], supported by OceanCare, that aims at establishing the preliminary plans for the development of an effective whale detection and localization system, which will be able to feed information into navigation systems for ship - whale collision avoidance. The EDELWEISS'14 sea trial was an initial step toward this goal, aiming at acquiring (a) acoustic data from a pinger to test and validate source localization algorithms in configurations compatible with sperm whale behavior, (b) accessory environmental data required for acoustic processing and, if possible, (c) actual sperm whale vocalization acoustic recordings.

The objectives and the set up of the sea trial took place according to the test plan. The generic areas of interest are presented in Figure 1.1. Most work concentrated in areas A, for possible sperm whale listening and in B1 (as a sheltered area) for sperm whale emulation activities using the acoustic pinger. Weather conditions in the area severely limited the period of effective work, as well as the number and duration of acoustic deployments. Acoustic equipment included two Acoustic Oceanographic Buoys (AOBs) equipped with 8-hydrophone vertical line arrays, and an on-line acoustic pinger equipped with own depth and temperature recorder, several self recording acoustic sensors, a towed sperm whale listening device array, and auxiliary CTD.

This document aims at providing, as much as possible, a complete description of the

[1] partnership formed by University of Basel (Switzerland), FORTH (Greece), CINTAL (Portugal) and Pelagos Cetacean Research Institute (Greece).

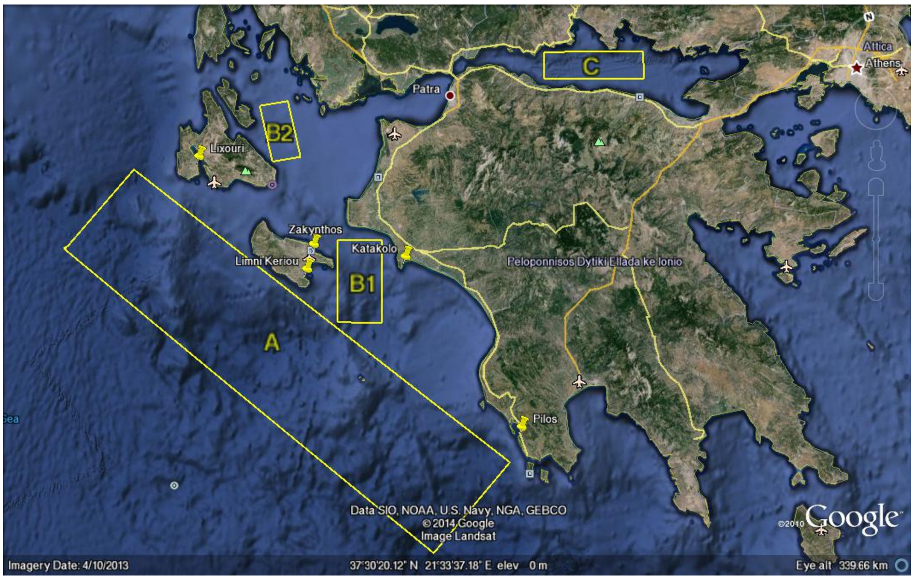

Figure 1.1: *EDELWEIS'14 working areas: the work concentrated in areas marked A and B1.*

various AOB datasets acquired during the EDELWEIS'14 sea trial, accessory non-acoustic data, and accompanying relevant information such as ship/buoys/pinger position, temperature profiles, bathymetry, and other concurrent data. The companion DVD contains all accessory environmental data sets and respective master routines for data manipulation and pre-processing. This report is organized as follows: section 2 provides a short description of the AOB2 specification both from the hardware and software perspectives; section 3 provides a log of the sea trial itself with various archival data sets (bathymetry, geometries and environmental information) recorded during the experiment; section 4 is a description of the acoustic data captured by the AOBs as well as all relevant information regarding signal transmission and preliminary results from the received data. Finally, section 5 concludes this report by giving some hints about most interesting sets, for posterior processing.

Chapter 2

The Acoustic Oceanographic Buoy - version 2 (AOB2)

The concept of the AOB platform exists since 2002 when, during the LOCAPASS project[1], a preliminary version, AOB1, was developed (see AOB1 report [1]) for more details). The AOB1, was tested during the Maritime Rapid Environmental Assessment (MREA) sea trial in 2003 off the Italian coast, north of Elba I. [2] and in 2004 off the Portuguese coast, approximately 50 km south from Lisbon [3]. The next generation of that platform, is the AOB2 hardware and software system, which is described in [4], and which was used during the the EDELWEIS'14 sea trial. Here only a brief description of AOB2 is given (section 2.1) in relation with the necessary characteristics for data processing. Apart from small details such as float type, color and so on, the two AOB2 buoys, which were deployed, are exactly the same in all respects but the sensor array. A detailed sensor array description is given in section 2.2 below.

2.1 AOB2 generics

The AOB2 is a light acoustic receiving device that incorporates the required 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 AOB2, in terms of size, weight and autonomy, are similar to those of a standard sonobuoy with additionally capabilities for local data storage, processing and online data transmission. Data transmission is ensured by seamless integration into a wireless LAN, which allows for network data transmissions within a range of up to 10/20 kms. Electronics and batteries are housed in two separate containers: (a) the battery container that houses a high performance Li-ion 15V / 48Ah battery pack, capable of operating the AOB2 more than 12 hours and weighting only 4.5 Kg; (b) the electronics container that hosts a PC104+ stack with both commercial off the shelf (COTS) and proprietary electronics boards specifically designed for the needs of the AOB2. The electronics stack also has a OEM GPS and a WLAN amplifier for the communications with the base station. The details of the electronic and mechanic parts are given in [5], while a brief description of the receiving arrays and data acquisition systems are given in the next two sections.

[1]Passive source localization with a random network of acoustic buoys in shallow water (LOCAPASS), funded by the Foundation of Portuguese Universities.

2.2 AOB2 receiving array

The main differences between the two AOBs that were deployed during the EDELWEIS'14 experiment are in the sensor arrays, since one array has 8 non-equispaced hydrophones and the other has 8 equispaced hydrophones. Thereafter we will distinguish references to them as AOB21 (non-equispaced) and AOB22 (equispaced). The two hydrophone arrays share the fact that they are light systems composed of dedicated balanced twisted pairs for each hydrophone and a power line attached to a 5 mm kevlar rope enveloped in a air fairing sleeve to maintain all wires together (see figure 2.1(a)). This system has a reduced water drag and allows for easy field maintenance when and if necessary. The hydrophone spacing and depth for the two arrays when deployed at sea is shown in figure 2.1(b). The

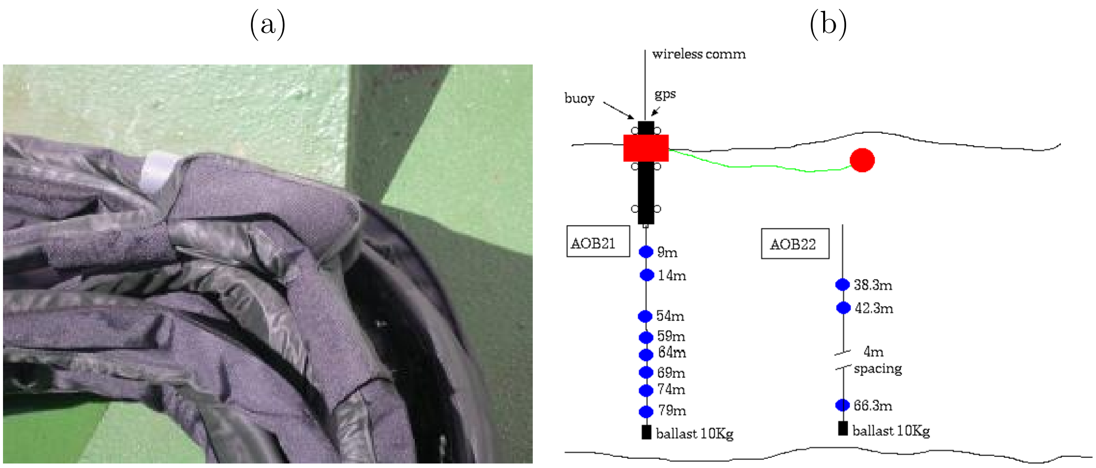

Figure 2.1: *Acoustic Oceanographic Buoy - version 2: receiving array hydrophone (a) and array structure for AOB21 and AOB22 (b).*

