Shallow Water Acoustics, 485-490, China Ocean Press (1997)

INTIMATE96: A SHALLOW WATER TOMOGRAPHY EXPERIMENT DEVOTED TO THE STUDY OF INTERNAL TIDES.

Xavier DÉMOULIN, Yann STÉPHAN
Military Center for Oceanography, EPSHOM, BP 426, 29275 Brest, France

Sergio JESUS
UCEH, Universidade do Algarve, 8000 Faro, Portugal

Emanuel FERREIRA COELHO
Instituto Hidrografico, 1296 Lisbon, Portugal

Michael B. PORTER
CAMS, New Jersey Institute of Technology, NJ 07102, Newark, USA

1. INTRODUCTION

The INTIMATE (INternal Tide Investigation by Means of Acoustic Tomography Experiment) project is devoted to the study of internal tides by use of acoustic tomography. The first exploratory experiment was carried out in June 1996 on the continental shelf off the coast of Portugal. A towed broadband acoustic source and a 4-hydrophone vertical array were used. Acoustic data were collected for 5 days, including legs where the source ship was moving and legs with the ship on station. Intensive environmental surveys (XBT, CDT, bottom and hull-mounted ADCP, thermistor chain, bathymetry, geoacoustic characterics of the sediments) were also conducted.
The purpose of this paper is to briefly discuss some effects of the environment on acoustic fluctuations. In particular, the influence of three different types of environmental parameters is put forward: source-receiver geometry, bottom reflection, energetic and temporal fluctuations due to barotropic and baroclinic tidal modes.
The paper is organized as follows. Section 2 describes the experimental strategy for the INTIMATE96 survey. Section 3 gives some viewpoints on the data analysis, focusing on the three issues mentioned above. Several axes of studies are given in conclusion.

2. THE INTIMATE96 EXPERIMENT

The INTIMATE96 experiment was carried out in the period of 10-19 June at the Nazaré site, on the continental shelf, 50 nautical miles north of Lisbon (Figure 1, left). This area was suitable to host the experiment because of the presence of strong internal tides and internal waves, previously hydrologically surveyed by the Instituto Hidrografico. This area was also chosen for

Shallow Water Acoustics, 485-490, China Ocean Press (1997)

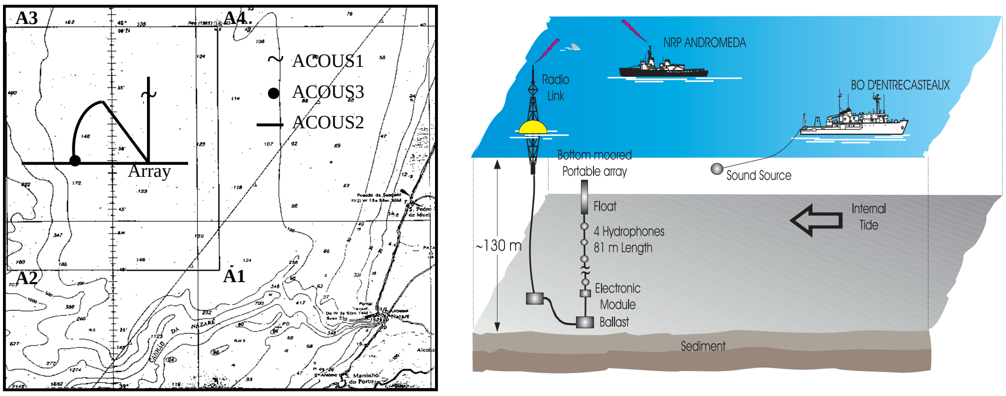

FIGURE 1. Site (left) and strategy (right) for the INTIMATE96 experiment. Hydrophones were located at 35, 70, 105 and 115 meters. Sound source was at 90 meters during stations.

its favorable characteristics in terms of bathymetry and geoacoustic bottom properties. Basically, the experiment has consisted of intensive acoustic emissions between a broadband source (towed by the French oceanographic vessel BO D'Entrecasteaux, hereafter DTX) and a 4-hydrophone array (Figure 1, right). Hydrophones were located at 35, 70 105 and 115 meters. The signals received on the phones were transmitted and processed aboard the Portuguese hydrographic vessel NRP Andromeda (hereafter AND) for real time analysis. Three acoustic phases were carried out:

