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

Ocean Acoustic Exploration (OAEx)

OAEx'10 EXPERIMENT
DATA REPORT and PROCESSING
Workshop

Centro de Investigação Tenológica do Algarve (CINTAL)
Universidade do Algarve
Campus de Gambelas, Faro, Portugal
June 2011

Abstract

This report includes the presentations of the OAEx'10 Experiment Data Report and Processing Workshop held 27-28th June 2011 at the University of Algarve. The objectives of this workshop were to finalize the OAEx'10 Experiment data report lead by IEAPM, present preliminary results from the different groups and discuss the next steps on data processing and data dissemination. The workshop occurred in a period were a large number of researchers from IEAPM, COPPE/UFRJ and UVic visited University of Algarve/Cintal in the framework of the OAEx programme, thus allowing to a broaden exchange of ideas within the group and synchronize the efforts of the different researchers involved.

Contents

Programme

OAEx'10 EXPERIMENT DATA REPORT AND PROCESSING WORKSHOP

27-28th June 2011

University of Algarve

Meeting room 3.18, FCT Building

June 27th

14:00-14:15 OPENING

14:15-14:45 GEOACOUSTICS PARAMETERS OF SEAFLOOR ON OAEX'S RESEARCH AREA - A CONTRIBUTION TO ACOUSTIC EXPERIMENTS

Simões, I. C. V. P. (1) Macedo, H. C. (1); Artusi, L. (1); Hermand, J. -P. (2); Abuchacra, R. C. (3); Figueiredo Jr., A. G. (3) , Alvarez, Y. G.(1); Romano, R.C.G. (1); Plouvier, L.(1),

(1)Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM,
(2)Université libre de Bruxelles (ULB) – Environmental Hydroacoustics Laboratory,
(3)Departamento de Geologia – LAGEMAR - Universidade Federal Fluminense – UFF

14:45-15:15 OAEx'10 Experiment : CONTRIBUTIONS FROM PHYSICAL OCEANOGRAPHY

Ana Cláudia de Paula, Leandro Calado, Wandrey de Bortoli Watanabe, Ricardo Marques Domingues, Eduardo Negri de Oliveira, Fernando de Oliveira Marin

Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM

15:15-15:30 Coffee Break

15:30-16:00 LFMs ARRIVAL PATTERNS at OAEx'10

Leonardo Martins Barreira, Fábio Contrera Xavier, Marcus Vinícius da Silva Simões, Celso Marino Diniz

Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM

16:00-16:30 SOME PRELIMINARY OBSERVATIONS OF OAEx SEA TRIAL AND GUIDELINES FOR FUTURE WORK

Salman Ijaz, António J. Silva, Sérgio M. Jesus

SiPLAB, ISR-Lisbon, University of Algarve

JUNE 28th

09:30-10:00 GEOACOUSTIC MODELING IN SHALLOW WATER SEDIMENT ENVIRONMENTS

Ross Chapman

University of Victoria

10:00-10:30 ACOUSTIC INVERSION WITH MFP FOR SEABED CHARACYERIZATION IN OAEx'10 EXPERIMENT

Lussac P. Maia(1), Lucia Artusi(2), Carlos E. Parente R.(1), Jean-Pierre Hermand (3)

(1)Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa em Engenharia (COPPE)/Federal University of Rio de Janeiro (UFRJ),
(2)Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM,
(3)Université libre de Bruxelles (ULB) – Environmental Hydroacoustics Laboratory

10:30-10:45 Coffee Break

10:45-11:15 PROPAGATION EXPERIMENTS WITH CAVITATION NOISE

Hugo Chaves, Benavides Xavier, Kleber Pessek, Luis Guimarães, Carlos Parente

Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa em Engenharia (COPPE)/Federal University of Rio de Janeiro (UFRJ)

11:15-11:45 BELLHOP TRANSMISSION LOSS PERFORMANCE EVALUATION FROM FIELD DATA OF OAEx'10 EXPERIMENT

Celso Marino Diniz, Marcus Vinícius da Silva Simões, Leonardo Martins Barreira, Fábio Contrera Xavier

Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM

11:45-12:15 NUMERICAL MODELING OF SIGNAL PROPAGATION IN THE CONDITIONS OF THE OAEx'10 EXPERIMENT

Orlando Rodriguez(1), , Fábio Contrera Xavier(2)

(1) SiPLAB, ISR-Lisbon, University of Algarve,
(2)Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM

12:15-14:00 Lunch

14:00-14:30 BAYESIAN SONAR PERFORMANCE PERSPECTIVES FOR CABO FRIO

Nélson Martins(1), Leandro Calado(2)

(1)SiPLAB, ISR-Lisbon, University of Algarve,
(2)Marinha do Brasil - Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM

