SEVENTH FRAMEWORK PROGRAMME
Marie Curie Actions-People
International Research Staff Exchange Scheme

Ocean Acoustic Exploration (OAEx)

1st OAEx Workshop Proceedings

Instituto de Estudos do Mar Almirante Paulo Moreira
Arraial do Cabo, Brazil
March 2010

INSTITUTO DE ESTUDOS DO MAR
ALMIRANTE PAULO MOREIRA
(ADMIRAL PAULO MOREIRA MARINE RESEARCH INSTITUTE)

1st OAEx Workshop
Ocean Acoustic Exploration

March, 22nd - 26th 2010
Arraial do Cabo, Rio de Janeiro, Brasil

Universidade Federal do
Rio de Janeiro

Université Libre de Bruxelles

University of Victoria

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Attendance list

- **UALG /PT**
  - **Sérgio Jesus**
  - **Nélson Martins**
  - **Paulo Felisberto**
- **ULB / BE**
  - **Jean-Pierre Hermand**
  - **Olivier Carrière**
- **IEAPM / BR**
  - **Marcus Vinícius da Silva Simões**
  - **Ana Cláudia de Paula**
  - **Lúcia Artusi**
  - **Helber Carvalho Macedo**
  - **Isabel Cristina Vendrameto Peres Simões**
  - **Leonardo Martins Barreira**
  - **Antônio Hugo Saroldi Chaves**
  - **Fernando de Oliveira Marin**
  - **Eduardo Giuseppe Rigoglio**
  - **Pablo Jabor**
  - **Leandro Calado**
- **COPPE / BR**
  - **Carlos Eduardo Parente Ribeiro**
  - **Luiz Gallisa Guimarães**
  - **Lussac Prestes Maia**
  - **Paulo Ricardo Brito de Araújo**
- **PETROBRAS / BR**
  - **Alexandre Coelho da Fonseca**
- **IPqM / BR**
  - **Fernando Luis Ribeiro da Rocha**
- **CASOP / BR**
  - **Warley Gripp Santana**


HOTEL A RESSURGÊNCIA
MARINHA DO BRASIL
INSTITUTO DE ESTUDOS DO MAR
ALMIRANTE PAULO MOREIRA
1st OAEx Workshop
Ocean Acoustic Exploration
March, 22nd - 26th 2010

Abstracts

ANALYSIS OF GEOACOUSTICS PARAMETERS (P-WAVE VELOCITY, POROSITY AND GRAIN SIZE) OF MARINE SEDIMENTS ABSTRACT

Lucia Artusi[1], Helber Carvalho Macedo[1], Isabel C. V. Peres Simões[1], Jean-Pierre Hermand[2]
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Avenue Franklin D. Roosevelt, 50 - B-1050Brussels, Belgium

The presentation is about the secondment of CF (T) Lucia Artusi, CF Helber Carvalho Macedo and CC (T) Isabel Cristina Vendrameto Peres Simões at ULB (Université libre de Bruxelles), on November, 2009. The secondment had been advised by Prof. Jean-Pierre Hermand at the Hydroacoustic Environmental Lab in order to attend the general purpose of Work Package 2 (WP2), what is to develop a detailed environmental model of the test area near Cabo Frio Island, based on archived data.

The depths at research area varies from 40 to 130 meters. The archived data are the detailed bathymetry, the sediment grain size of the seafloor and the P-wave velocity (Vp) of sub-bottom layers.

The bathymetric data were collected on board of TAURUS Hydrographic vessel, owned by Brazilian Navy. Two different echosounders were used: EM1000 and EM1002. The data set is a raw data, consisted of bathymetric and backscatter data.

The seismic data were collected last October on board of OCEAN SURVEYOR vessel, with Geopulse equipment. Two lines were acquired and still need to be processed.

The core campaign was held in June 2009, on board of DIADORIM, an IEAPM's research ship. Twelve cores were obtained, some of them with almost 2 meters of length. They were sent to UFF (Fluminense Federal University in Niterói), to be analyzed with Geotek Multi-Sensor Core Logger.

The Core Logger is a system to perform automated measurements including compressional wave velocity and magnetic susceptibility. The compressional wave velocity reflects the physical characteristics of sediment. It means that sediment composition, degree of compactation and size of grains can interfere in p-waves results. The acoustic impedance, the porosity and density values are calculated after the Vp and magnetic measurements.

The cores were logged longitudinally, in two orthogonal positions (zero degree and 90 degree). Two months later, another measurement at zero degree orientation was taken. These measurements lagged in time make possible to check if some anisotropy or heterogeneity happen inside the layers, beyond the natural loss of water, the decomposition of organic matter and the compaction of sediments. To avoid layers disturbance, .the cores were transported in vertical position.

Vp is influenced by core diameter and local temperature. During work processing, we found out an unacceptable variation in Vp values. Working with Prof. Jean-Pierre we found out that the reason was that core tubes had been deformed. The data had been corrected and the lines are matching now. The Vp information refers to the sediment column, below the seafloor.

After the measurements, the cores were split in the middle and photographed. At every 10 cm, samples of sediments were collected and sent to the lab to analyze the fraction of grain size of sediments.

All those data will support the environmental model for the research area.

Another activities conducted during the secondment were: an extensive bibliography research; the enrollment as a ULB's visitor researcher; an academic visit to the Museum of Musical Instruments; and a lecture given by Professor Hermand at the Royal Military Academy within the scope of Marie Curie Program. Also Prof Hermand donated to IEAPM the book Acoustic Sensing Techniques for the shallow water environment, 2006.

IMPULSE RESPONSE INTERPRETATION OF A VERY SHALLOW WATER ACOUSTIC CHANNEL

Hugo Chaves[1], Lucia Artusi[1], Helber Carvalho Macedo[1], Isabel C. V. Peres Simões[1], Raimundo Nonato[1], Paulo Felisberto[2], Paulo Santos[2]
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This presentation describes an experiment conducted in the framework of OAEx project in front of Ilha dos Porcos, Arrail do Cabo, Brasil. The objectives of the experiment were to test the equipments available at IEAPM, test the whole acquisition chain at sea conditions, acquire acoustic field data to exercise basic signal processing procedures and to made some simple propagation condition analysis, made a rough classification of the sediment by comparing features observed in real data with the outputs of the propagation models (arrival structure, travel time, signal spread, transmission loss.

The acoustic data acquisition system were tested at IEAPM Acoustic Laboratory facilities. It was compound of 2 hydrophones (one with preamplifier) connected to a Laptop's sound card. The acquisition program was running in Matlab and the data were saved in mat-files. The sound source used was an active sonar sound source. Taking in account the characteristics of source and hydrophones, the signal used in the sea trial was a sequence of chirp signals and multitones in the band 3000-4000Hz. The signal was generated using a PC sound card driven by a Matlab script. The area chosen to perform the experiment was off the Ilha dos Franceses/Ilha de Cabo Frio, thus inline with the interest area identified previously. Due to weather conditions, the sea trial was conducted in a alternative site (Ilha dos Porcos). The sound source was suspended from RV Diadorin at 10m depth and the hydrophones system from a small boat (Leg) at 10m and 15m depth. The acoustic measurements were performed in 8 stations, ranging from 100m to 1200m in range independent track. Simultaneously with the acoustic measurements CTD and XBT measurements were conducted. The positioning of the deployments was obtained from GPS systems on board of both ships and from Diadorin radar. Initial acoustic data processing showed that the signal acquired by the hydrophone at 15m was clipped, thus further processing was done with the hydrophone at 10m only. From the raw signal arrival patterns were computed. Despite the sea conditions observed during the sea trial and the high frequency of the signal, the measured arrival patterns were stable. Applying the ray tracing propagation model Bellhop and assuming a sand sediment arrival patterns were modelled and compared with measured ones. A first analysis based on arrival pattern time spreading leads to consider that sediment was softer than sand. Using a trial and error approach it was estimated that the sediment was mud.

AN ACOUSTIC INVERSION EXERCISE WITH SAGA, USING TEMPERATURE (T) AND SALINITY (S) DATA COLLECTED NEAR THE CABO FRIO COAST

Fernando Marin
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The presentation showed the work that was done in the October 2009 secondment, that integrates the WP 2 mentioned in the Annex I - 'Description of Work' of the EU OAEX Program Proposal FP7 230855. This secondment consisted of carrying out an interdisciplinary study, by deriving an acoustic inversion exercise, considering oceanographic features typical of Cabo Frio cape, provided by partner IEAPM.

The Cabo Frio area is known to be prone to great variability, as exposed to a north-eastern wind-driven upwelling regime during most of the year. The OAEx Program comprises a series of acoustic experiments in this area, with the objective of carrying out acoustic inversion for the estimation of oceanographic and geoacoustic parameters needed by acoustic models, to forecast sonar ranges.

To carry out an acoustic inversion exercise with SAGA, we used temperature (T) and salinity (S) data collected near the Cabo Frio coast. It comes from CTD, XBT, MBT and Nansen bottle profiles respecting to several years, taking part of the Raw Database of the Acoustic Environment Forecast System for Naval Operations Planning (SISPRES), from the Brazilian Navy. These data were arranged in monthly files, from January to December, giving rise to three-dimensional fields of T, S and sound speed (svel), where each month is characterized by a single field. The month of December was selected for analysis, for the greatest amount of data.

The outline of the Presentation was: INTRODUCTION (Purposes), DATA SET, THEORY (Literature Review, Main Applications of Underwater Acoustics, Speed of Sound in Sea-Water, Forward and Inverse Problems, Acoustic Inversion, EOF, SAGA and some concepts), METHODOLOGY (Data Analysis, Considerations), RESULTS and CONCLUSIONS.

FEATURE ORIENTED MODELS USED IN ACOUSTICAL OCEANOGRAPHY

L. Calado[1], A. C. de Paula[1], J. P. Hermand[2], O. Carrière[2], N. E. Martins[3], O. Rodriguez[3]
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Synoptic oceanic and acoustical predictions require the best, as possible, specification of initial conditions. To provide the required synoptic environment, knowledge-based feature models (FMs) have been used by regional simulations and operational forecasting for the past two decades, in many parts around the word, associated with specific purposes. Feature Oriented Regional Model (FORM) is a technique that uses previous knowledge of oceanographic features, the development of parametric (Features Models) and numerical models. Multi-Scale Objective Analysis (MSOA) was the tool used to merge different data set scales, keeping each data set characteristic and resulting in smooth field. As Brazil Current has a complex dynamic, it was develop parametric models to main oceanographic features off Cabo Frio (RJ, Brazil) coast (upwelling and eddy).

It was developed a Feature model based on acoustic to inversion purpose for coastal upwelling in Cabo Frio region, as well as it was applied the Regional Oceanic Model System (ROMS) with high resolution grid to provide the environment to test this methodology. The objective was to verify if this tool is huge enough to be used for acoustical purposes to recognize time evolution of the environment, shallow water acoustic tomography.

Also the temperature and salinity fields were developed, based on Feature Model techniques to simulated water environmental field, to be applied as scenarios for a average profile, a coastal upwelling and an eddy at Cabo Frio, to define the sound propagation and localize sound sources.

The proposed scheme presents the FM technique, added to numerical modeling for ocean forecasting, as a tool that allows predicting the acoustic environment.

SONAR PERFORMANCE PREDICTION IN CABO FRIO

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Sonar performance prediction is carried out off Cabo Frio (Brazil). The aim is to arrive at the detection probability of a hypothetical existing sonar, in passive mode. In opposition to standard approaches, in which sonar performance is computed with climatologies, here, two oceanographic scenarios from the POM ocean prediction model are tested. One scenario is a barotropic ocean; the other, a cold-core vortex. Following Ref. [C.M. Ferla and M.B. Porter, "Receiver Depth Selection for Passive Sonar Systems", IEEE Journal of Oceanic Engineering, vol. 16, no. 3, 261-278, 1991], the acoustic source is assumed to be at an unknown depth. Hence, for each source-receiver range, the probability is computed as a weighted average of the probability corresponding to each possible depth. As a means of assessing sonar performance as a function of receiver depth, for an unknown source-receiver range, the final measure of performance is given in range units - the 'detection radius' -, as an integral of range-dependent detection probabilities. The results show that the cold-core vortex induces an increased detection radius. In summary, it is encouraged the inclusion of coupled ocean-acoustic prediction systems with detection probability indicators, as operational tools for the time-varying ocean environment.

CLASSIFICATION OF THREE-DIMENSIONAL OCEAN FEATURES BY TWO-DIMENSIONAL ACOUSTIC SAMPLING

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The estimation of water column properties is routinely done by resorting to acoustic inversion methods. The problem is ill-conditioned and computationally intensive, if each of a huge set of spatial points is a free parameter in the inversion. Empirical orhogonal functions (EOFs) are efficient in the regularization of the inversion, providing a set of principal components with a few (2, 3) coefficients to estimate. At small scales, only the vertical variability is considered in the definition of the EOFs. The extension of the approach to larger scale anisotropic fields requires horizontal discretization into sectors, with the estimation of range-dependent coefficients. This becomes unstable and complicated by higher computational costs, and has been overcome by two-dimensional depthrange EOFs, in the past. The present work extends the empirical orthogonal function concept to three dimensions, assessing the performance of the inversion for an instantaneous sound speed field constructed from measures off Cabo Frio, Brazil. The results show that: 1) 3 EOFs are insufficient to represent the field; 2) the acoustic observations do not carry enough information on the underlying sound speed field. Further studies are required, specially to remove the ambiguity, by adding acoustic transects.

FEATURE-ORIENTED ACOUSTIC TOMOGRAPHY: UPWELLING AT CABO FRIO (BRAZIL)

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Data assimilation in coastal environments is a hard task due to the strong coupling between state variables and forcing and the lack of data on the scale of interest. Acoustic tomography can compensate for the scarcity of measurements and complete standard data set with valuable synoptic measurements on temporal and spatial scales suitable to a regional circulation model.

In a previous work, we showed that the acoustic monitoring of the central position of a seasonal thermal front was feasible by coupling a basic feature model and appropriate inversion techniques involving full-field acoustic propagation modeling [Carri'ere & Hermand, 2009]. In this work, we apply this technique on a different feature model which describes the coastal upwelling that occurs on the southeastern coast of Brazil and in particular the Cabo Frio area. Recent work has already applied such features model for regional modeling and simulation purposes [Calado et al., 2008].

During the summer, when coastal upwelling is more common and robust due to favorable forcing conditions in this area, the surface temperature difference between the stratified waters off shore and upwelled waters near the coast is most of the time greater than 8 degrees centigrade. As coastal upwelling occurs, the waters follow the shelf break and the isotherms bend upwards in the vicinity of the continental slope. In most situations the resulting sharp variations of the sound-speed field, associated with a varying bathymetry, create a strong coupling between the acoustic propagation modes that cannot be neglected.

In the first part of the work, we study the characteristics of the acoustic propagation in vertical slices of the Cabo Frio environment in the range from 200 Hz to 800 Hz, and compare complex-valued acoustic fields synthesized through different simulated upwelling situations, taking into account the range-dependent bathymetry and seabottom acoustic properties. The geoacoustic model is derived from a set of multibeam, seismic and sediment core data obtained in the framework of an Ocean Acoustic Exploration IRSES project [Carvalho et al., 2009].

Based on the forward modeling results, the second part of this paper applies a Kalman-based data assimilation scheme enabling the tracking of the principal parameters of the sound-speed field in the vertical slice, using the upwelling feature model to parameterize the environment. The proposed scheme considers the regular measurements of multi-frequency, fullfield acoustic data on a vertical array of receivers that are assimilated in the basic feature model to continuously correct the prediction of the time-evolving physical parameters of the Cabo Frio upwelling. To cope with the nonlinearity between the environmental parameters and the resulting acoustic measurements, advanced nonlinear extensions of Kalman filters are required. More specifically, it is shown that the ensemble Kalman filter (EnKF) outperform the common extended Kalman filter (EKF).

GEOACOUSTIC INVERSION AND SOURCE PASSIVE LOCALIZATION IN SHALLOW WATER

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The geoacoustic characterization of the seabed is a complex task, often solved by inversion techniques. In the same way, it can be solved passive source localization problems. The inversion of acoustic pressure data generally uses the well known Matched Field Processing (MFP) method, which is a frequency domain approach and it is generally used with the sparse sampling in frequency of a multitone signal and a dense array of hydrophones. Alternatively, it is possible to use the time domain processing Model Based Matched Filter (MBMF), which exploits the time dispersion characteristics of a broadband coded signal in a shallow water channel using the corresponding impulse response. This work presents theoretical ground and two experiments using respectively MFP Bartlett multifrequencies and MBMF in a frequency domain version, both applied to pressure data registered on a sparse hydrophone array, from a source emitting broadband signals during the Maritime Rapid Environment Assessment (MREA/BP'07) experiments in south of Elba island, off the coast of Italy [Hermand & Le Gac, 2007]. Signals multitone and linearly frequency modulated (LFM) over the frequency range 300-1600Hz were emitted by the source, whose distance from the vertical array receiver decreased slowly in a range independent environment. The cost functions were used to estimate the best field through MFP and analogous MBMF inversion technique. The processing applied to a sequence of emissions in intervals of one minute produces stable results which are in agreement with the earlier experiment Yellow Shark, showing the feasibility of the methods.

IEAPM Highlights

Marcus Simões
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Since OAEX starting date on February 1st 2009, IEAPM is deeply committed into collaborated and contributed with the best in personnel and material resources to fulfill OAEX goals, milestones and deliverable. The results of the work done to deliver to all partners the best conditions and equipment to realize a data collecting experiment focused on a sea cruise near Cabo Frio Island on Arraial do Cabo in Rio de Janeiro are presented. During this year IEAPM improve its research vessel fleet acquiring by opportunity the RV Finder which was renamed to "Aspirante Moura"receiving Brazilian Navy visual indicative U-14. Furthermore, sets of new oceanographic, hydrographic, geologic and acoustic equipments are being acquired to improve our participation and commitment in OAEX goals. This presentation outline IEAPM responsibilities on OAEX, shows U-14 pictures and list the equipments, on board conditions and resources to the scientific personnel and crew.

Presentations

Ocean Acoustic Exploration

ANALYSIS OF GEOACOUSTICS PARAMETERS (P-WAVE VELOCITY, POROSITY AND GRAIN SIZE) OF MARINE SEDIMENTS

CF(T) Lucia Artusi
CF Helber Carvalho Macedo
CC(T) Isabel C. V. Peres Simões
Prof. Jean-Pierre Hermand

Brussels, Belgium
November - 2009

SUMMARY

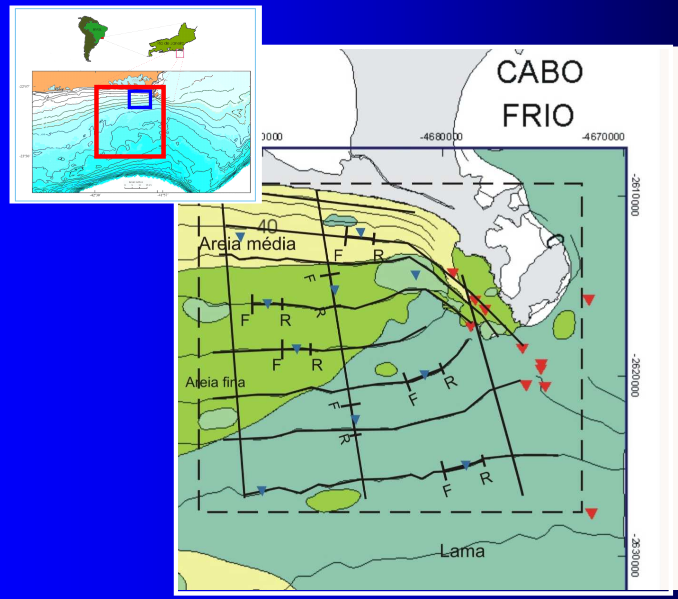
EXPERIMENT AREA – OAEX PROJECT - PLANNING

GENERAL PURPOSE OF SECONDMENT

SPECIFIC PURPOSE

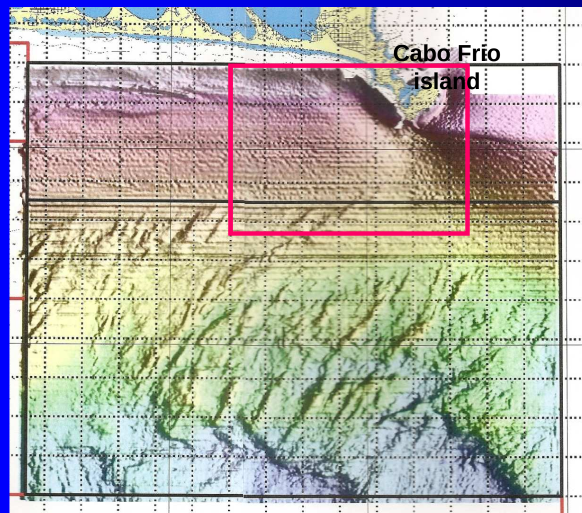
ACTIVITIES

FINAL REMARKS



GENERAL PURPOSE
To develop a detailed environmental model of the test area near to Cabo Frio island, based on archived data

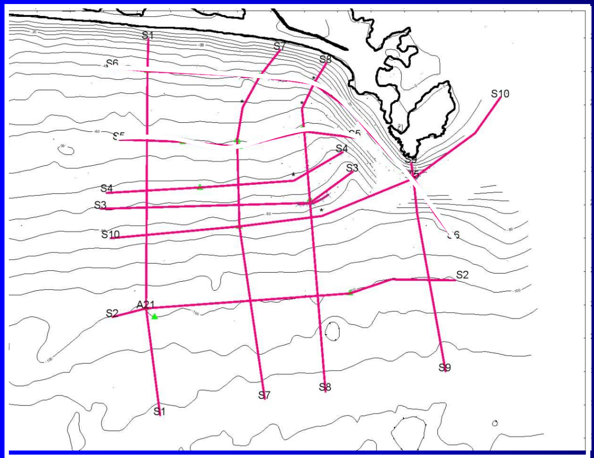
SPECIFIC PURPOSE
Analyze the bathymetric data, seismic and geological cores



Bathymetric data set
NHo Taurus
2005 e 2008

EM 1000 (2005)
EM 1002 (2008)

Ocean Acoustic Exploration



Seismics data

Ocean Surveyor
October, 2009

Geopulse/GeoAcoustics

Ocean Acoustic Exploration

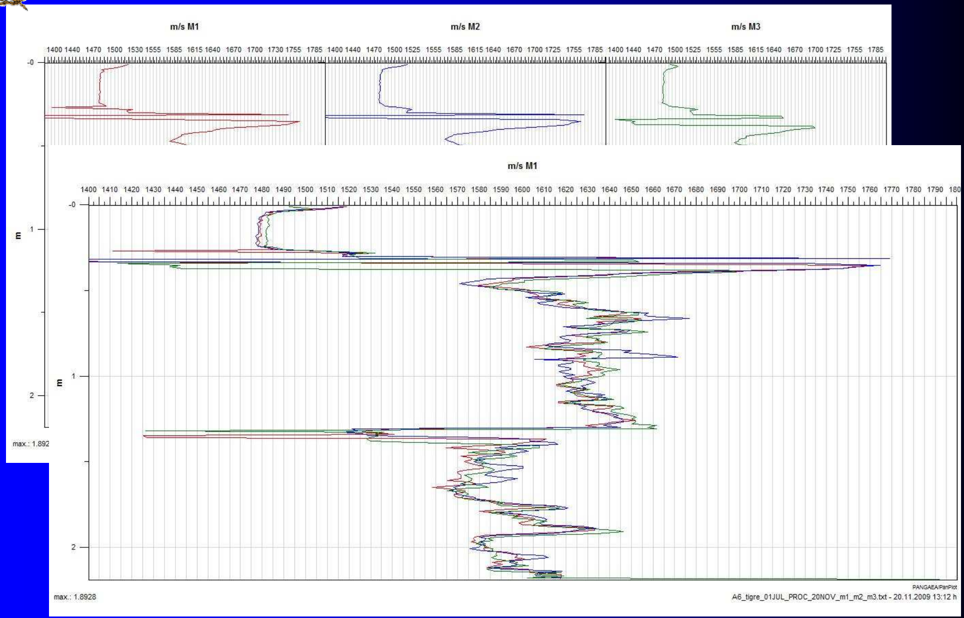
Ocean Acoustic Exploration

GEOTEK Multi-Sensor Core Logger

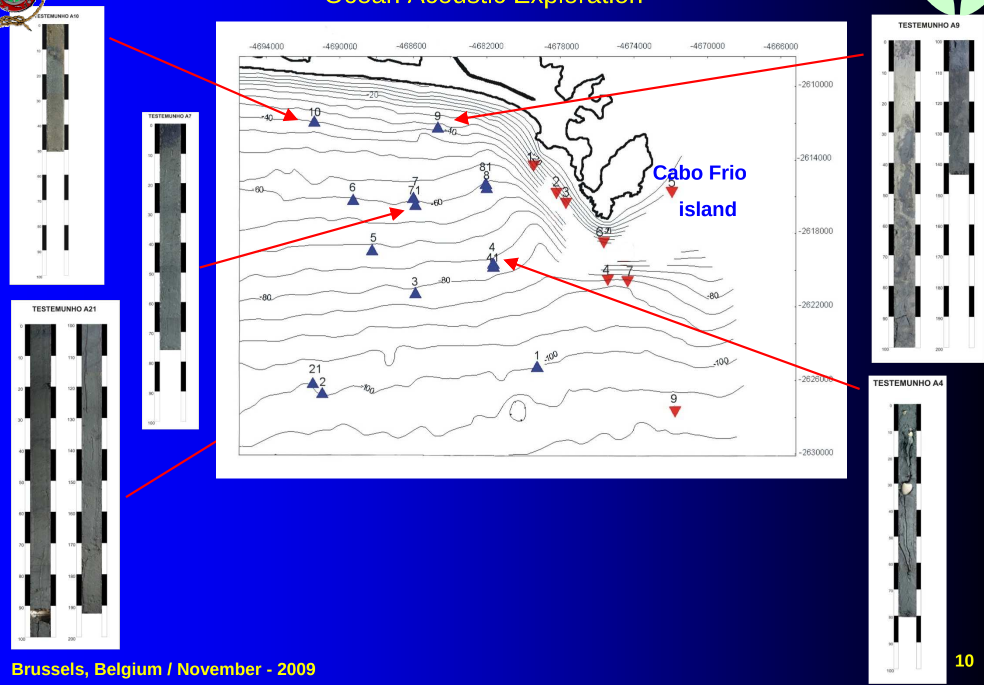
- compressional wave velocity (Vp)
- magnetic susceptibility
- acoustic impedance
- porosity
- density

