Acoustic Tomography Ocean Monitoring System (ATOMS)

Contract number: PDCTM/P/MAR/15296/1999

12-month Progress Report

Coordinating Institution: CINTAL - Centro de Investigação Tecnológica do Algarve

Partners: Instituto Hidrográfico
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Part A - Coordination Report

1 Progress

During the first twelve months of activity of the project "ATOMS - Acoustic Tomography Monitoring System", here below designated as ATOMS, a number of important preliminary activities took place. These activities include the design and assembling of the autonomous radio buoy data acquisition system, the development of the inversion algorithms for range dependent tomography and the characterization of the upwelling filaments along the Iberian Peninsula from archival data.

Making reference to the Technical Annex of the proposal, most of the effort during this first project year was devoted to tasks 1 and 2. Task 1 started right after the begining of the project with the INTIFANTE'00 sea trial from 9 - 29 October 2000. This sea trial was essentially required for the testing of the Ultra Light Vertical Array (ULVA) acquired and built during project INTIMATE (Praxis XXI - contract 2/2.1/MAR/1698/95). The data set acquired during this sea trial covers a number of relevant aspects for ATOMS and thus serves as test data for the development of algorithms. In terms of specific sub-tasks, A1.1 has been terminated and sub-tasks A1.2. to A1.4 are well underway (progress and conclusions can be found in Part B and references therein). Task 2 was effectively started in January 2001 with both the setup of the acoustic source specifications (A2.1) and the design of the receiving system modifications (A2.3-A2.4). At this time sub-task A2.1 has been terminated and the tomographic acoustic source has been ordered to a specialized company in France (see details and characteristics in Part B). Sub-task A2.2 has been partially accomplished in the sense that the system has been designed and assembled, while the testing is underway and is expected to terminate in the next 2-3 months. Sub-task A2.3 has also been started and new data acquisition software is under developement in relation with the progress of the hardware testing. During this first year the project team described in the project proposal was completed with the hiring of Mr Ângelo Carmo by EST in January 2001, of Mr. Ricardo Sanchez by CIMA in April 2001 and Mr. Cristiano Soares and Dr. Vanessa Corre, both by CINTAL in February and July 2001, respectively.

2 Terminated tasks

Task 1: Methods and algorithms

Sub-task A1.1: Archival data compilation
Responsible: CIMA
Duration: 1-12 months

Due to the contracting of a Research Assistant, this sub-task was initiated in April 2001. The National Oceanographic Data Center (NODC) data base was acquired and other historical observations in the target region were compiled. A detailed analysis of this data, along with additional observations from our database and sea surface temperature satellite images, was performed. A long-term picture of the circulation scheme along the southern Portuguese coast was depicted. A full revision of the cold upwelling filament characteristics was carried out. The hydrographic and dynamic structure of filament features were simulated to be used as an input in the simulation of the acoustic inversion process. As a result of this sub-task a working document was presented at the ATOMS meeting, Faro, June 2001 and a publication was presented at the ICES Conference, Oslo, September 2001. This sub-task was successfully completed.

Task 2: Acoustic system assembling

Sub-task A2.1: Determine acoustic source specifications
Responsible: CINTAL
Duration: 1-3 months

Due to the completion of the INTIFANTE'00 sea trial in October 2000, this task was delayed until November 2000. The specifications and first contacts were made during November and the final "Acoustic Source Specifications" draft was prepared in January 2001. An international bid was announced during January with a deadline for proposals in February 15th. More than 15 companies were contacted for that bid that included not only the acoustic source itself but also the cable and the power amplifier. During the period March - July the negotiation was intense and the final decision was made to award the purchased to the french company Eramer S.A.. The delivery is scheduled for March 2002 well on time for the ATOMS sea trial to take place on July of the same year. This sub-task is now terminated.

3 Tasks under completion

Task 1: Methods and algorithms

Sub-task A1.2: Development of scale-independent tomography inversion methods.
Responsible: CINTAL
Duration: 1 - 18 months

This sub-task was delayed until June 2001, since it required the overall oceanographic characterization of the ocean basin as input for the simulation. That characterization included a mean temperature field with a few localized realistic features for acoustic detection. The work is now proceeding normally however, a delay of 3 to 6 months is expected in this task. This delay has no impact in the development of the project since there is no direct link between the outcome of this task and the other remaining tasks.