14:30-15:30 FUTURE WORK PLANNING

Attendance list

- UALG /PT
  - Sérgio Jesus (sjesus@ualg.pt)
  - Nélson Martins (nmartins@ualg.pt)
  - Paulo Felisberto (pfelis@ualg.pt)
  - Orlando Rodriguez (orodrig@ualg.pt)
  - António Silva (asilva@ualg.pt)
  - Salman Ijaz (ssiddiqui@ualg.pt)
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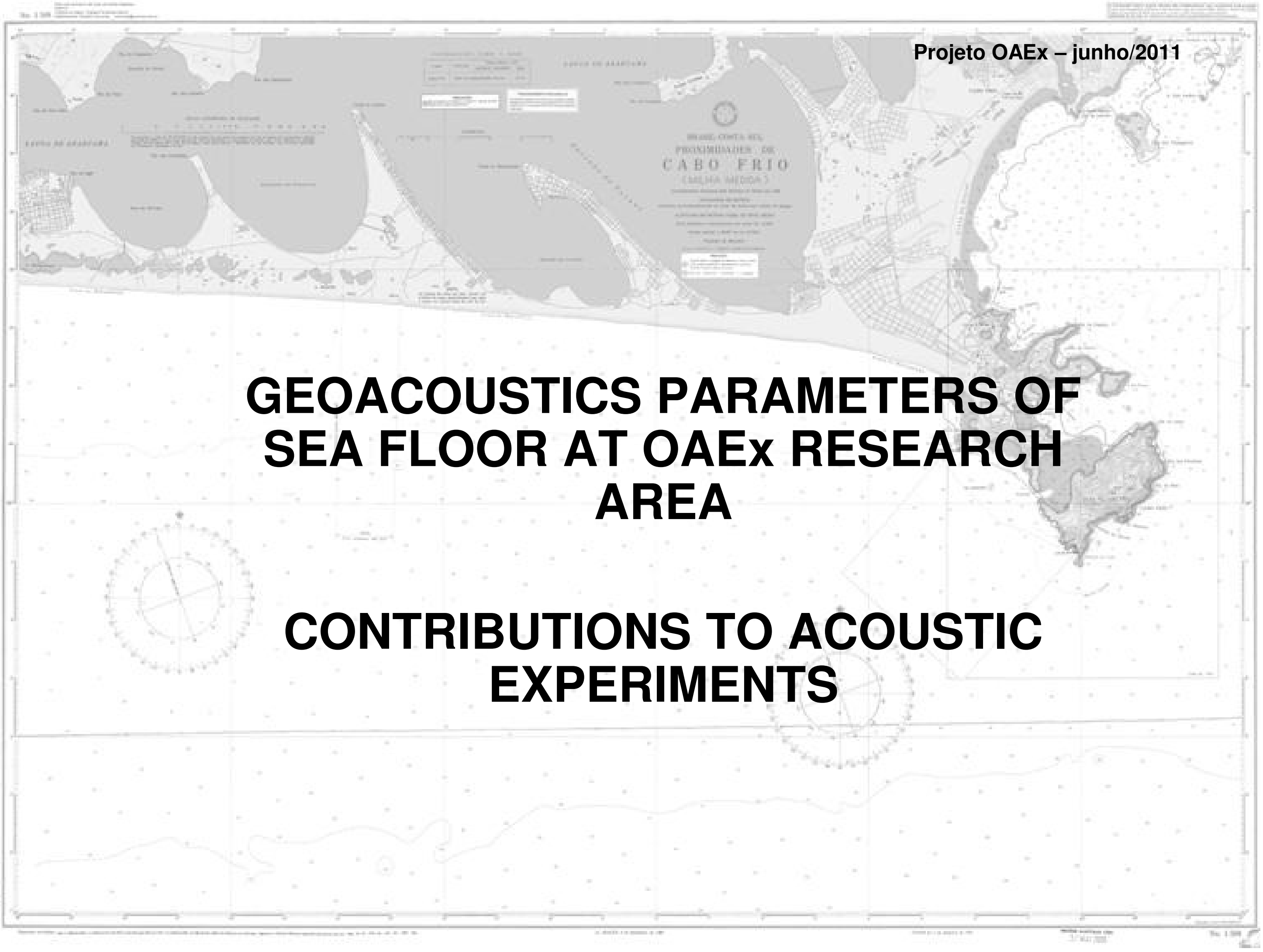
  - Hugo Chaves (hugochaves1@gmail.com)
  - Benevides Xavier (bcbxavier@yahoo.com)
  - Lussac Maia (lussacmaia@gmail.com)
- UVic / CA
  - Ross Chapman (chapman@uvic.ca)


FACULDADE DE

Presentations



Projeto OAEx – junho/2011

GEOACOUSTICS PARAMETERS OF SEA FLOOR AT OAEx RESEARCH AREA

CONTRIBUTIONS TO ACOUSTIC EXPERIMENTS

Simões, I. C. V. P. [1] ;
Macedo, H. C. [1];
Artusi, L. [1];
Hermand, J-P. [2];
Abuchacra, R. C. [3];
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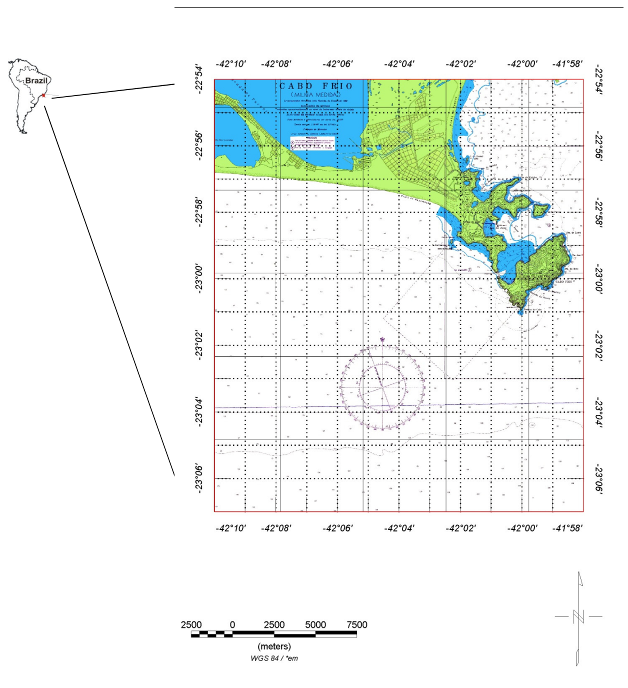
1 *Instituto de Estudos do Mar Almirante Paulo Moreira – IEAPM*
2 *Université libre de Bruxelles (ULB) – Environmental Hydroacoustics Laboratory*
3 *Marine Geology Laboratory (LAGEMAR) - Universidade Federal Fluminense – UFF*

INTRODUCTION

- Shallow water acoustic propagation is strongly influenced by interaction with the seabed
- Geacoustics models are based on measured, extrapolated and predicted values
- Although the recent acoustical development, in Brazil we are still taking the first steps in geoacoustic research
- Information gathered will be useful on planning acoustic experiments, improve better models of submarine propagation and increase the accuracy of predictive sonar range.

GOAL

- To know the geological/geoacoustical settings
- Data presented: multibeam data, surface sediments analyses, side scan data, high resolution seismic data and geological cores.
- To present average values and statistical analyses of laboratory determined properties of the various sediment types as compressional wave velocity (Vp), density, acoustic impedance and porosity; the relations between these parameters and grain size of sediments and the influence of time, orientation and composition of subottom layers.