Ocean Acoustic Exploration

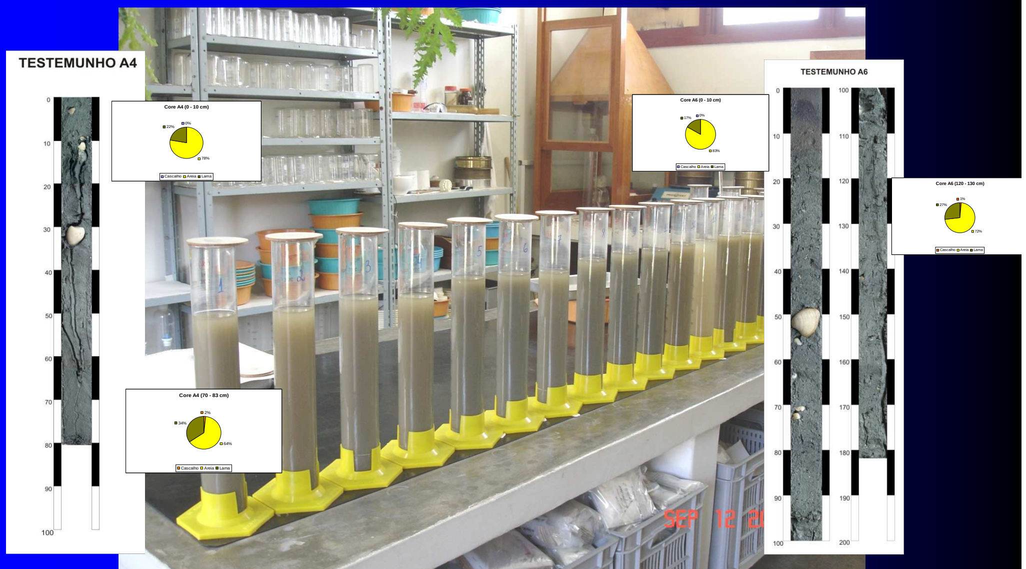
Ocean Acoustic Exploration



Ocean Acoustic Exploration



Ocean Acoustic Exploration



Ocean Acoustic Exploration

Subject of papers	Quantity of papers
Acoustics in Water	14
Bioacoustics	12
Geoacoustic Inversion	36
Experiments (in situ and at laboratory)	62
Source localization	12
Morphology and backscattering	34
Signal Processing	20
Environmental Noise	13
Seismic	19
Publications identified but not accessed	49
TOTAL	**269**

1. Standard values of P-velocity, magnetic susceptibility, acoustic impedance, porosity and density to each sub-bottom layer;
2. Influence of time and direction of measures while logging the core (gas bubbles, decomposition of organic matter and compaction)
3. Reflexion coefficients of the surperficial layer of sea bottom
4. Thickness and geometry of the sub-bottom layers where the acoustics experiments will be held
5. Support the environmental model of Cabo Frio area

1st OAEx workshop
IEAPM – Arraial do Cabo
March 2010

Impulse response interpretation of a very shallow water acoustic channel

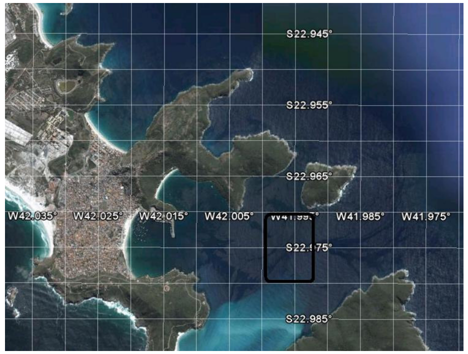
H. Chaves, L. Artusi, R. Nonato, H. Carvalho, I. Peres (IEAPM)
P. Felisberto, P. Santos (ISR/CINTAL/UALG)

Summary

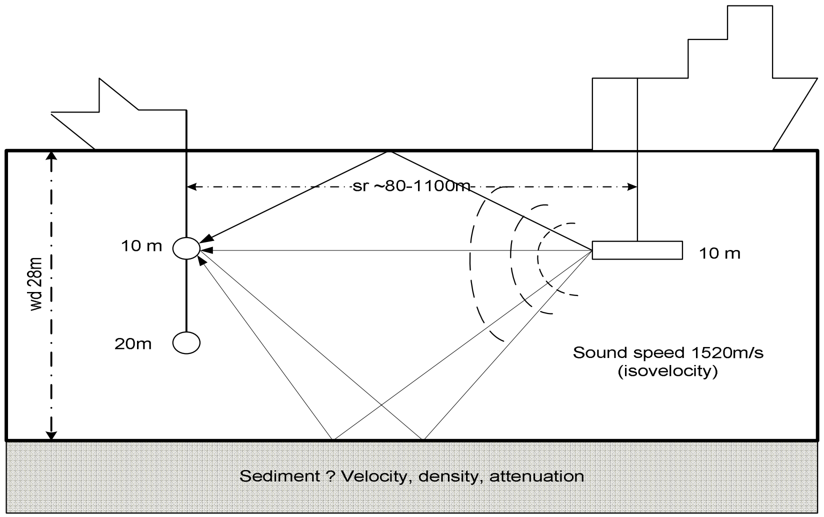
- Experiment overview
- Channel impulse response
- Acoustic propagation modelling
- Data interpretation
- Conclusions and future work

Ilha dos Porcos Experiment

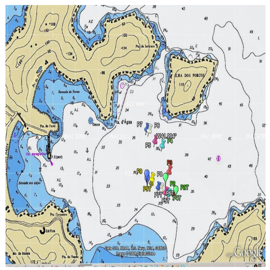
- 21th July 2009
- Very shallow water area
  - water depth: 28m
- XBT stations
- Emitting system:
  - active sonar source suspended @ 10m
  - band 3000-4000Hz
  - LFM and Multitones
- Receiving system:
  - 2 hydrophones suspended @ 10m, 20 m
- Stations
  8 ranges from 80m~1100m

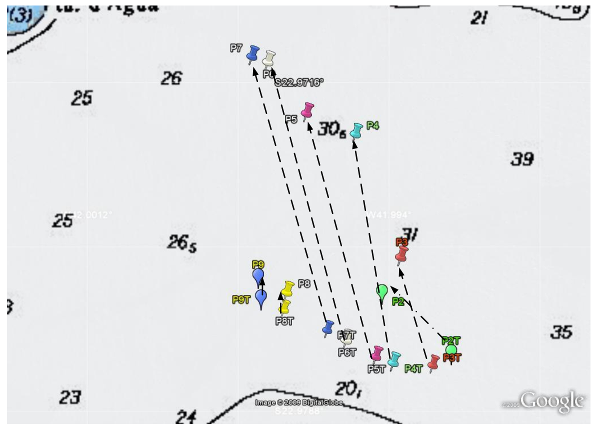


Ilha dos Porcos Experimental Setup



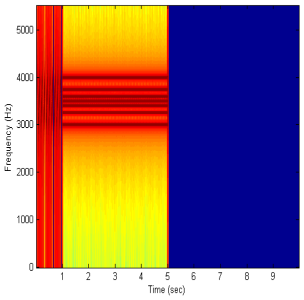
Stations location



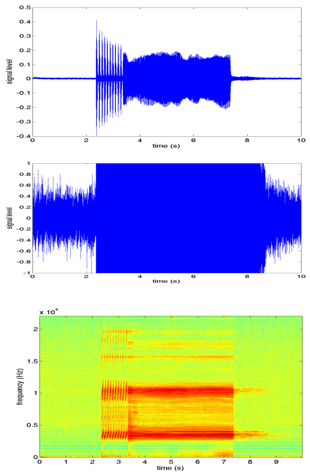


Signals

- emitted
- series of 10 LFM-CHIRP between 3-4 kHz with 50 ms, silence 50ms
- Tone pulses (3, 3.25, 3.4, 3.5, 3.6, 3.75, 4 kHz) during 4 sec, silence 5 sec.
- 5 minute

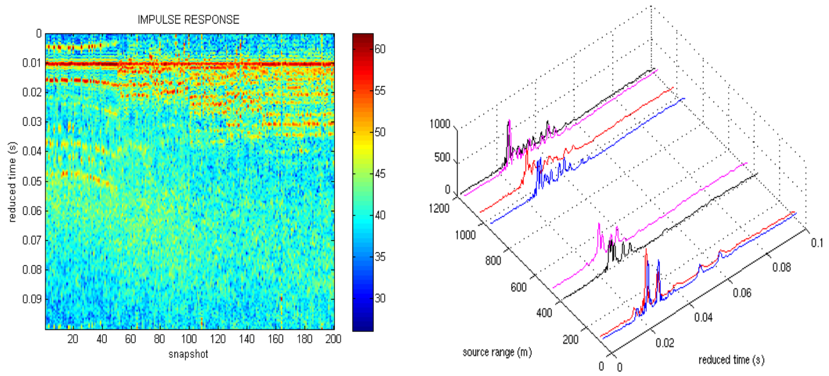


- received



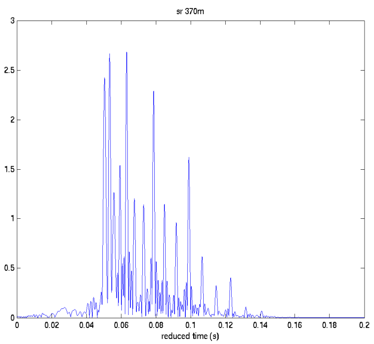
Impulse response

- estimated by crosscorrelation between emitted lfm and received signals (hydrophone @ 10m)

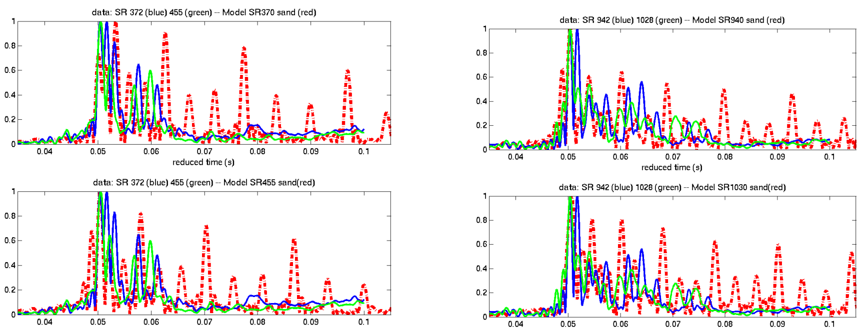


Impulse response modeling

- Ray trace acoustic model (Bellhop)
- Simulation parameters
  - Water Column
    - Source frequency= 3500 Hz
    - Depth= 28 meters
    - Sound Speed= 1520m/s (isovelocity, measured with XBT)
    - Water density= 1024 kg/m3
  - Sediment Parameters
    - Type: Medium Sand
    - Velocity: 1750 m/s (isovelocity)
    - Density= 1800 kg/m3
    - Attenuation= 0,6 dB/m/kHz

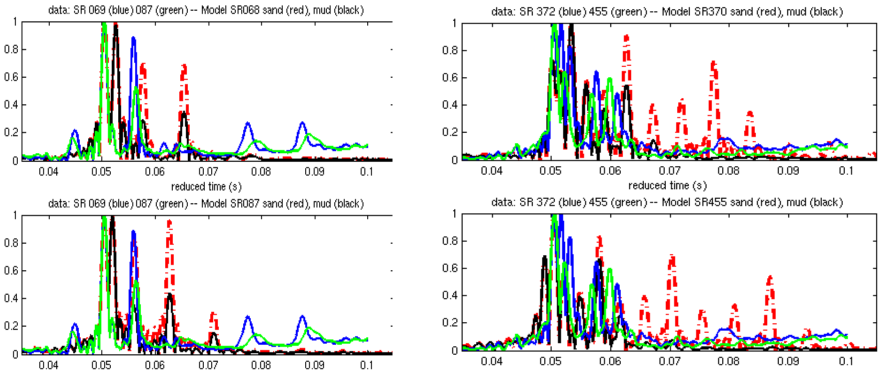


Measured vs modeled IR(1)



Measured vs Modeled IR (2)

- **new sediment parameter** :Velocity: 1600 m/s (isovelocity), density= 1400 kg/m3, attenuation= 0,4 dB/m/kHz



conclusions and future work

- Acquired knowledge in planning and conducting an acoustic sea trial
- Available equipments were tested
- Basic signal processing procedures were practiced
- Acoustic modeling using ray tracing (Bellhop) were practiced
- General characterization of the bottom by trial and error

- Apply acoustic inversion methods to estimate environmental parameters (make a fine tune of the bottom characteristics)

OAEx Joint Research Programme

"**OAEx**: **O***cean* **A***coustic* **Ex***ploration*"

I Workshop

"An acoustic inversion exercise with SAGA, using temperature (T) and salinity (S) data collected near the Cabo Frio coast."

Lt Cdr Fernando de Oliveira **Marin**
Ocean Projects Division

IEAPM, 24th March 2010.

OAEx Joint Research Programme

Secondment Place:

SiPLAB (*Signal Processing Laboratory*)
Faculdade de Ciências e Tecnologia (FCT)
Universidade do Algarve - Campus de Gambelas
Faro - Portugal

Period:

28th September to 23rd October 2009

"An acoustic inversion exercise with SAGA, using temperature (T) and salinity (S) data collected near the Cabo Frio coast."

Summary

Purposes

OAEx Purpose

Develope synergies and reinforce collaboration between the EU (Portugal and Belgium), Brazil and Canada in the field of ocean acoustic monitoring and marine technologies.

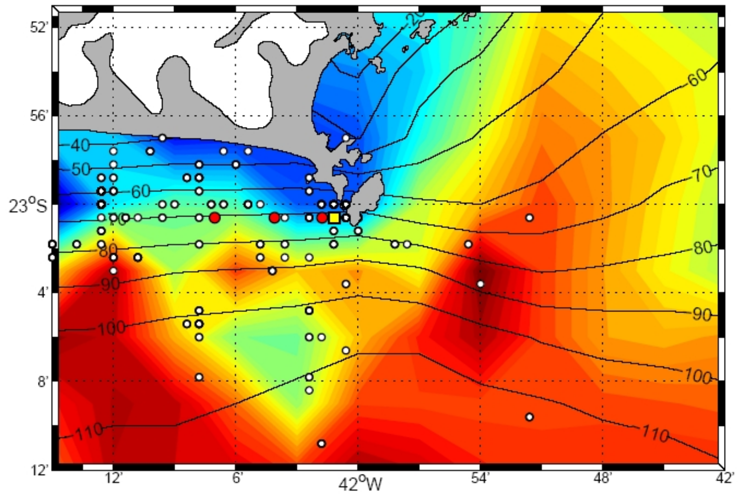
Portugal Secondment Purpose

- **General Purpose**: Carry out an interdisciplinary study, seeking to understand the main acoustic inversion methods and deriving an acoustic inversion exercise.
- **Specific Purpose**: Carry out an acoustic inversion exercise with SAGA, using temperature (T) and salinity (S) data collected near the Cabo Frio coast.

Dataset

- Database: **SISPRES Database**;
- Data: Temperature (**T**) and Salinity (**S**);
- **Data of several years arranged in monthly files, from January to December, that was acquired by**:
  - **CTD** (*Conductivity, Temperature and Depth*);
  - **XBT** (*Expendable Bathythermograph*);
  - **MBT** (*Mechanical Bathythermograph*); e
  - **Nansen Bottles**.
- The month of **December** was selected for analysis, for the greatest amount of data that highlight the upwelling.

Dataset - December data were selected for analysis



In the Figure, the **white circles** are the positions of the **December data**. The background is the interpolation of temperature data. The **yellow square** represents the **receiver (R)**, and the **red circles**, the positions to be occupied by the **source (S)**.

Literature Review - Forward Models

- A **forward model** is an important tool in predicting the sound pressure at a given point in space, being an essential element in many acoustic inversion methods [*Soares & Jesus*, 2005].
- **Acoustic inversion** can be loosely defined as an optimization problem, in which we seek the environmental picture corresponding to the acoustic field modeled observables that best match a given observation carried out by one or more hydrophones [*Caiti et al.*, 2006].
- The inversion software package **SAGA** (**S**eismo **A**coustic inversion using **G**enetic **A**lgorithms) has been developed for assisting in estimating environmental parameters [*Gerstoft*, 2007].

Introduction - Underwater Acoustics - Main Applications

Underwater Acoustics - Civilian and military applications

infer

- Bathymetric Sounders (measurement of water depth);
- Fishery Sounders (detection and localisation of fish shoals);
- Sidescan sonars (acoustic imaging of the seabed);
- Sediment Profiles (stratified internal structure of the seabed);
- Active and Passive Sonars (Detect targets, Acquire the target-radiated noise);
- Acoustic Communication Systems;
- **Acoustic Tomography** (Changes in the acoustic field can be related to changes in temperature).

Theory - Speed of Sound in Sea-Water

A simplified formula [Medwin, 1975], but good only to 1 km depth:

$$c = 1449,2 + 4,6T - 0,055T^2 + 0,00029T^3 + (1,34 - 0,01T)(S - 35) + 0,016z$$

where

- **c** : sound speed ($m\ s^{-1}$);
- **T** : temperature ($^\circ C$);
- **S** : salinity (PSS-78); e
- **z** : depth (m).

UNESCO **standard algorithm**, 1983: [*Chen & Millero*, 1977]

Theory - Forward Problem

Forward Problem

transmitted signal ⇒ | Model, Geometry of propagation, bottom, sound speed | ⇒ received signal

A known parameter set **m** of a channel propagation will produce a set of data **d**:

$$F(\mathbf{m}) = \mathbf{d}$$

Theory - Inversion Problem

Inversion Problem

Model
+
Received Signal (transmitted signal) $\Rightarrow$ Geometry, Bottom, $c(z)$ *likely* $\Rightarrow$ Geometry, Bottom, $c(z)$ *true*

Given a measured data set **d** the model **m** that best models the data may be found by 'solving

$$F^{-1}(\mathbf{d}) = \mathbf{m}$$

Theory - Acoustic Inversion

Acoustic Inversion - Short Definition

Resolution of an inverse problem.

The four large inverse problems

- Sources Localization;
- Characterization of the seabed;
- **Acoustic Tomography** (Get from precise measuremets of travel time or others properties of acoustic propagation, the state of the ocean traversed by the sound field.);
- Acoustic Communications (the most difficult).

Theory - EOF

- **Empiric Orthogonal Functions** (EOF): a powerful tool for analyzing a large amount of data and also provide a quick interpretation;
- EOF are the eigenvectors of the correlation matrix of the observations;
- With origin in **Oceanography**, EOF are being used intensively in underwater acoustics;
- An advantage is the computational cost.

Theory - EOF

- The acoustic inversion considered the EOF-based model in Eq. 1 below for the sound speed. The goal is then to estimate the coefficents α_n:

$$c(z) = \bar{c}(z) + \sum_{n=1}^{n} \alpha_n EOF_n(z) \qquad (1)$$

- The advantage of using EOF is due to the fact that only a few EOF (2 or 3 in most cases) are enough to represent a profile with an acceptable error;

Theory - The software package SAGA

SAGA (**S**eismo **A**coustic inversion using **G**enetic **A**lgorithms):

- Created by P. Gerstoft, the University of California at San Diego;
- Developed for assisting in estimating environmental parameters;
- the package consist of nine modules, one for each forward model. Among them, we use:
  - **SNAP** (*normal modes*);
  - **SNAPRD** (*adiabatic normal modes*);
- The SAGA calculates the **Bartlett estimator** for a range of likely values of the coefficients of **EOF** α_1, α_2 and α_3.

Theory - Some concepts used in the SAGA

Objective Function

One of the most important tasks in carrying out an inversion by means of optimization is to define a proper objective function.

Genetic Algorithm

Genetic algorithms (GA) are a class of optimization algorithms that use techniques similar to biological evolution to solve optimization problems. Operations:

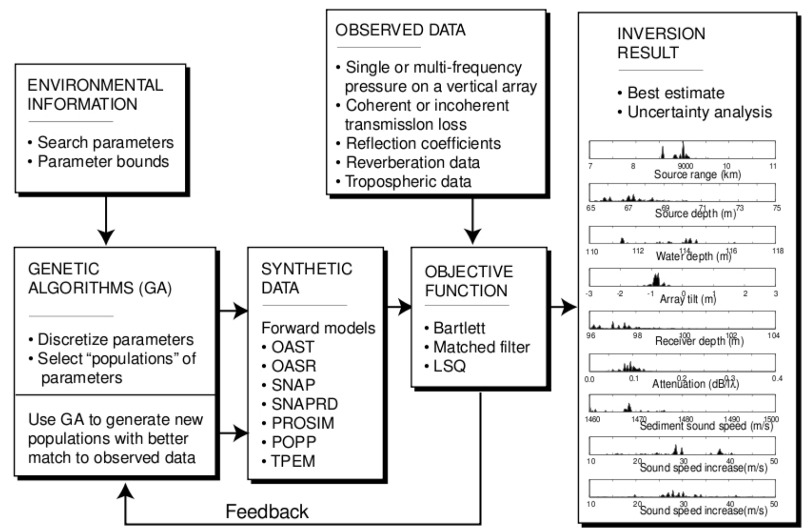
- **Selection**;
- **Cross-over**;
- **Mutation**; and
- **Replacement**.

Theory - Acoustic Inversion with SAGA

We can divide the inversion process into five parts:

- (I) Discretization of the environment and discretization or transformation of the data;
- (II) Efficient and accurate forward modeling;
- (III) A suitable objective function;
- (IV) Efficient optimization procedures;
- (V) Uncertainty analysis.

Theory - SAGA: Computer code for inversion of observed data



1. Introduction
   - Purposes
2. Dataset
3. Theory
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   - Underwater Acoustics: Main Applications
   - Speed of Sound in Sea-Water
   - Forward and Inverse Problems
   - Acoustic Inversion
   - EOF
   - SAGA and some concepts
4. Methodology
   - Data Analysis
   - Considerations
5. Results
6. Conclusions

Methodology - T e S Data Analysis

- Vertical Sections of T, S and svel;
- Horyzontal Distribution of T and S;
- Choose the month where there was the largest number of data collected at the Cabo Frio coast, seeking the upwelling;
- Choose the location for the receiver (array of 3 hydrophones) and the positions to be assumed by the source;
- Calculation of the EOF, to use in the inversion process.

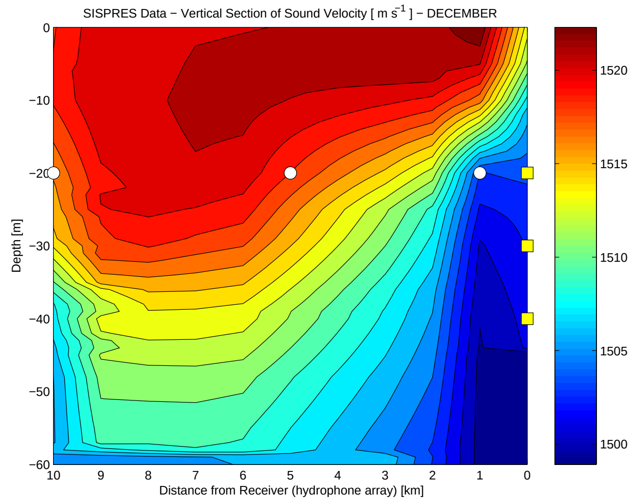
Methodology - Considerations

- Month: **December**;
- Number of hydrophones considered: **03**;
- Depth considered for the source: **10 m**.
- Vertical spacing between the hydrophones: **10 m**.

Table: Positions selected for S and R, to use in SAGA simulations. Datum WGS-84.

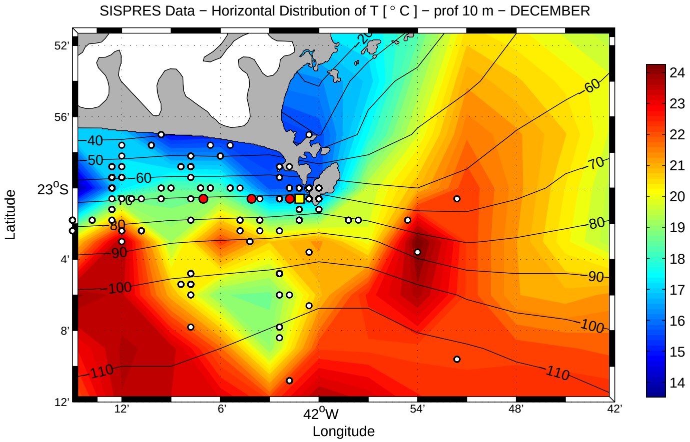
Equipment	R	S (Pos1)	S (Pos2)	S (Pos3)
Distance from R (km)	0	1	5	10
Latitude (S)	23° 00.6’	23 ° 00.6’	23 ° 00.6’	23 ° 00.6’
Longitude (W)	042° 01.2’	042° 01.8’	042° 04.1’	042° 07.0’

Methodology - Considerations



Vertical section of sound speed for December. The **three yellow squares** represent the receiver, and the **white circles**, the positions to be occupied by the source.

Methodology - Considerations



Map of T [° C] as background, obtained by interpolation. In the Figure, the **white circles** are the positions of the **December data**. The **yellow square** represents the **receiver (R)**, and the **red circles**, the positions to be occupied by the **source (S)**.

Methodology - Considerations

First Step:

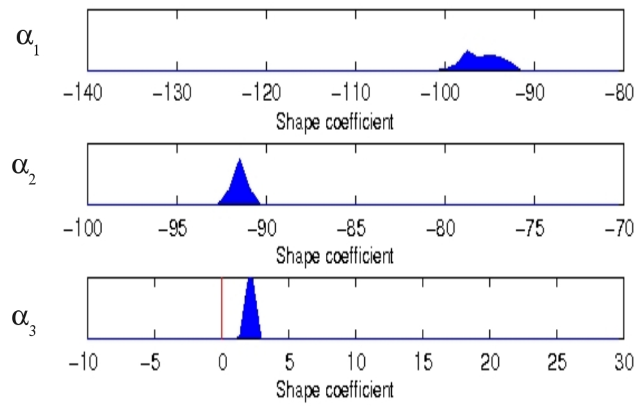
- From the T and S data, we obtained the sound velocity field;
- Next, we extract the profiles of the field in the positions of source and receiver;
- Subsequently, we use these profiles as input parameters in the module of SAGA SNAPRD to obtain synthetic acoustic data (sound pressure: the frequency domain);
- The SAPRD was used considering the strong horizontal anisotropy of the local. In this case, we solve a **forward problem**.

Methodology - Considerations

Second Step:

- Due to the small distance between the source and the receiver, we assume horizontal isotropy;
- Thus, we consider the SNAP module of SAGA to solve the inverse acoustic and used as input parameters the synthetic acoustic data generated with SNAPRD.

Results - EOF coeficients



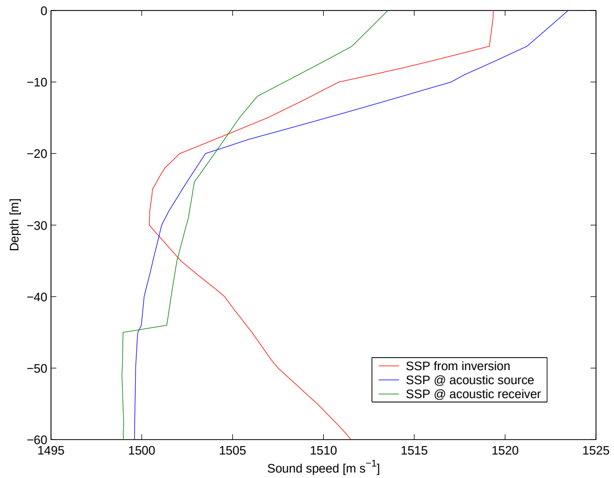
Result of the 1 km-inversion for the first three EOF coefficients. The red line indicates the inversion starting values (zeros – sound speed profile coincident with the average profile for the area). Looking at these curves, we can see that the coefficients α_3 and α_1 are the **best** and **worst** well-determined, respectively, according to the spread of the corresponding probability densities.