- ACOUS1: 25-hour acoustic station 5.6 km north from the hydrophone array. The purpose of ACOUS1 was to collect data in a flat bottom configuration and with the direction of acoustic propagation along an isophase line of the internal tide. During the station, CTD and XBT profiles were done every 2 hours respectively by AND near the array and by DTX at the station point.
- ACOUS2: 10-hour acoustic leg with a moving source. The purpose of ACOUS2 was to collect data in various environmental configurations (source depth, propagation range and bathymetric variations). A CTD yoyo was performed by AND near the array and XBT launches were performed by DTX along the acoustic tracks (bathymetric profiles were also done with a 50 m resolution).
- ACOUS3: 25-hour acoustic station 6.8 kilometers west of the hydrophone array. The purpose of ACOUS3 was to collect data in a slope-bottom configuration and with a direction of acoustic propagation across the isophase lines of the internal tide. During the station, CTD and XBT profiles were done every 2 hours respectively by AND near the array and DTX at the station point.

3. DATA ANALYSIS

3. 1. Some environmental considerations

The mean sound speed profile exhibits a smooth downward refracting gradient (Figure 2). It also reveals that the mixed layer is very thin. On many profiles, it is not even present. This environment differs significantly from usual schematic representation (layer model).

The medium variability in the area is characterized by isotherms oscillations due to internal tides. Figure 2 clearly exhibits a 20-30 m amplitude of isotherm oscillations forced at the M2 period (12h25mn). The presence of internal tides has also been confirmed on thermistor chains and moored adcp data [1]. The internal tides are propagating in the East-West direction (perpendicular to the slope).

Shallow Water Acoustics, 485-490, China Ocean Press (1997)

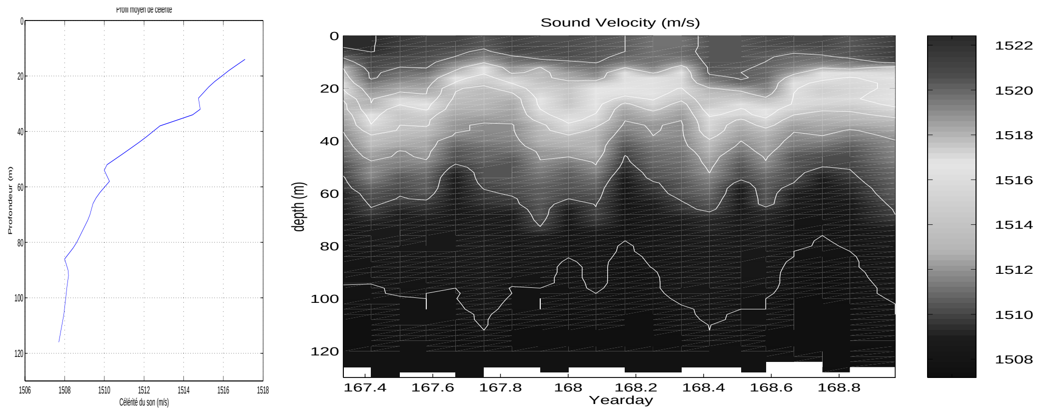

FIGURE 2. Mean sound speed profile (left) and sound speed temporal series near the vertical array (CTD station).

The bathymetry in the area is characterized by North-South isobaths. The vertical array was positioned to allow a reference acoustic configuration with a flat bottom (130 meters depth) along the acoustic track. In the range dependent station (ACOUS3), the bottom varies from 130-150 m.

A seismic SPARKER survey was performed by the Instituto Hidrografico to evaluate the sedimentogical bottom structure. A coring survey was done by DTX during the experiment. It revealed that the bottom structure is composed of a fine sand layer (between 0.5 m. and 1 m.), a fine shell layer (between 0.5 m. and 1 m.) and a limestone substratum.

3. 2. Some acoustical considerations

The emitted signal is a Linear Frequency Modulation (LFM) chirp from 300 to 800 Hz. The chirps lasted for 2 s and were emitted every 8 seconds (the time reference being controlled by a GPS clock). The acoustic signals were transmitted and processed aboard AND for real time analysis. The signals were sampled at 6000 Hz and stored on VHS tapes of approximately 3 hours each. On each tape, data are stored in files corresponding 320 seconds of data. At the final step, acoustic data have been compiled on CD (24 CDs). At the reception, a GPS synchronisation signal is added to the received signal to keep the same temporal reference as the emission system (to allow absolute temporal datation).