Sea floor

- Bathymetry
  - multibeam echosounder – 95 kHz
  - nautical charts (1503, 1505 e 1508)
  - TAURUS hydrographic ship

- Surface geological samples
  - samples on Banco Nacional de Dados Oceanográficos da Diretoria de Hidrografia e Navegação (BNDO/DHN)
  - Van-Veen and Gibbs

- Sidescan sonar
  - Sonar Klein Serie 5000 - 100/500 kHz
  - Ocean Surveyor ship
  - SonarWiz5

Projeto OAEx – junho/2011

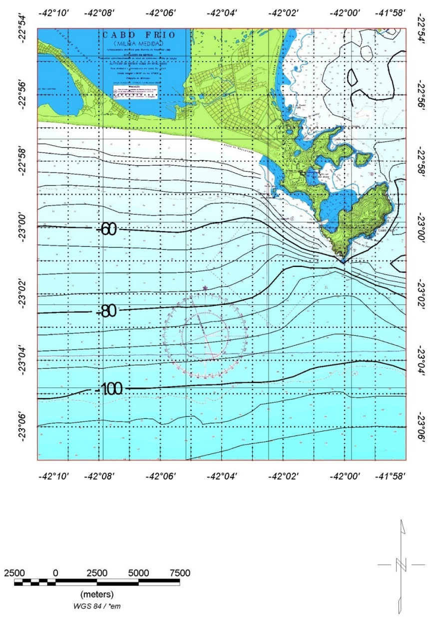
Sub Sea floor

- Seismic
  - Geopulse 3,5 kHz (Geoacoustics)
  - SonarWiz5
  - Ocean Surveyor ship

- Geological Cores
  - Piston core
  - DIADORIM ship
  - Multi-Sensor Core Logger
  - granulometric analyses and CaCO3 contents

Projeto OAEx – junho/2011

Bathymetry



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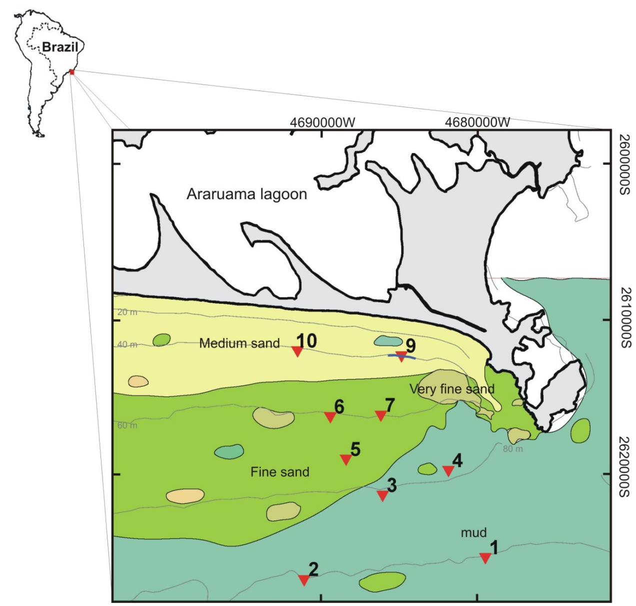
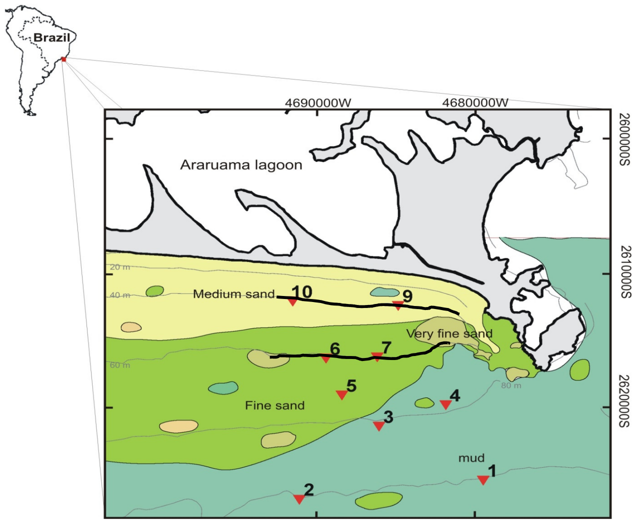
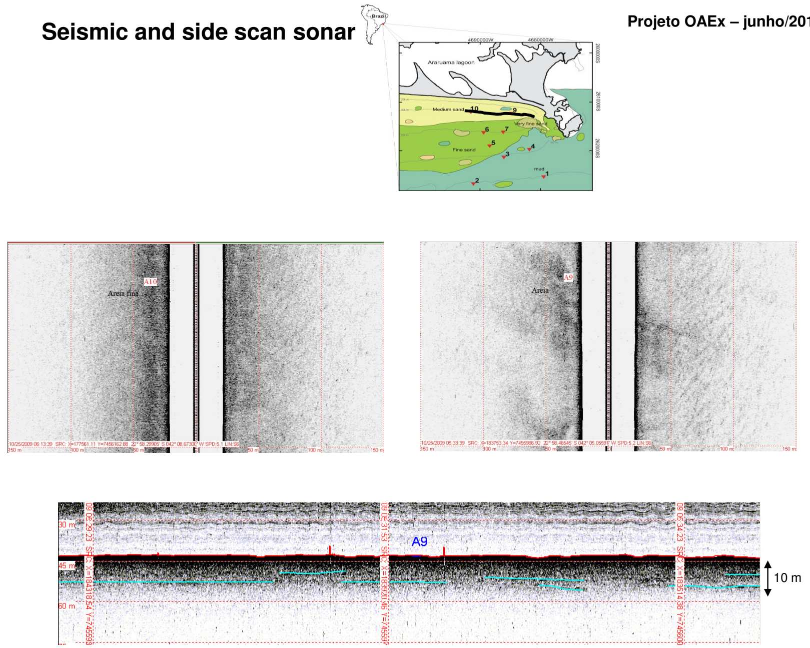
Seafloor sediments