Table: EOF coefficients in the R and S positions, against the inversion result.

Coefficient	Pos R	Pos S	Result
α_1	-126,92	-121,11	-96,97
α_2	-79,74	-65,46	-91,21
α_3	-6,23	20,53	2,53

The Tab. 1 shows the first three EOF coefficients in the receiver (R) and source (S) positions, against the result of the 1 km-inversion. The verified difference between the values is attributed to the environmental mismatch and to the fact that the EOF coefficients can compensate mutually to generate a given sound speed profile and corresponding acoustic field, according to Eq. 1.

Results - Sound Speed Profiles



Sound speed profiles used in the generation of the acoustic data (blue and green, for source and receiver positions, respectively), and the inversion outcome (red).

Conclusions

- Looking at the sound speed profiles, the divergence observed in the deeper layer is attributed to the fact that we consider in the process of inversion, isotropy in thermal and bathymetric horizontal, not considered in the generation of acoustic field. And to the fact that the sound speed profiles are downward refracting, implying that the most insonified layers are not accurately observed by the superficial acoustic system;
- The acoustic inversion technique allowed to estimate coastal oceanographic properties of Cabo Frio, with a fair accuracy in the upper layers, by using a shallow acoustic source. For this reason, we can think of the use of acoustic inversion techniques as a tool to complement in situ and satellite data, for future rapid environmental assessments of this area.

Acknowledgments

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  for the pleasant reception.

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Feature Oriented Models used in Acoustical Oceanography

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The methodology to construct the thermohaline fields using Feature Models

- **Análise Objetiva de Multiplas Escalas (AOME)**
  Multi-scale Objective Analysis (MEOA)
- **Modelos de Feições para o Sistema Corrente do Brasil (CB)**
  Feature Models for the Brazil Current (BC) System
- **Previsão de curto Período**
  Short-range forecasting

Condicionamento da localização acústica de fontes induzido por um regime costeiro de ressurgência
Conditioning the location of sound sources induced by a coastal upwelling regime

Condicionamento da localização acústica de fontes induzido por um regime vórtice oceânico
Conditioning the location of sound sources induced by an oceanic eddy

Tomografia acústica usando Modelo de Feição para a ressurgência costeira
Acoustic tomography using Feature Model for a coastal upwelling

Considerações finais
Final remarks

Introdução
Introduction

Previsão de ambientes hidrodinâmicos e acústicos requerem a melhor especificação possível das condições iniciais.

Para prover esta sinopcidade, a técnica de Modelos de Feições (MF) tem sido usada para simulações e sistemas operacionais de previsão há duas décadas, em diversas partes do mundo.

Synoptic oceanic and acoustical prediction requires the best, as possible, specification of initial conditions.

To provide this synopticity, knowledge-based feature models (FMs) have been used by regional simulations and operational forecasting for the past two decades, in many parts of the word.

Modelos Regionais Orientados por feições (MROFs)
Feature Oriented Regional Model System (FORMS)

O Modelo Regional Orientado por Feições é uma técnica que alia o conhecimento prévio de feições oceanográficas, com o desenvolvimento de modelos paramétricos (Modelos de Feições) e modelagem numérica.

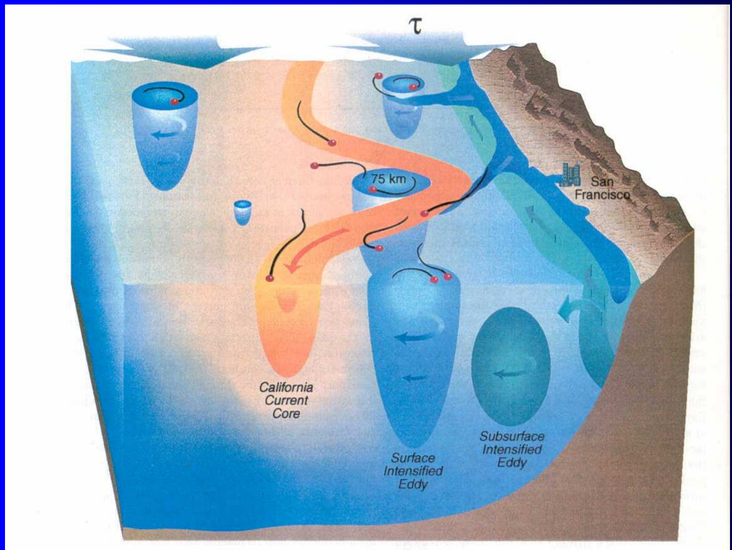
The Feature Oriented Regional Model is a technique that uses previous knowledge of oceanographic features, the development of parametric models (Features Models) and numerical models.

MROF em outros oceanos
FORMS in other sites

Local Site	Aplicação Application
Borda oeste do Atlântico Norte North Atlantic Western Boundary	Modelagem Operacional Operational Modelling
Estreito da Sicília Strait of Sicily	Análise Dinâmica Dynamical Analysis
Baía de Monterey Monterey Bay	Previsão em tempo real – verão de 2003 Real-time forecasting - summer 2003
Corrente do Brasil Brazil Current	Interação Meandro-Corrente-Ressurgência Meander-Current-Upwelling Interaction
Golfo Pérsico, Mar da Arábia e Mar Vermelho Persian Gulf, Arabian Sea, Red Sea	Simulação das Monções Monsoon Simulations
Águas Chilenas – Corrente Norte de Humboldt Chilean Waters - Northern Humboldt Current	Modelagem biofísica acoplada Nested Biophysical Modeling

Sistema Corrente da Califórnia

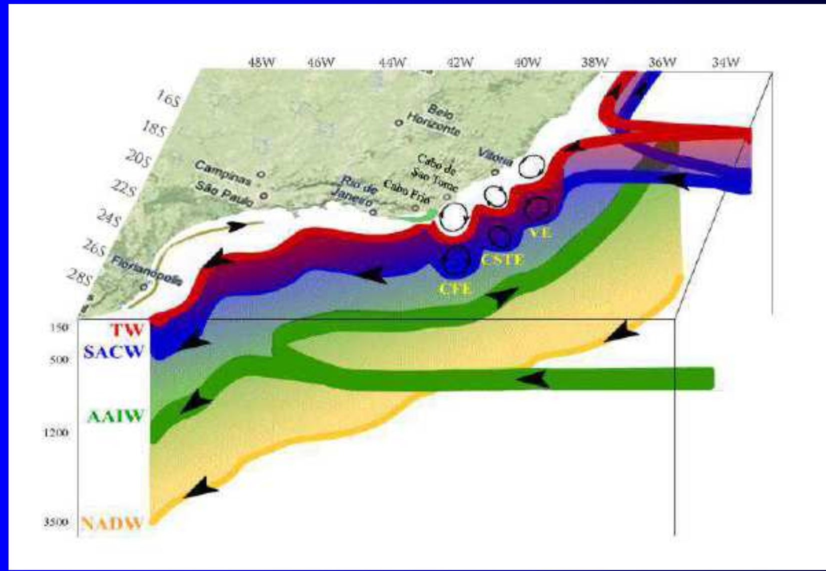
California Current System



Brink et. al 1991

Sistema Corrente do Brasil

Brazil Current System



Calado et. al 2008

Metodologia MROF

FORMS Methodology

Imagens de Satélite
Satellite images

Dados Hidrográficos (T&S)
Hydrographic data (T&S)

Modelos de Feição para frentes oceânicas, vórtices, ressurgência, filamentos, etc
Feature Models for oceanic fronts, eddies, upwelling fronts, filaments, etc

Admensionalização
Non-dimensionalization

Background de climatologias sazonais ou dados sinóticos modelados
Background seasonal climatology or synoptic modeled data

Redimensonalização com imagens de satélites
Re-dimensionalization with satellite images

Análise Objetiva de Multiplas Escalas
Multi-scale Objective Analysis

Modelos Regionais Orientados por Feições
Feature Regional Oriented Models

Campo Inicial de Densidade
Initial density field

Simulação Acústica
Acoustic simulation

Simulação Química/Biológica
Chemical/biological simulatiion

Simulação Hidrodinâmica de Previsão
Forecasting hydrodynamic simulation

Previsão Acústica
Acoustic forecasting

Previsão Química/Biológica

A Análise Objetiva de Múltiplas Escalas (AOME)

The Multi-Scale Objective Analysis (MSOA)

$$C(x_j, y_j, t_j, x_i, y_i, t_i) = (1 - a^2) e^{(b^2 + c^2)}$$

onde

$$a^2 = \frac{R_x^2}{X_{zero}^2} + \frac{R_y^2}{Y_{zero}^2};$$

$$b^2 = -0.5\left(\frac{R_x^2}{X_{decay}^2} + \frac{R_y^2}{Y_{decay}^2} \right);$$

$$c^2 = -0.5 \frac{\delta t^2}{t_{decay}^2}$$

$$R_x = x_p \cos(\phi) + y_p sen(\phi) + \delta t u_{phase}$$

$$R_y = y_p \cos(\phi) + x_p sen(\phi) + \delta t v_{phase}$$

$$\phi = lc_{rot} - grid_{rot}$$

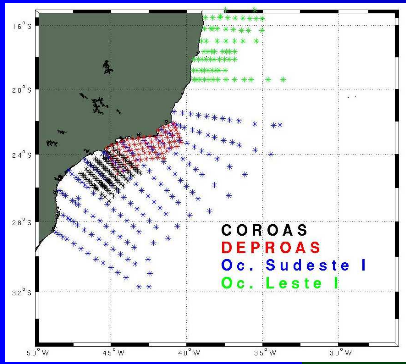
$$\delta t = t_j - t_i$$

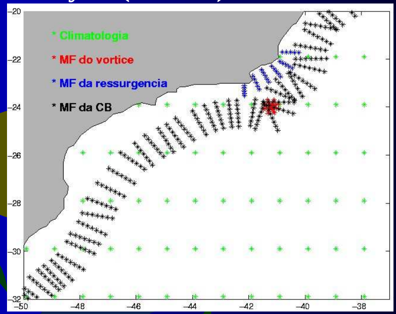
$$x_p = x_j - x_i; \quad y_p = y_j - y_i$$

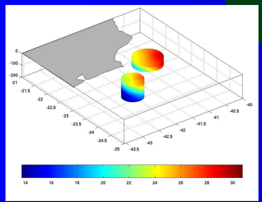
Carter and Robinson, 1987

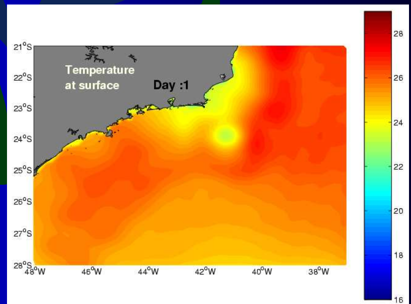
A Análise Objetiva de Múltiplas Escalas (AOME)

Multi-Scale Objective Analysis (MSOA)





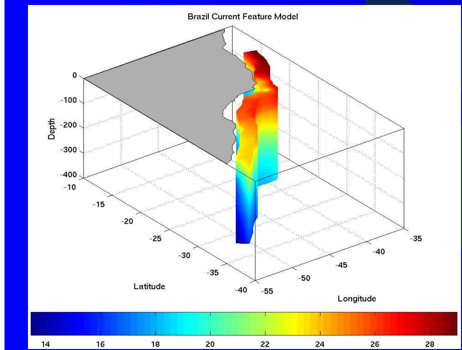


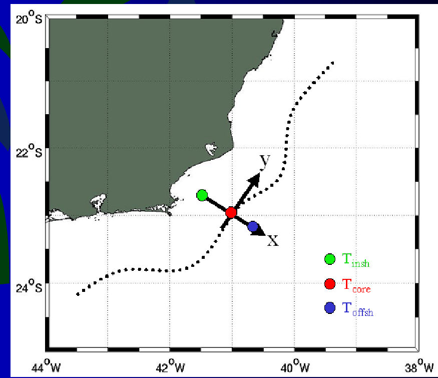


Modelo de Feição para a CB

Feature Model for BC

$$T_i(x,z) = [T_{i_o}(x) - T_{i_b}(x)]\Phi(x,z) + T_{i_b}(x);$$





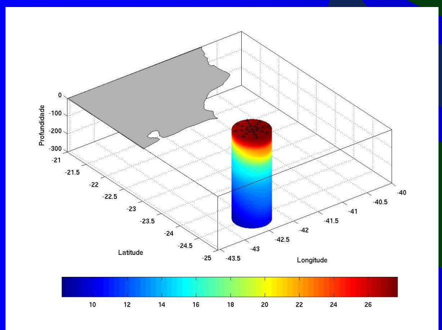
Calado et. al 2008

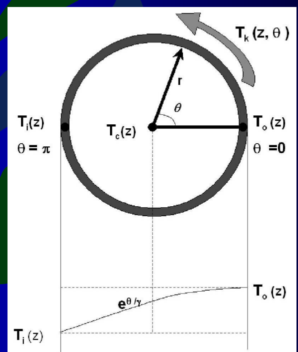
Modelo de Feição para os vórtices da CB

Feature Model for BC eddies

$$T(r,z,\theta) = T_k(z,\theta)(1-e^{-r/R}) + T_c(z)e^{-r/R};$$

$$T_k(z,\theta) = [T_i(z) + \frac{(T_o(z)-T_i(z))}{2}e^{\theta/\gamma}(1+cos\theta)];$$





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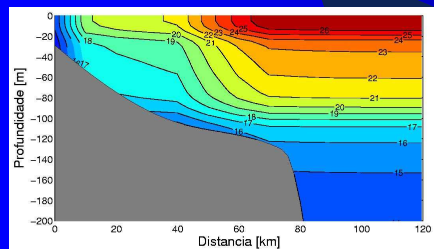
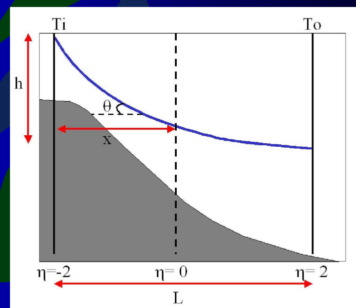
Modelo de Feição para a ressurgência costeira

Feature Model for coastal upwelling

$$m(\eta,z) = \frac{1}{2} + \frac{1}{2}tanh[\frac{\eta - \Theta \times z}{\gamma}];$$

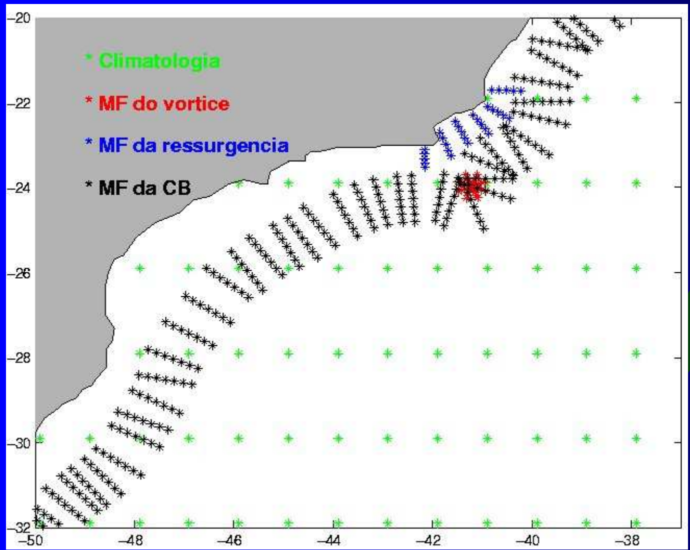


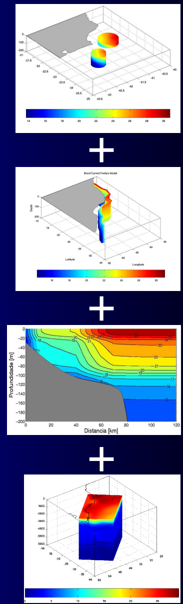


Calado et. al 2008

Criando um campo inicial termohalino para simulação numérica

Creating an initial thermohaline field for numerical simulation

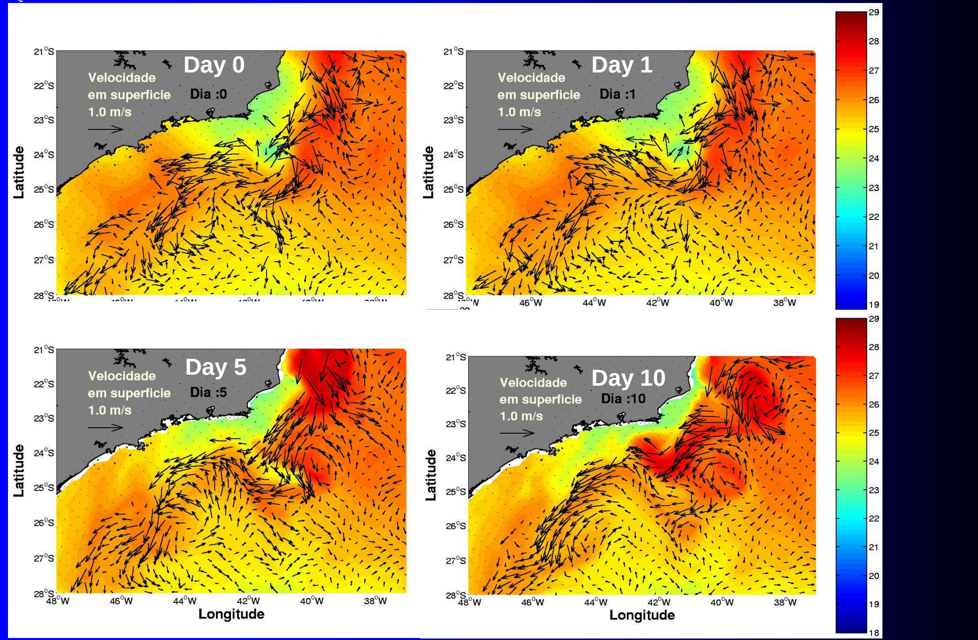




Calado et. al 2008

Previsão de curto período

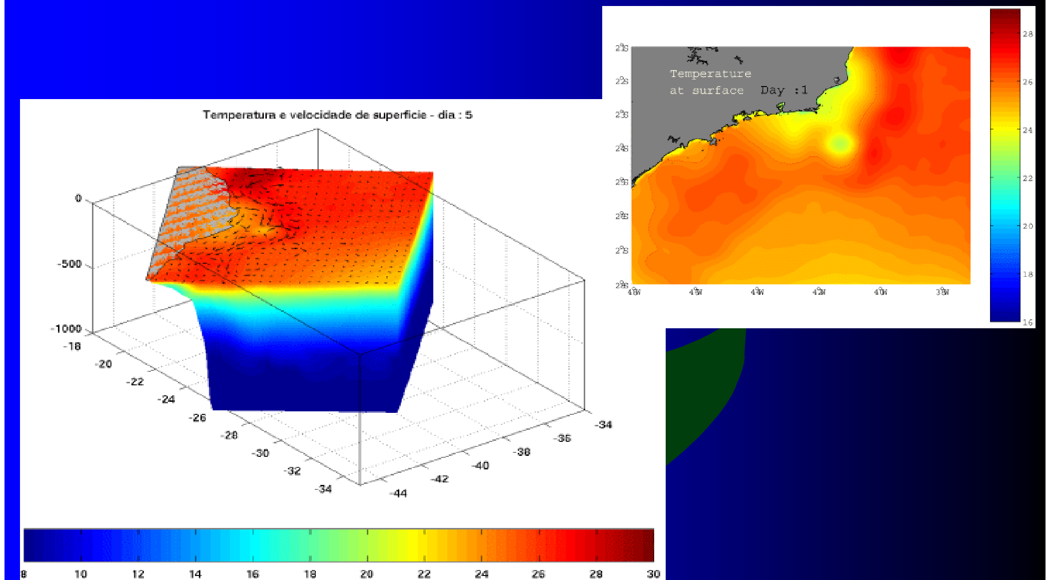
Short-range forecasting



Calado et. al 2008

Previsão de curto período

Short-range forecasting



Calado et. al 2008

Propagação dos raios acústicos utilizando Modelo de Feição

Acoustic rays propagation using Feature Model

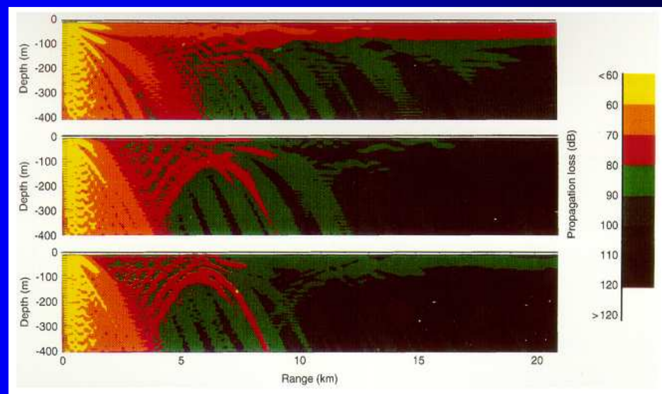
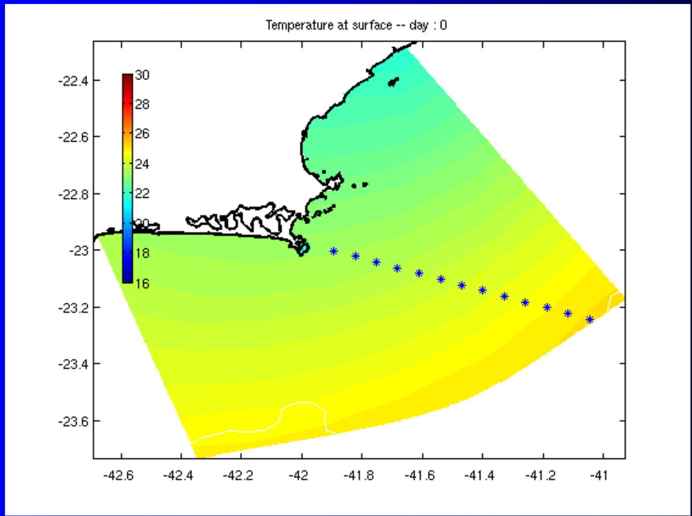


Figura 1: Contornos da perda de propagação em um meandro, freqüência de 400Hz e fonte a 50m da superfície. No painel superior encontra-se o resultado da climatologia, seguido do obtido pelo modelo de feição e do oriundo de dados observados. (Small et al., 1997).

Figure 1: Contours of propagation loss on a meandering, 400 Hz and 50 m from the source surface. In the top panel is the result of the climatology, followed by the obtained by the Feature Model and come from the observed data. (Small et al., 1997).

Cenários simulados via MF para um regime de um perfil médio e de ressurgência costeira

Scenarios simulated via a FM scheme for a medium profile and coastal upwelling



Cenários simulados via MF para um regime de um perfil médio e de ressurgência costeira

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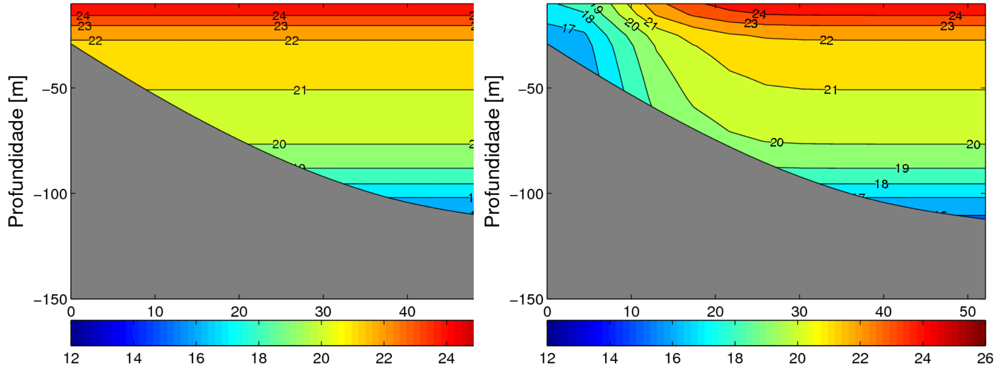


Seção com perfil médio

Section with mean field

Seção com ressurgência utilizando MF

Section with upwelling using FM

Condicionamento da localização acústica de fontes induzido por um regime costeiro de ressurgência

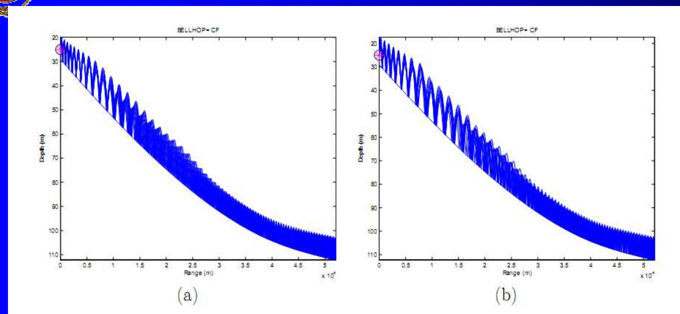
Conditioning location of sound sources induced by a coastal upwelling regime

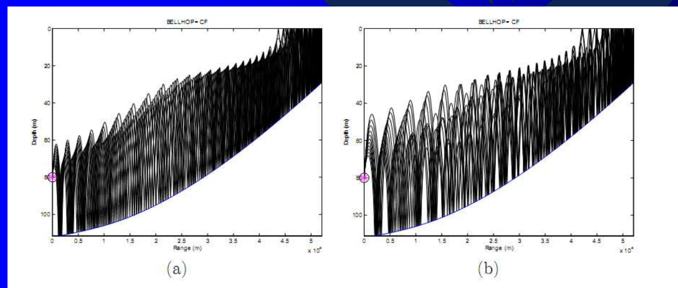
O regime de propagação foi estudado inicialmente com o traçamento de raios de águas rasas para águas profundas e no sentido oposto, tanto para o perfil médio da velocidade do som, como para o campo da ressurgência.

The propagation scheme was originally studied with the ray path from shallow to deep waters and into the opposite direction, for the mean profile of sound speed as well as for the upwelling field.