AOB21 array has 8 hydrophones oddly distributed in the 70 m total acoustic aperture, at depths of: 10, 15, 55, 60, 65, 70, 75 and 80 m. The ensemble hydrophone - pre-amplifier was manufactured by Sensor Technology (Canada). The hydrophone sensitivity is -193.5 $\pm$ 1 dBV re 1 μPa 20° C for both broadside and endfire up to 18 kHz and with a flat frequency response from 1 Hz up to 28 kHz. The pre-amplifier is a low noise differential amplifier that has a constant gain of 40 dB in the whole frequency band of interest between 10 Hz up to 50 kHz. Its noise has been measured to be smaller than 20 nV/$\sqrt{Hz}$. The AOB22 array has 8 hydrophones equally spaced at 4 m from the first hydrophone, which is located at 37.3 m from the bottom of the buoy container, totaling approximately 38.3 m from sea surface. The hydrophones are manufactured by Sensor Technology (Canada) and are the same for both arrays. The pre-amplifier of the AOB22 array was manufactured by Cintal. In order to obtain some surface wave decoupling the AOB21 array has been fitted with a set of bungees between the topmost attachment point of the array and the bottom of the buoy container. Measurements of the array oscillation made in the past has not confirmed the effectiveness of this system.

2.3 AOB2 data acquisition

The data acquisition for EDELWEIS'14 was performed by a dedicated ADC board serially connected to a DSP board. The ADC board is an LTC1864 model from Linear Technology based on successive approximation with 16 bits, four modules and a total aggregate frequency per module of 250kHz. The anti-aliasing filters are 8 pole low-pass analog Chebyshev implementations with a cutoff frequency of 16 kHz. As explained above due to the pre-amplifier constant low gain of 40 dB when working in the high frequency range of the bandwidth, it is often necessary to adapt the ADC sensitivity according to the source - receiver distance. The ADC has an internal variable gain setting allowing for configurable input sensitivities of ±1, ±2, ±5 and $\pm$ 10 volts. The gain setting of ±1 volt was used throughout the EDELWEIS'14 trial in both AOBs. The sampling frequency is derived by a high precision timer board that itself gets the synchronization tops for its internal clock from the GPS 1PPS signal.

2.4 Timing

The time system adopted throughout the experiment is UTC, therefore Greek local time -3 hour. For further simplicity in time referencing, UTC time is converted to Julian UTC time which uses a continuous day numbering from January 1 of each year and then day time as a fraction of the day. A WARNING regarding the convention used for converting actual calendar UTC date and time to UTC Julian time: There are two possibilities, one is to consider January 1st as "day 1", and the other is considering January 1st as "day 0". In this data report and in agreement with the master clock on board of AOB2 the former has been used. As an example, day August 5, 2014 15:00 local Greek time will be coded as Julian time 217.5 UTC (in practice the routine jd.m - see DVD in attach - should be used for the conversion and a -3 hours shift from local Greek to Julian UTC time).

Chapter 3

The EDELWEIS'14 sea trial

3.1 Generalities and sea trial area

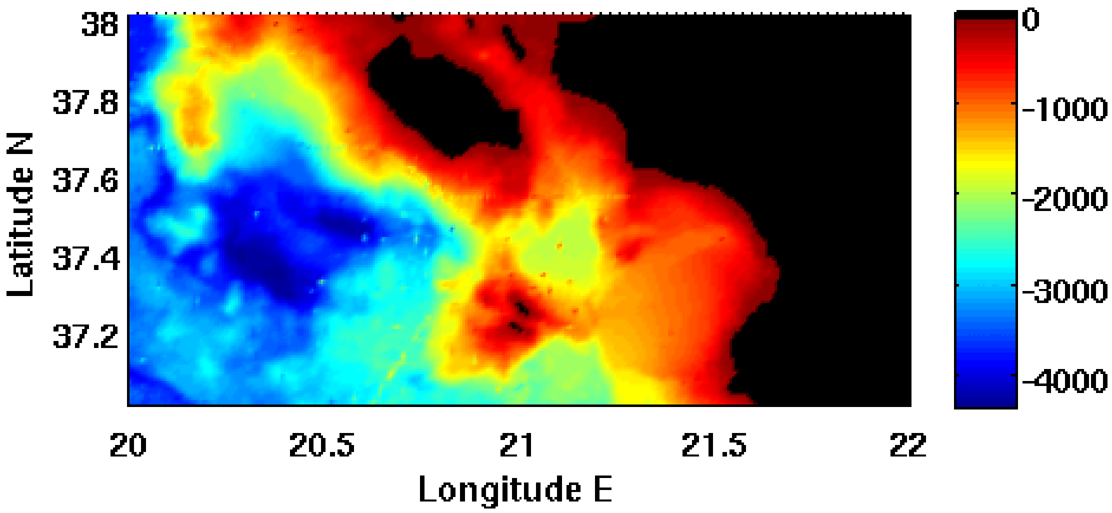

Figure 3.1: *EDELWEIS'14 experiment area off the west and south coast of Zakynthos Island as drawn from Sandwell and Smith topography database with a 30sec-arc resolution.*

The bathymetry of the selected area for the EDELWEIS'14 sea trial is shown in figure 3.1 and corresponds approximately to the A and B1 boxes of figure 1.1. Unfortunately, there is no better (higher resolution) bathymetry information than that of the general topography maps provided by Sandwell and Smith 30sec-arc resolution, which is around 900 m terrain resolution. This resolution may be sufficient for general drawing of navigation paths during the sea trial but is clearly insufficient for drawing detailed bathymetry maps for acoustic propagation and data processing.

The weather in this area is generally moderate dominated by north-northwest winds sometimes up to 10/20 knots, and with almost no tidal influence in this period of the year. The sea currents follow a variable pattern, but which in general tends to circulate north-to-south, either across the channel between Zakynthos and the Peloponnese, or along the western coast of the island to the Adriatic Sea (north), or to eastern Mediterranean (south). During the testing period the sea was generally calm in the southern side with sea state 0 or 1 in the morning, increasing to 2 in the afternoon/evening, and a bit more agitated at the western side going up to sea state 3 in some days during the afternoon. There were no direct measurements of currents, waves, or bottom properties during the experiment. At large scale, the bottom structure of the area is largely dominated by the subduction zone of the European and Asian plates that create the Hellenic Trench itself with the deepest point in the Mediterranean sea (the Calypso Deep) to the southwest of the port of Pylos, right at the southern tip of the work area A. There is no other historical or archival data about the area.

3.2 Ground truth measurements

As mentioned earlier water-column measurements were performed during EDELWEIS'14 including standard CTD casts carried out with a hand held RBR Concerto CTD, a single temperature point measurement obtained with an RBR TD device co-located with the Online pinger, and a 12-sensor thermistor string co-located and drifting with the AOB22. While CTD casts were punctual in time and space, the measurements made with the TD recorder lasted throughout the entire deployment of the pinger and moved along space (over time) with it. Meanwhile, the AOB thermistor chain also covered a certain area along the array drift.