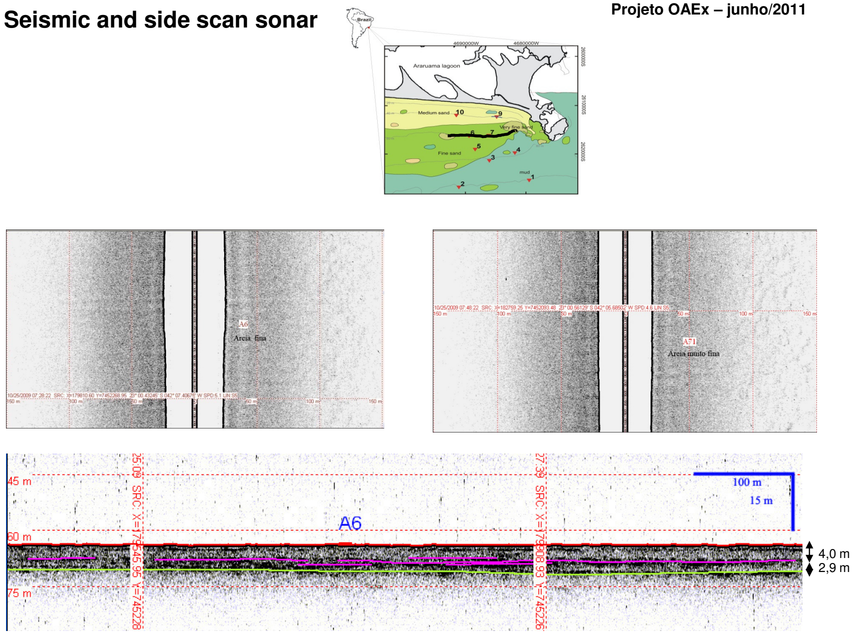
Seismic and side scan sonar



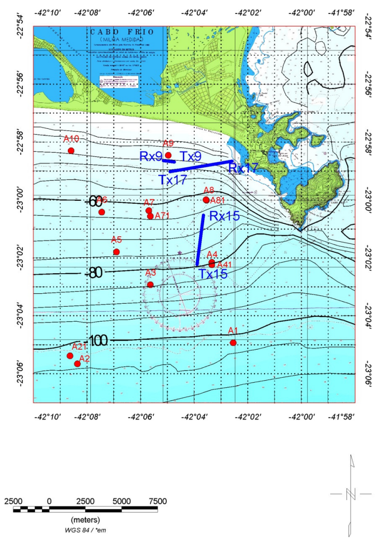
Seismic and side scan sonar



Seismic and side scan sonar



Cores



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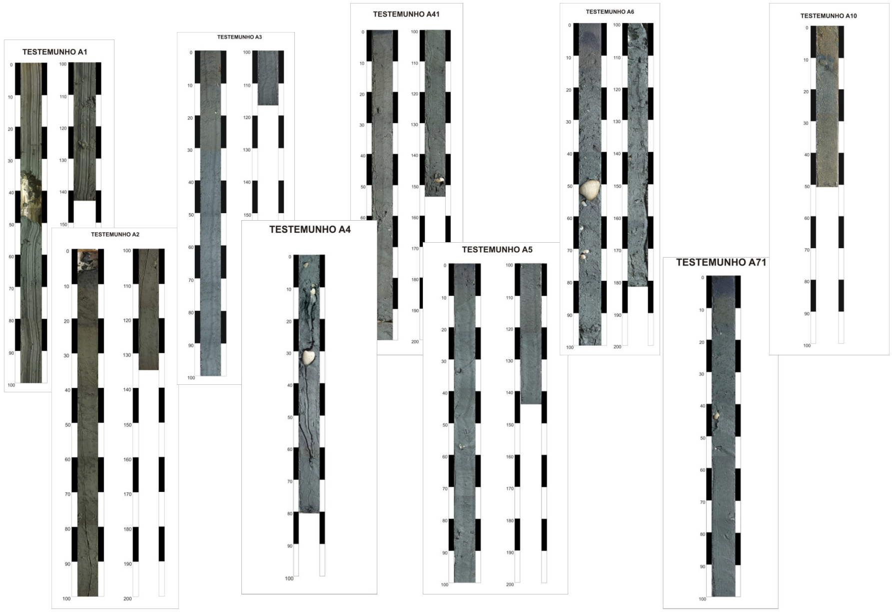

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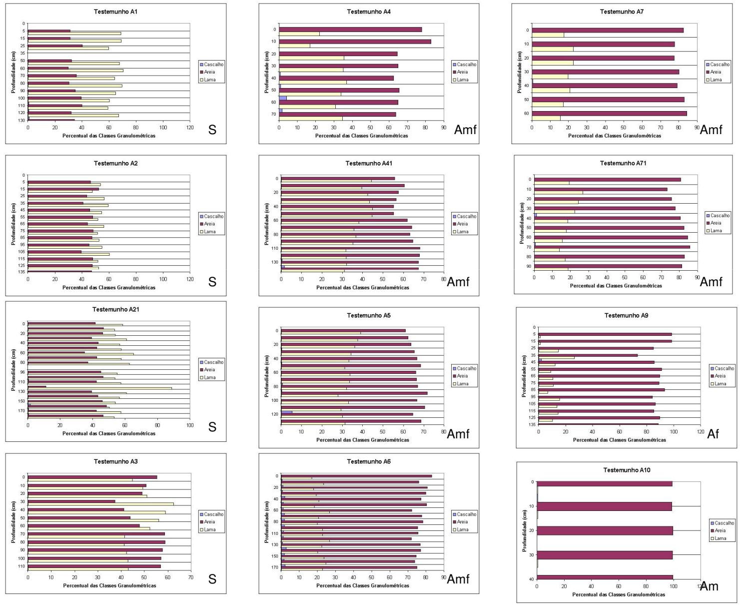
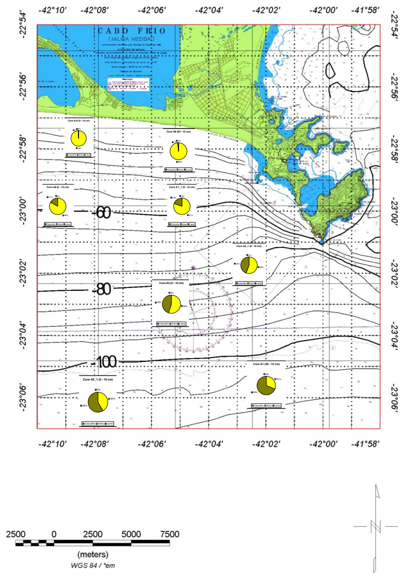
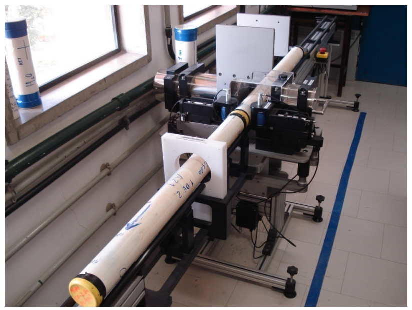