Traçamento de raios

Ray path





a) campo médio
mean field

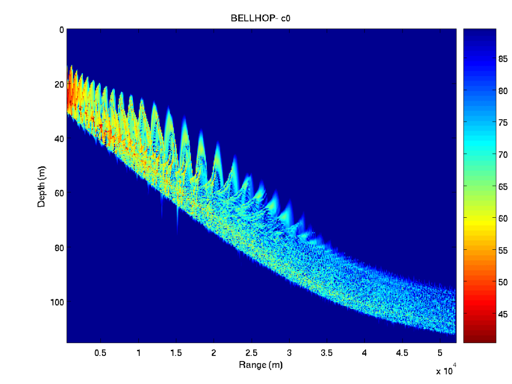
b) ressurgência
upwelling

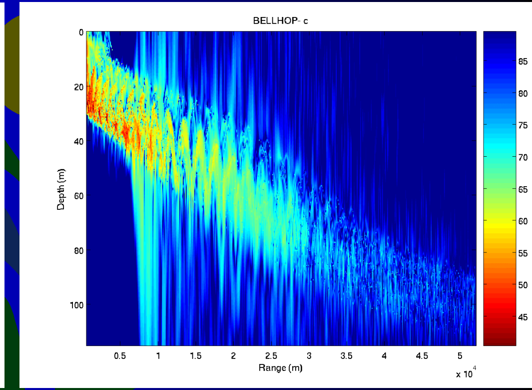
Águas rasas para águas profundas
From shallow to deep water

Águas profundas para água rasas
From deep to shallow water

Perdas de transmissão na propagação do sinal de águas rasas para águas profundas

Signal propagation Transmission Losses from shallow water to deep water



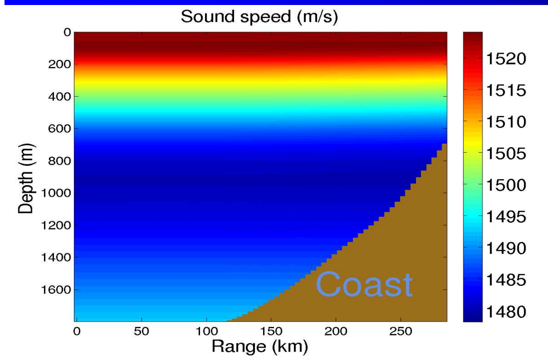


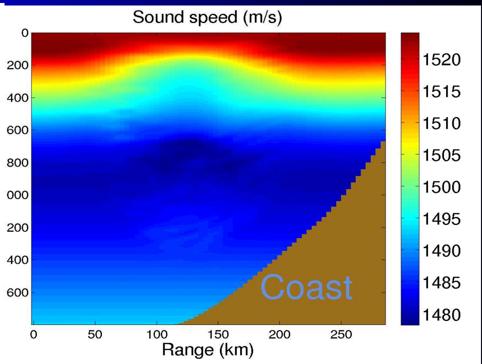
A) campo médio
mean field

B) ressurgência
upwelling

Cenários simulados via MF para um vórtice da CB

Scenarios simulated via a FM scheme for a BC eddy





Cenário médio

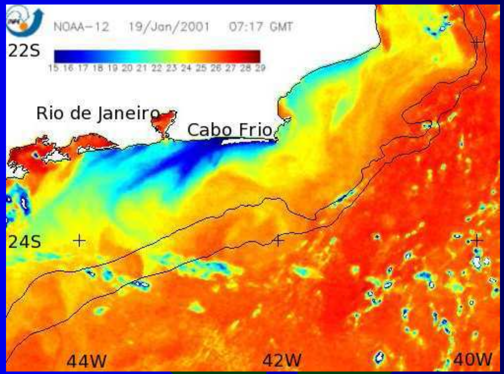
Mean scenario

Cenário com um vórtice oceânico via MF

Scenario with an ocean eddy via FM

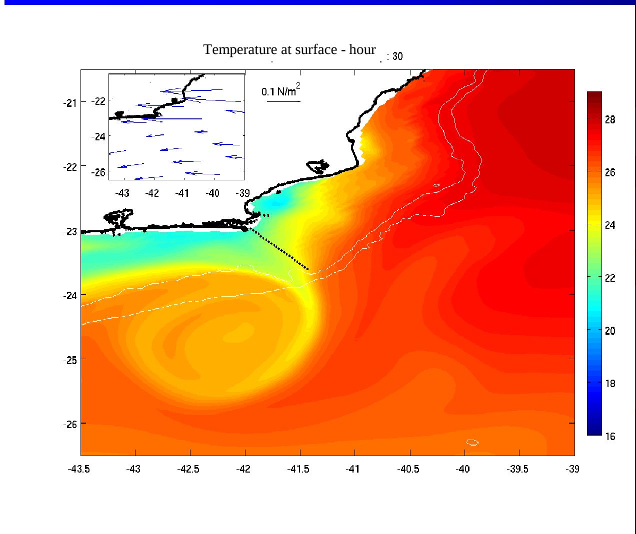
Tomografia acústica via Modelo de Feição para a ressurgência de Cabo Frio

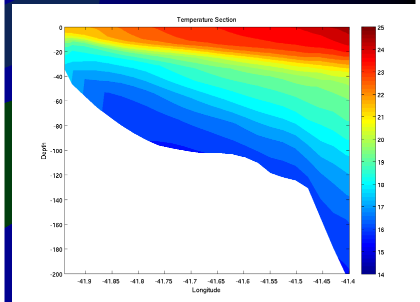
Feature-oriented acoustic tomography: Upwelling at Cabo Frio



Tomografia acústica via Modelo de Feição para a ressurgência de Cabo Frio

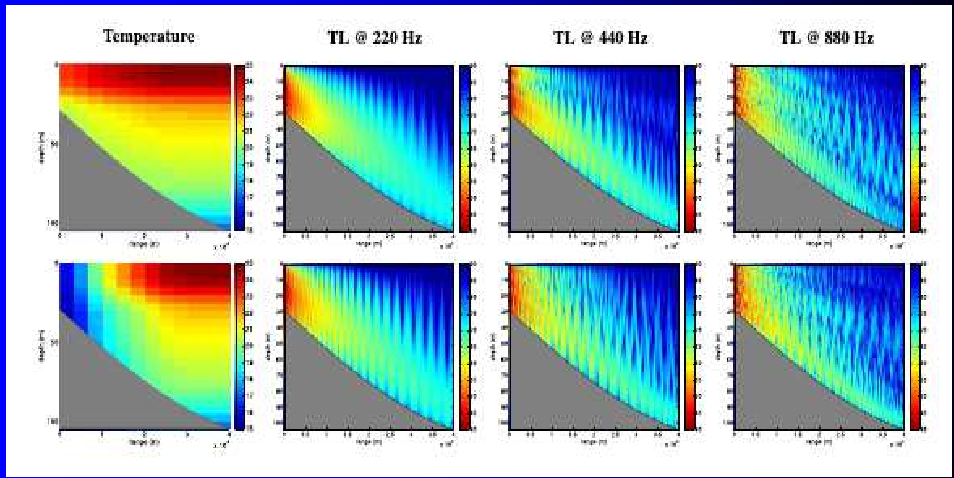
Feature-oriented acoustic tomography: Upwelling at Cabo Frio





Tomografia acústica via Modelo de Feição para a ressurgência de Cabo Frio

Feature-oriented acoustic tomography: Upwelling at Cabo Frio



Considerações finais

Final Remarks

Modelos de Feições são ferramentas adequadas para previsões ambientais de usos múltiplos.

Essas ferramentas sugerem, com a incorporação de detecção de feições oceanográficas por sensores orbitais, que tal caracterização pode ser realizada em tempo real.

Feature Models are appropriate tools for environmental forecasting of multiple uses.

These tools suggest, with the incorporation of detecting oceanographic features by orbital sensors, such characterization can be performed in real time.

Considerações finais

Final Remarks

O esquema proposto apresenta a técnica dos MFs, aliada à modelagem numérica de previsão oceânica, como ferramenta que possibilita prever o ambiente acústico.

The proposed scheme presents the FM technique, added to numerical modeling for ocean forecasting, as a tool that allows predicting the acoustic environment.

Obrigado

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Sonar performance prediction in Cabo Frio

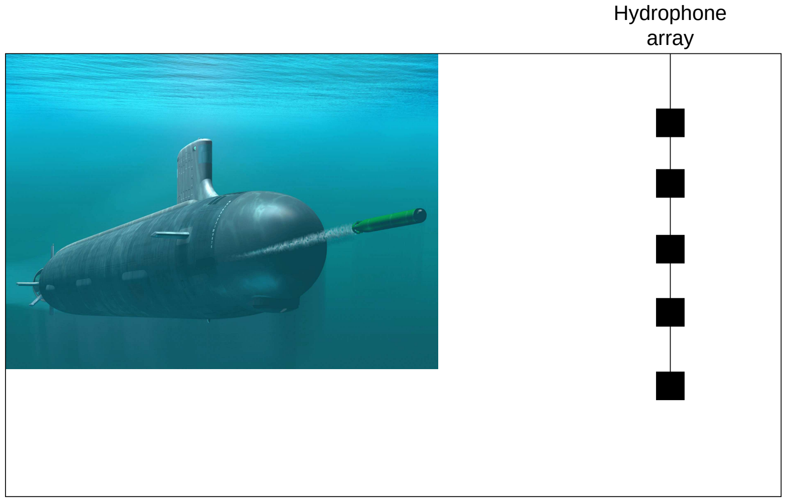
Nélson Martins[1], Leandro Calado[2], Sérgio Jesus[1] and Marcus Simões[2]

[1]Institute for Systems and Robotics
Centro de Investigação Tecnológica do Algarve, Portugal

[2]Brazilian Navy
Instituto de Estudos do Mar Almirante Paulo Moreira, Brazil

1st OAEx Workshop, March 2010

Problem: to determine the performance of an existing sonar, under different oceanographic conditions



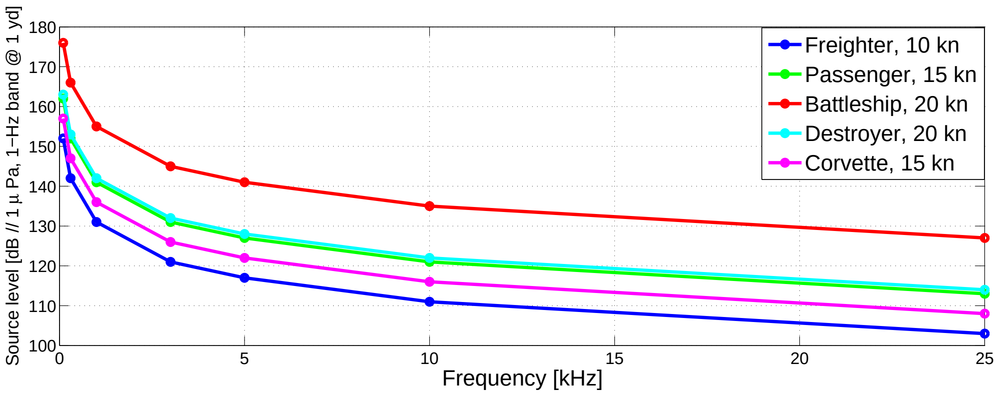
$$p_D = ?$$

Underwater targets radiated noise

Sources of radiated noise on ships, submarines and torpedoes (Urick, *Principles of Underwater Sound*, 1983):

- Machinery noise
  - Propulsion machinery (diesel engines, main motors, reduction gears)
  - Auxiliay machinery (generators, pumps, air-conditioning equipment)
- Propeller noise
  - Cavitation at or near the propeller
  - Propeller-induced resonant hull excitation
- Hydrodynamic noise
  - Radiated flow noise
  - Resonant excitation of cavities, plates and appendages
  - Cavitation at struts and appendages

Ship source levels

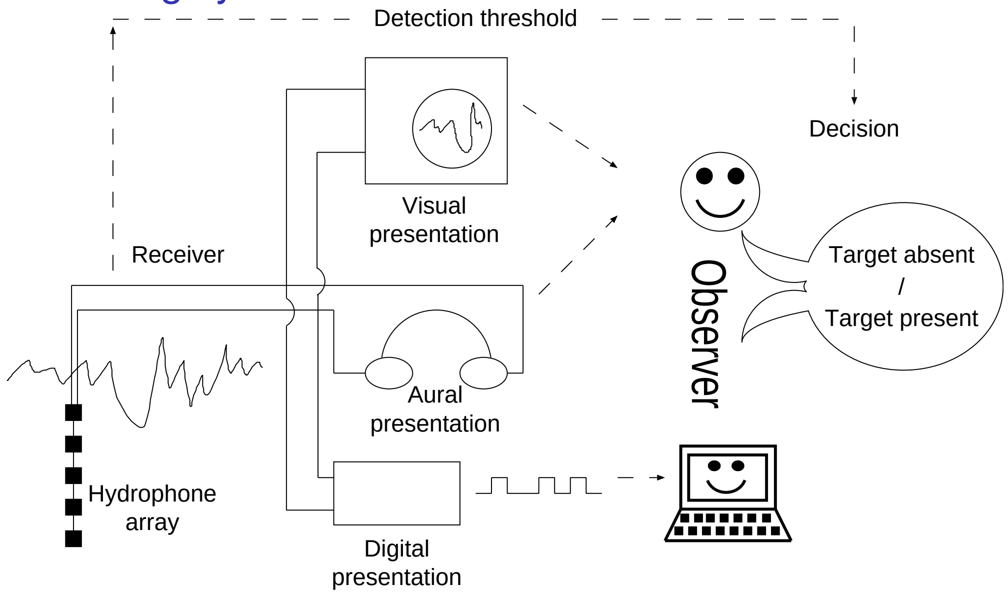


[adapted from (Urick, *Principles of Underwater Sound*, 1983)]

(World War II measurements)

Submarines, torpedoes: even more restricted access

Receiving system



Detection threshold

$$\text{SNR} = 10 \log \frac{S}{NL} ,$$

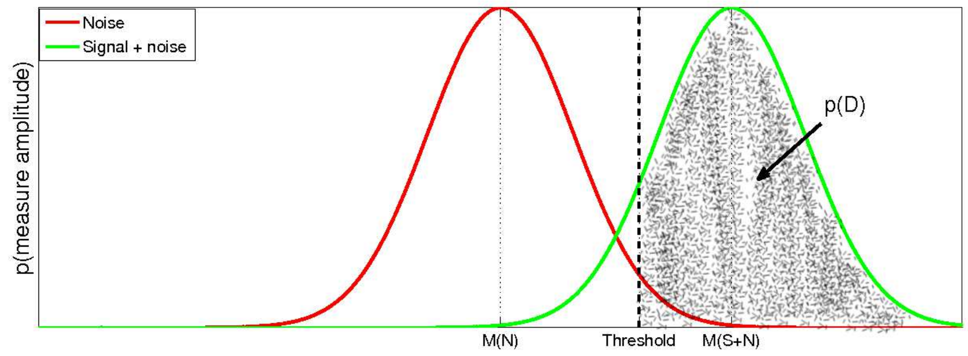
S: signal power in the receiver bandwidth;
N: noise power in a 1-Hz band.

DT: ratio required for detection at some preassigned level of correctness of the detection decision

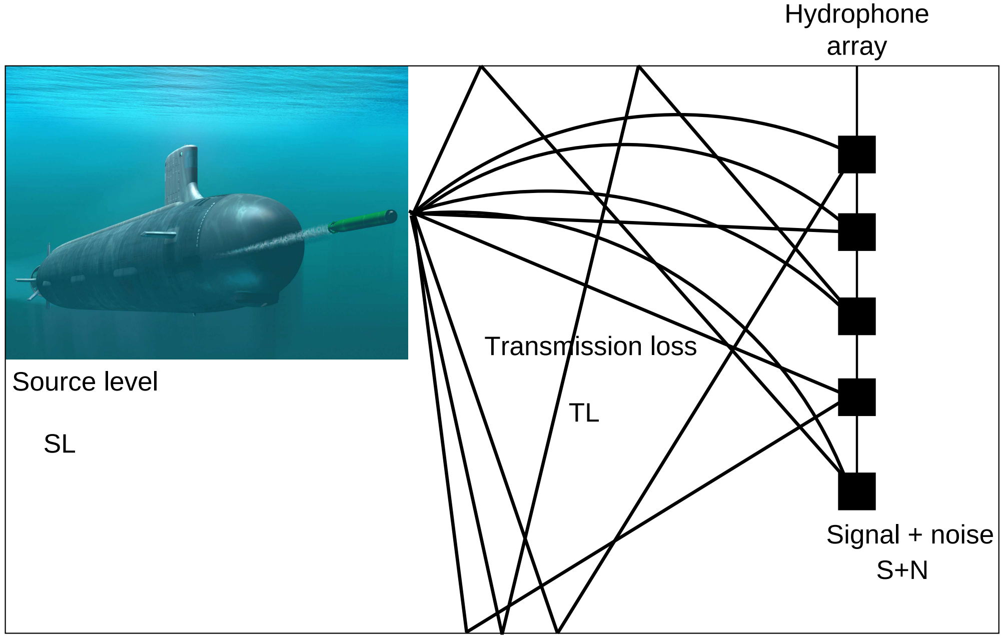
Compare SNR to DT, for decision-making

		Decision	
		Sig. present	Sig. absent
De facto	Sig. present	Correct detection $p(D)$	Miss $1 - p(D)$
	Sig. absent	False alarm $p(FA)$	Null decision $1 - p(FA)$

Detection probability — Gaussian assumption

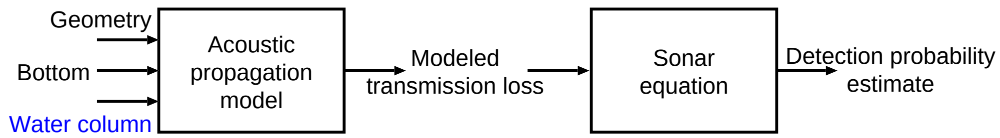


From source to receiver — propagation



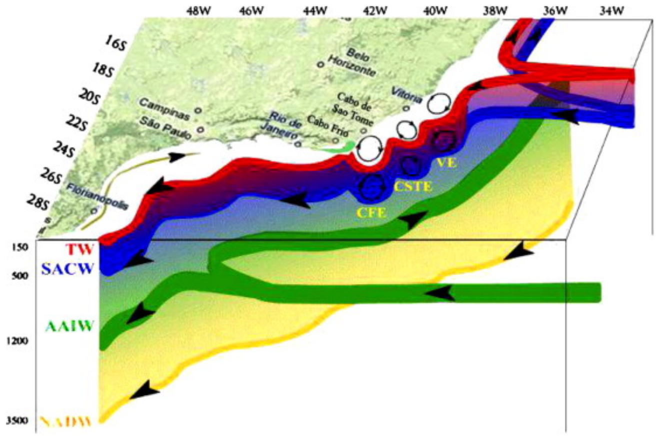
Signal loss by propagation

Acoustic propagation modeling



Particular case: Cabo Frio

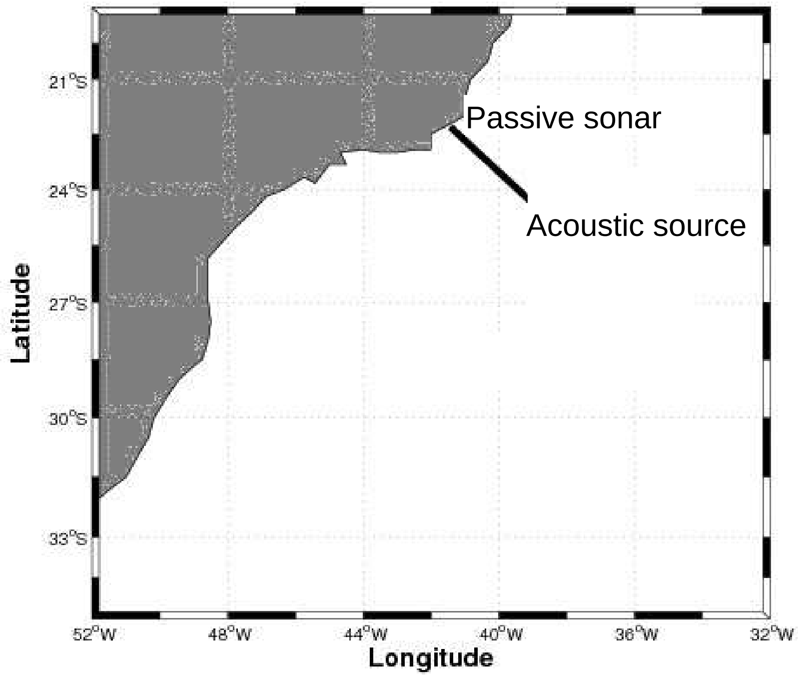
Oceanography of Brazil — Brazil Current system



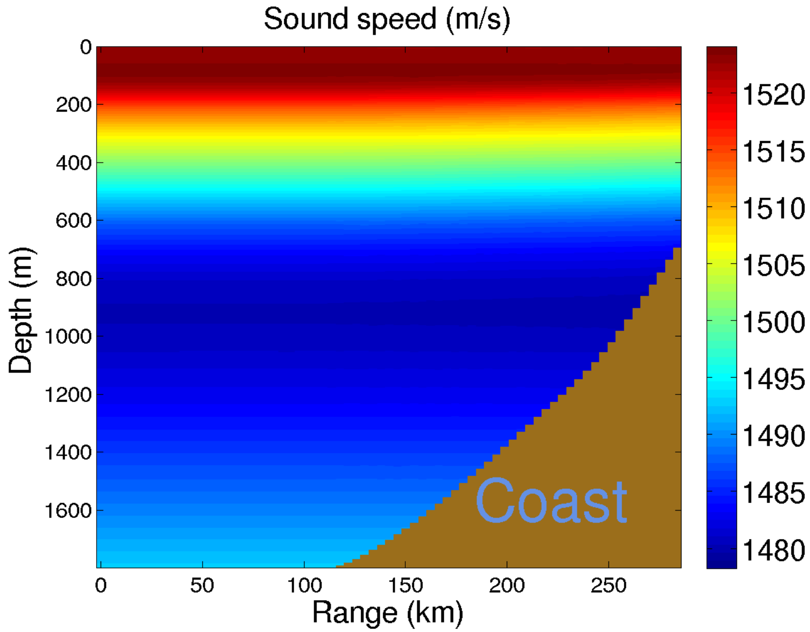
Coastal and oceanic circulation features off southeast Brazil. Water masses: Tropical Water (TW), South Atlantic Central Water (SACW), Antarctic Intermediate Water (AAIW) and North Atlantic Deep Water (NADW). Eddies: Vitória (VE), Cabo de São Tomé (CSTE) and Cabo Frio (CFE)

[Reproduced from L. Calado, A. Gangopadhyay, I.C.A. da Silveira, Feature-oriented regional modeling and simulations for the western South Atlantic: Southeastern Brazil region, Ocean Modelling, Volume 25, Issues 1-2, 2008, Pages 48-64]

Simulation scenario

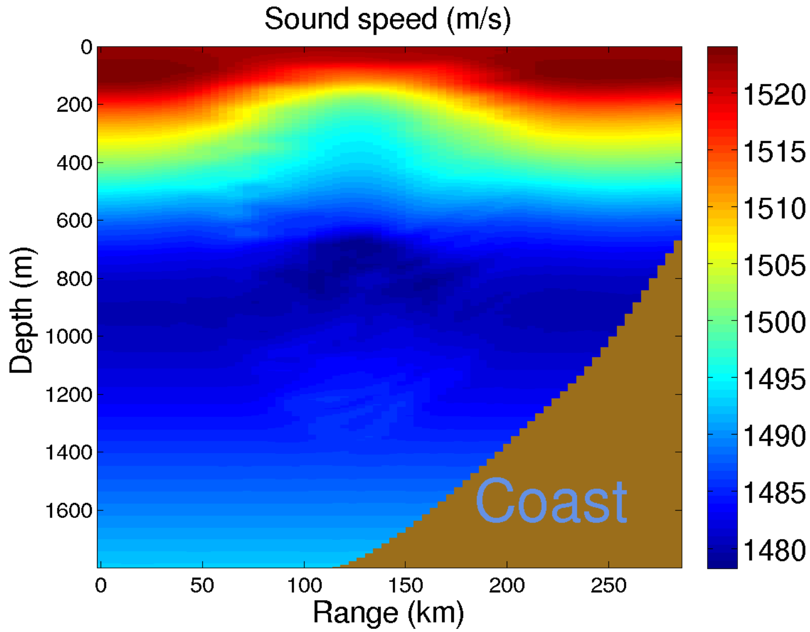


Simulated oceanography # 1: barotropic condition



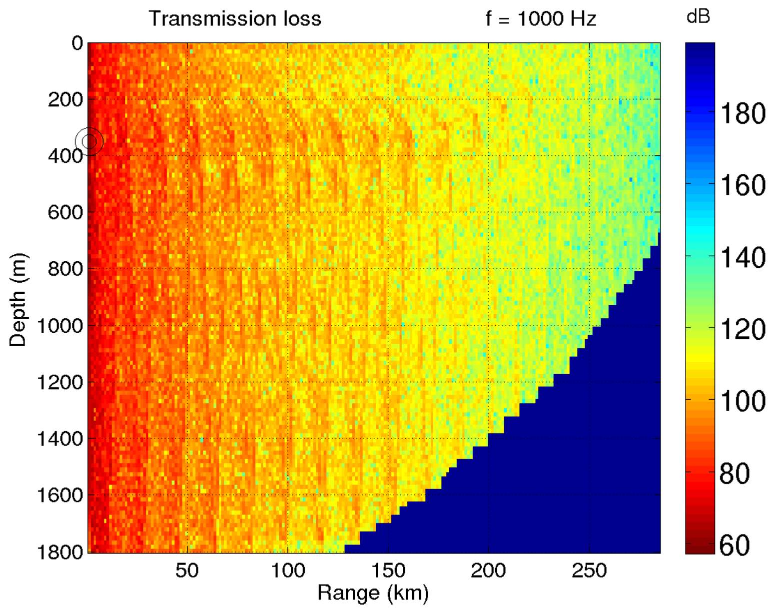
(Princeton Ocean Model simulation)

Simulated oceanography # 2: cold-core vortex



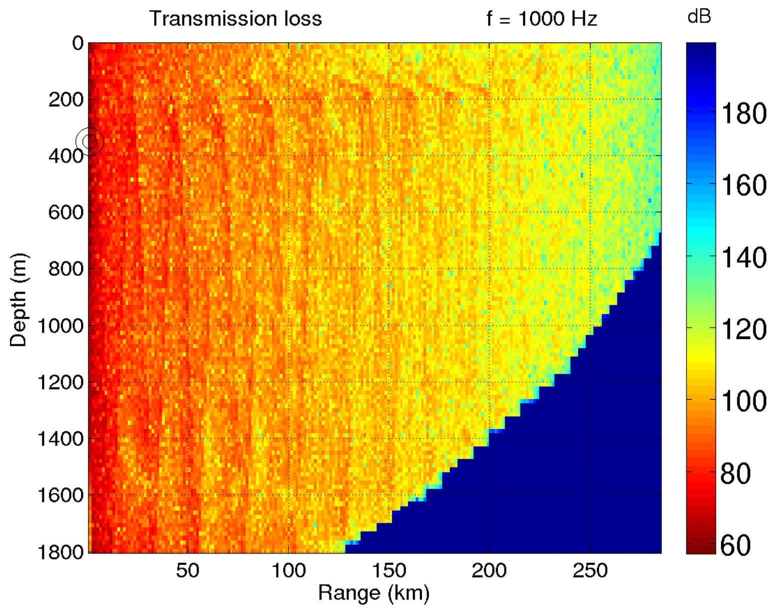
(Princeton Ocean Model simulation)

Acoustic target @ (280 km, 350 m) — barotropic



(KRAKEN Normal Mode Model simulation)

Acoustic target @ (280 km, 350 m) — vortex



(KRAKEN Normal Mode Model simulation)

Acoustic target @ (280 km, 350 m) — vortex

Cold-core vortex

↓

drives acoustic energy to the surface

(Snell's law)

Sonar equation

SNR @ receiver vs. threshold: SL - TL - NL + DI = DT,

DI: directivity index of receiver array

Figure-of-merit of the sonar: FM = SL - NL + DI - DT

Signal excess: $\mathrm{SE}(\mathrm{FM}, r, z_r|z_s) = \mathrm{FM}\text{-}\mathrm{TL}(r, z_r|z_s)$

Detection probability (Gaussian fluctuating signals)

Environment fluctuations $\Rightarrow$ random signal in random noise

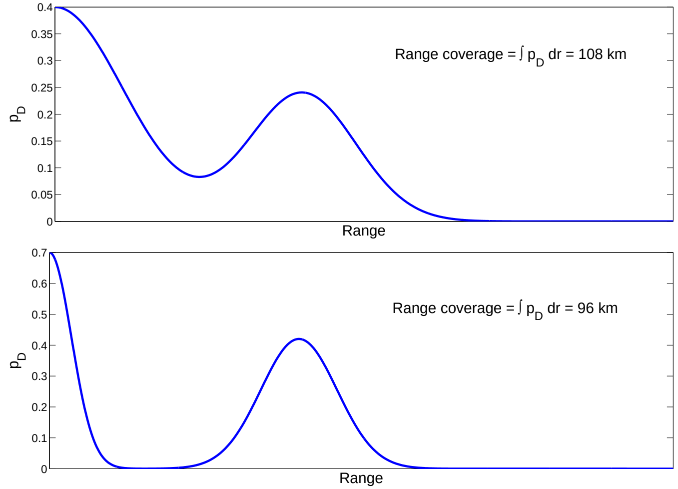
$$p_D(\mathrm{SE}) \;=\; \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\mathrm{SE}} \exp\left[\frac{-x^2}{2\,\sigma^2}\right]\,\mathrm{d}x,$$

σ: SE standard deviation (fluctuation indicator)[1]

[1] Ferla and Porter, *Receiver Depth Selection for Passive Sonar Systems*, JOE 1991

'Detection radius'

Which is the optimum depth for an horizontal array?