Sub-task A1.3: Tomographyc inversion of filament features.
Responsible: CINTAL
Duration: 6 - 18 months

This task started right from the begining with the analysis of the data acquired during the INTIFANTE'00 sea trial. There are two internal reports and two conference papers published on the work done on the INTIFANTE'00 data set. In parallel, the input from task 1.1 and the arrival of Dr. Vanessa Corre, allowed to produce an internal report with results obtained on simulated data regarding the performance of tomographic inversion on a range-dependent environment similar to that of the upwelling filament. This task is on time and proceeding.

Sub-task A1.4: Analysis of SST satellite data.
Responsible: CIMA
Duration: 1 - 24 months

During the first 12 months of activity of the present project, the historical SST database was started to be browsed. A database consisting in hardcopies and digital images related to the southern Portuguese area is being constructed. Additionally, contacts with host institutions that will supply AVHRR (Advanced Very High Resolution Radiometer) and WSC (Wind Scatterometer) files for the study area on a regular basis were initiated. Special acquisition procedures will be implemented over the weeks previous to the sea trial. Very special attention will be paid to online acquisition of SST pictures during the cruise itself. This sub-task is on time.

Task 2: Acoustic system assembling

Sub-task A2.2: Adaptation of the existing ULVA system.
Responsible: EST
Duration: 1-18 months

After the system architecture was chosen, the implementation started in three main streams: development of the electronic interface to the actual ULVA system, new processing hardware purchase and integration (main processor board and other peripherial boards), acquisition and remote control software development. The project and construction of the electronic interface boards were concluded. At this time electronic and functional tests have begun. This part of the task is delayed about a month due to problems experienced with electronic components availability at resellers.

Sub-task A2.3: Hardware and software implementation.
Responsible: EST
Duration: 1-18 months

The main processor and other peripheral boards were purchased and tested. Two radio modems are still under purchase that will be completed in the next few weeks. The acquisition software was ported to the new system. The communication and control software is under development. This task will be concluded before the first sea trial, in full agreement with the work plan.

4 Conclusion

In this first project year two sub-tasks have been duelly terminated on time with the planned schedule. A large number of sub-tasks have been initiated at project start and are now underway with expected results during the next project year. At this time the project has produced a total of 10 documents: 5 internal reports, 4 international conference papers and 1 paper has been submitted to an international journal (see annex). There are no delays forseen in this project for the next 12 month, that is expected to flow in perfect agreement with the detailed work plan set forth in the proposal Technical Annex.

Part B - Scientific Report

1 Introduction

Ocean Acoustic Tomography (OAT) has been initially developed as a technique for large (100-1000 km) scale monitoring of the temperature in the deep ocean [1],[2]. In the last decade the methods developed for OAT in the deep ocean have been progressively adapted to study smaller scale phenomena in coastal waters [3],[4], [5],[6],[7],[8]. The scales involved are now of the order of 10's of km's applied mostly on the continental platform or on the continental slope. The environment becomes very shallow (50-200 m depth), range-dependent and involves a significant acoustic interaction with the seafloor, making it relatively complex to model and predict. At such small scale, the interest of OAT is focused on the detailed evolution of ocean temperature in range and time and not so much on the integral long term variation. There is a need for methods and techniques being able to, when possible, extract range-dependent variations of ocean temperature from acoustic measurements.

Most of the acoustic propagation models commonly available until the midlle 80's were range independent - in other words, they assumed that the characteristics of the physical environment where the signal was propagating was common to the source and the receiver. The parabolic equation approximation was the first approach to a more realistic range-dependent solution to the wave equation. Others have followed, ranging from weakly range-dependent approaches based on adiabatic or coupled mode approximations of the normal mode expansion and to high-frequency capable range-dependent ray-tracing codes.

Range-dependent models have been used in matched-field source localization and geo-acoustic inversion with some degree of success. Instead, range-dependent inversion for ocean properties was proposed by Chiu et al. with a mild success [3]. In that reference the method employed included a mixture of a classical travel time inversion method based on ray-tracing and a normal mode approximation (WKB). In practice there are several questions that can be raised when a range dependent inversion is sought: 1) how to setup de range dependent model of the real propagation slice ?, 2) how sensitive is the inversion method to errors made on that model ?, 3) what performance can be expected for identifying the time-space evolution of oceanographic features in the range-dependent track ? and 4) what is the optimal source array geometry for feature identification ? Some of these questions can be generically answered while others are strongly dependent on the problem at hand.