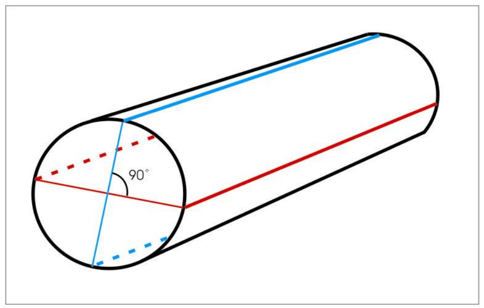
Cores



Cores

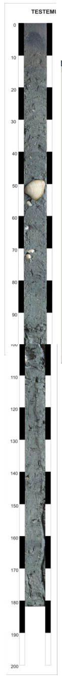
GEOTEK Multi-Sensor Core Logger (MSCL)

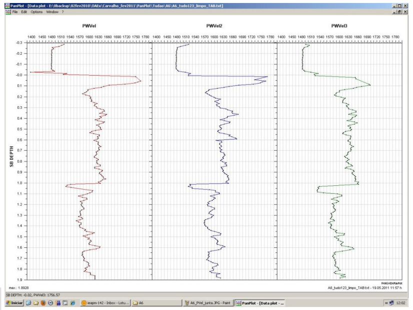


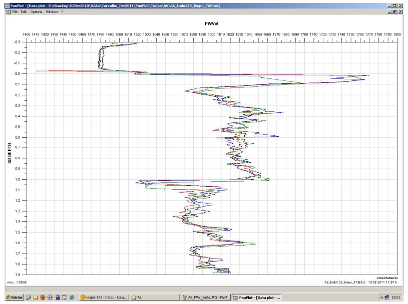


compressional wave velocity (Vp), bulk density and porosity

acoustic impedance







Sediment	Average Vp (m/s)
Medium sand (1 to 2 Φ)	1671
Fine sand (2 to 3 Φ)	1684
Very fine sand (3 to 4 Φ)	1606
Coarse silt (4 to 5 Φ)	1551
Medium silt (5 to 6 Φ)	1544

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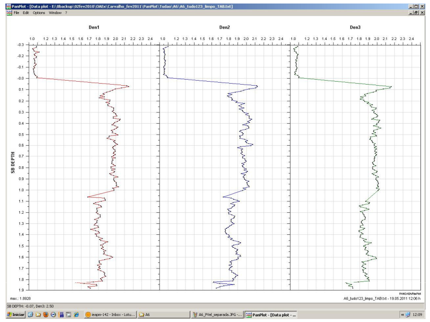
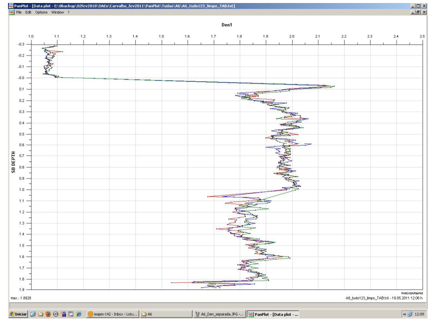
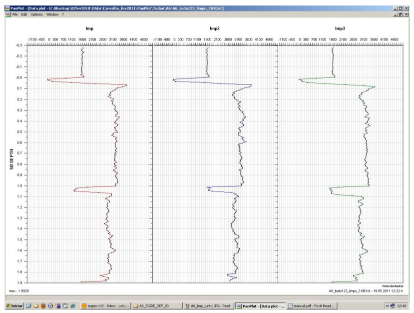
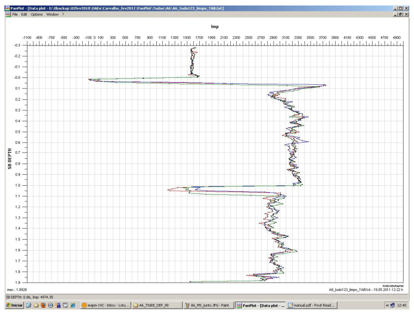




Sediment	Avereage Density (g/cm3)
Medium sand (1 to 2 Φ)	2,191
Fine sand (2 to 3 Φ)	1,996
Very fine sand (3 to 4 Φ)	1,869
Coarse silt (4 to 5 Φ)	1,770
Medium silt (5 to 6 Φ)	1,674

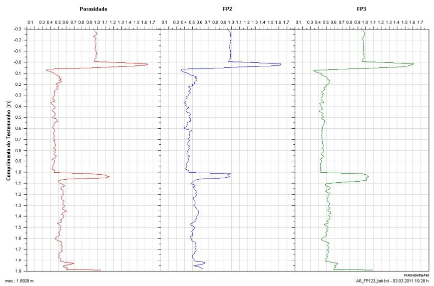
Projeto OAEx – junho/2011

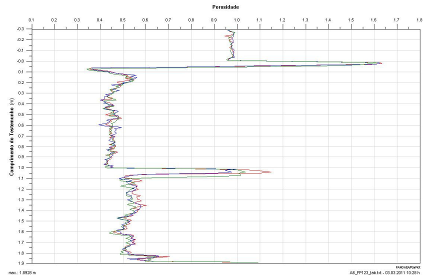




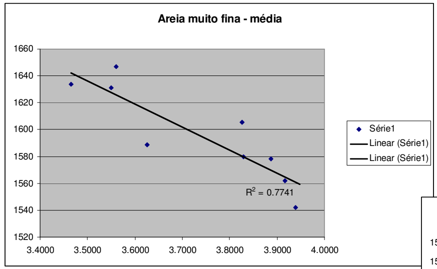
Sediment	Acoustic impedance
Medium sand (1 to 2 Φ)	3755,41
Fine sand (2 to 3 Φ)	3312,24
Very fine sand (3 to 4 Φ)	2948,03
Coarse silt (4 to 5 Φ)	2709,76
Medium silt (5 to 6 Φ)	2732,54

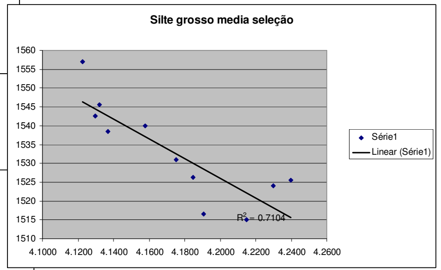
Projeto OAEx – junho/2011

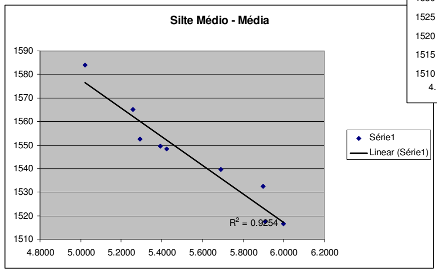




Sediment	Porosity (%)
Medium sand (1 to 2 Φ)	32,4
Fine sand (2 to 3 Φ)	43,7
Very fine sand (3 to 4 Φ)	51,1
Coarse silt (4 to 5 Φ)	56,2
Medium silt (5 to 6 Φ)	56,7







Very fine sand (3 to 4 Φ), coarse silt (4 to 5 Φ) and medium silt (5 to 6 Φ) show a good negative correlation.