'Detection radius':

$$R(\mathrm{FM}, z_r|z_s) \;=\; \int_0^{\infty} p_D(\mathrm{FM}, r, z_r|z_s)\,\mathrm{d}r$$

Detection probability — unknown source depth

Acoustic target @ (280 km, unknown depth)

$$p_D^{\mathrm{USD}}(\mathrm{FM}, r, z_r) \;=\; \int_0^{\infty} p(z_s)\, p_D(\mathrm{FM}, r, z_r|z_s)\,\mathrm{d}z_s,$$

$p(z_s)$: probability density of target depth

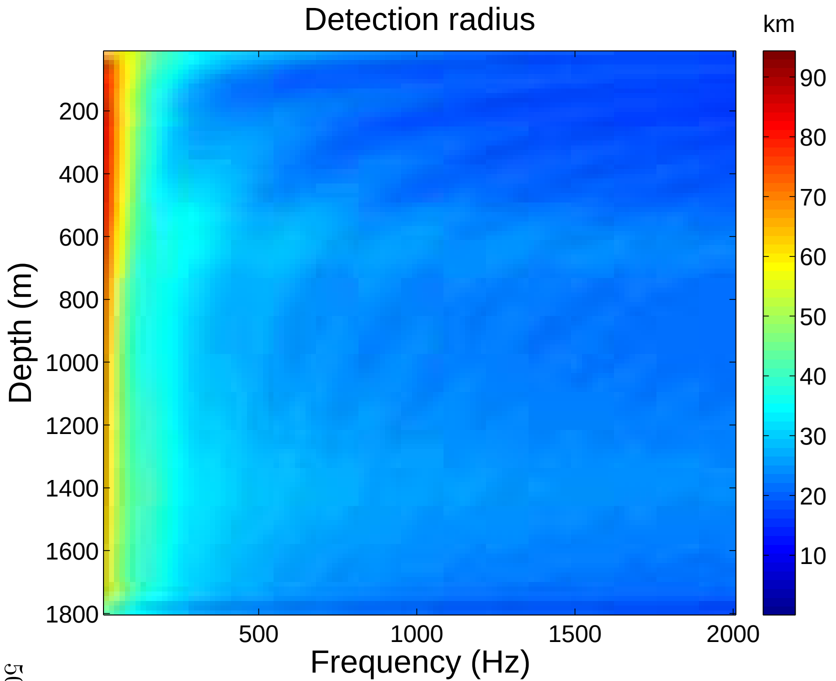
$$R^{\mathrm{USD}}(\mathrm{FM}, z_r) \;=\; \int_0^{\infty} p_D^{\mathrm{USD}}(\mathrm{FM}, r, z_r)\,\mathrm{d}r$$

Simulation — numerical values

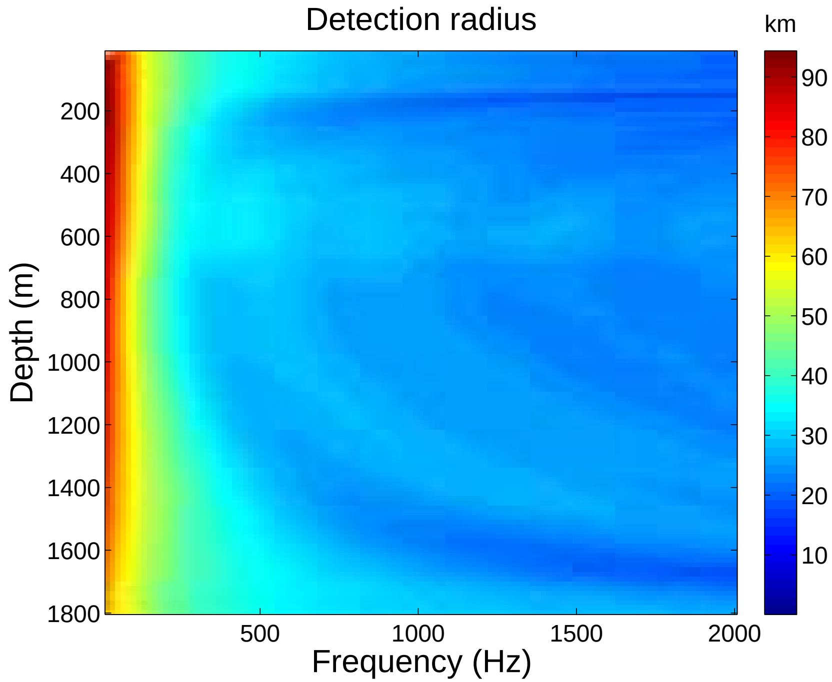
FM = 80 dB

σ = 8 dB
(from an archive of real-world detection exercises)[2]

‘Detection radius’ — barotropic



‘Detection radius’ — vortex



‘Detection radius’ — vortex

Cold-core vortex

↓

Increases the detection radius

(Increases the detection probability)

(Warm-core vortex should decrease p_D)

Conclusion

- Brazilian current system imposes severe changes on propagation patterns
- Simulated cold-core vortex shown to increase ‘detection radius’
- Sonar equation, if applied with climatologies, could fail
- Gain: incorporating acoustic-oceanographic prediction modules in Brazilian Navy computational tools

Classification of three-dimensional ocean features by two-dimensional acoustic sampling

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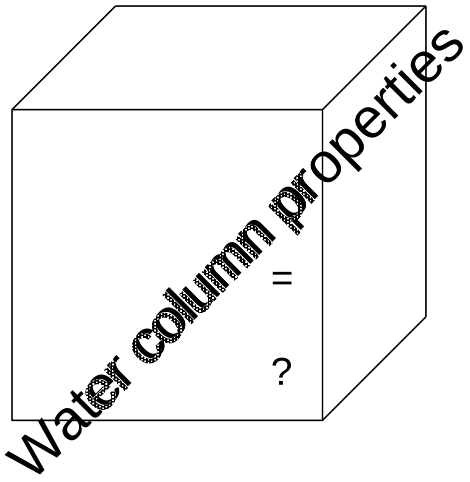
Brazilian Navy
Instituto de Estudos do Mar Almirante Paulo Moreira, Brazil

1st OAEx Workshop, March 2010

Problem: to determine instantaneous three-dimensional water column properties



In particular: sound speed field
(function of temperature and salinity)

Acoustic sensing -> acoustic tomography

- Relatively easy-to-deploy observation systems
- Fair to high accuracy in ocean geometric and water column properties estimation
- Complement to integral systems such as gliders, for intermediate-scale observation (tens of m–10 km)?

Ocean acoustic tomography demonstrations:

- Monterey Bay Experiment (Mercer, *J. Acoust. Soc. Am.*, 1989)
- Gulf Stream Experiment—part of SYNOP (Chester, *The Synoptician Newsletter*, 1991)
- Heard Island Experiment (Baggeroer, *Physics Today*, 1992)
- INTIMATE ’96 Experiment (Démoulin, *SWAC’97*, 1997)

Acoustic tomography: averages over the turbulent ocean

Tomography: technical aspects

Acoustic field properties = function(water column properties)

Tomography: solves the equation w.r.t. the water column properties

Among many approaches, we find the detection-with-parameter estimation approach, *e.g.* Bartlett estimator:

$$P(\boldsymbol{\theta}) = \frac{1}{K}\sum_{k=1}^{K} \mathbf{w}_k(\boldsymbol{\theta}, f_k)^{\mathrm{H}}\, \hat{\mathbf{R}}(\boldsymbol{\theta}_0, f_k)\, \mathbf{w}_k(\boldsymbol{\theta}, f_k),$$

$\boldsymbol{\theta}$: candidate water column properties
f_k: frequency
$\boldsymbol{\theta}_0$: true water column properties
$\mathbf{w}_k$: simulated acoustic distortion @ receiver points
$\hat{\mathbf{R}}$: acoustic data correlation matrix estimate

Correlation structure $\rightarrow$ acoustic (observable) match philosophy

EOFs — concept

EOFs express joint variability.

For example, observations @ spatial points $P_1, P_2, ..., P_N$, along time, can be statistically characterized.

$P_1, P_2, ..., P_N$ can lie on a straight line, a plane, the 3D space, etc.

EOFs — concept

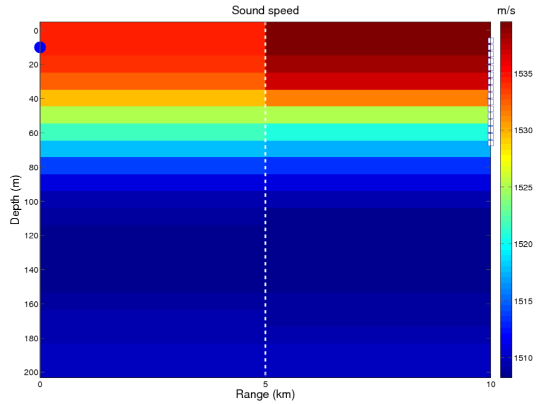
Deaveraged data vector:

$$\mathbf{x} = \begin{bmatrix} x(P_1) \\ x(P_2) \\ \vdots \\ x(P_N) \end{bmatrix} \qquad (1)$$

Correlation matrix: $\mathrm{E}[\mathbf{x}\mathbf{x}^{\mathrm{T}}]$

EOFs are the eigenvectors of the correlation matrix

Tomography example: 'bipolar' (2 sectors) transect —range-independent (RI) approach



Acoustic observation parameters:

- Transition @ 5 km
- Source @ 10 m
- 16 hydrophones, 4 m-spaced (AOB-type array), from 6 m, @ 10 km
- Frequencies: 500–1000 Hz, 50 Hz-spaced

Tomography example: 'bipolar' transect —RI approach

Sound speed representation:

$$c(z) \quad = \quad \overline{c}(z) + \sum_{k=1}^{2} \alpha_k \hat{EOF}_k(z),$$

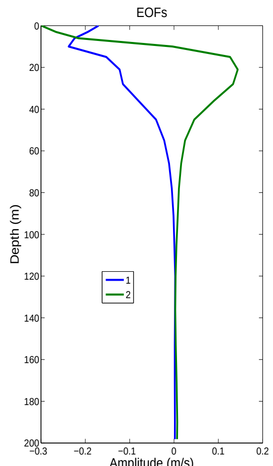
$\overline{c}(z)$: average profile; $\hat{EOF}_k(z)$: EOF estimates

EOFs:

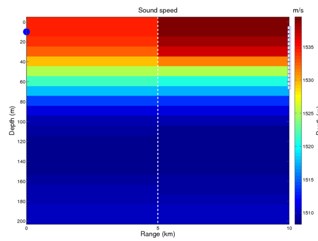
- One-dimensional basis functions (orthonormal) for $c(z)$
- Eigenvectors of sound speed true correlation matrix

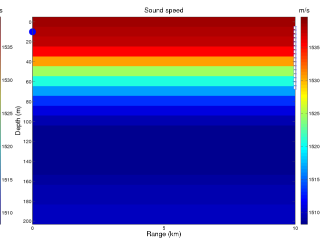
Why EOFs?

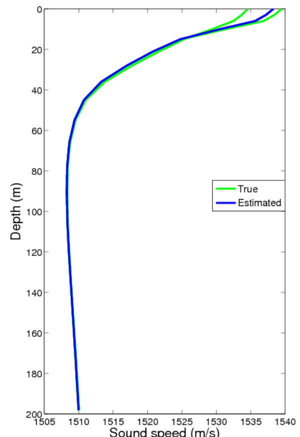
- Regularization of the acoustic inversion problem
  - Physically-meaningful solutions
  - Solution space search optimization
- Low computational cost



Tomography example: 'bipolar' transect —RI approach







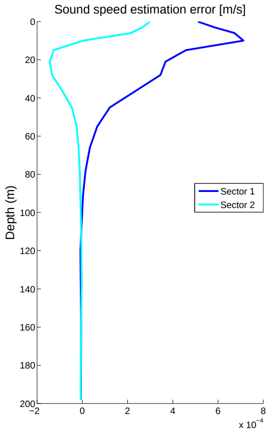
Inversion confidence: 91.5% (frequency-incoherent Bartlett fit)

Profile estimate borrowing characteristics from true ones

Example: ‘bipolar’ transect —RD approach

In each $m-th$ sector:

$$c_m(z) = \overline{c}(z) + \sum_{k=1}^{2} \alpha_{km}\, E\hat{O}F_k(z), \quad m = 1, 2$$

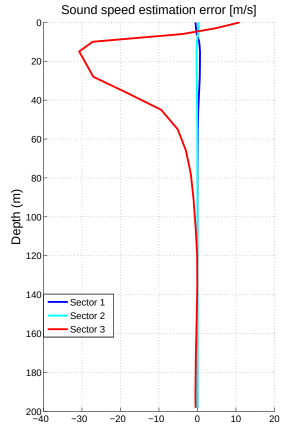


Inversion confidence: 100%
(frequency-incoherent Bartlett fit)

Profiles estimates extremely accurate

Example 2: ‘tripolar’ transect —RD approach

	Sector 1		Sector 2		Sector 3	
	Coef. 1	Coef. 2	Coef. 1	Coef. 2	Coef. 1	Coef. 2
True	10	-20	30	-40	50	-60
Estimated	12.0	-22.8	29.5	-38.9	-66.0	42.9



Inversion confidence: 99.8% (frequency-incoherent Bartlett fit)

$\boxed{\text{Good acoustic match} \not\Rightarrow \text{good detailed environmental match}}$

Limitations of one-dimensional EOFs

- Wrong solutions
- High computational cost: 2 parameters for each sector
- Non-representativeness of a single EOF set for all sectors

Three-dimensional (3D) EOFs

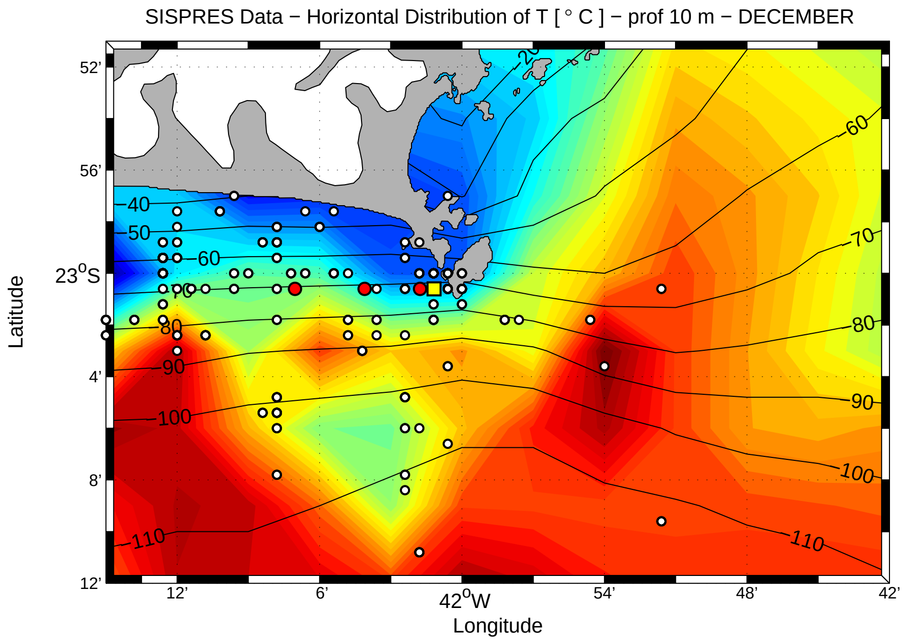
$$c(x, y, z) \;=\; \overline{c}(x, y, z) + \sum_{k=1}^{K} \alpha_k\, E\hat{O}F_k(x, y, z),$$

$\overline{c}(x, y, z)$: average 3D sound speed field

α_k: coefficients

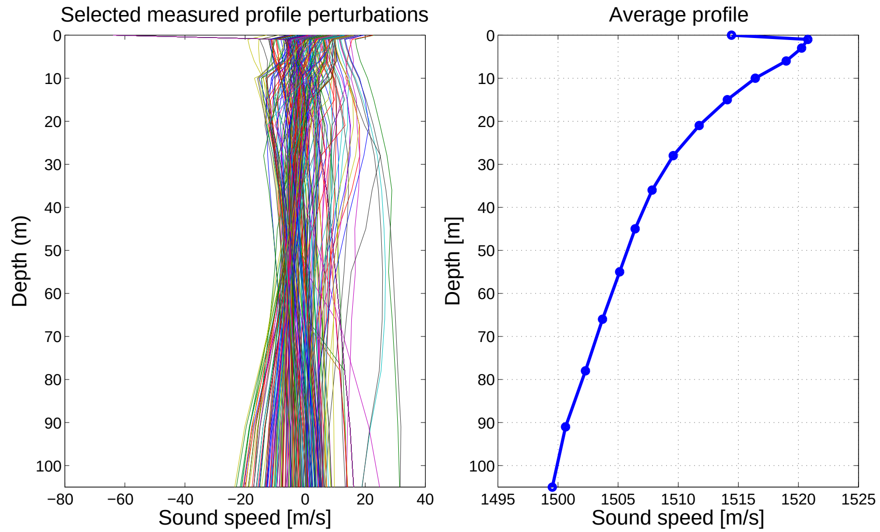
$E\hat{O}F_k(x, y, z)$: 3D k-th EOF estimate

Oceanographic data



(2260 casts, no time information within month)

Oceanographic data



Spatio-temporal Gauss-Markov interpolation

$$[R_{\delta c}]_{ij}(\Delta x, \Delta y, \Delta z, \Delta t) = \mathrm{E}[\delta c_i \, \delta c_j] =$$

$$\sigma^2_{\delta c}\left[1-\left(\frac{\Delta t}{T}\right)^2\right] \mathrm{e}^{-\frac{1}{2}\left[\left(\frac{\Delta x}{L_x}\right)^2+\left(\frac{\Delta y}{L_y}\right)^2+\left(\frac{\Delta z}{L_z}\right)^2+\left(\frac{\Delta t}{T}\right)^2\right]},$$

$$\sigma^2_{\delta c}, L_x, L_y, L_z, T = ?$$

Correlation model parameters estimation — $\sigma^2_{\delta c}$

$$\begin{aligned}\hat{\sigma}^2_{\delta c} &= \frac{1}{K}\sum_{k=1}^{K}[\delta c(x_k, y_k, z_k, t_k)]^2 \\ &= 52.3\ \mathrm{m}^2/\mathrm{s}^2.\end{aligned}$$

Correlation model parameters estimation — L_z

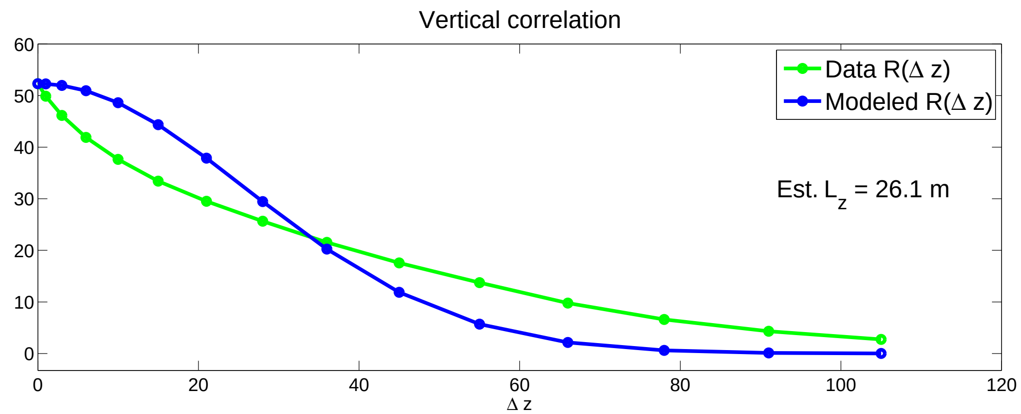
$$\hat{R}(0,0,\Delta z,0) \;=\; \frac{1}{K}\sum_{k=1}^{K}\delta c(x_k,y_k,z_k,t_k)\,\delta c(x_k,y_k,z_k-\Delta z,t_k)$$

Model:

$$R_{\delta c}(0,0,\Delta z,0) = \sigma^2_{\delta c}\, e^{-\frac{1}{2}\left(\frac{\Delta z}{L_z}\right)^2}$$

Least-squares fit to $\hat{R}(0,0,\Delta z,0)$, according to the model, given $\hat{\sigma}^2_{\delta c}$

Correlation model parameters estimation — L_z



Correlation model params. estimation — L_x, L_y and T

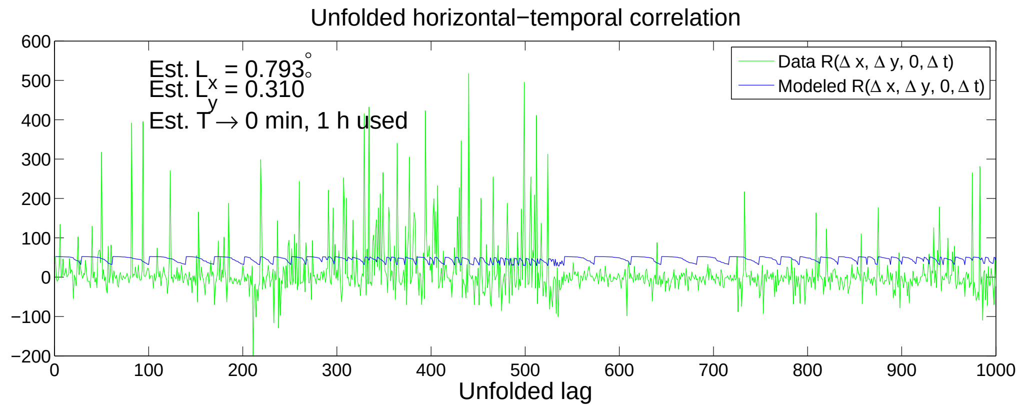
$$\hat{R}(\Delta x,\Delta y,0,\Delta t)$$

$$= \frac{1}{K}\sum_{k=1}^{K}\delta c(x_k,y_k,z_k,t_k)\,\delta c(x_k-\Delta x,y_k-\Delta y,z_k,t_k-\Delta t)$$

Model:

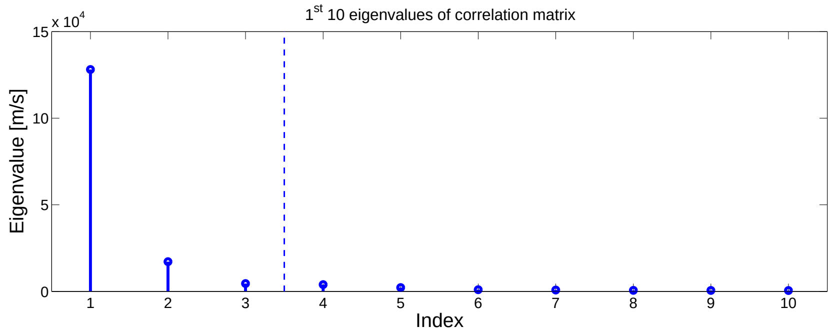
$$R_{\delta c}(\Delta x,\Delta y,0,\Delta t) = \sigma^2_{\delta c}\left[1-\left(\frac{\Delta t}{T}\right)^2\right] e^{-\frac{1}{2}\left[\left(\frac{\Delta x}{L_x}\right)^2+\left(\frac{\Delta y}{L_y}\right)^2+\left(\frac{\Delta t}{T}\right)^2\right]},$$