3.2.1 CTD casts

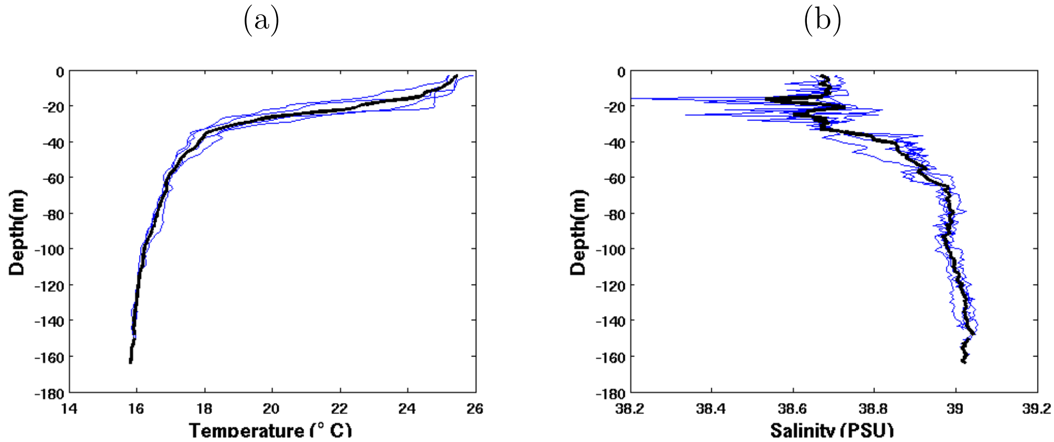

Figure 3.2: *recorded CTD casts from R/V Nereis using the RBR Concerto hand-held CTD: temperature (a), salinity (b). In all cases the black thick curve represents the mean profile.*

Four CTD casts were performed with the hand-held RBR Concerto CTD: one on August 5 (at 10:18), two on August 6 (at 9:53 and at 13:26) and one on August 9 (at 10:24). These casts were performed generally before and/or after deploying the Online pinger. The data are shown in figure 3.2 (temperature (a), and salinity (b)), and in figure 3.3[1] (dissolved O_2 (a), dissolved O_2 concentration (b), and sound velocity (c)). In all plots the black thick curve represents the mean profile. A pronounced thermocline of 17°C can be

[1]the RBR Concerto CTD was fitted with an additional dissolved oxygen probe which results are also shown for completeness.

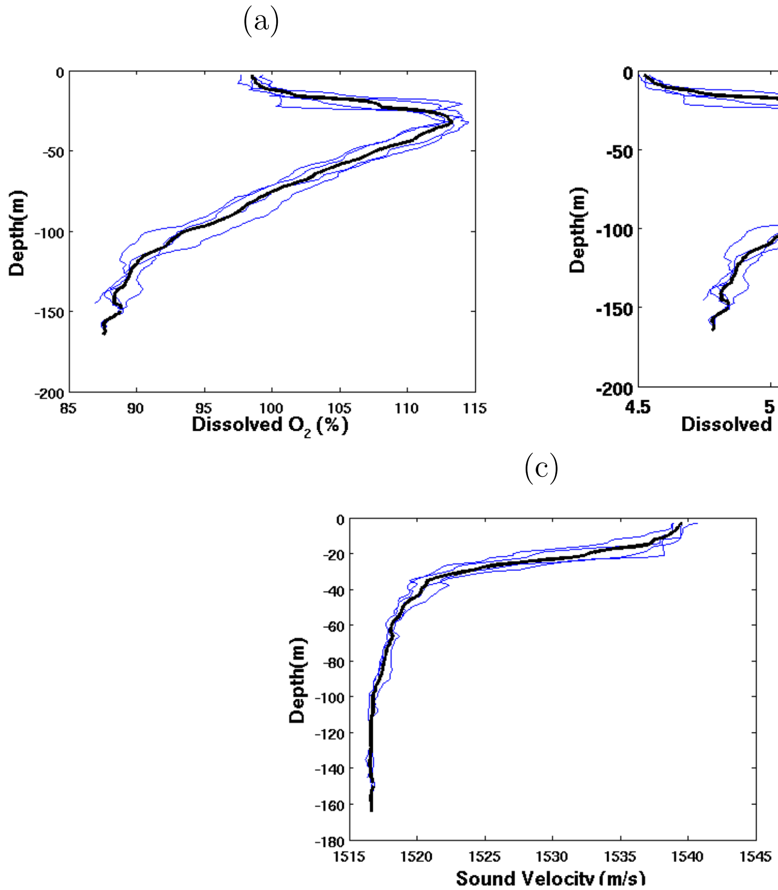

Figure 3.3: *recorded CTD casts from R/V Nereis using the RBR Concerto hand-held CTD: dissolved O_2 (a), dissolved O_2 concentration (b) and calculated sound velocity (c). In all cases the black thick curve represents the mean profile.*

observed extending down to 40 m depth, with a relatively small variation over the whole data set, in the period and area of interest.

3.2.2 Temperature - Depth recordings (TDR)

The temperature sensor of the RBR TDR device co-located with the pinger source enabled to obtain temperature time and space readings as the source was towed along the experiment geometry. Due to the small weight of the pinger, it oscillated up and down in the water column as the R/V Nereis moved faster or slower, effectively obtaining water column temperature profiles. The data reconstructed profiles are shown in figure 3.4. These are not typical CTD casts but rather represent a sampling of the water column temperature as a consequence of multiple oscillations along time and space in a similar fashion as a Moving Velocity Profiler (MVP). One can notice slight temperature fluctuations on the multiple casts due to micro-variations along time and space, which are particularly visible in the shallower part of the profiles.

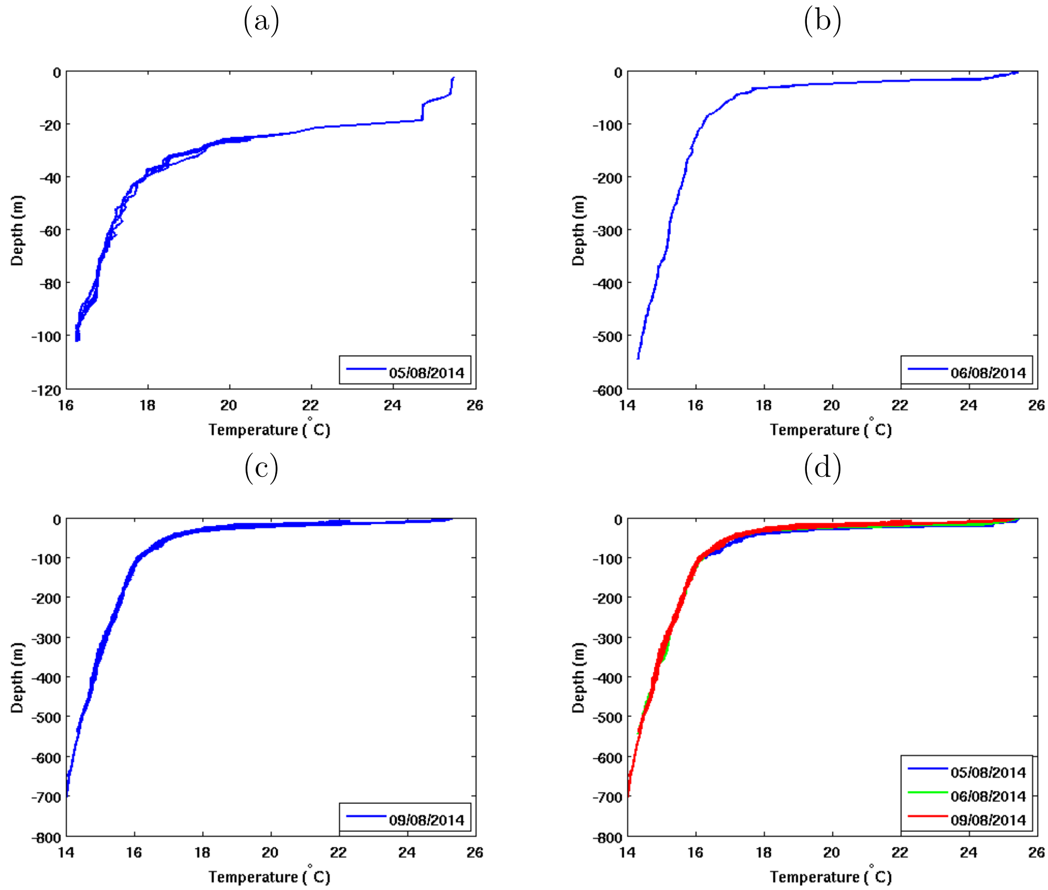

Figure 3.4: *recorded temperatures with TD recorder co-located with Online pinger during up and down geometry tow on: JD 217 (a), JD 218 (b), JD 221 (c) and all casts superimposed in a single plot (d).*

3.2.3 AOB thermistor string

The AOB22 was fitted with a digital array of 12 temperature sensors. These temperature sensors were located at the following depths: 6, 14, 22, 30, 34, 38, 42, 46, 50, 54, 58 and 62m. The data recordings are shown in figure 3.5. Plots (a) to (c) correspond to deployment days 217, 218 and 221 respectively, while plot (d) shows the mean profiles computed for each day.