The acoustic signal processing mainly consists in the usual pulse compression. Each sequence of the received signal is correlated with the emitted signal replica (matched filter). During ship stations, an incoherent averaging is performed: Received signals are averaged over a 10 minutes period to increase the S/N ratio. During legs when the ship is moving, no incoherent processing is done. Finally, all sequences are lined up on the leading edge (first arrivals) to filter out source and receiver position fluctuations.

Figure 3 presents the relation between group velocity and phase velocity for normal mode interpretation. Group velocity is associated with the arrival time of the acoustic energy and phase velocity is related to emission angles. It can be noted that this diagram depends weakly on frequency so that all interpretations can be done at the central frequency. The diagram can be split in two parts. On one hand, phase velocities lower than the maximum speed in the water column correspond to refracted energy (ray or modes) in the thermocline (see upper left of Figure 3). On the other hand, phase velocities greater than the maximum speed in the water column correspond to surface-reflected energy. Note that bottom reflection is systematic. It can be seen from Figure 3 that a minor part of the energy is refracted in the thermocline and that

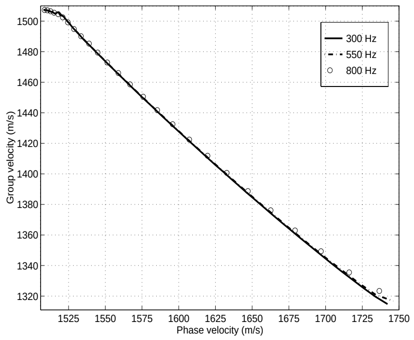

FIGURE 3. Group velocity vs phase velocity in the INTIMATE96 environment.

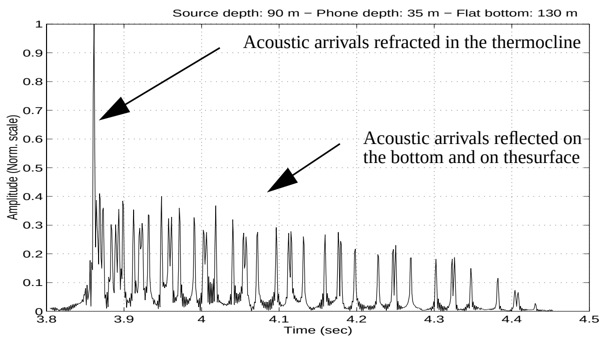

FIGURE 4. Exemple of synthetic received signal.

this energy travels faster with a strong focusing effect (several modes have very similar group velocity). It also reveals that the major part of the energy is bottom-surface reflected and arrives later and largely spread in time.

3. 3. Interpretation of several parameter of acoustical variability

Figure 4 presents a synthetic received signal computed from KRAKEN [2] corresponding to the first acoustic station (ACOUS1). As expected from the analysis of Figure 3 , the signal is composed of two types of arrivals. The first energy packet is dominated by water column effects. It is composed of fast unresolved arrivals and the global amplitude is higher partly due to firsts modes interferences. The other part of the signal is composed of resolved arrivals. These arrivals are surface-bottom reflected rays with a decreasing amplitude mainly due to both an increase in the number of reflections and bottom loss with angle.

3. 3. 1. Range-Depth influence

Figure 5 represents a transition between two acoustic phases: a station and a leg where the ship is moving. During the station, the propagation range remains constant and the source depth (measured by an autonomous pressure sensor) is also constant. Real data show the first energy packets with unresolved arrivals and the multipath structure composed of four arrivals. During the second acoustic phase, the ship is moving towards the receiver (decreasing range). Due to the ship motion, the source depth gets lower. The effect on propagation is clearly put forward by Figure 5. One the one hand, the 4-rays structure disappears. Each quadruplet is splitting into two doublets (Figure 5, middle). On the other hand, as range decreases, there are fewer number arrivals. Note also that when the range decreases, unresolved arrivals in the first packet tend to be resolved due to a geometric effect.