Correlation model params. estimation — L_x, L_y and T



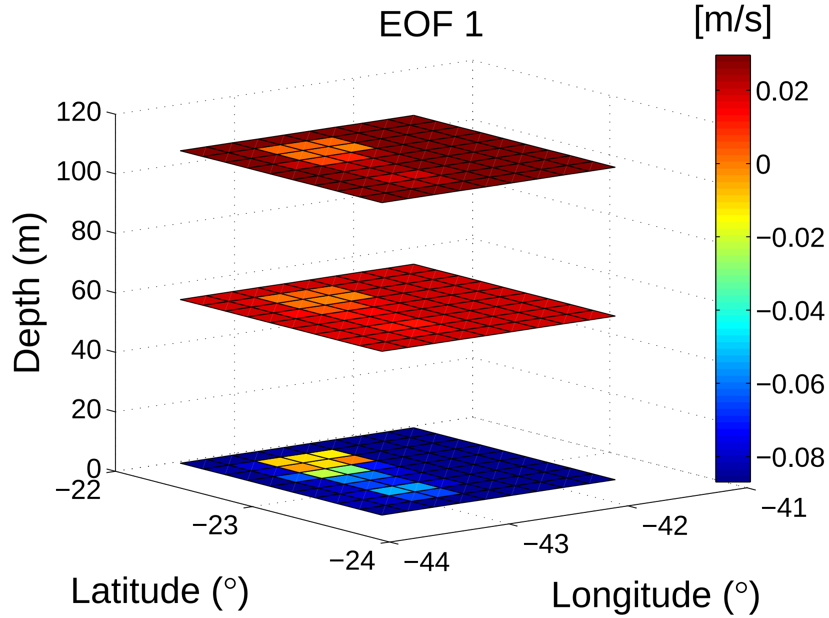
Significant model misfit

EOFs — eigenvalues

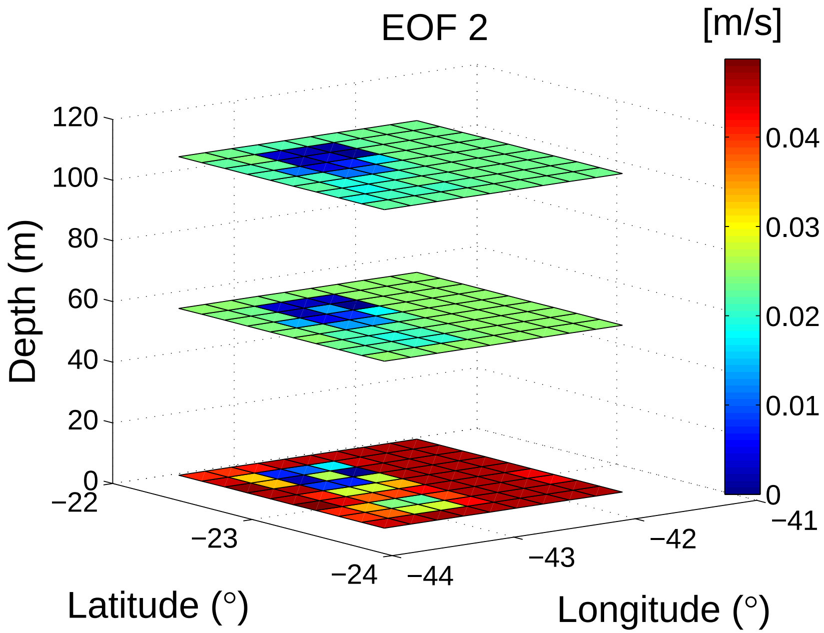


3 EOFs ‘explain 92.0 % of sound speed field variability’

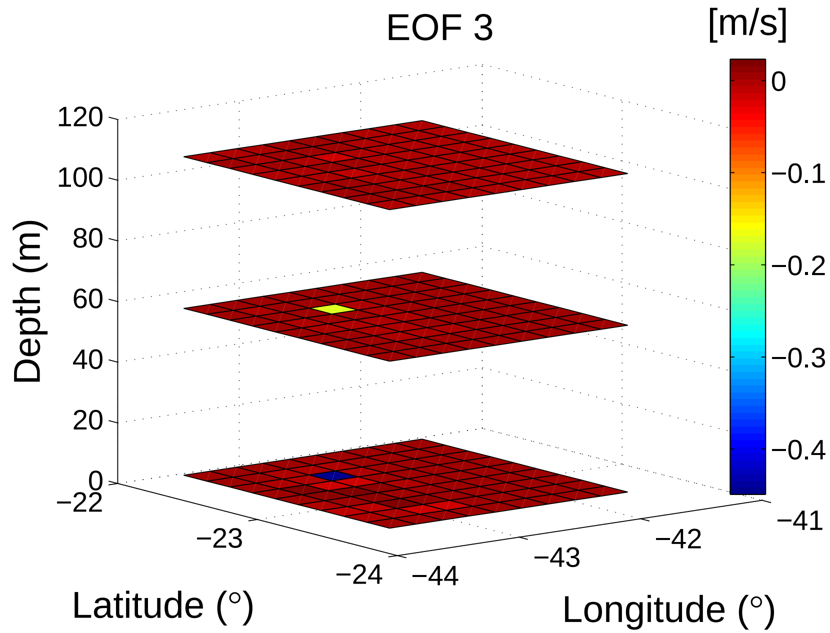
3D EOF plots



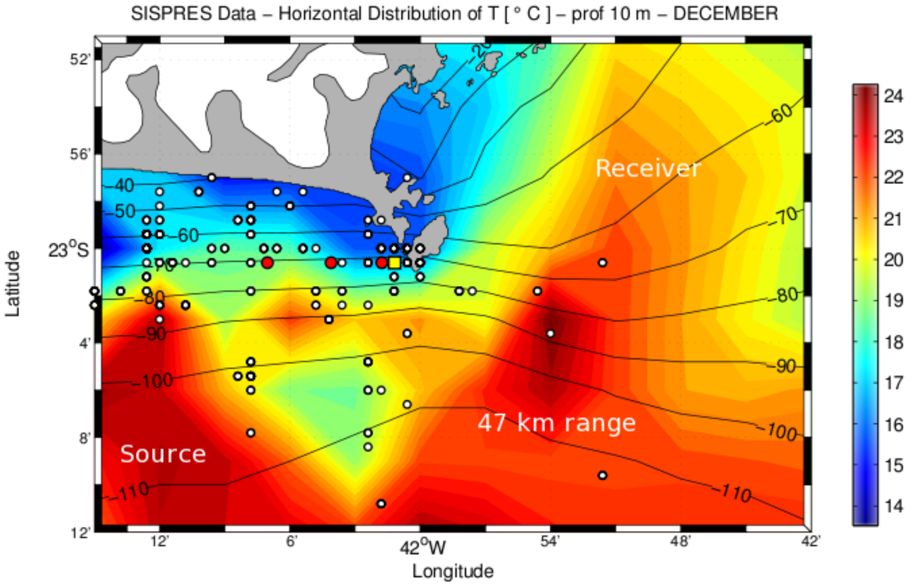
3D EOF plots



3D EOF plots

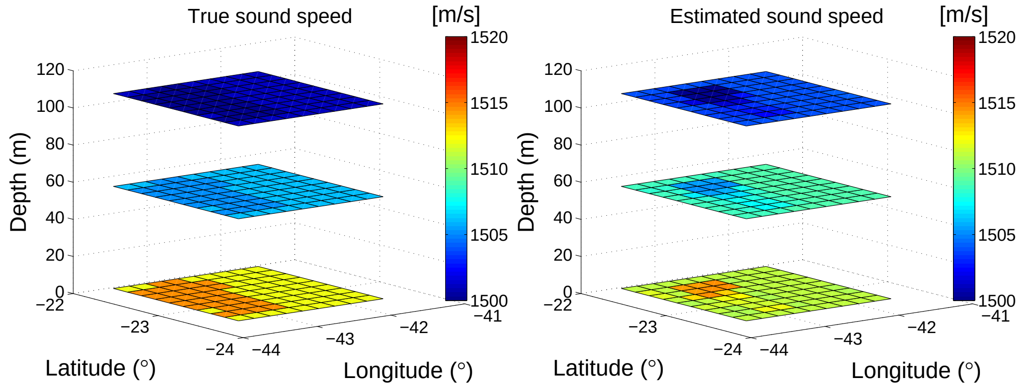


Acoustic system



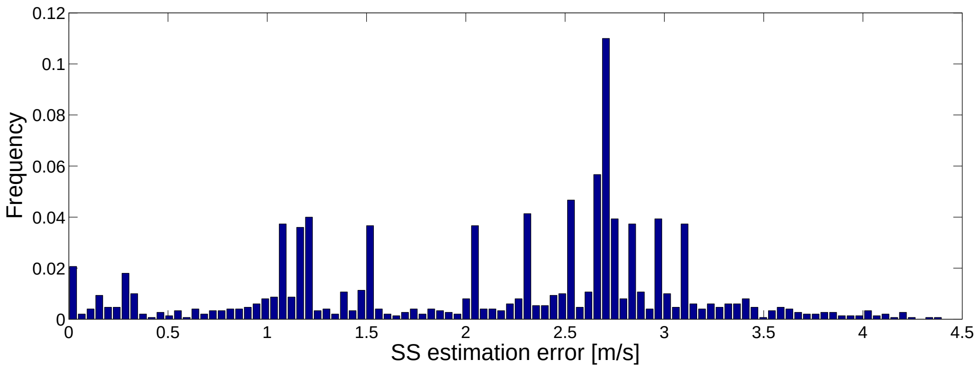
500–900 Hz, 100-Hz spaced

Acoustic inversion results



True coeficients 23.7 10.1 -0.405 [m/s]
Estimated coeficients 92.9 100 -2.05 [m/s]
Acoustic 'trust' (Bartlett fit): 100%
SS projected into true 3 EOF coefficients (not shown) also exhibits significant deviations

Acoustic inversion results



Mode: 0.587 °C

Conclusion & further steps

- Unsufficient coverage of the area with the 2D acoustic system
- Good oceanographic data set?
  - No time information, etc...

Further steps:

- Increase the number of EOFs
- Increase the number of vertical acoustic sections (more acoustic arrays)
- After success, choose optimum positions for the acoustic system (genetic algorithm), and frequencies → tool for acoustic sea trial planning

Feature-oriented acoustic tomography: Upwelling at Cabo Frio (Brazil)

O. Carrière(1), J.-P. Hermand(1), L. Calado(2), A. C. de Paula(2), and I. C. A. da Silveira(3)

(1) Environmental hydroacoustics lab., Université libre de Bruxelles (U.L.B.), Belgium
(2) Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira, RJ Brazil
(3) Instituto Oceanográfico da Universidade de São Paulo, São Paulo, SP Brazil

OAEx Workshop, Arraial do Cabo, RJ , Brazil
March 2010

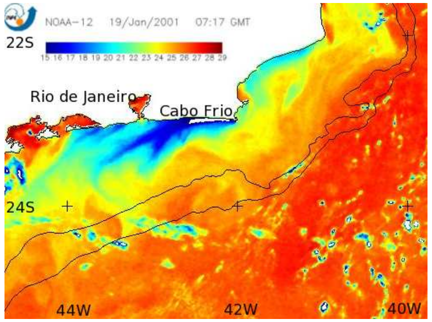
Part of this work was presented at the IEEE/OCEANS 2009 conference, Biloxi, USA

Outline

Outline

Upwelling Front in Cabo Frio

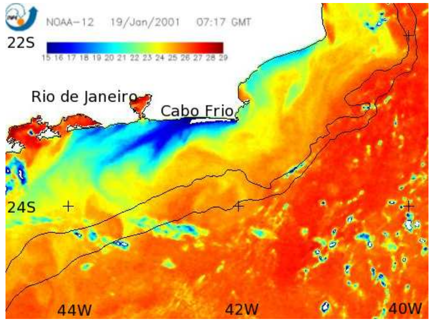
The coastal upwelling in CF (23°S) occurs when the South Atlantic Central Water, carried by Brazil Current (BC), "climbs" the shelf break, and the isotherms (as well as isopycnals) bend upwards in the vicinity of the continental slope.



AVHRR image from 10/01/2001. The blueish-yellow colors are associated with the cooler and fresher Coastal Water on the shelf, and the reddish colors mark the presence of the warmer and saltier Tropical Water.

Upwelling Front in Cabo Frio

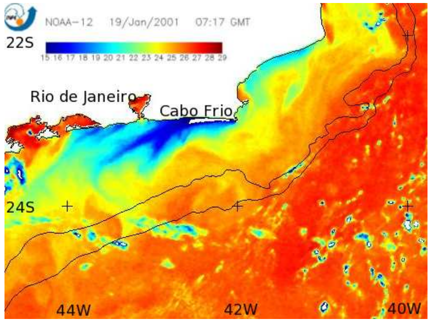
ΔT_{surf} between the Brazil Current front and upwelled waters near the coast is most of the time greater than 10°C during the summer



AVHRR image from 10/01/2001. The blueish-yellow colors are associated with the cooler and fresher Coastal Water on the shelf, and the reddish colors mark the presence of the warmer and saltier Tropical Water.

Upwelling Front in Cabo Frio

The main forcing of coastal upwelling in CF is the persistent winds northeast, that typically blow for several days.

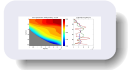


AVHRR image from 10/01/2001. The blueish-yellow colors are associated with the cooler and fresher Coastal Water on the shelf, and the reddish colors mark the presence of the warmer and saltier Tropical Water.

Outline | Introduction | Feature Model | Acoustic tomography | Results | Conclusions

Motivation

- Oceanic forecasts require the best possible specifications of density initial conditions. Therefore, precise knowledge or monitoring of the synopticity of coastal and oceanic systems are fundamental for the initialization of oceanic numerical forecasting model ;
- Acoustics is the only measurement tool able to monitor large regions over the whole water column depth in a synoptical way ;
- Acoustic tomography should provide estimates that are suitable for data assimilation purposes ;
- This work investigates the use of oceanic feature model as a range-dependent parameterization scheme for the inversion of multifrequency acoustic transmissions in a coastal environment.



O. Carrière, J.-P. Hermand, L. Calado, A. C. de Paula, I. C. A. da Silveira | Feature-oriented acoustic tomography: Upwelling at Cabo Frio (Brazil)

Outline | Introduction | Feature Model | Acoustic tomography | Results | Conclusions

Outline

O. Carrière, J.-P. Hermand, L. Calado, A. C. de Paula, I. C. A. da Silveira | Feature-oriented acoustic tomography: Upwelling at Cabo Frio (Brazil)

Outline | Introduction | Feature Model | Acoustic tomography | Results | Conclusions

Feature-oriented regional modelling

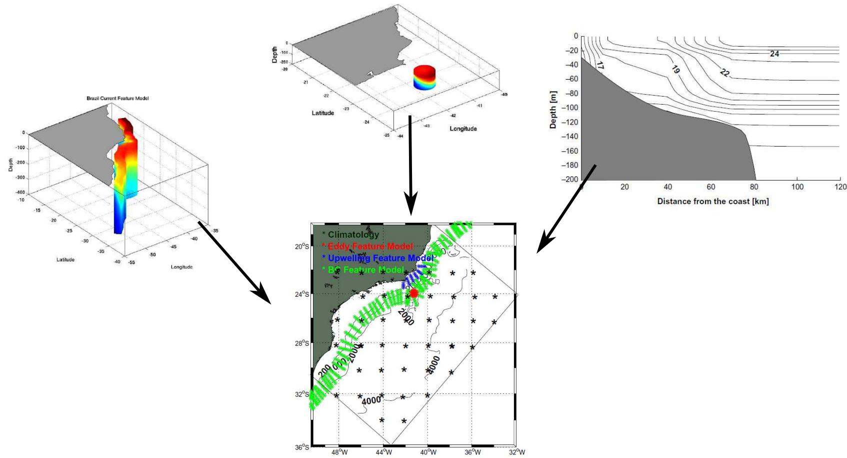


Figure: L. Calado et al., "Feature-oriented regional modeling and simulations (FORMS) for the western South Atlantic: Southeastern Brazil Region." *Ocean Modelling*, vol. 25, pp. 48–64, 2008.

O. Carrière, J.-P. Hermand, L. Calado, A. C. de Paula, I. C. A. da Silveira | Feature-oriented acoustic tomography: Upwelling at Cabo Frio (Brazil)

Theoretical feature model

The feature model approach enables the representation of the complex coastal feature in a low-dimensional scheme.

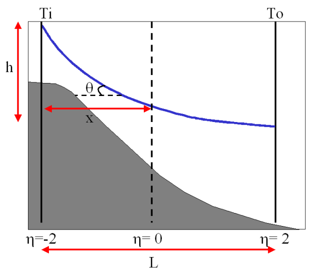
An upwelling feature model is derived from the continental shelf-slope front feature model developed by Gangopadhyay, 2002.

$$T(\eta, z) = T_o(z) + [T_i(z) - T_o(z)]m(\eta, z),$$

where

$$m(\eta, z) = 0.5 + 0.5 \tanh\left[\frac{\eta - \theta z}{\chi}\right]$$

is a meld function.



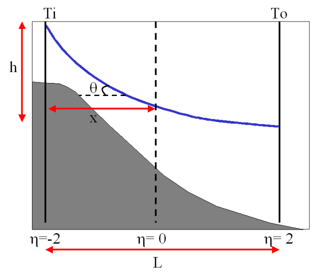
- η: cross-frontal distance from the axis of the front ;
- z: positive vertically upward ;
- $T(\eta, z)$: upwelling frontal temperature distribution ;
- $T_i(z)/T_o(z)$: inshore/offshore temperature profile ;
- $\theta = \mathrm{atan}(h/x)$: slope of the front ;
- χ: e-folding half-width of the front $(= L/2)$.

Theoretical feature model

The meld function $m(\eta, z)$ is rewritten as

$$m(\eta, z) = f(\gamma),$$

where the parameter γ varies between 0 (no upwelling, i.e. horizontally stratified environment) and 1 (maximal upwelling).



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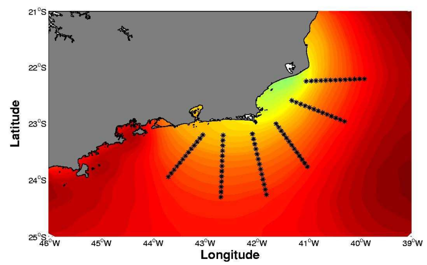
Outline

Approach

- Define several radials across the environment ;
- Invert acoustic data to provide a picture of the upwelling feature on the different radials (vertical slices) ;
- Combine the radials with appropriate correlation length to reconstruct the 3D-picture of the sounded area ;
- Assimilate the results in a multi-scale analysis.



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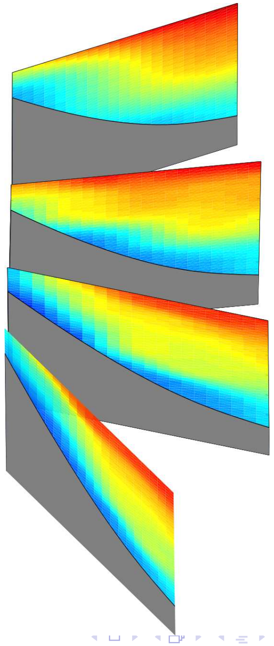
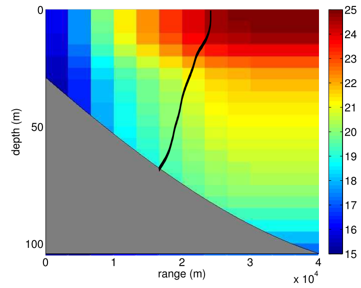


Feature model as a parameterization scheme

- Range-integrated SSP is not meaningful ;
- Vertical slice tomography can resolve range-dependent features by constraining the inverse problem (*range-resolving* tomography); with a resolution suitable for DA in regional models ;
- For a specific oceanic feature, the integration of the *a priori* can be done with a feature model for the parameterization of the environment (*feature-oriented* acoustic inversion).



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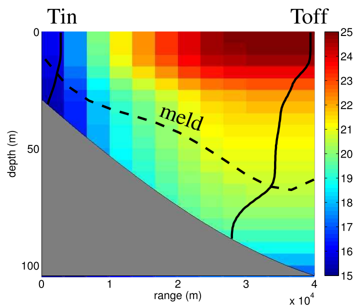


Characteristics of acoustic propagation

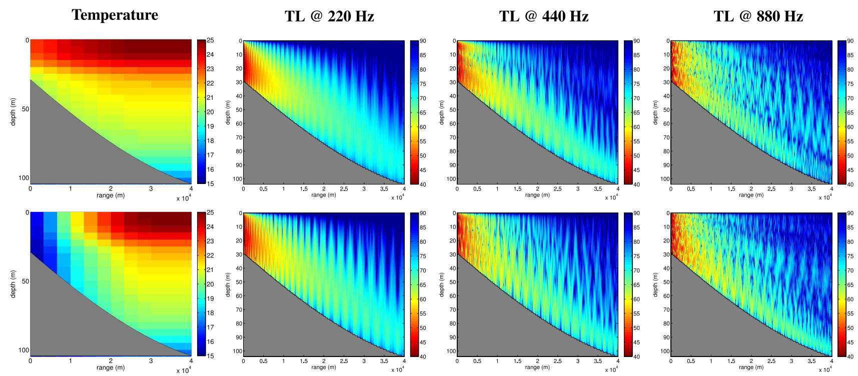


Figure: Coherent transmission losses (in dB) in absence of upwelling (top) and with a strong upwelling (bottom) for three frequencies [220 Hz, 440 Hz, and 880 Hz]. The corresponding temperature fields of the vertical slice are shown on the left side

Synthethic Acoustic Setup

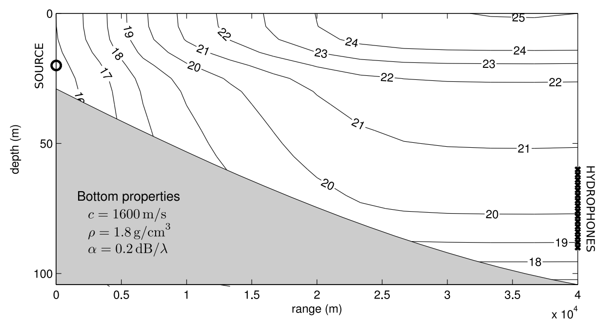


Figure: Synthetic acoustic configuration for a vertical slice of the Cabo Frio coastal area. The temperature field (in °C) depicts a typical upwelling feature.

State-space model

The dynamics of the environment (parameters) and the resulting acoustic measurements are embedded in a Gauss-Markov state-space model.

$$\mathbf{x}(t_k) = \boldsymbol{\mathcal{A}}[\mathbf{x}(t_{k-1})] + \mathbf{w}(t_k)$$
$$\mathbf{y}(t_k) = \boldsymbol{\mathcal{C}}[\mathbf{x}(t_k)] + \mathbf{v}(t_k)$$

- $\mathbf{x}$: state vector (FM parameter) ;
- $\mathbf{y}$: acoustic measurements ;
- $\boldsymbol{\mathcal{A}}$: dynamical model ;
- $\boldsymbol{\mathcal{C}}$: measurement model ;
- $\mathbf{w}(t_k)$, $\mathbf{v}(t_k)$: zero-mean Gaussian random vectors of covariance R_{ww} and R_{vv}, respectively.

Bartlett representation

The N-frequency acoustic measurements are merged into a Bartlett processor, defined as

$$\phi(\gamma) = \frac{1}{N}\sum_{n=1}^{N} \frac{\mathbf{p}^\dagger(\gamma,\omega_n)R(\omega_n)\mathbf{p}(\gamma,\omega_n)}{||\mathbf{p}(\gamma,\omega_n)||^2||\mathbf{d}(\omega_n)||^2} \quad (1)$$

- γ: model vector ;
- $\mathbf{p}(\gamma,\omega)$: predicted (replica) field vector of the acoustic-pressure observations across the VA at frequency ω ;
- $\mathbf{d}(\omega)$: vector of acoustic-pressure measurements across the VA at frequency ω ;
- $R(\omega)$: spatial correlation matrix of the complex acoustic data at frequency ω

$$R(\omega) = \mathbf{d}(\omega)\mathbf{d}^\dagger(\omega).$$

Kalman processor

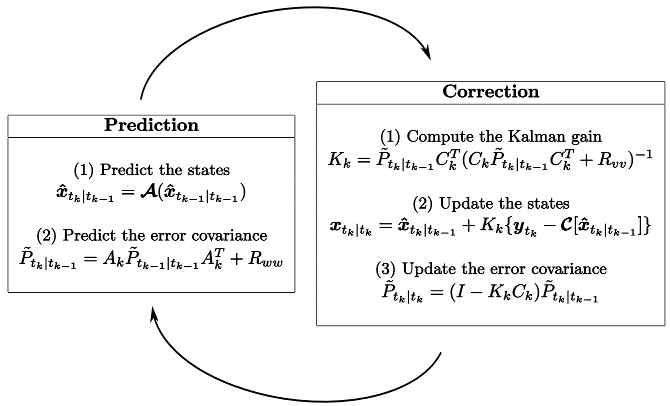
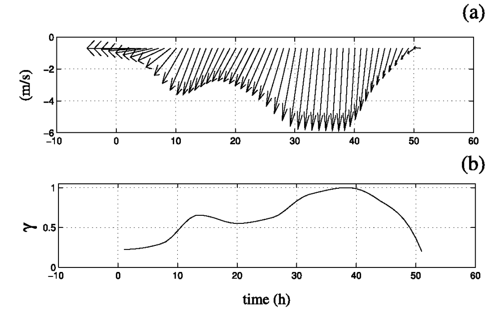


Figure: Diagram of the EKF algorithm in a predictor-corrector form. The matrices A and C are the Jacobians of the transition and the measurement function, respectively. The EnKF algorithm shows a similar structure, but covariance matrices and Jacobians are replaced by stochastic ensemble of realizations.

Outline

Wind-driven scenario

The upwelling in Cabo Frio is strongly correlated to the wind force and direction. For this preliminary study, the simulation scenario for the variation of the upwelling parameter γ is based on real wind data (Jan-Feb 2001). These typical wind variations were found to initiate the upwelling feature and increase gradually its force.



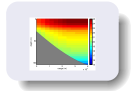


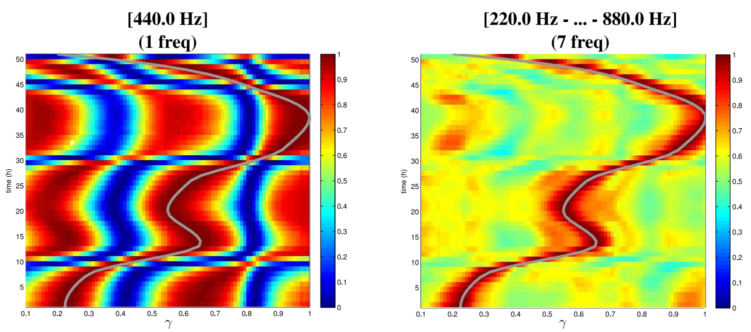
Figure: (a) Wind force and direction during 51 hours. (b) Upwelling parameter deduced from the wind data.

Bartlett sensitivity

Typically, the cost function is multimodal.

- Higher frequencies show more and higher local peaks ($\sim$ more ambiguity) ;
- Lower frequencies show larger peaks ($\sim$ higher uncertainty).

Use of multiple frequencies = trade-off between these two opposite features.



The gray line is the tracked value (global maximum).

Simulation results

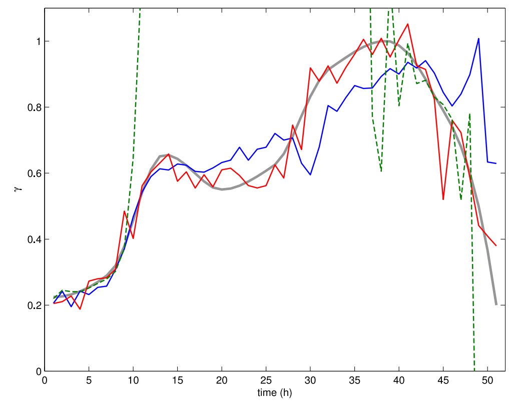


Figure: Simulation results for the tracking of the upwelling parameter γ using an EKF (dashed green line) and EnKF (solid red lines), with the joint filtering of seven third-octave frequencies between 220 Hz and 880 Hz. The EnKF tracking with a single frequency (440 Hz) is shown in blue. The true value of γ is the gray solid line.

Tracked temperature field

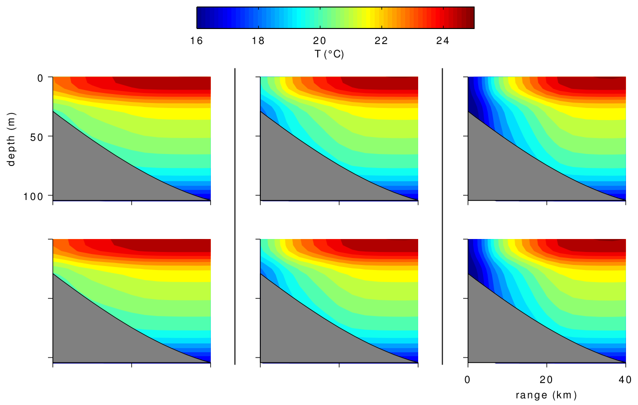


Figure: Evolution of the temperature field given by the scenario (upper line) and tracked by the EnKF (lower line), with the joint filtering of seven third octave frequencies between 220 Hz and 880 Hz. Twenty hours separate each column.

Outline

Conclusions ...

- The tracking of the main feature of a coastal upwelling can be carried out by the sequential filtering (Kalman) of acoustic measurements on a vertical array ;
- The joint inversion of several frequencies reduces the error estimates and stabilizes the filter ;
- Ensemble methods (EnKF) are required to track continuously the upwelling parameter, outperforming the standard EKF ;
- Further work is currently done to apply the feature model on realistic ocean predictions (ROMS).