3.2.4 Empirical Orthogonal Functions

It is common to obtain the orthogonal decomposition of the water column temperature data according to

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

where $\bar{T}(z)$ is the mean temperature profile, α_i are the EOF coefficients, $U_i(z)$ are the EOF's and H is the water depth. For calculation purposes the maximal depth is taken equal to the least maximum depth of each profile along the whole profile set. The TDR had only three casts with variable maximum depths and was not used for the EOF calculation. The EOF calculation for the CTD and thermistor chain (TC) casts are shown in figure

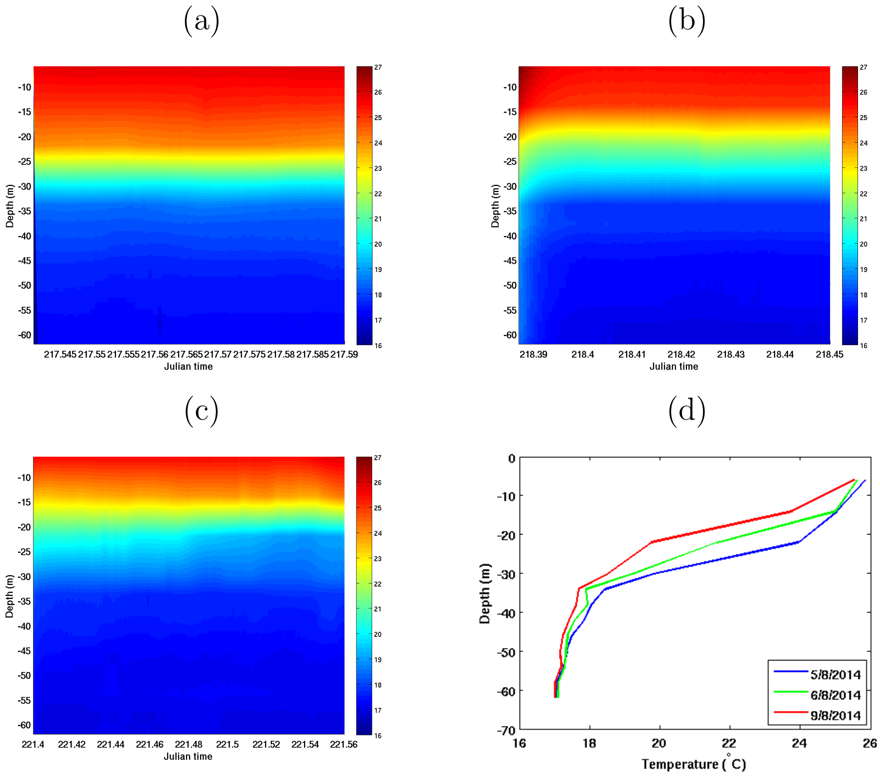

Figure 3.5: *AOB22 thermistor string data for deployment days JD 217 (a), JD 218 (b) and JD 221 (c); mean temperature profiles are shown for the three days on plot (d).*

3.6: the correlation matrices for CTD and TC are shown in (a) and (b), respectively, the EOFs are shown in (c) for CTD (left) and TC (right), and finally energy amount per EOF is shown in plot (d) for CTD (up) and TC (down). These data sets seem to be driven by a single EOF which is a sign of a deterministic nature. This could be the case of the CTD's due to the reduced number of measurements (only four casts) but it is more difficult to infer in the case of the thermistor chain that has a large number of recordings (over 20.000). EOFs show a similar pattern for both sets, despite taking into account that they correspond to different water column spans.

3.3 Deployment geometries

AOB21/2 deployments during EDELWEIS'14 where all in free drifting configuration as reported in table 3.1. The experiment type (objective) and acoustic transmissions / events are also mentioned. The GPS of AOB21 had several periods of malfunction. For

Year day	Julian	AOB2	Experiment	Transmissions
Tue August 5	217	1 & 2	eng. test	Online pinger
Wed August 6	218	1 & 2	short drift	Online pinger
Sat August 9	221	1 & 2	Event I	Online pinger

Table 3.1: *Acoustic Oceanographic Buoy (AOB) deployments during EDELWEIS'14.*

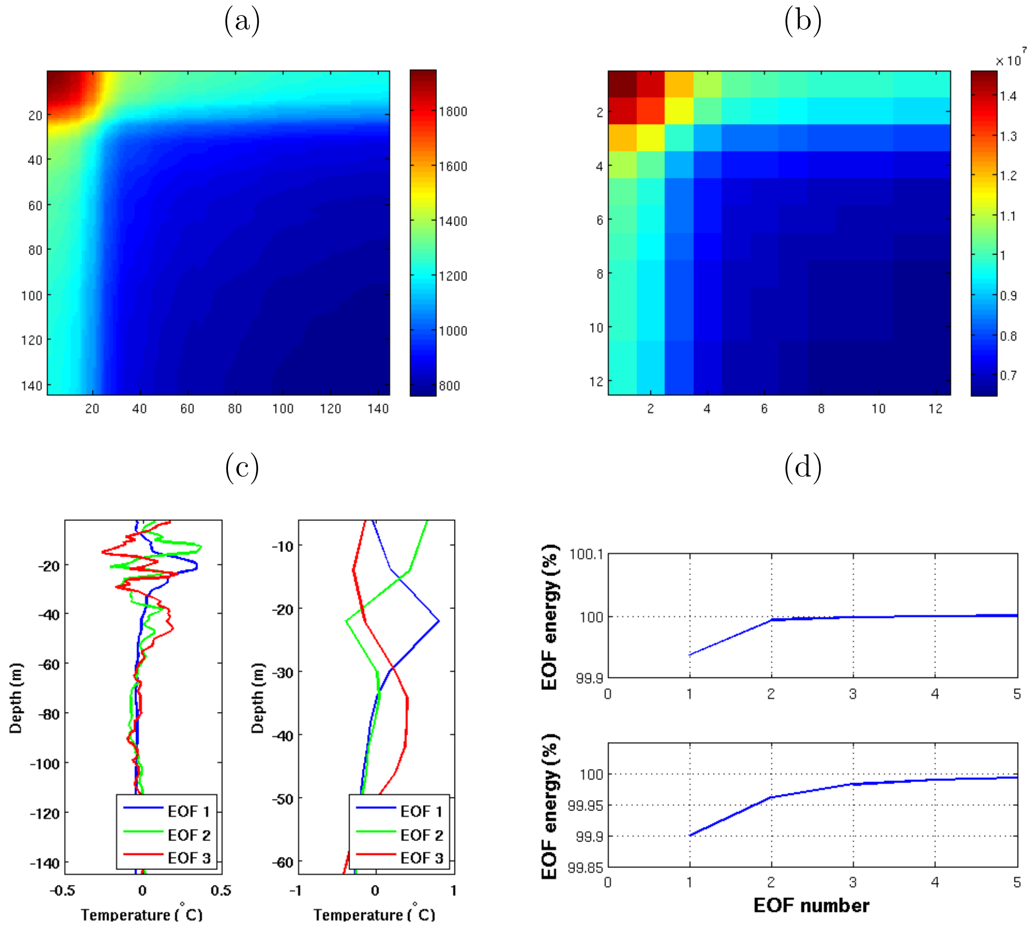

Figure 3.6: *empirical orthogonal functions (EOFs) for the CTD and TC data sets: correlation matrices for CTD and TC in (a) and (b), respectively; EOFs for CTD (c-left) and TC (c-right) and EOFs energy for CTD (d-up) and TC (d-down).*

this reason only the GPS track of AOB22 will be reported and used for source - receiver range estimations (see section 3.3.4). To facilitate the readability of the plot the data are displayed only during the acoustic pinger operation. The depth of the acoustic source Online pinger is reported in section 3.3.5.