Generic answers can be given based on existing data with characteristics similar to those that can be found in the upwelling filament. For example the INTIFANTE'00 data set contains data obtained along strong range-dependent environments. Since the range-dependency is known (submarine canyon) a model mismatch study can be easily performed. Other answers are not so generic and one has to ressort to simulation studies based on existing cold water filament descriptions. Such detailed description, that exist for California upwelling regime, was used as input in our simulations.

2 The INTIFANTE'00 data set

During the INTIFANTE'00 sea trial a complete data set of more than 60 hours worth of acoustic data was acquired (documents 1 and 2 in annex). At least two events are interesting test cases for ATOMS: one is the 24 hour time-series along a range-independent environment and the other is the acoustic transmissions across the submarine canyon. The 24 hour time series are interesting in order to determine possible time variability in the mean temperature field and its influence in the acoustic signal transmission. A preliminary assessment has shown that model predictions allowed to track arrivals along time with a high correlation in three of the hydrophones. In the transmissions over the submarine canyon, that represents a very strong environmental dependency in a short range, a crude bathymetric model allowed to obtain relatively good correlations between the model predictions and the actual data. A preliminary assessment of the INTIFANTE'00 data set potential for shallow water acoustic tomography is contained in document 3 (in annex).

Work done in parallel, has shown that the sensitivity of matched field processing is highly dependent on frequency. In particular, tests performed on a data set collected in the Strait of Sicily during the ADVENT'99 sea trial in the band 800 - 1600 Hz, have shown that correct source localization was only possible due to the inclusion of an accurate parameterization of the sound speed profile along time (see documents 4 and 5 in annex). A common debate in acoustic matched-field processing (and ocean tomography) is whether broadband transmissions should be coherently or incoherently combined to achieve better performance in terms of parameter identification. In order to clairify this issue, that has a certain impact in the data processing under ATOMS, data analysis and simulations lead to the conclusion that cross frequencies have relevant information for computing the processor output when those frequencies are chosen in a relatively narrowband (100 Hz max). Moreover, the phase of the acoustic field is not important for the final result and a highly computationally efficient incoherent cross-frequency processor was proposed (see document 6 in annex).

3 The acoustic tomography source

During November 2000, Cintal started to gather information regarding available source types suitable for acoustic tomography. Previous experience with various types of sources lead to a overall specification of a bandwidth from 200 to 1000 Hz and a necessary source level of at least 200 dB. Additional specifications were set as minimum and maximum source depth of 30 and 300 m, respectively and a manageable weight and size of approximately 300 Kg and 2 m^3. Obviously, source tow cable and power amplifier should match source specs in terms of power handling and tow tension.

The cooperation of several experienced teams at Centre Militaire Oceanographique - SHOM, Brest, France and at the Acoustics Branch of the NATO - SACLANT Undersea Research Centre, La Spezia, Italy, was requested.

The amalgamation of opinions and experience resulted in a document, known as the technical specifications for a broadband acoustic source (number 7 in annex). That document actually describes a two-transducer sound source covering a larger bandwidth than that necessary for tomographic experiences, since the secondary HF transducer was supposed to cover the needs for another CINTAL project.

After negotiation, the proposal made by Eramer S.A., Toulon, France, actually met the required criteria with a good balance between source efficiency, company experience and cost. Eramer's proposal is based on a Janus-Helmoltz transducer that has the advantage of having a high eficiency with a low source volume and weight. Source delivery is scheduled for March 2002.

4 Characterization of cold filament structures

The existence of cold filaments extending seaward from spatially intermittent locations along the upwelling coast has become an intriguing topic. It was most conspicuous along the eastern boundary regions of the Pacific coast of North and South America and the Atlantic coast of Iberia. Under the objective of developing an application of the integrated acoustic system to monitor the Cape São Vicente filament area, a description of the southern Portuguese coast was required. A characterization of filament structures on the basis of observations done along the California Current System (CCS) and the western Iberian Peninsula (IP) is being done (document 8 in annex).

Thanks to a search through the bibliographic database, historical observations were compiled. Basically, these data came from a series of individual hydrographic stations taken along the southwestern Portuguese coast between 1900 and 1998. Most of them were extracted from the CD Rom provided by the World Ocean Database 1998 (v.2.0, Jan. 2000), prepared by the Ocean Climate Laboratory from the National Oceanographic Data Center (NODC, 2000). Additional stations from our database were added to the NODC data set and a long-term picture of the circulation scheme along the southern Portuguese coast was depicted.