Workshop - Ocean Acoustic Exploration (OAEx) project

INSTITUTO DE ESTUDOS DO MAR ALMIRANTE PAULO MOREIRA

ARRAIAL DO CABO – RJ
BRAZIL
22 A 26/03/2010

Geoacoustic inversion and source passive localization in shallow water

For:

BRAZILIAN NAVY
CENTER SUPPORT FOR OPERATING SYSTEMS
(CASOP)

In:

FEDERAL UNIVERSITY OF RIO DE JANEIRO
(UFRJ)
ALBERTO LUIZ COIMBRA INSTITUT OF POST-GRADUATE STUDIES AND RESEARCH IN ENGINEERING
(COPPE)

M.SC. DISSERTATION
CC(CA) LUSSAC PRESTES MAIA

ADVISOR:
PR DSC CARLOS EDUARDO PARENTE RIBEIRO
CO-ADVISOR:
PR PHD JEAN-PIERRE HERMAND

SUMMARY

INTRODUCTION

- Sound propagation on shallow water >> bottom and sediments layer properties
  - att-sed, c-sed , att-bot, c-bot and densities
- Geoacoustic inversion
  - Non-destructive way
- Passive source localization
  - requires some knowledge of the seabed
  - discrete

INTRODUCTION

- Inversion techniques >> estimate physical parameters
  - Geometric parameters
    - SD, RD, SR-range, tilt, depth, thickness
  - Geoacoustic parameters
    - Att, speeds and densities
- focalization – small search space where there are knowledge (measurement eqpt., earlier exp.)

OBJECTIVES

- Wave theory for geoacoustic inversion and passive source localization
- Two experiments
- Real data recorded on MREA/BP'07 (SE Elba Island, off coast Italy) [J.R.P., NATO document]
  - Use:
    - matched field techniques
    - genetics algorithms optimization

THEORETICAL GROUND

- Wave Equation

(linearized in a homogeneous medium without movement)

$$\frac{\partial \rho'}{\partial t} + \rho_0 \nabla \cdot v' = 0$$

$$\rho_0 \frac{\partial \vec{v}'}{\partial t} + \nabla p' = 0$$

$$\rho' = \frac{1}{c^2} p'$$

$$\frac{1}{c^2}\frac{\partial^2 \psi}{\partial t^2} - \nabla^2 \psi = 0$$

$$\xi = \nabla \psi \qquad p = -\rho \frac{\partial^2 \psi}{\partial t^2}$$

THEORETICAL GROUND

- Helmholtz equation

$$k^2(r)\,\psi(r,\omega) + \nabla^2 \psi(r,\omega) = 0$$

$$\left[k^2 + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{\partial^2}{\partial z^2}\right]\psi(r,z) = P_\omega \frac{\delta(r)\delta(z-z_s)}{2\pi r}$$

- Waveguide: boundary conditions
  - Continuity of pressure
  - Continuity of vertical particle velocity
- Shallow water – after crit. angle >> waveguide
- Multiple reflections (bottom, free surface), long distance propagation

THEORETICAL GROUND

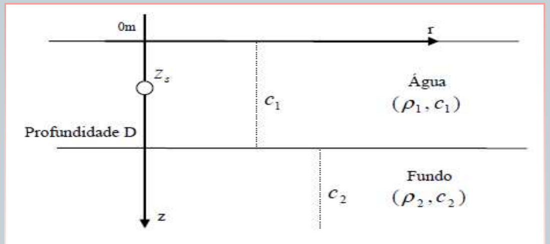
- Range-independent env., far field
- Solution: separation of variables $\psi(r,z) = \varphi(r)\zeta(z)$
  - (or option: wavenumber integration)
- Normal modes model - ideal waveguide of rigid bottom

$$\varphi_m(r) = \frac{i}{4\rho}\zeta_m(z_s)\,H_0^{(1,2)}(k_{rm} r) \qquad H_0^{(1)}(k_{rm} r) \cong \sqrt{\frac{2}{\pi k_{rm} r}}\, e^{-i\left(k_{rm} - \frac{\pi}{4}\right)}$$

$$p(r,z) = \frac{i}{2\rho\sqrt{2\pi}}\frac{e^{-i\pi/4}}{\sqrt{r}}\sum_{m=1}^{\infty}\zeta_m(z_s)\,\zeta_m(z)\frac{e^{ik_{rm} r}}{\sqrt{k_{rm}}}$$

THEORETICAL GROUND

- More realistic Pekeris waveguide – two fluid layers



Modes: poles of the transcedental equation

$$\tan(k_{z,1}D) = -\frac{i\rho_2 k_{z,1}}{\rho_1 k_{z,2}}$$

(discrete spectrum k2<kr<k1)

Solution

$$\psi(r,z) \cong -\frac{iP_\omega}{2D}\sum_{m=1}^{M}\left[a_m(k_{rm})\ \sin(k_{zm}z)\sin(k_{zm}z_s)H_0^{(1)}(k_{rm}r)\right]$$

$$p = -\rho\frac{\partial^2\psi}{\partial t^2}$$

THEORETICAL GROUND

- Foward-model (shallow water range-independent , far field) >> numerical model SNAP [Jensen&Ferla,1979]
- Inversion with matched field: correlation between predicted fields and observed field

Observed signals (stochastic >> noise)

$$\vec{x}(t) = \int_0^T \vec{h}(t-\tau)s(\tau)d\tau + \vec{u}(t) \Rightarrow \vec{X}(\omega) = \vec{H}(\omega,\vec{\theta})S(\omega) + \vec{U}(\omega)$$

Math expectation of correlation matrix obs data

$$C_{XX} = E[\vec{X}(\omega)\vec{X}^H(\omega)]$$

Conventional Bartlett processor normalized

$$P(\omega,\vec{\theta}) = \frac{\vec{H}^H(\omega,\vec{\theta})C_{XX}(\omega)\vec{H}(\omega,\vec{\theta})}{\vec{H}^H(\omega,\vec{\theta})\vec{H}(\omega,\vec{\theta})}$$

THEORETICAL GROUND

- Results: optimum value of cost function (processor)
- Cost function in this work [Gerstoft, 2007]:

(indicial notation)

p = obs ; q = predicted

- MFP Bartlett multifrequency

Coherent in space
Incoherent in frequency

$$R_{jl,i} = E\left[p_{ij}\ p_{il}^H\right]$$

$$\phi = \sum_{i=1}^{N_{freq}}\sum_{j=1}^{N_{hd}}\left[R_{jj,i} - q_{ij}^*\sum_{l=1}^{N_{hd}} R_{jl,i}q_{il}\right]$$

- MBMF frequency domain version

Coherent in frequency

$$\phi_F = 1 - \frac{1}{N_{freq}}\sum_{j=1}^{N_{hd}}\frac{\left|\sum_{i=1}^{N_{freq}} p_{ij}^*\ q_{ij}\right|^2}{\sum_{i=1}^{N_{freq}}\left|p_{ij}\right|^2\ \sum_{i=1}^{N_{freq}}\left|q_{ij}\right|^2}$$

- Big search space >> global optimization (simulated annealing, genetic algorithms,...)
- Correlations and optimization >> numerical model SAGA
- Prepare data and plotting >> Matlab pre/post-processing rout.

THEORETICAL GROUND

- Bayesian inference $p(m/d) = \dfrac{p(d/m)\,p(m)}{p(d)} \propto £(m)\,p(m)$
- pdf *a posteriori* = £(m) * pdf *a priori*
- Inversion results
  - *a Posteriori* Probability Distribution(PPD)
    - multidimensionality – plotting 1D marginal PPD
  - Optimum values:
    - MAP or bestfit– maximize pdf *a posteriori*
    - ML or most likely – maximize likelihood function
    - Mean – mean marginal PPD

METODOLOGY

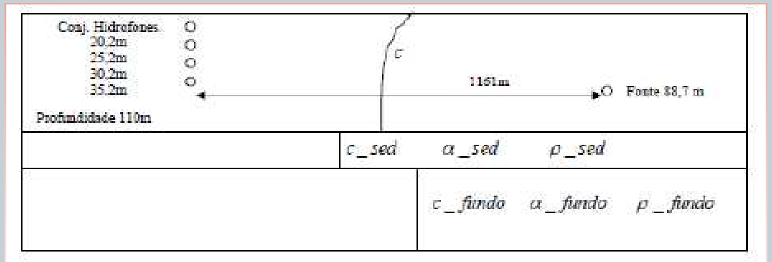
Net of modeled acoustic pressure fields
SNAP

Measure of match with observed field(real data)
Suitable cost function (two experiments)
Genetic alg. optimization
SAGA

Post-processing to estimate optimum values
Plotting results
Analysis
SAGA / Matlab routines

METODOLOGY

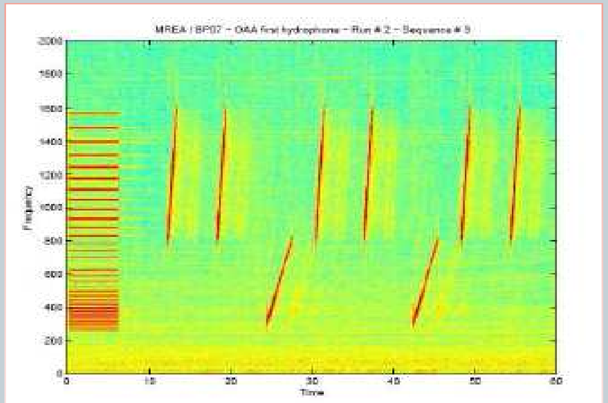
- Basic geometry
  - Water column (110m) – sediment layer (8m) – bottom (halfspace)
  - Source ~89m
  - Ocean acoustic array (ULB) ~ 4 hyd (each 5m)
  - SR range – decreases slowly (~1630 to 1130m in 32 minutes)



[MAIA *et al.*,2009]

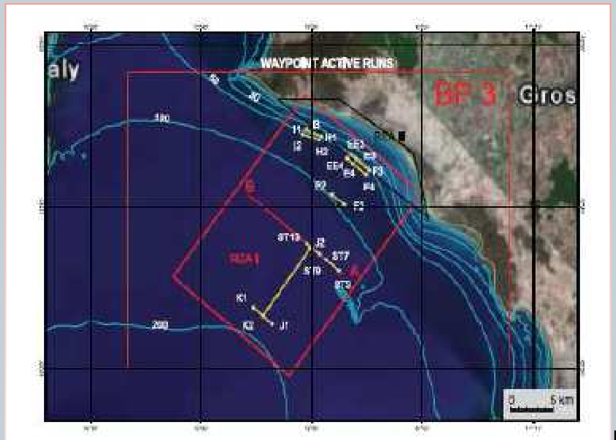
METODOLOGY

- Emmited signals
  - MULTITONE CW (32 tones, 260-1560Hz, 6s)
  - LFM MF (800-1600Hz, 1s) and LFM LF (300-800Hz, 3s)



METODOLOGY

- Data >> MREA/ BP'07, run#2, line ST3-ST7
  - Acoustic data from Laboratoire d'Hydroacoustique Environnementale ULB



[LE GAC & HERMAND, 2008]

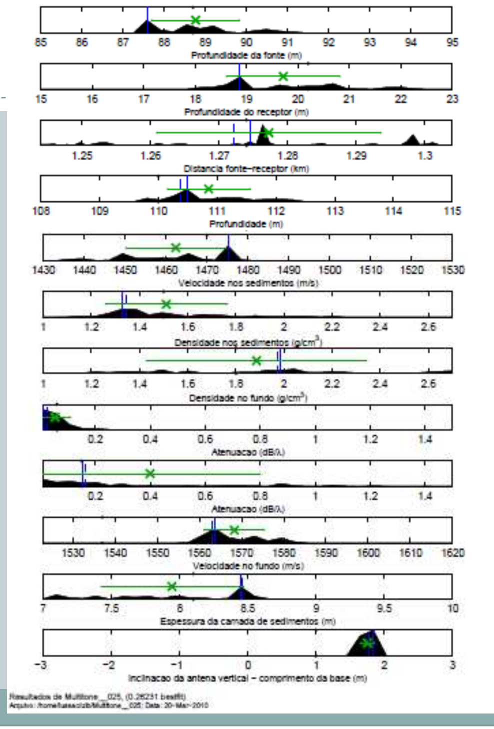
EXPERIMENT I

- Thirty-two emissions of signal MULTITONE CW each minute
  - 6s, 32 tones, 260-1560Hz
- Pre-processing for expectation of correlation matrix
  - Signal divided in 11 part with 50% overlap, Tukey window, mean of 11 correlation matrices >> expectation
- Cost function Bartlett MFP multifrequencies
  - Coherent in space, incoherent in frequency
- Optimization: genetic algorithms
- Inverted physical parameters (15) (*focalization)
  - SD/ RD/ SRR*/depth/ 3 EOF coeficient from SSP databank*/ att-sed/ c-sed/ rho-sed/ att-bot/ c-bot/ rho-bot/ thickness/ tilt

EXPERIMENT I

Ping number 25 (e.g.)
Marginal *a posteriori* probability distributions
(EOF coeff not presented)

Green – mean marginal PPD
Blue – maximum a posteriori
Dashed blue – most likely

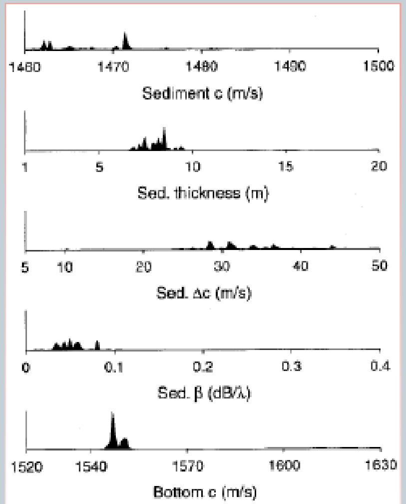


EXPERIMENT I

Comparison ping25
with Yellow Shark'94
(run of 4,5 km on same line)

Parmt - Yellow Shark'94 - MREA/BP'07 Exp. I

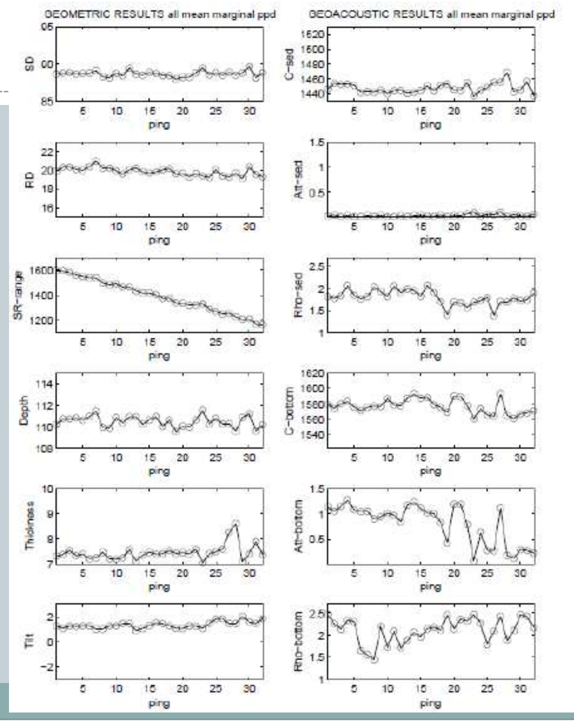
C-sed -	~ 1472 m/s	- ~ 1475 m/s
Thickness -	~ 8.5 m	- ~ 8.4 m
Att-sed -	~ 0.06 dB/λ	- ~ 0.01 dB/λ
C-bottom-	~ 1547 m/s	- ~ 1564 m/s



[HERMAND & GERSTOFT, 1996]

EXPERIMENT I

Evolution 32 pings
(mean marginal PPD)
MFP Bartlett multifreq.



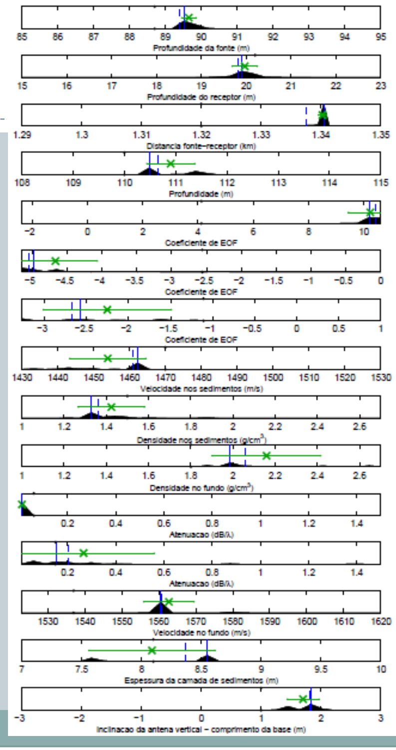
EXPERIMENT II

- Thirty-two emissions of signal LFM LF each minute
  - 3s, 300-800Hz
- 502 samples of LFM LF signal (1st each sequence)
- Cost function MBMF on frequency domain version
  - Coherent in frequency
- Optimization: genetic algorithms
- Inverted physical parameters (15) (*focalization)
  - SD/ RD/ SRR*/depth/ 3 EOF coeficient from SSP databank*/ att-sed/ c-sed/ rho-sed/ att-bot/ c-bot/ rho-bot/ thickness/ tilt

EXPERIMENT II

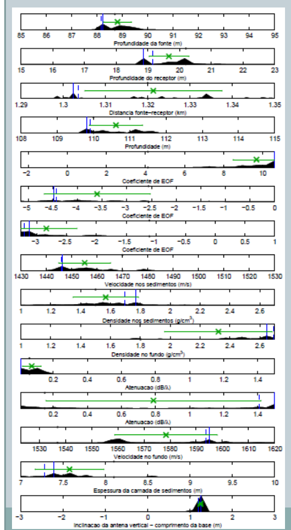
Ping number 22 (e.g.)
Marginal *a posteriori* probability distributions

Green – mean marginal PPD
Blue – maximum a posteriori
Dashed blue – most likely

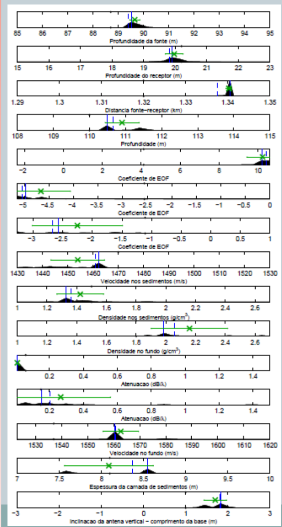


EXPERIMENT II

Comparison ping 22 - MPF Bartlett and MBMF freq domain - mean marg. PPD



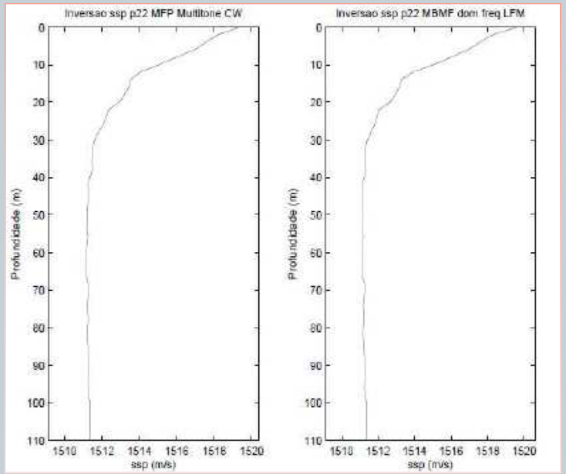
Parâmetro fisico	MFP Bartlett - p22	MBMF dom freq - p22
SD	88.8m (+- 0.05)	89.7m (+-0.02)
RD	19.7m (+-0.08)	19.9m (+-0.04)
SR-range	1321.3m (+-0.03)	1340.3m (+-0.01)
Depth	110.6m (+-0.1)	110.9m (+-0.07)
C-sed	1455.1m/s (+-0.1)	1453.9m/s (+-0.1)
Rho-sed	1.57g/cm³ (+-0.13)	1.42g/cm³ (+-0.1)
Rho-bottom	2.32g/cm³ (+-0.21)	2.15g/cm³ (+-0.15)
Att-sed	0.07dB/λ (+-0.036)	0.01dB/λ(+-0.003m)
Att-bottom	0.79dB/λ (+-0.4)	0.27dB/λ (+-0.2)
C-bottom	1578.47m/s (+-0.2)	1562.8m/s (+-0.1)
Thickness	7.57 m (+-0.14m)	8.08 m (+-0.2m)
Tilt	1.24m (+-0.01m)	1.70m (+-0.04m)



EXPERIMENT II

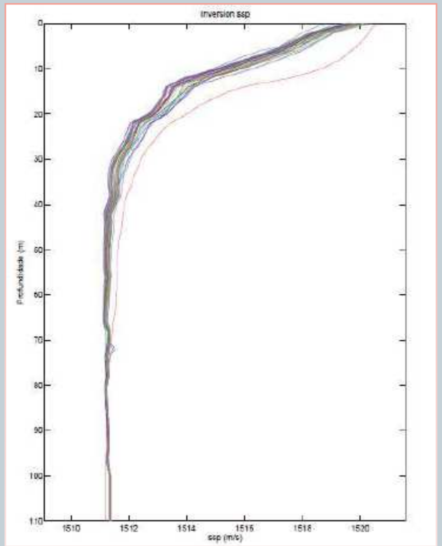
- Comparison ping 22 for ssp - MPF Bartlett and MBMF freq domain

Parâmetro fisico	MFP Bartlett - p22	MBMF dom freq - p22
Coeficiente da 1ª EOF ssp	9.676 (+-0.091)	10.233 (+-0.061)
Coeficiente da 2ª EOF ssp	-3.604 (+-0.209)	-4.668 (+-0.117)
Coeficiente da 3ª EOF ssp	-2.843 (+-0.121)	-2.253 (+-0.178)



EXPERIMENT II

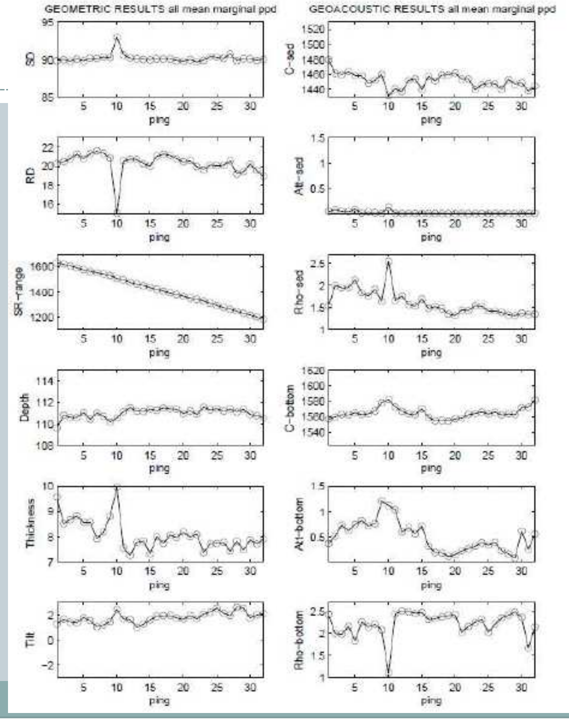
- Plotting of 32 SSP from the coef. 3 first EOF inverted with MBMF freq domain



EXPERIMENT II

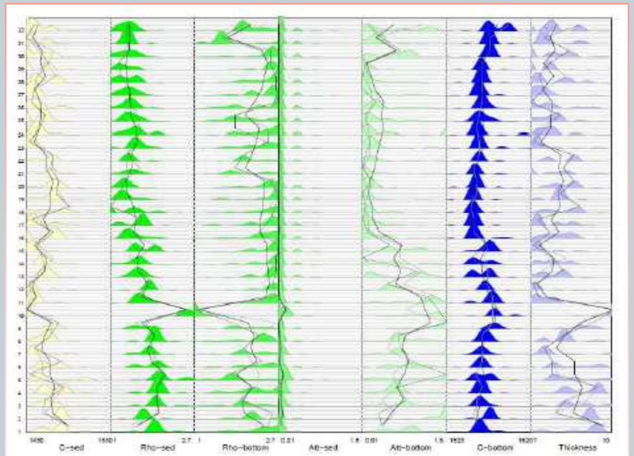
Evolution 32 pings (mean marginal PPD)

MBMF freq domain version



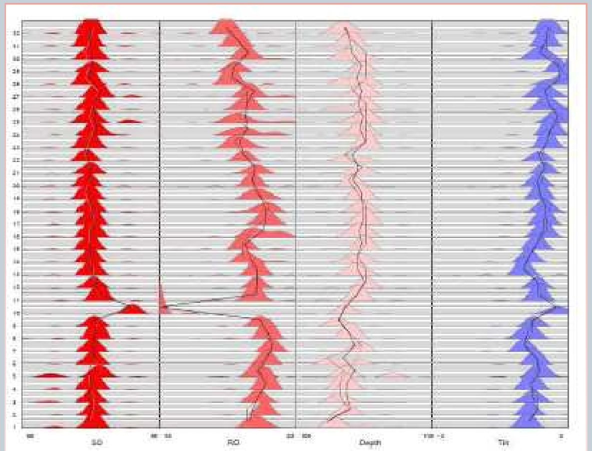
EXPERIMENT II

Plotting pattern PLEDS for 32 distributions MBMF frequency domain version – Geoacoustic Parameters



EXPERIMENT II

Plotting pattern PLEDS for 32 distributions MBMF frequency domain version – Geometric Parameters



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- And others ...

CONCLUSION

- Shallow water acoustic propagation >> somewhat complicated process in a difficult environment for accurate modeling
- Acoustic inversion experiments >> sensitive to modeling errors (support of measuring equipments: CTD, pressure sensors, echobathimetry, ...)

CONCLUSION

- Space coherent MFP Bartlett multifrequency processor >> capable to reach reasonable results even on sparse array (4 hyd.)
- Frequency coherent MBMF in frequency domain version processor >> suitable for dense sampling of LFM signal and sparse array, good for operational employment

Instituto de Estudos do Mar Almirante Paulo Moreira
IEAPM

MARINHA DO BRASIL

INSTITUTO DE ESTUDOS DO MAR
ALMIRANTE PAULO MOREIRA
(ADMIRAL PAULO MOREIRAMARINE RESEARCH INSTITUTE)

1st OAEx Workshop
Ocean Acoustic Exploration
March, 22nd - 26th 2010
Arraial do Cabo, Rio de Janeiro, Brasil

MARINHA DO BRASIL – INSTITUTO DE ESTUDOS DO MAR – ALMIRANTE PAULO MOREIRA

COPPE UFRJ
Universidade Federal do Rio de Janeiro

UNIVERSIDADE DO ALGARVE

ULB
Université Libre de Bruxelles

University of Victory

I OAEx Workshop
IEAPM highlights

FEV2009-FEV2010

Summary

- Objectives
- Workplan 2009/2010
- Tasks on DoW for 2009-2011
- Perspectives on Sea trial planning and execution
- News

Objectives

The main objective of the OAEx exchange programme is to enhance collaboration and fill the scientific and technological gap to specifically define methodologies, technologies and procedures for the implementation of underwater acoustic environmental monitoring and communication networks to be integrated in the surveillance and monitoring of critical at sea infrastructures.