Conclusions

Physical and acoustic properties coincide well with bathymetry

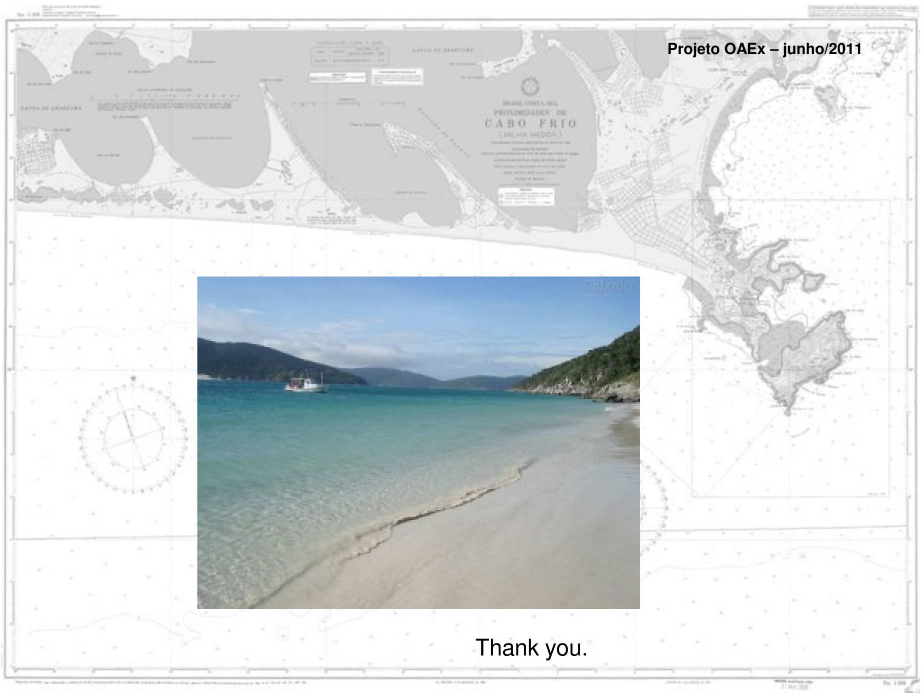
Compressional wave velocity decreases seaward where porosity and clay content increase

The sediment texture governs the physical and acoustic properties

Geoacoustic behavior coincides relatively well with Hamilton and Bachman (1982) and Kim et al (2001)

These data were tested with Bellhop model with good results

Future acoustic experiments should consider these results.



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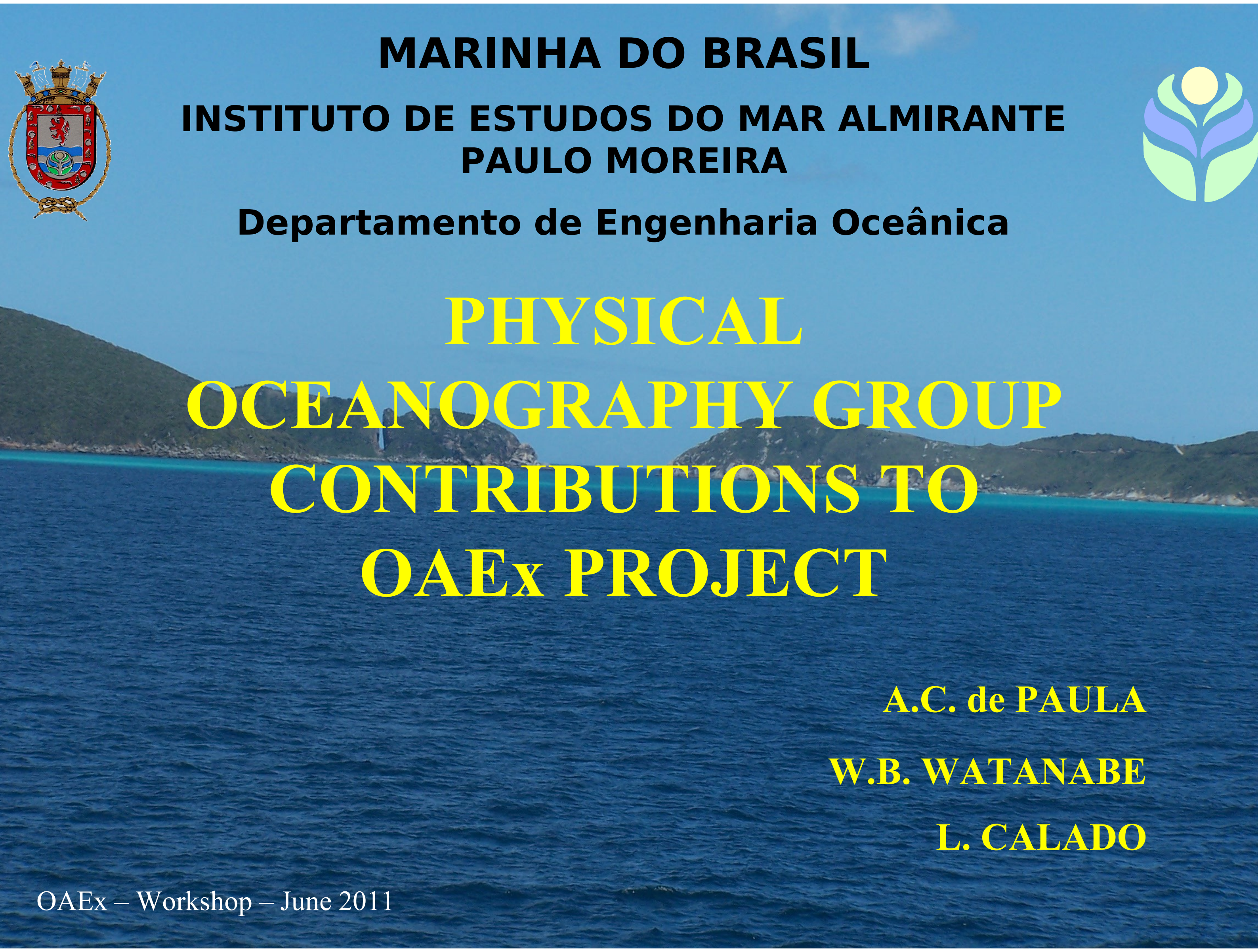
MARINHA DO BRASIL
INSTITUTO DE ESTUDOS DO MAR ALMIRANTE PAULO MOREIRA
Departamento de Engenharia Oceânica
PHYSICAL OCEANOGRAPHY GROUP CONTRIBUTIONS TO OAEx PROJECT
A.C. de PAULA
W.B. WATANABE
L. CALADO
OAEx – Workshop – June 2011