3.3.1 AOBs drift during day 217 (August 5, 2014)

The AOB22 drift during JD 217 is shown in figure 3.7 (thick red line), along with the R/V Nereis GPS track (black line), as well as the CTDs and AOB deployment and recovery positions (red square marks). This day was used for engineering tests and so the area was close to the Zakynthos Island and relatively shallow (depths below 500m). The drift of both AOB21 and AOB22 was due North and nearly parallel as it can be seen from the deployment - recovery positions. Two CTDs were taken, one at each end of the approximate North - South track.

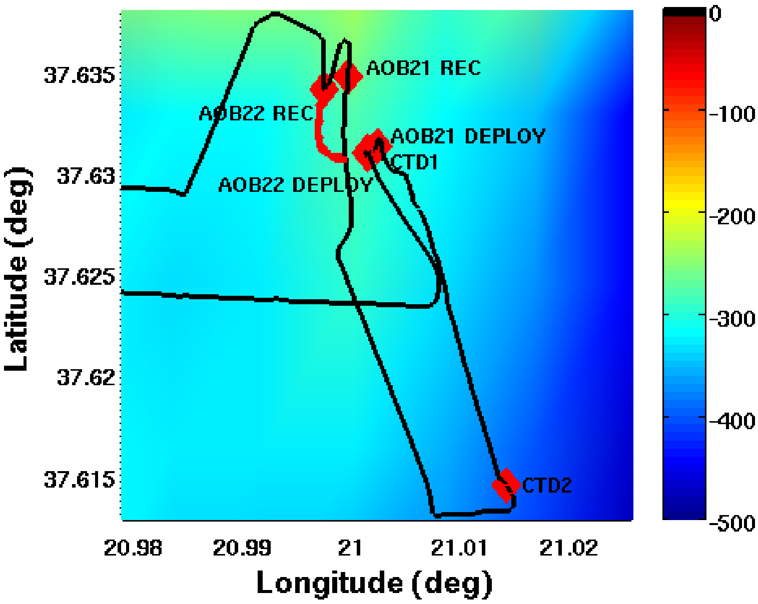

Figure 3.7: *Day 217 (Aug 5, 2014): GPS estimated AOB22 drift (thick red line) and R/V Nereis track (black line), CTD1, CTD2, AOB21 and AOB22 deploy and recovery positions (red square marks).*

3.3.2 AOBs drift during day 218 (August 6, 2014)

The AOB22 drift during JD 218 is shown in figure 3.8 (thick red line), together with the R/V Nereis GPS track (black line), and also the CTD and AOBs' deployment and recovery positions (red square marks). This day an attempt was made to perform Event

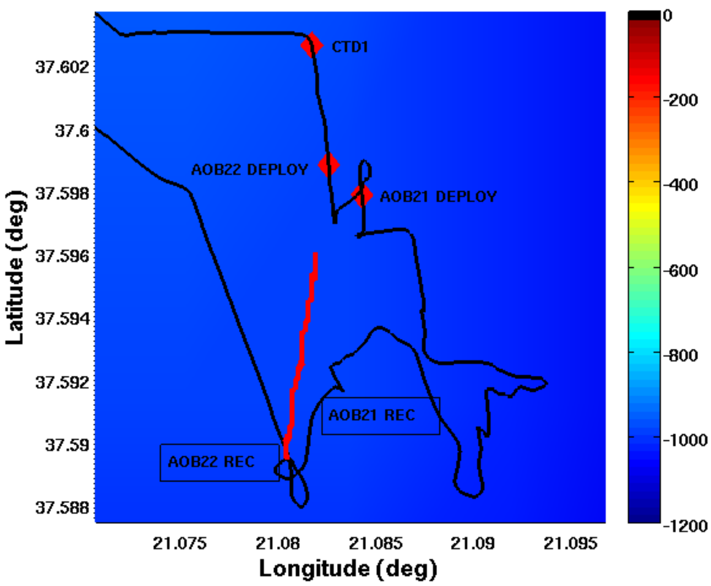

Figure 3.8: *Day 218 (Aug 6, 2014): GPS estimated AOB22 drift (thick red line) and R/V Nereis track (black line), CTD, AOBs' deploy and recovery positions (estimated).*

I, but the weather rapidly deteriorated and the experiment was aborted. The deployment took place in an area of much deeper water than in the previous day, to the south east of Zakynthos in the open channel to the Peloponnese. The AOBs were deployed at short distance from each other. A considerable time elapsed until the pinger deployment which explains why the red line representing the AOB22 track starts well away from the deployment position (track is shown only during acoustic transmissions for readability). The drift of both AOB21 and AOB22 was due South. One CTD was made before the deployment of the AOBs. Since the exact moment of the AOB recovery was not GPS marked, the approximate locations are shown by the respective labels and enclosed in a text box.

3.3.3 AOBs drift during day 221 (August 9, 2014)

The AOB22 drift during JD 221 is shown in figure 3.9 (thick red line), together with the R/V Nereis GPS track (black line), CTD and AOB deploy and recover positions (red square marks). Event I, was performed during this day. The two AOBs were deployed

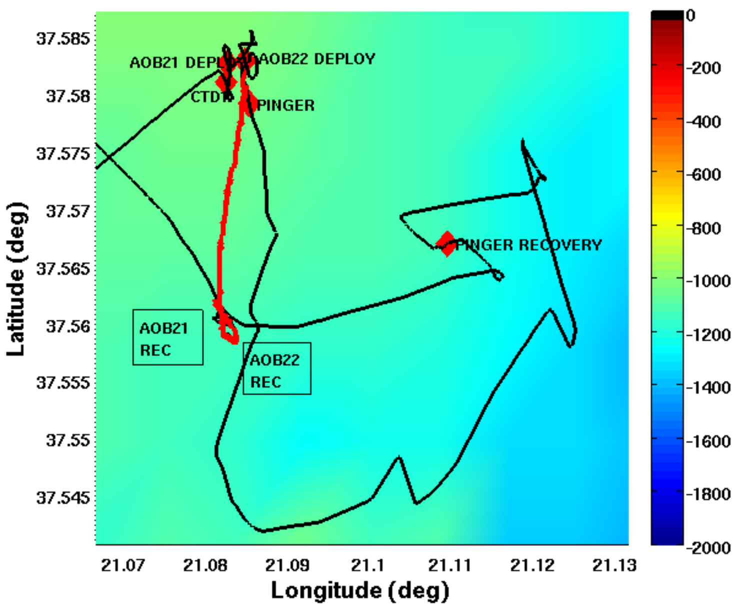

Figure 3.9: *Day 221 (Aug 9, 2014): GPS estimated AOB22 drift (thick red line) and R/V Nereis track (black line), CTD, AOBs deploy and recovery positions (estimated).*

in the deeper waters of the Zakynthos - Peloponnese channel (water depth $\approx$ 1000m). The AOBs were deployed at short distance from each other and Event I was performed according to the Test Plan, as R/V Nereis was slowly drifting south and making stations along an arc-shaped transect to the east (see Fig. 3.9). In the mean time the AOBs experienced a fast drift south, possibly pushed by the current and surface-induced waves due to the North wind. Five stations can be clearly seen as periods where the movement track is interrupted by a period of south drift: two short periods on the south track and three others during the arc-shaped track to the east. Source - receiver distance and time of occurrence of these stations can clearly be pinpointed from the respective plots of sections 3.3.4 and 3.3.5. The long arc to the east was eventually interrupted since with the AOB drift, R/V Nereis had crossed the AOB's line as foreseen in the test plan. The

AOBs were recovered under strong wind conditions evolving from 4 to 5 Beaufort. Since the exact moment of AOB recovery was not GPS marked, the approximate locations are shown by the respective labels and enclosed in a text box.