3. 3. 2. Sediments caracterization

The phase velocity of the last arrivals is lower or equal to the bottom compressional speed. We have built several group-phase velocity diagrams with different bottom types. On each diagram, we have computed the difference of group velocity of first and last arrivals. This difference can be related to the total temporal spreading of received signals. By matching this difference with actual data, we have estimated the bottom compressional speed to 1750 m/s. This is in good agreement with our coring measurements (fine sand).

3. 3. 3. Internal tide influence

a. Barotopic effect

Figure 6 represents the acoustic data on hydrophone 3 (115 m) for the ACOUS1 phase (25-

Shallow Water Acoustics, 485-490, China Ocean Press (1997)

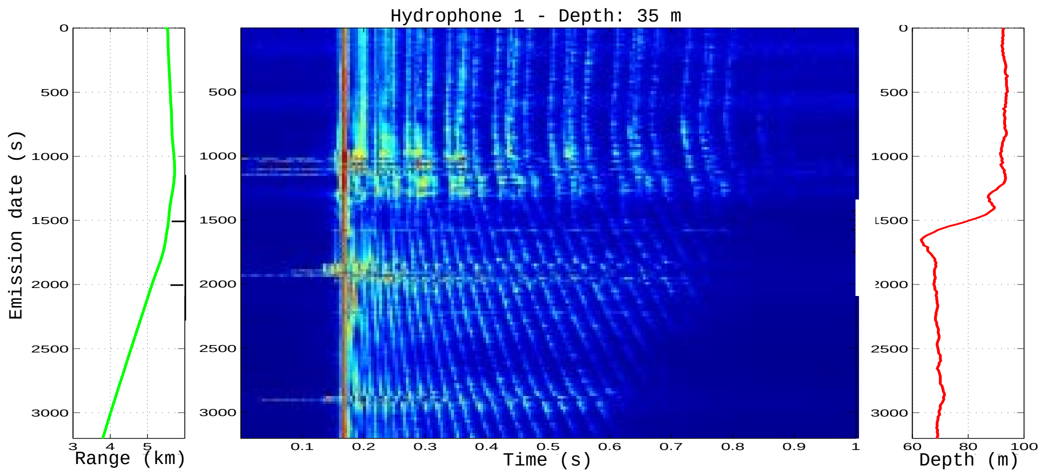

FIGURE 5. Influence of range-depth configuration on acoustic arrivals. Left: Propagation range obtained from GPS localization. Middle : Acoustic data. Right: Source depth from pressure sensor measurement.

hour station). Late arrival fluctuations can be correlated to the tide prediction in the INTIMATE area. These fluctuations are due to changes in the surface elevation at the M2 period (12h25mn) which affect path geometry (in particular path lengths). It is interesting to note that the influence is greater on late arrivals. This can also be predicted by superposing several group-phase velocity diagrams corresponding to several water depths.

b. Baroclinic effect

Figure 7 describes three consecutive XBT profiles measured at 2 hour intervals during the first acoustic station. Two main oceanographic features are represented:

- first, a global deepening of the thermocline (profiles 1 and 3) due to the first baroclinic mode. Such a phenomenon increases the mean value of sound speed over the water column. As a result, surface-bottom reflected rays travel faster. On the other hand, rays refracted in the thermocline are not sensitive to this phenomenon. As a consequence, thermocline deepening tends to decrease the global spreading of the signal. It can also be noted that the amplitude of first arrival is modified. These two effects are shown on Figure 7 on synthetic and actual data.

- second, sound speed profiles 1 & 2 seem to exhibit a shear effect (thermocline deepening