Thus, long-term volume transport estimates could be calculated for the area under study. It could be seen that during the upwelling season, the upwelling jet conveys between 0.7-1.0 Sv equatorwards parallel to the bathymetry. However, significant cross-shelf recirculations on the order of 20% of the main jet (in terms of volume transport) were observed. This fact was interpreted as the upwelling filament may leave a print upon the mean transports in spite of the strong averaging of the historical dataset (see details in document 9 in annex).

5 Autonomous bouy data acquisition system

The main objective of the conversion of the actual ULVA to an autonomous data acquisition system is to obtain "better" data and higher mobility. Since, on its present configuration, the ULVA has no capability to store the acquired data locally, those must be sent by a radio link to a remote location - usually a research vessel - where the data is stored. Abord the research vessel the raw data is stored in a DAT recorder and interfaced to a PC-based system for monitoring and online processing. The radio link is a weak part of this system, since very often it causes data dropouts and noise. Also, the power consumption of the transmitter at the array side, reduces the autonomy of the whole system, which is the strongest impairment, since the ocean processes generally need long observation periods. The procedures used to change the energy supplies at the array side are very dependent on the sea state and involve a high risk for the personnel and for the equipment, even in a quiet sea.

In order to compensate the above described drawbacks of the ULVA system, it was proposed to transform the actual system into an autonomous acquisition system with local storage facilities, lower power consumption and the capability of remote quality control of the acquired data. Also the usage of "open technologies" was considered a must, to allow easy upgrade of the system in the future. In that sense, a low power consumption embedded PC was chosen as the core of the system. This kind of approach allows to use a broad availability of software development tools and hardware peripheral boards.

The system runs embedded NT (eNT) which is a convenient OS since a scalable kernel can be constructed, and is a *de facto* standard, so nearly all peripheral boards can run under the same system. At the moment we have a board to provide digital interface and an accurate timing and a positioning peripheral board. This embedded OS also provide a standard file system support for the disks were data are stored. The standard communications facilities like a TCP/IP stack are also avaliable with this OS, which is important to develop the remote control system in a transparent fashion. The communication link for remote data quality control will be implemented by standard radio modems to keep the system in a high level of portability and upgradability. In order to interface the actual acquisition system some electronic boards will be replaced by two newly projected. That is seen as the most risky part of the project. At the moment the electrical and functional tests of those boards is being started.

The control software is under development while the data acquisition and storage software was already tested in a stand alone version. Afterwards, efforts will be concentrated towards system integration and packing into the buoy.

6 Conclusion

Remote sensing satellite sea surface temperature (SST) data has shown that cold water filaments were extending outwards Iberian Peninsula capes to the open ocean in phase, or just after, strong forcing upwelling regimes along the west coast of Portugal. These phenomena are in most respects similar to those observed and studied off the Californian coast. A conclusion at this stage of the research is that a significant cross-shelf transport (about 20% of the alongshore jet) in the target region can be recognized as a signal left in the mean transport by the recorrent occurrence of the cold filament feature. There are, however, still open questions which can be summarized as follows: how does the onset and offset of the filament occurs and what is development of the filament in water column. Since the filament is - at the ocean scale - a transient phenomena and it suffers from the time-space aliasing of traditional sampling techniques. Conversely, geo stationnary satellite observations do not suffer from such aliasing but can not penetrate the water mass. These two drawbacks of existing observation techniques are the motivation for using ocean acoustic tomography (OAT).

OAT is able to produce depth detailed observations with very high time resolution. The problem is that current OAT images are a range integration of the temperature along the ocean slice being observed. In other words, as far as OAT is concernned, the ocean behaves as a range independent media. This is the main problem addressed in the ATOMS project: how to estimate range-dependent parameters from acoustic tomography observations ?

So far, there are three main conclusions that can be drawn at this stage of the study:

- the acoustic field observed on a vertical array of sensors can only be accurately reproduced in the frequency band 800-1600 Hz when the water column characteristics are duelly modelled and time parameterized. Conversely, the observation of the acoustic field in the same frequency band allows for an accurate description of the time evolution of the temperature field upon the estimation of its parameters.

- incoherent combination of the acoustic field across-frequencies in a relatively small band (100 Hz) allows to obtain better matching results than the incoherent combination of auto-frequency terms in the same band. Incoherent cross-frequency estimation is shown to have the same performance than coherent methods in the same band with only a fraction of the computation cost.