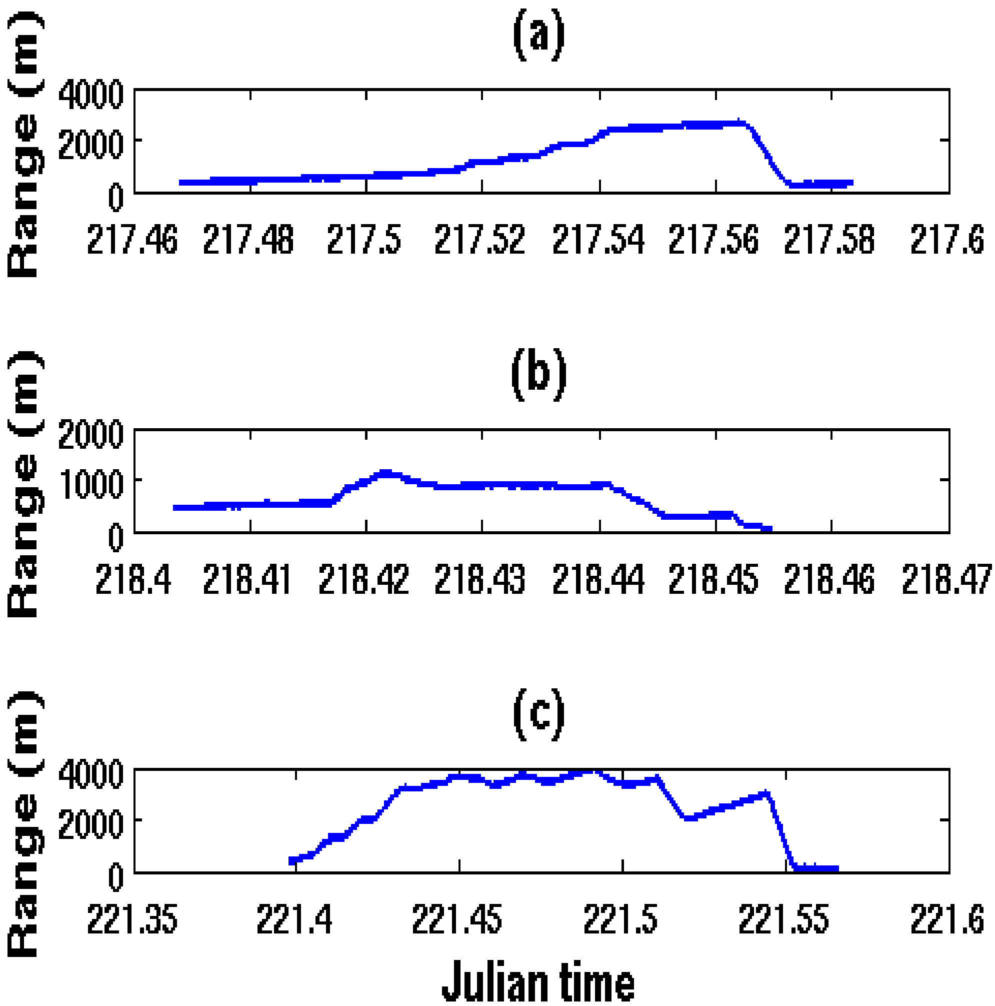

Figure 3.10: *estimated source - receiver range as the GPS measured distance between R/V Nereis and AOB22 during JD 217 (a), JD 218 (b) and JD 221 (c).*

3.3.4 Source - receiver range

The drift plots shown in the previous sections were used to obtain an estimate of the source - receiver range. As explained above only GPS data from AOB22 will be used as receiver position while source location will be taken by the R/V Nereis position, which, as we know, is only a very rough estimate of the Online pinger's location. The error comes from the fact that the pinger was relatively light in the water and a long cable of several hundred meters to 1km in some occasions resulted in a considerable drag to very shallow depths when the boat was moving. These pinger depth oscillations can be clearly seen in the plots of the next section. The estimated R/V Nereis - AOB22 ranges are shown in Figure 3.10 for day JD 217 (a), JD 218 (b) and JD 221 (c). The start time is approximately synchronized with the start time of the pinger transmission while the end time in these plots is close to the buoy recovery time (and so, well beyond last acoustic transmission). The longest range was attained during day JD 221 with nearly 4000m. At the end of each run there is an abrupt range variation with a rapid decrease, normally coinciding with the pinger recovery and closing range for AOB22 recovery.

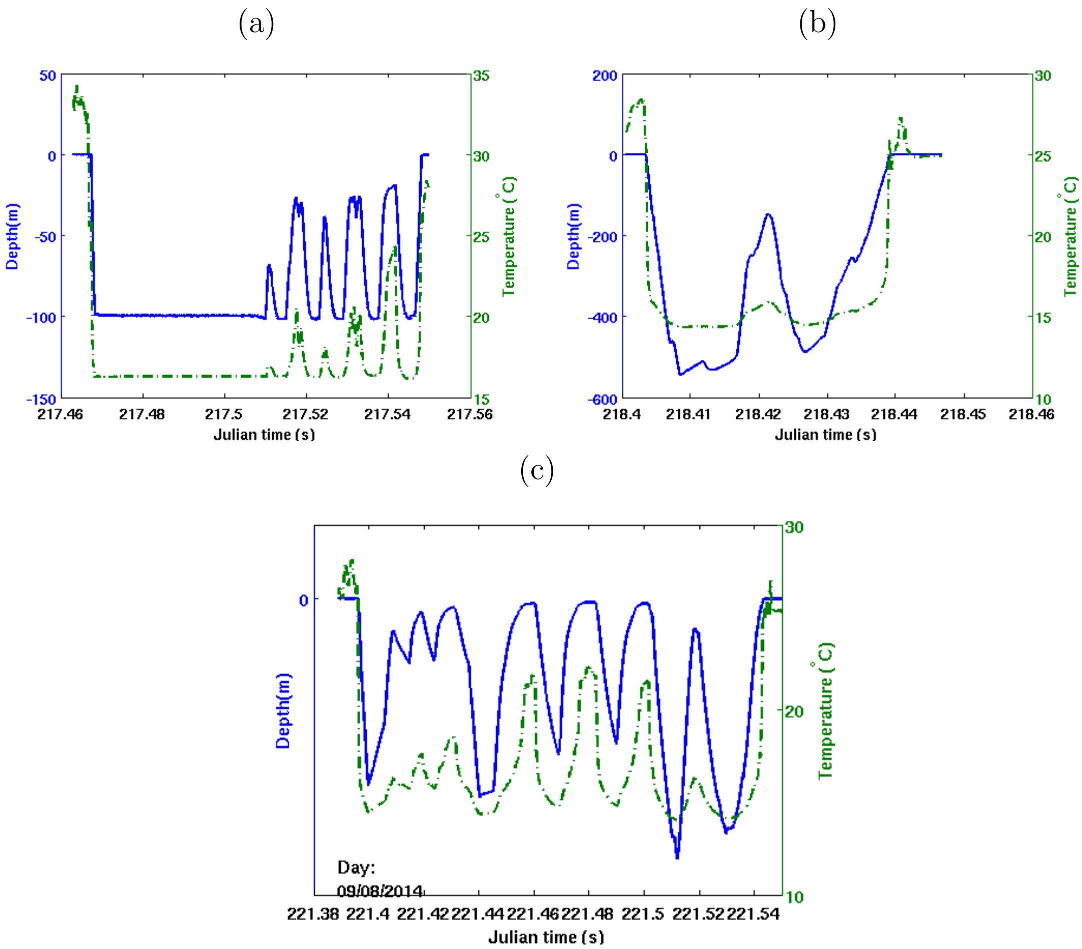

Figure 3.11: *Online pinger depth and temperature recordings obtained with the TDR self-recorder during JD 217 (a), JD 218 (b) and JD 221 (c).*

3.3.5 Online pinger (source) depth

Active signals were transmitted from R/V Nereis with an Online pinger that had an attached RBR Temperature-Depth self-recorder (TDR). Temperature profiles obtained with the TDR were already discussed in section 3.2.2. The Online pinger depth data obtained with the TDR are reported in Figure 3.11, for JD 217, JD 218 and JD 221 in (a), (b) and (c), respectively. In day JD 217 the pinger was deployed at 100m depth (100m cable) and remained relatively stable in depth for some time. Thereafter boat movement caused various depth jumps up to as shallow as 20m depth with the corresponding oscillations in water temperature. As explained above, in day JD 218 the deployment was much deeper with a 600m long cable. R/V Nereis moved for a while with the corresponding elevation of the pinger, before the experiment was aborted and the pinger was recovered. JD 221 was the longest deployment and also the most interesting since it corresponds to Event I as described in the test plan. A cable scope of 600m in the first 3 stations and 1000m in the remaining stations was deployed, while strong depth oscillations (up to 25m depth) can be seen at several occasions during the pinger tow. The temperature curve very closely matches these depth oscillations, effectively performing a sampling of the water column along range and time.