In particular, this exchange will focus on the following:

1. *Investigation of the performance characteristics required for acoustic*
2. *environmental monitoring and data transmission over underwater acoustic channels;*
3. *Definition of the requirements and suggestion of methodologies for the implementation of a generic monitoring network in Cabo Frio (Brazil)*;
4. *Experience exchange regarding the NEPTUNE network requirements, methodologies and specific algorithms for integration, data transmission and overall network infrastructure*.

5. Experiments on Cabo Frio site

Workplan 2009/2010

1. The Cabo Frio environmental model
2. Water Column activities
    1. Environmental invertion for upwelling
    2. Environmental inversion for source localization

Work plan visits IEAPM to CINTAL (Fall 2009)

(proposal)

1 The Cabo Frio environmental model

The work actually being put in place in the contect of OAEx, leads to the idea of conducting an acoustic experiment in the Cabo Frio area during Fall of 2010, as mentioned in the project Grant Agreement Annex I. Most of the work during this first project year is directed towards: i) getting acquainted with the acoustic modelling tools and the techniques for environmental inversion; ii) the environmental modelling of the target area and running of forward / inverse acoustic simulations using the modelled environment; iii) make an exploratory assessment of the equipment requirements for the experiment.

The environmental modelling work was arbitrarly divided in bottom and water column. Bottom work would deal with the recollection of historical and in situ acquired information into an unique coherent framework for acoustic modeliing purposes. Historical information would take into account bathymetric data and geological information. In situ acquired data would group seismic records, bottom sampling, cores and bottom reflectivity surveys. Water column would group essentially all previously acquired XBT, CTD, XCTD, thermistor chain and equivalent water sampling measurements, including Hansen bottles. Obviously, this study would require a space coherent (and also time coherent for the water column) analysis of this *a priori* information.

The Cabo Frio environmental model would serve as the basis for extracting meaningfull canonical scenarios for acoustic modelling/inversion.

2 Water column activities

2.1 Environmental inversion for upweling

One of the scopes of using acoustics for water column sound speed inversion is to offer a suitable technique for remote monitoring of water column variations and predict their effect on environmental monitoring and sonar detection. This activity would include the use of a suitable propagation model being able to cope with mild to medium range dependency, such as any normal mode model, ray tracing or parabolic equation. It will also require the usage of a model-based approach for acoustic inversion, incorporating either a matched-field or a Bayesian inference method for inversion. Spatial and temporal scales should cover those appropriate for simulating the experimental area at hand, i.e., approximately 10 km in range and several days to one week in time. The canonical geoacoustic parameters should be used in the model, along relevant propagation tracks (e.g. parallel and/or perpendicular to the coast). The SAGA software package incorporates all the necessary features for the analysis required in this study with the advantage of saving a quite a substantial amount of time in programming and other software development tasks.

2.2 Environmental inversion for source localization

In this part of the study the environmental model will be used for extracting relevant forward acoustic responses for simulating the acoustic field at selected locations so as to determine source localization / detection performance. Again, any suitable acoustic

Tasks on DoW for 2009-2011

Task	Description	Lider	Partners
1.1	*Work preparation in Brazil* (kick off meeting)	CINTAL	CINTAL, ULB, COPPE, UVIC e IEAPM.
1.2	*Plans for development of an underwater acoustic network*	UVIC	CINTAL, ULB e UVIC.
2.1	*Simulation study*	UVIC	CINTAL, COPPE, ULB e IEAPM.
2.2	*Sea trial planning and execution*	IEAPM	CINTAL, ULB, COPPE e IEAPM.
2.3	*Communication equipment testing.*	UVIC	CINTAL, ULB e UVIC
2.4	*Real data analysis.*	IEAPM	CINTAL, ULB, UVIC, COPPE e IEAPM
3.1	*Acoustic inversion aspects*	ULB	CINTAL, COPPE, ULB e IEAPM.
3.2	*Communication aspects (scientific and technological)*	CINTAL	CINTAL, ULB, UVIC, COPPE e IEAPM.
3.3	*Underwater acoustic networking*	UVIC	CINTAL, ULB e UVIC

Perspectives on Sea trial planning and execution

- U-14 "Asp Moura Research Vessel"
- New set of equipment for:
  - Acoustics
  - Oceanography
  - Geology and Geophysics
  - Hidrography
  - Biology

U-14 "ASP Moura Research Vessel"

U-14 "ASP Moura Research Vessel"

- **Communication Systems**
- VHF DSC, Sailor mod. RT 4822
- VHF GMDSS Jotron (3 units)
- VHF Shipmate, mod. 8400
- Navtex, mod ICS Nav- 5
- Inmarsat Mini-M, mod. NERA worldphone, data,fax.
- Intercom and PA system
- Video surveillance, all open deck and engine rooms
-
- **Propulsion**
- **Main Engine :** MAN / 9L 20/27. 892 kW (1213 BHP) 1000 rpm
- **2 x Aquamaster :** Rolls Royce/Ulstein. 360º, US 401/2000, mech. power transfer
- **Bow Thruster:** Brunvoll 150 Hk (Tunnel)
- **Auxiliary engines :** 3 x Scania 14/14 M. 223k W /1500rpm
- **Alternator:** 3 x 210 kV A 150 Hz/380V 3-phase
- **Service Speed :** 9 knots
- **Fuel :** 2.8m^3 per day
- **Lube Consumption:** 20Ltr per day
- **Endurance :** 10 days
- **Range :** 2.160 n/miles @ service speed

U-14 "ASP Moura Research Vessel"

- **Tank/s Capacity**
- **Bunker capacity :** 33m^3
- **Drinking water :** 30m^3
- **Sewer :** 4,5m^3
- **Ballast :** 64,4m^3
- **Accomodation**
- **Marine Crew:** 8 crew in 3x doubles & 2x single cabin
- Captain, 1st Mate, 2nd Mate, Chief Engineer, 2nd Engineer, ETO, Cook (AB/Wiper)
- **Clients:** 11 people in 5x doubles & 1x single cabin
- **Air-conditioning :** Independent units
- **Air heating :** Electrical, independent units and central unit
- **Deck Space**
- **Deck Space Area with A Frame**
- **Deck Space Area without A Frame**
- With A-Frame module: 94.3m^2
- Without A-Frame module: 113m

U-14 “ASP Moura Research Vessel”

- <u>Survey Equipment Installed</u>
- **Survey equipment setup**
- **On/Off Line Room Layout**
- **Multibeam echosounder :** Simrad EM 3000 D
- **Multibeam echosounder :** Reson Seabat 8160 3,000m range, 50 kHz, 1.5 x 1.5 degree beams
- **Motion sensor :** 1xMRU Seatex Seapath 200
- **Data storage :** 1x Sun station
- **DGPS :** Trimble 5700
- **Network :** 6xPC’s, notebooks, printers
- **Software :** Merlin, Neptune, Poseidon, Triton, C-Floor, PDS 2000, Olex chart plotter, interface with EM 3000 D (real time), Navipac - survey navigation and data acquisition. Note; use of Navipac requires a valid software key which can be client supplied or rented. **RIB Work Boat :** Model; Polarcirkel 24, Length 7.3m, Width 2.7m, Weight 1000kg, Max cargo 1200kg, Max persons 12. Outboard Mariner 150hp, Simrad CE 40 Chart plotter-differential GPS antenna-echo sounder.

U-14 “ASP Moura Research Vessel”

- <u>Deck Mounted Equipment</u>
- **RIB / Deck Crane :** 7TM, max reach 6.4m, max load at 6.4m = 1,000kg
- **A-Frame Jib Doppler Deployment Pipe Cargo Hoist Plans** (Click Here) (.pdf)
- **Container Plan** (Click Here)
- **Hydrographical winch :** Double section slip-ring winch (8mm wire 1000m)
- **A-Frame: (Aft) :** (SWL 995kg) for handling of Klein sonar or sampling. 1,000m (8mm) WIRL
- **A-Frame : (Port side) :** (SWL-5t) for clearance work, grab sampling, ROV launch etc. Inc: double drum (2x5t) hydraulic winches on gantry.
- **500mm Gate Valve-Penetration** in cargo hold.
- **Jib:** (Stb Side) (SWL - 1.5t) with hydraulic power block (28") for handling ROV umbilical, ropes etc.
- **Doppler Deployed Pipe:** (Stb Side)
- **Cargo Hold Hoist :** (SWL - 2t)
- **Container - deck sockets:** 10' & 20'

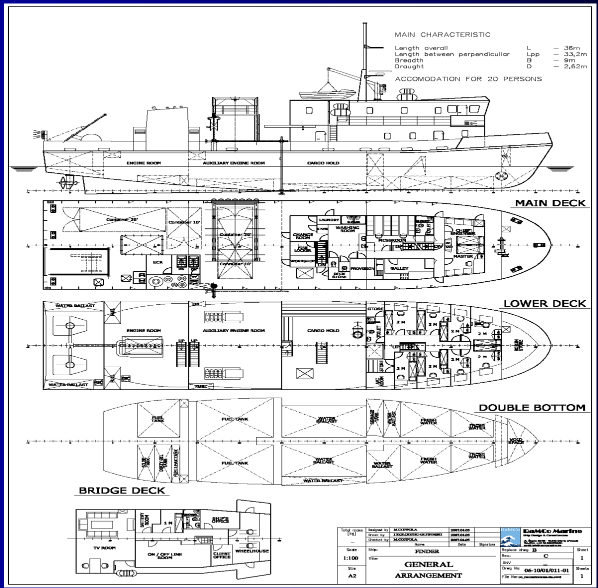
U-14 “ASP Moura Research Vessel”

- <u>Research & Over The Side Equipment</u>
- **Multi parametric sounder :** 1x Midas CTD + 6000m Titanium
- **Current profiler :** 1x ADCP RDI worhorse long ranger 75kHz
- **Side Scan Sonar :** Klein 3000
- **ROV :** Seaeye Falcon 300m depth, extended frame + manipulator. **On / Off line survey operations room**
- <u>Work Facilities</u>
- **Small client office**
- **Recreation / Meeting room :** 42” flat screen for video/digital presentation, film, TV channels.
- **Auxiliary engine room:** Mechanical/Engineering work shop, aluminium and steel welding.
- **Cargo hold :** Storage space, storage for samples and cargo total area approx 30m²

U-14 “ASP Moura Research Vessel”

- <u>Diving Equipment</u>
- **Suits :** 2x Viking HD dry diving suits
- **Masks :** 2x KMB communication masks
- **Communication :** 2-lines Dive-phones including 2x divers phone cables
- **UW-scooter :** 2x UW scooters
- **Accessories :**Fins, weight belts, gloves, harnesses, uw lights, instruments, tools etc.
- **Air Supply :** Air-cylinders with back-pack.
- **First Aid :** Oxygen breathing apparatus and ventilation kit.
- **HP Compressor :** Bauer HP compressor, 100l/min, 200 BAR
- **Pick-up Boat :** NORSAFE pick up/rescue boat, cradle, davit, 25hp outboard.

U-14 “ASP Moura Research Vessel”



U-14 “ASP Moura Research Vessel”

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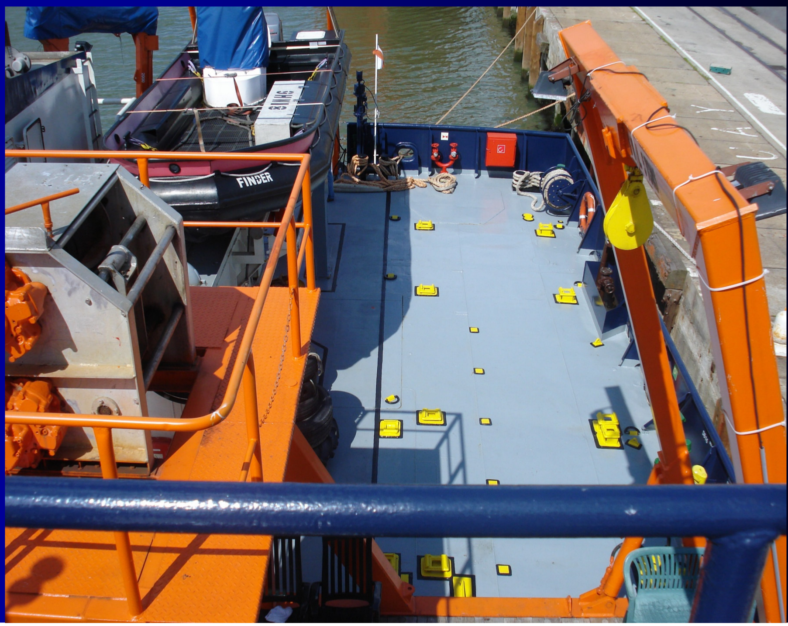


U-14 “ASP Moura Research Vessel”

U-14 "ASP Moura Research Vessel"

List of equipment on U-14

Equipment	Description	CNE	Deliver place	Time delivery	Manufacturer
Binocular	Binóculo de Visão Noturna NVBNVYGRCI 12553-180 Voyager-CGTI (Gen. 2+) 4,5x forstørrelse	**CNBE**	Navio (Sandefjord - Noruega)	10 days	ATN / OPTLINE - Noruega
CTD	MiniCTD Profiler	**CNBE**	CNBE	7 weeks	Valeport / Reino Unido
ROSETTE + CTD	Citadel CTD Sensor, Rosette Sampler, 12 liter Niskin bottle ...	**CNBW**	CNBW	12 weeks	Teledyne / EUA
CTD	MIDAS CTD+ Multi-Parameter CTD + Termosalinógrafo	**CNBE**	CNBE	6 weeks	Valeport / Reino Unido
Cable & Winch	DT MODEL DT1020EHLW AS PER ATTACHED SPECIFICATIONS	**CNBW**	CNBW	6 weeks	DT MARINE / EUA
XBT system	MK21 USB/DAQ Ass'y, Surface; LM-3A Hand Held Launcher with 100 Ft. Cable; 96 un T-4 XBT Probe; 96 un T-5 XBT Probe; 96 un T-7 XBT Probe; T-10 XBT Probe	**CNBW**	CNBW	60 days	Lockheed Martin Sippican / EUA
piston core	KC-Denmark A/S (piston corer) Piston core Model 13.600 (270Kg)	**CNBE**	Brasil	4 weeks	KC-Denmark A/S (piston corer)
Box Core	KC-Denmark A/S Box Core Model 80.100-50 (1.000 cm2/penetration 50cm) (2.000cm2)	**CNBE**	Navio (Sandefjord - Noruega)	10 days	KC-Denmark A/S (Van-Veen) KC-Denmark A/S (Box corer)
Van-Veen	KC-Denmark A/S Van-Veen Bottom Grab (2.000cm2)	**CNBE**	Navio (Sandefjord - Noruega)	10 days	KC-Denmark A/S (Van-Veen) KC-Denmark A/S (Box corer)
ECDIS	XXX	DSAM	XXX	XXX	XXX
Diver suite	Conjunto de mergulho para 04 pessoas	**CNBE**	Navio (Sandefjord - Noruega)	7 days	SMS Group Norway AS
Diving Compressor	Compressor de mergulho, sistema de cascata, cilindro extra e tanque de segurança	**CNBE**	CNBE	20 days	Tecnisub
ROV	SeaLion-2 ROV with 1,000 foot depth rated housing bulkhead connectors, 250 foot cable, topside control console with built-in 15 inch monitor, front and rear NTSC format color	**CNBW**	CNBW	2 weeks	JW FISHERS MFG., INC / EUA
Multibean	Post Processing Software, Training in Brazil,.	**CNBE**	Brasil	1 semana	Eiva / Denmark
Mulitbean SW and Training	Navigation Planning and Control System, Remote Helmsman Display, Kongsberg EM 3000, Reson SeaBat 8160, Installation, Setting to Work	**CNBE**	Navio (Sandefjord - Noruega)	1 semana	Eiva / Denmark
Current Meter		**CNBE**	CNBE	5 weeks	Nortek
Fluxometer		**CNBE**	CNBE	15 days	KC Denmark S/A
Microscope	Microscópio Axio Scope A1 com acessórios	**CNBE**	CNBE	60 days	Zeiss
Amplifier Lens	Corpo de estereomicroscópio Discovery V.8 com sistema de aumento Zoom 8:1 (10x . . . 80x)	**CNBE**	CNBE	60 days	Zeiss
Purifying Water System for wet Lab		**CNBW**	CNBW	60 days	Millipore Corporation

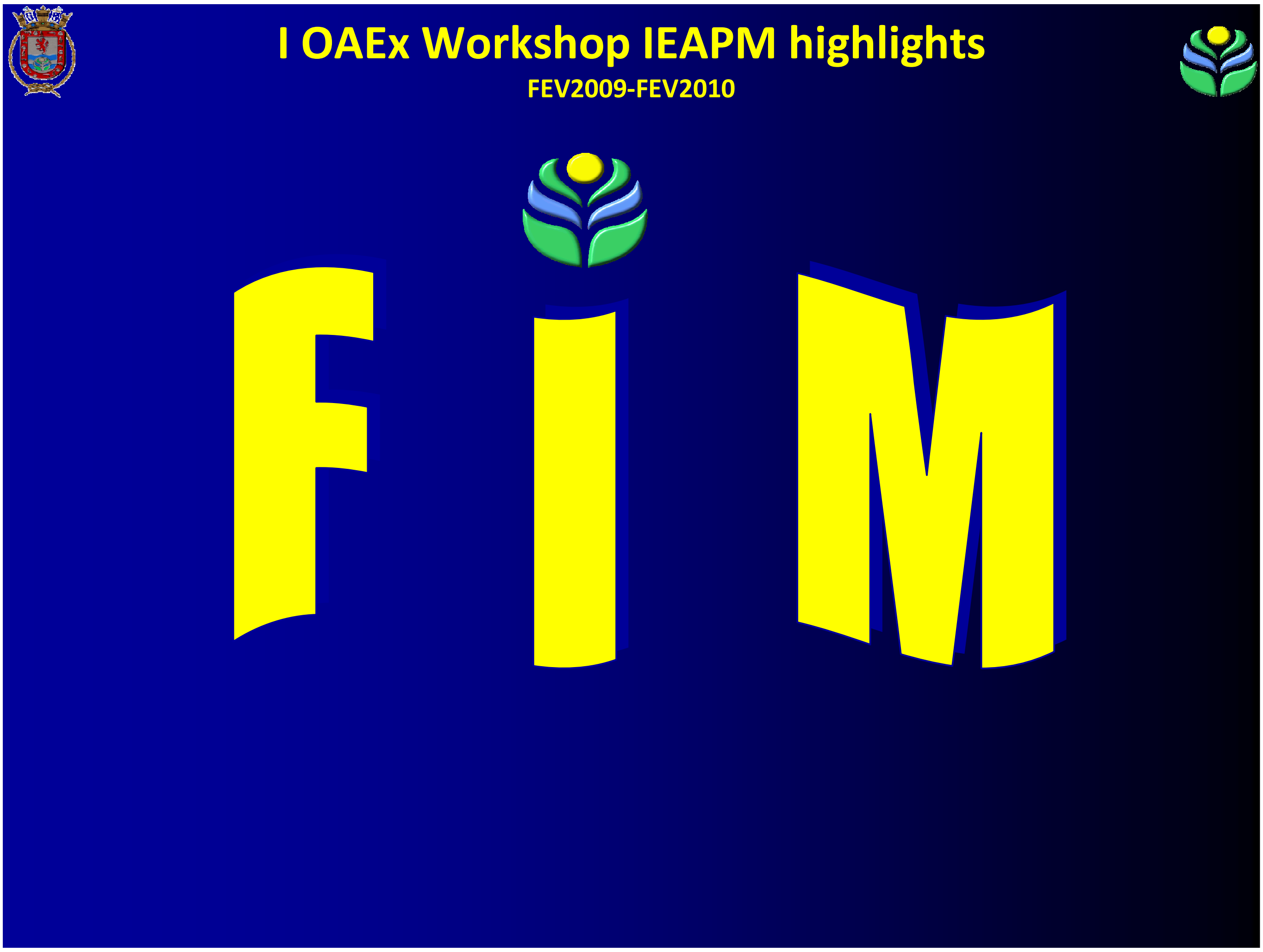
List of equipment on Acoustic Lab

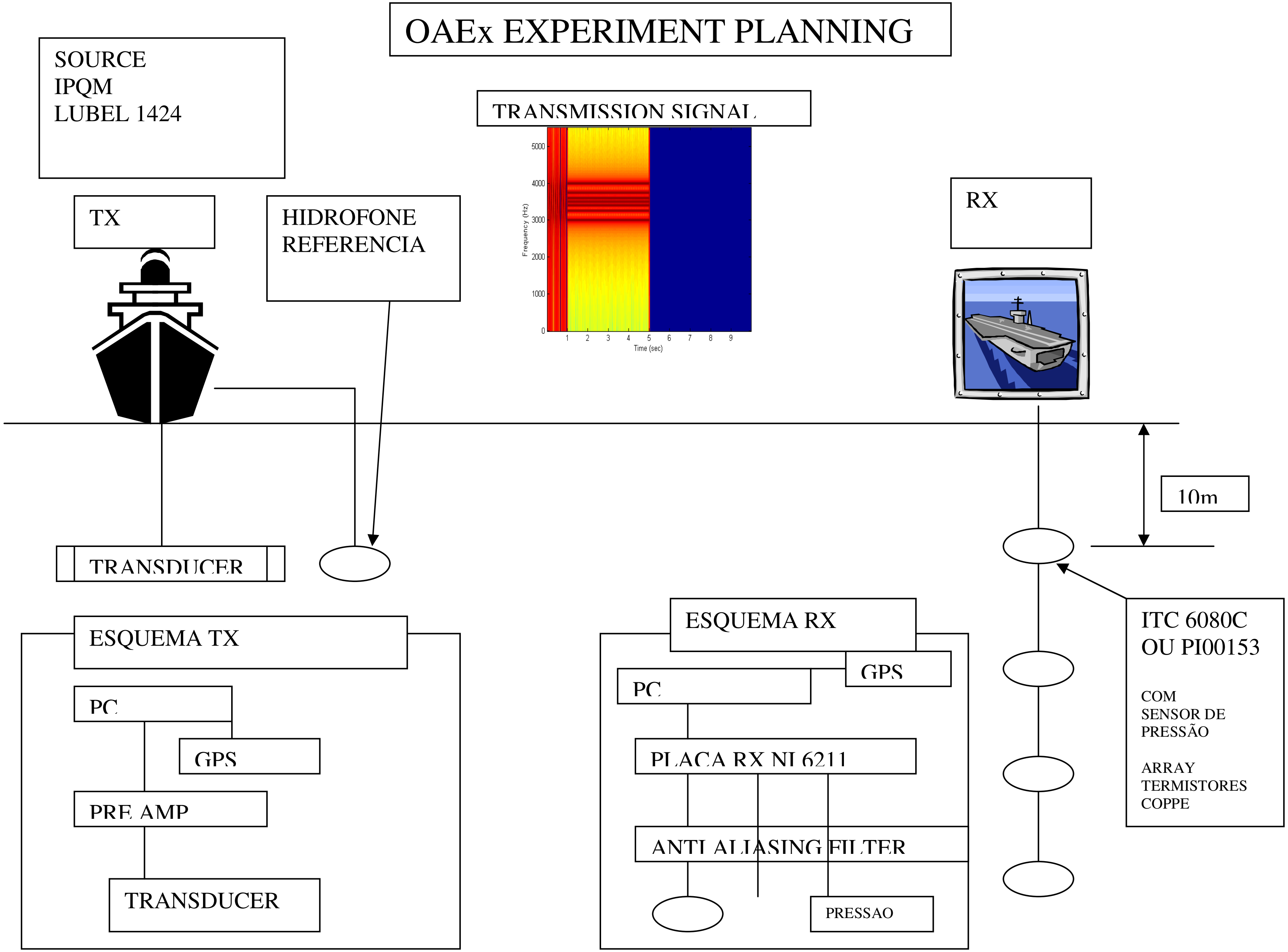
Item	Descrição do Equipamento	QTD
01	Transformador de Impedância Modelo-133	01
02	Amplifier Modelo 7500 (Krohn-Hite)	01
03	Power Supply Modelo P-11 Série 81 (Ithaco)	01
04	Eletronic Filter Modelo 4113 (Ithaco)	03
05	Amplier Modelo 453 (Ithaco)	03
06	Hidrofone ITC-1032 Nº de Série > 529 sem pré-amplificador	01
07	Hidrofone ITC-8073C Nº de Série > 054 com pré-amplificador alimentação 12VDC	01
08	Hidrofone ITC-6080C Nº de Série > 1525 e 1526 com pré-amplificador alimentação 24VDC	02
09	Hidrofone ITC-1001 Nº de Série > 275 sem pré-amplificador	01
10	Hidrofone PI 00-153-8229 (Equipamento do Submarino Amazonas)	30
11	Transdutor do Sonar EDO-610 da MOFRAG F DEFENSORA	10
12	Fonte Geradora (equipamento do IPqM)	01
13	Transdutor Sonar (equipamento do IPqM)	01
14	Osciloscópio Tektronix TDS 2004B	01
15	Placa de Áudio NI USB 6211	02
16	Rádio Infinium Transmiter	01
17	Rádio Infinium Receiver	02
18	Fonte de Alimentação 117VCA / 12 VDC	02
19	Antena Direcional	02
20	Cabo Hidrofone DSS-2 emprestado pelo CASOP	300 M
21	Cabo AWG 22 (cabo achado)	800 M
22	Multímetro Analógico	01
23	Multímetro Digital	01
24	Alicate Amperímetro	01
25	Capacímetro Digital	01
26	Estação de Solda	01
27	Máquina de Furar	01
28	Impressora Multifuncional HP C4280	02
29	Monitor AOC 19" LCD	03
30	Computadores Intel Co 262 DUO E 4500	03
31	No Break SMS 600 VA Net Station	04
32	Alicate de Bico Redondo	01
33	Alicate Universal	01
34	Jogo de chave tor	01
35	Jogo de chave de fenda	01
36	Jogo de chave Allen	01

Item	Descrição do Equipamento	QTD
37	Jogo de chave de relógio	01
38	Sugador de solda	01
39	Alicate de corte de 6"	02
40	Alicate de pressão 10"	03
41	Notebook HP Compac	01
42	PRC Motorola EP-450	02
43	Carregador de Bateria Lento	01
	In acquisitions on USA	Qtd
	Hydrophones ITC 6080	2
	TSS-2 SS Type hydrophone cable	2400 m
	Amplifier cdi 2000	1
	Underwater acoustic transducer LL-1424	1

News

- Two new PhD courses aproved (UALG and COPPE) one M.Sc (Miami University) and 3 proposal submited;
- Upgrade on the acoustic work force (four New civilian emploees);
- BB.BICE (Brazilian Bureau for Enhancing the International Cooperation with the European Union) proposal oportunities
- Brazilian funding agency oportunities for new projects throughout SECCTM (Navy Science and Technology Secretary)


I OAEx Workshop IEAPM highlights
FEV2009-FEV2010
FIM


OAEx EXPERIMENT PLANNING
SOURCE
IPQM
LUBEL 1424
TX
HIDROFONE
REFERENCIA
TRANSMISSION SIGNAL
Frequency (Hz)
Time (sec)
RX
10m
TRANSDUCER
ITC 6080C
OU PI00153
COM
SENSOR DE
PRESSÃO
ARRAY
TERMISTORES
COPPE
ESQUEMA TX
PC
GPS
PRE AMP
TRANSDUCER
ESQUEMA RX
GPS
PC
PLACA RX NI 6211
ANTI ALIASING FILTER
PRESSAO