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- ***Leandro Calado***
- ***Wandrey de Bortoli Watanabe***
- ***Eduardo de Negri Oliveira***

PARTICIPANTS

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- ***Carolina Mayumi Sato***
- ***Arthur Ramos***
- ***Gabriel Serrato***
- ***Gabriel Codato (BSc Thesis, in prep)***

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Fernando de Oliveira Marin

Felipe Sarquis Aiex Maneschy

Ricardo Marques Domingues

External collaborators

Ilson Carlos Almeida da Silveira

Leandro Ponsoni – Brazilian PhD student at ULB

Contents

PARTICIPANTS

SECONDMENTS

SCIENTIFIC AND TECHNICAL CONTRIBUTIONS

RESULTING PUBLICATIONS

SECONDMENTS

Brazilians abroad

Marin: UAlg (Sep 2009)

Ana Cláudia: ULB (Nov 2009)

Leandro: ULB (Oct 2010)

Ana Cláudia: UAlg (Jan 2011)

Portugueses at IEAPM

Nélson (twice)

Orlando

Belgian at IEAPM

Olivier (twice)

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SCIENTIFIC AND TECHNICAL CONTRIBUTIONS

Regional Ocean Dynamics

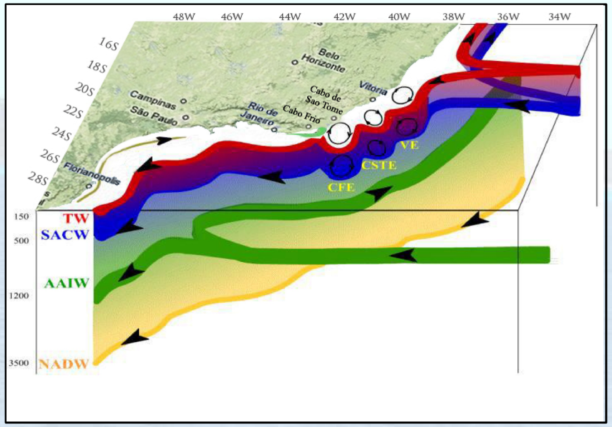
Multi-scale Objective Analysis

Use of oceanographic circulation models

Oceanographic Feature Models

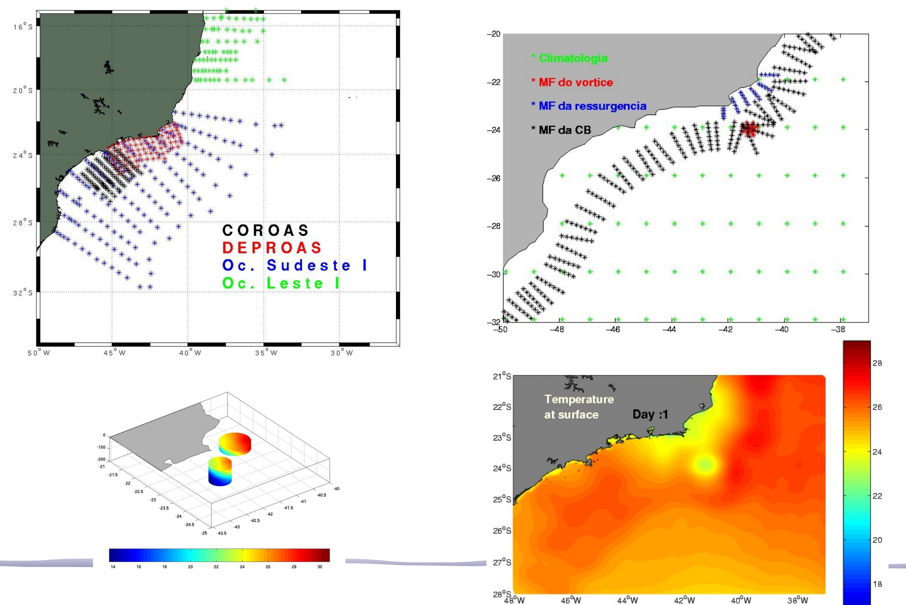
Collecting oceanographic data in the OAEx cruise

Regional Ocean Dynamics



Cortesy: R. A. Mattos

Multi-scale Objective Analysis (MSOA)



Ocean Circulation Modeling

Regional Ocean Modeling System (ROMS)

3D ocean parameters modeling

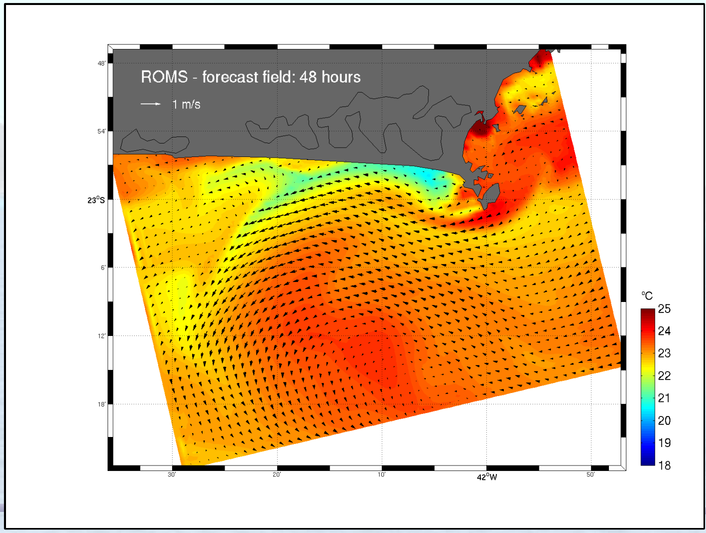
Wind forcing (scaterometter data)