Chapter 4

Acoustic data

During EDELWEIS'14 both passive acoustic signals from sperm whales and active acoustic signals from an underwater source were expected. Unfortunately, no sperm whales were to be spotted during the extensive trial survey and therefore the acoustic testing was dedicated to the acoustic source emitted signals, as described below.

4.1 Emitted signals

Active signals were transmitted from a preprogrammed Online pinger towed by R/V Nereis during the three days devoted to acoustic testing. The generic characteristics of the Online pinger are described in table 4.1. The Online pinger's maximal depth and

Power output	20W ± 3 dB
Beam pattern	omnidirectional
Center frequency	11.150 kHz
Pulse duration	5 ms
Pulse repeat period	5 s
Weight in air	11.5 Kg
Pressure rating	300 bar (3000 m)

Table 4.1: *Online pinger and transmitted signal characteristics.*

frequency band were specifically chosen to represent sperm whales. The pinger output signal was measured during an engineering test prior to the EDELWEIS'14 experiment, and is shown in Fig. 4.1 as an effective shape of a sinusoid windowed by a 5 ms box-car-shaped signal (upper plot) with the spectrum peak located at approximately 11150 Hz (lower plot).

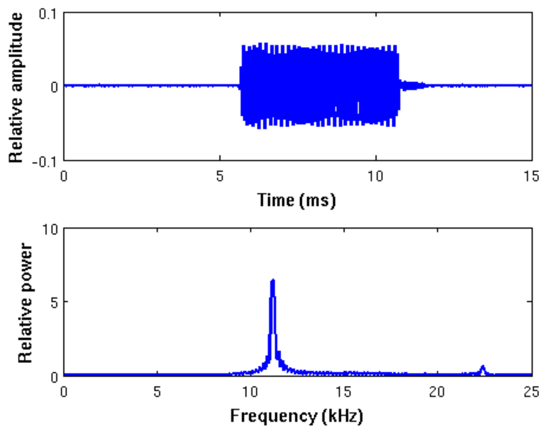

Figure 4.1: *Online pinger signal output in time (up) and frequency (down).*

4.2 Received signals

4.2.1 Data format and synchronization

The collected data, both acoustic and non-acoustic, received at the AOB21/2 are stored on files using a proprietary format that can be parsed in MATLAB using the m-file ReadUAN.m, which is to be found in directory `/m-files/read-signals/` of the DVD-disc attached to this report. An overview of this format is the following:

- **ASCII header:** cruise title, UTC GPS date and time of first sample on file, Lat - Lon GPS position, characteristics of non-acoustic and acoustic data such as sampling frequency, number of channels, sample size and total number of samples
- **non-acoustic data:** temperature data in binary format
- **acoustic data:** acoustic data in binary format

Each data file contains 24s worth of acquired data and there should be no data loss between files. Data files were created in sequence, with file names representing the Julian day, hour, minutes and seconds, and followed by the extension ".vla". The time used in the file name is obtained from the computer clock so it should not be used for precise synchronization purposes since it may differ (and in practice always does) from the GPS time in the header. When the GPS is in orderly operation **the time and position stamp in the header of each file is the exact GPS - GMT time of the first acoustic sample in the file** and it can/should be used for synchronization, positioning and time of flight measurement purposes, if required.

The sampling frequency used during EDELWEIS'14 was Fs = 50000 Hz. The Lat/Lon location written in the header of the data files is given by the AOB2 GPS string at the time of the first sample. A decimal degree notation was used in order to simplify its usage for calculation and plotting purposes (inside Matlab, for example).

The listing of the m-file data reader is given in directory `/m-files/read-signals/` of the attached DVD-disc, together with a few auxiliary routines for data visualization.

Synchronization issues during EDELWEIS'14

Unfortunately during EDELWEIS'14 the GPS of AOB21 was not always working properly, so the GPS string in the header of the respective data files was voided and it simply shows the time since the internal buoy computer was turned on, which is unusable for synchronization or localization purposes. Instead the data sets contain a GPS_TimeTag.log file which contains the time tags at 24s interval. Pairing these time tags with each file can allow - in principle - for a precise data synchronization. The buoy position is written under the form of a NMEA string on the file gps.log, for each deployment day and for each AOB. As shown in section 3.3 only the GPS position of the AOB22 was usable for the whole sea trial. The GPS on the AOB21 only worked during short periods many of which during tests on board.

Additionally during JD 221 (Aug, 9), for unknown (possibly hardware) reasons the data transfer between the acquisition board and the CPU was "on hold" for an unknown time lapse. This happened twice during the day at around 9h12 and 9h13, which corrupted the synchronization for the remaining of the day therefore creating serious difficulties for the localization process whenever precise synchronization between buoys is required. The amount of time lost is approximately known and also known to be a multiple of a block size of 65536 samples, which represent exactly 1.31072s. These two pieces of information may be used, together with the acoustic data itself and the experiment geometry, to attempt to resynchronize the data stream for that day. Alternatively, a localization process that does not require precise synchronization between the two buoys should be devised.

4.2.2 Received waveforms

Typical received AOB signals during EDELWEIS'14 are shown in Fig. 4.2, as a spectrogram of a 48s data sample (2 concatenated data files) of the AOB22 hydrophone #8 (at 66.3m depth), which was recorded on August 5 (JD 217) at 11h14 UTC. Periodic pings at the correct 11.1 kHz frequency can be seen (a), and the respective time waveforms in (b). The power spectrum peak was exactly estimated at 11182 Hz. The spectrogram

(a) (b)

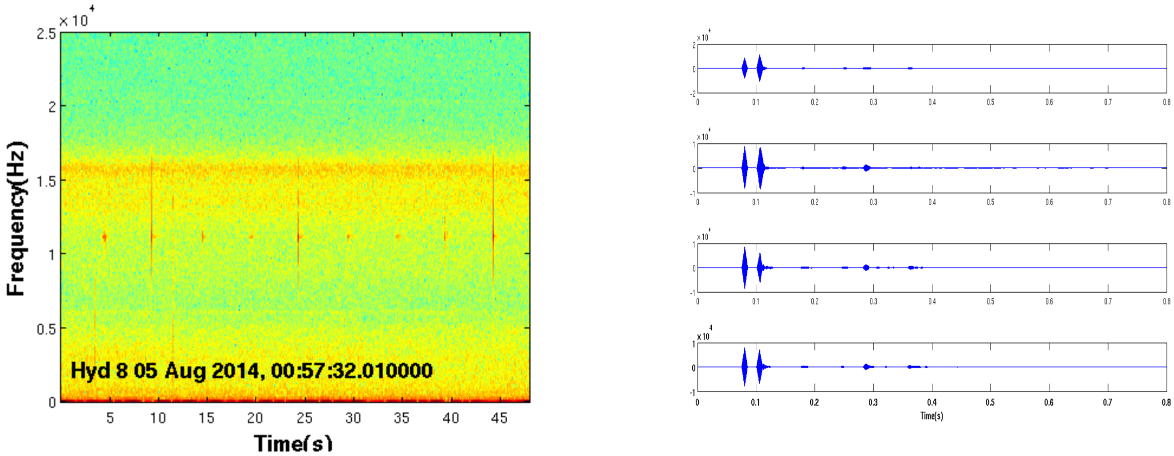

Figure 4.2: *AOB22 hydrophone 8 at 66.3m depth on day JD 217 at 11:14 UTC: 48s spectrogram (a) and 4 successive pings after detection and windowing in a 0.8s window.*

clearly shows a low frequency noise and a frequency filter with a cutoff frequency at approximately 16 kHz as imposed by the analog anti-aliasing filters in the AOB unit. The periodic pings are clearly seen superimposed time to time by acoustic glitches. These glitches, which are possibly due to vertical array movement, are broadband spikes that sometimes perturb the ping detection (especially those with high intensity). The five successive time waveforms shown in figure 4.2(b) are perfectly synchronized after transmitted signal correlation and detection. Some ping variability can be seen in relative amplitudes and late arrivals.