- acoustic inversion tests, on range-dependent data simulated according to oceanic observations off the Californian coast, have shown that it is possible to detect a few degrees Celsius offset in the temperature profile on a 20 km slice when observed in a 200 km long transect. The performance was shown to be relatively robust to noise. These are encouraging preliminary results that are being pursued (see document 10 in annex).

References

[1] Munk W. and Wunsch C. Ocean acoustic tomography: A scheme for large scale monitoring. *Deep Sea Research*, 26(A):123–161, 1979.

[2] Munk W., Worcester P., and Wunsch C. *Ocean Acoustic Tomography.* Cambridge Monographs on Mechanics, Cambridge, University Press, 1995.

[3] Chiu C.-S., Miller J.H., Denner W., and Lynch J.F. Forward modeling of the barents sea tomography vertical line array data and inversion highlights. In O. Diaschok et al, editor, *Full Field Inversion Methods in Ocean and Seismo-Acoustics*, pages 237–242, Kluwer Academic Publishers, Netherlands, 1995.

[4] Chiu C.-S., Miller J.H., and Lynch J.F. Forward coupled-mode propagation modeling for coastal acoustic tomography. *J. Acoust. Soc. America*, 99(2):793–802, 1996.

[5] Lynch J.F., Gouliang J., Pawlowicz R., Ray D., and Plueddemann A.J. Acoustic travel time perturbations due to shallow-water internal waves and internal tides in the barents sea polar front. *J. Acoust. Soc. America*, 99(2):803–821, February 1996.

[6] Apel J.R., Badiey M., Chiu C.-S., Finette S., Headrick R., Kemp J., Lynch J.F., Newhall A., Orr M.H., Pasewark B.H., Tielbuerger D., Turgut A., von der Heydt K., and Wolf S. An overview of the 1995 swarm shallow-water internal wave acoustic scattering experiment. *IEEE Journal of Oceanic Engineeering*, 22(3):465–500, July 1997.

[7] Apel et al. The new jersey shelf shallow water acoustic random medium propagation experiment (swarm). In Zhang R. and Zhou J., editors, *Shallow-Water Acoustics: Proceedings of the SWAC'97 Conference*, pages 213–218, China Ocean Pres, Beijing, 1997.

[8] Elisseeff P., Schmidt H., Johnson M., Herold D., Chapman N.R., and McDonald M.M. Acoustic tomography of a coastal front in haro strait, british columbia. *J. Acoust. Soc. Am.*, 106((1)):169–184, July 1999.

A List of project publications

[**1.**] JESUS S. "Tomografia Passiva Costiera - Data Report, Phase 1", SiPLAB Report 01/01, March 2001.

[**2.**] JESUS S., SILVA A. e SOARES C., "INTIFANTE'00 Sea Trial Data Report - Events I,II and III", SiPLAB Report 02/01, May 2001.

[**3.**] JESUS S.M., COELHO E.F., ONOFRE J., PICCO P., SOARES C. and LOPES C., " The INTIFANTE'00 sea trial: preliminary source localization and ocean tomography data analysis", accepted in MTS/IEEE Oceans 2001, Hawai, USA, November 2001.

[**4.**] SOARES C., SIDERIUS M. and JESUS S.M., "MFP source localization in the Strait of Sicily", submited Journal of Acoust. Soc. of America, May 2001.

[**5.**] SOARES C.J., SIDERIUS M. e JESUS S.M., "MFP source localization in the Strait of Sicily", accepted in MTS/IEEE Oceans 2001, Hawai, USA, November 2001.

[**6.**] JESUS S.M. e SOARES C., "Broadband Matched Field Processing: coherent vs. incoherent ", MTS/IEEE Oceans 2001, Hawai, USA, Novembro 2001 (invited).

[**7.**] *Technical specifications of a broadband acoustic source*, CINTAL, University of Algarve, Faro, December 2000.

[**8.**] SÁNCHEZ R.F. and RELVAS P., "Occurrence and structure of upwelling filaments along western boundary coastal transition zones. The case of the Iberian Peninsula", Internal Report, CIMA - University of Algarve, Faro, July 2001.

[**9.**] SÁNCHEZ R.F. and RELVAS P., "Volume transports in the upper layer west of cape São Vicente", SW Portugal. ICES CM 2001/W:17, Oslo, September 2001.

[**10.**] CORRE V., "Estimation of the Properties of a Range-Dependent Ocean Environment: a Simulation Study", SiPLAB Report 03/01, October 2001.

(attached to this report)