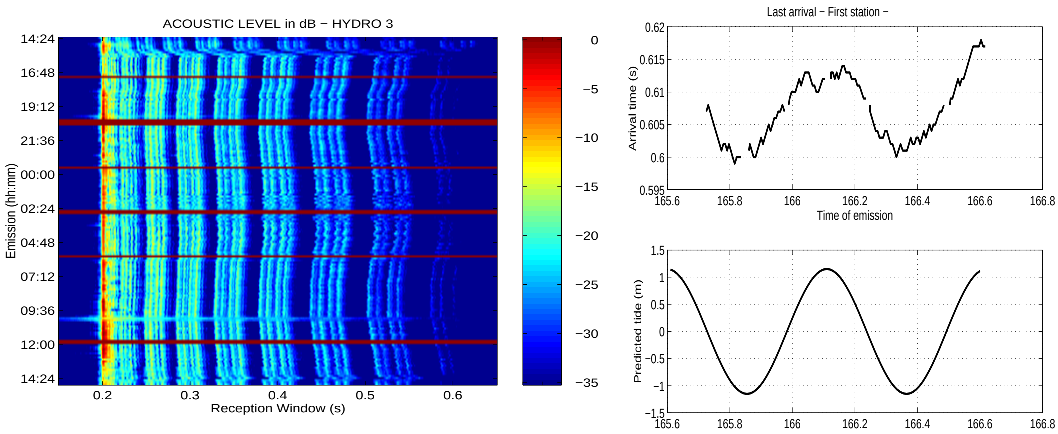

FIGURE 6. Influence of the barotropic tide on late arrivals. Left: Acoustic data image for ACOUS1 (station north of the receiver). The phone depth is 115 m. Right: Arrival time estimation of the last arrival (up) and tide prediction (down).

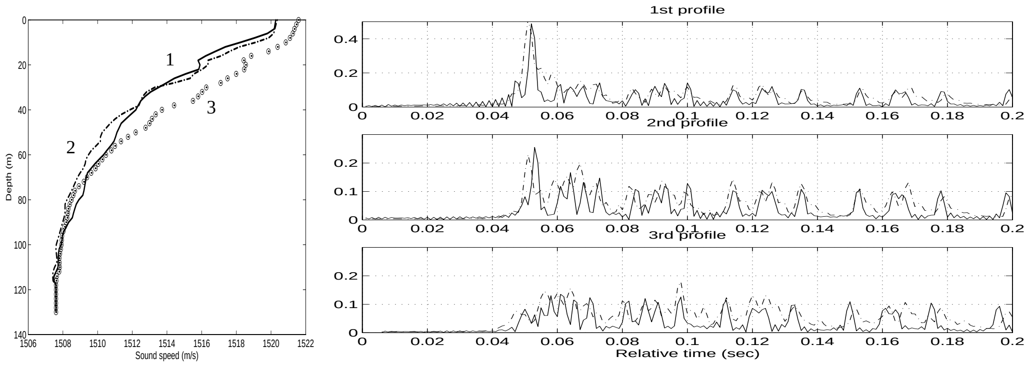

FIGURE 7. Influence of the hydrologic fluctiations on received acoustic sequences (ACOUS1, hydrophone 35 m). Left: Thre consecutive XBT profiles. Right: received sequences (real in solid, synthetic in mixt).

below 40 meters and thermocline rising above). This may be an effect of the second baroclinic mode. The influence observed on synthetic and actual data is the modification of the first energy packet, compared to surface reflected arrivals. On the other hand, times of propagation are not affected.

4. CONCLUSION

This paper has shown some aspects of the influence of enviromental parameters on acousting propagating in a shallow water environment. This gives several directions for INTIMATE96 data interpretation. The instrumental geometry influence may be usefully exploited for source localization purposes, as discussed in [3]. Investigations are in progress for geoacoustic caracterization of the sediments. Concerning the tide effect, in-depth studies are in progress to confirm the ideas presented in this paper. From the forward problem consideration, it seems already reasonable to think that amplitude and time inversion could be efficient to retrieve sound speed field. It is also interesting to note that this could be done without absolute propagation time and instrumental positionning.

REFERENCES

[1]. INTIMATE96 data report, in preparation.

[2] M.B Porter (1991) «The KRAKEN normal model mode program», Rep. SM-243, SACLANT.

[3] M. Porter, S. Jesus, Y. Stéphan, X. Démoulin and E. Coelho (1997) «Exploiting reliable features of the ocean channel response», in this volume.

ACKNOWLEDGMENT: The partners of the INTIMATE project wish to thank the staff of NRP ANDROMEDA, the staff of BO D'ENTRECASTEAUX and people of Mission Océanographique de l'Atlantique (aboard D'ENTRECASTEAUX) for their kindness and devotion during the experiment. We also wish to thank the SACLANT Undersea Research Center for lending the Portable Array System and Roberto Chiarabini (SACLANTCEN) for his participation in the array preparation, deployment and use. Thanks to T. Folegot (CMO) for data processing routines [Work supported by SHOM-IH-UAL-ONR].