4.3 Channel variability

A common practice during preliminary processing consists in matched filtering of the incoming data with the emitted signal, so as to obtain an estimate of the channel acoustic impulse response. This processing, also known as time-compression, gives a channel response estimate that is better 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 according to the medium variability and in space according to the experiment geometry. During EDELWEIS'14 both the emitting source (pinger) and the receiving array were moving over time, and so time and space variability effects are mixed in the estimated channel response, which can only be separated by introducing *a priori* knowledge of the system geometry or appropriate simultaneous space-time processing. In this preliminary assessment it is important to assert the channel variability both along the sensor array (which to some extent defines the diversity of the received field) and along time. Even if the spatial aperture of the array is more or less fixed and does not oscillate with time, the same does not hold for the channel geometry, and therefore it is important to define what is meant by channel variability over time. In this respect, there is a short time variability, on the scale of a few seconds -, and there is a longer term variability on the scale 15 minutes up to the hour or so, which is an environmental-induced variability. Here we will be mostly concerned with the later.

In order to illustrate this topic the received signals were pulse compressed during the duration of the continuous transmissions on JD 217 and JD 218 as shown below. Figure 4.3 shows the 12-snapshot windowed average estimated channel impulse responses obtained during JD 217 for hydrophone #3 of AOB22. Figure 4.4 shows the pulse compression results for the same AOB and hydrophone but for JD 218 (August 6).

Several preliminary remarks can be made:

- figure 4.3 shows the typical CIR of a shallow water waveguide: it starts with the direct path and is followed by the surface-reflected and bottom-reflected paths. First arrivals are close to each other, later arrivals correspond to steeper grazing angles and are further apart. As time goes by source opens range and as absolute travel time increases (not shown) relative time intervals between arrivals decreases. The end of the reception is controlled by the bottom critical angle beyond which the acoustic energy penetrates the bottom. Fluctuations on the late arrivals can also be seen on the CIRs as the source moves away from the receiver;

- figure 4.4 shows the direct (first) and the surface-reflected (second) arrival in a deep water scenario. When the source is located at greater depths the two arrivals have a maximal separation. When the source gets shallower the separation is smaller. The CIRs B shape is because the figure shows receptions from two stations (deep source)

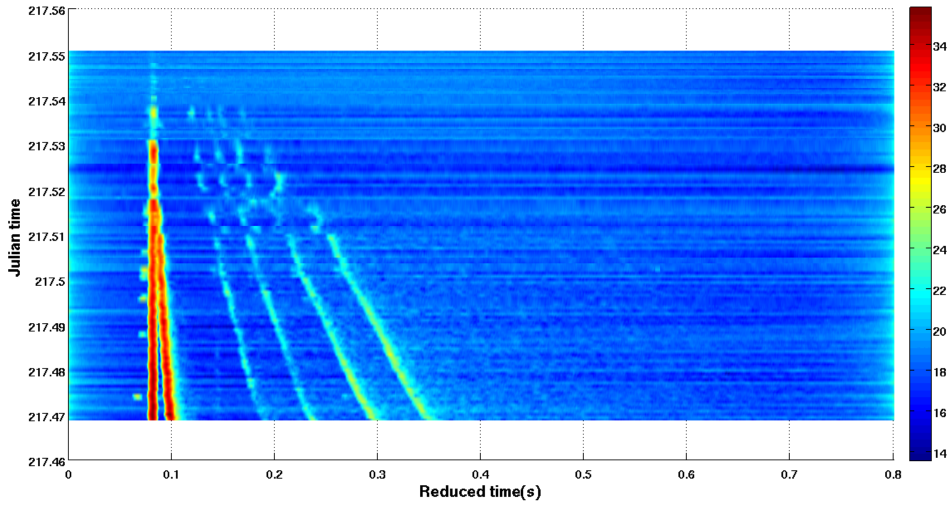

Figure 4.3: *drift of JD 217 12-snapshot estimated channel impulse responses (CIR) along time as received on hydrophone #3 (at 46.3m depth) of AOB22.*

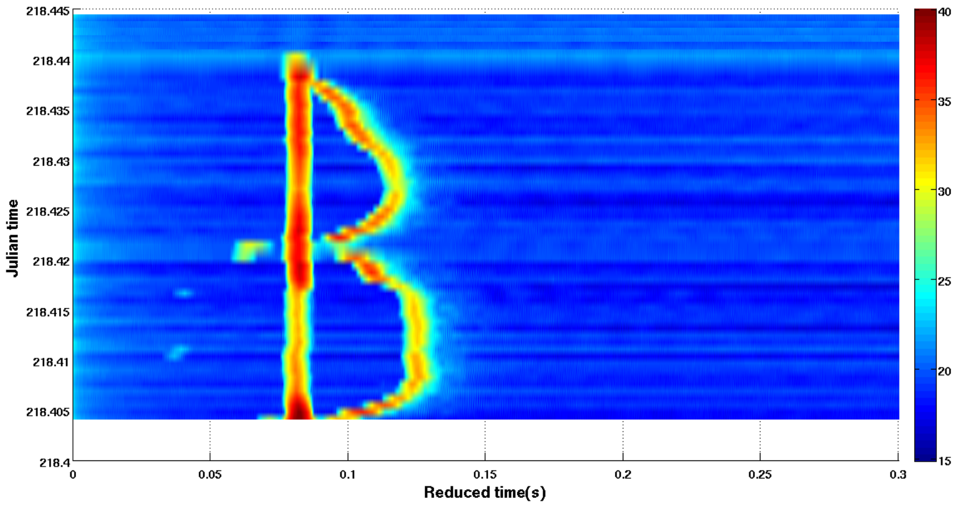

Figure 4.4: *drift of JD 218 12-snapshot estimated channel impulse responses (CIR) along time as received on hydrophone #3 (at 46.3m depth) of AOB22.*

and the transit between the stations (shallow source), as can be seen by comparing with the source depth plot of figure 3.11(b).

Chapter 5

Summary and future analysis

The EDELWEIS'14 sea trial was planned and executed as a preliminary assessment for the development of a future sperm whale monitoring system, with the objective of collecting acoustic data to support the testing of localization algorithms. These algorithms could then be used for sperm whale (near real-time) localization as part of an early warning system. The acoustic equipment employed consisted of two existing AOBs with their vertical arrays and one Online acoustic pinger. The acoustic signals emitted by the pinger, as an emulation of sperm whales for testing purposes, were received on the drifting AOBs that were deployed relatively close to each other. The acoustic data clearly shows the pinger signals that positively correlate with the emitted signal. Localization algorithms require the approximate knowledge of the array's position which is partially hindered by the malfunction of the GPS and time synchronization of one of the AOBs. However, those problems may be overcome by using side information and the acoustic data *per-se*. Interestingly enough, environmental (water column) information is formed by three sets that give a relatively good account of the environmental variability in the area.

Next steps include the recordings of real sperm whales for testing detection and identification algorithms to be used in conjunction with the localization methods mentioned above and provide spatial sperm whale tracking through time. These algorithms should run on data acquired by specifically designed bottom fixed systems positioned in strategic locations with sufficient gain to cover the area of interest, avoiding the risks inherent to constant deployment - recover operations and the dependency on favorable weather conditions.

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Appendix A

EDELWEIS'14 DVD content

The acoustic data gathered with the AOBs during the EDELWEIS'14 sea trial is far too large to be copied into permanent digital support such as DVD. Other material such as environmental information, auxiliary GPS, bathymetry, depth and temperature recordings as well as processing and reading routines are put together in a single support DVD for future use. The material of the DVD is listed in table A.1.

Table A.1: *DVD content for EDELWEIS'14 AOB2 drifts*

DVD		**EDELWEIS'14**
Dir	**Sub-dir**	**Contents**
readme		
docs	report	this data report
	test-plan	EDELWEIS'14 test plan
	Nereis-logs	Nereis log book + electronic file
non-acoust	CTD-siplab	RBR Concerto data
	aob-ts	AOB thermistor strings
	bathymetry	bathymetry
	gps-log	AOB2,Nereis gps - logs
	TD-forth	TD recordings
acoustic	pinger	pinger.mat
m-files	read-signals	vla format reading