Tidal forcing (altimetry based model)

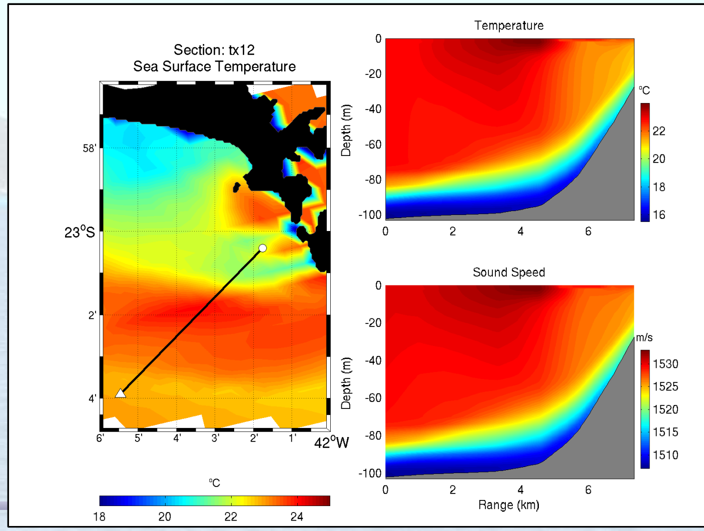
Initial conditions: SST+Upwelling Feature Model

Output can be used as input for acoustic models

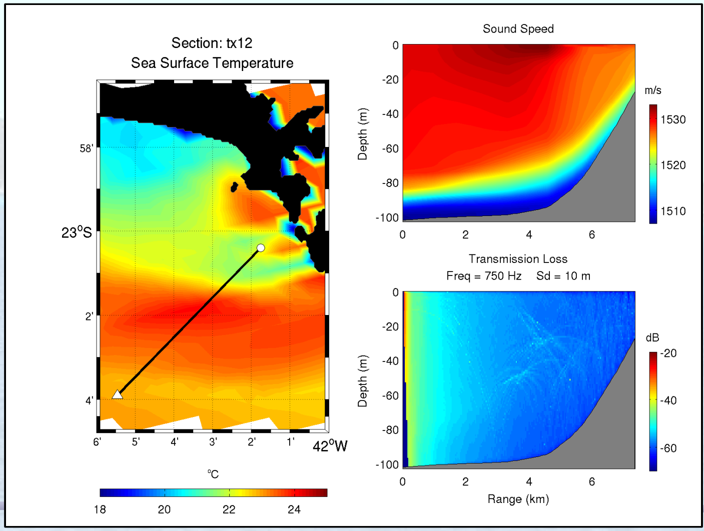
Ocean Circulation Modeling



Ocean Circulation Modeling

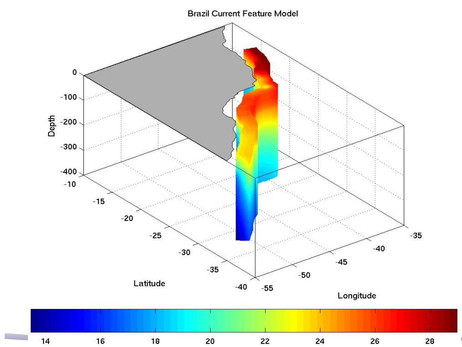


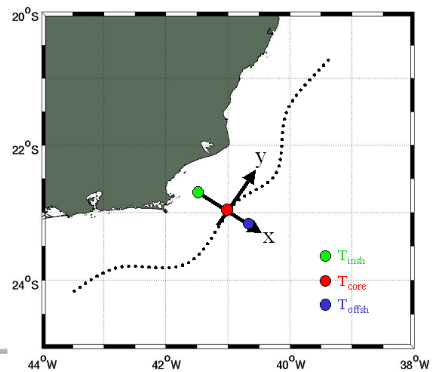
Ocean Circulation Modeling



Oceanographic Feature Models

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

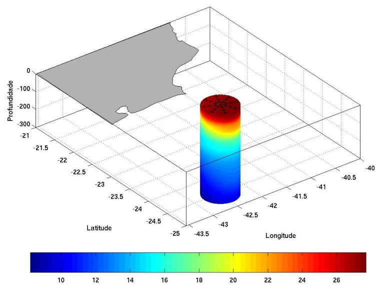


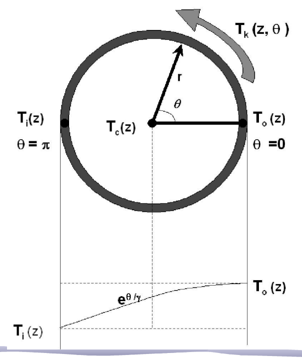


Feature Model for BC eddies

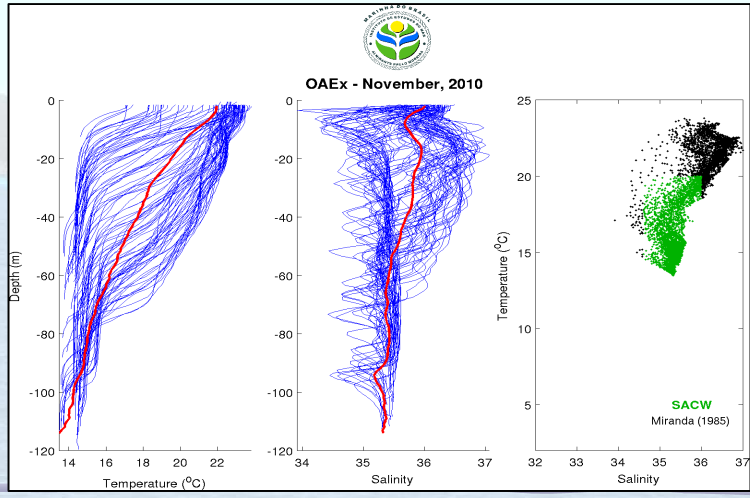
$$T(r,z,\theta) = T_k(z,\theta)(1 - e^{-r/R}) + T_c(z)e^{-r/R};$$

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

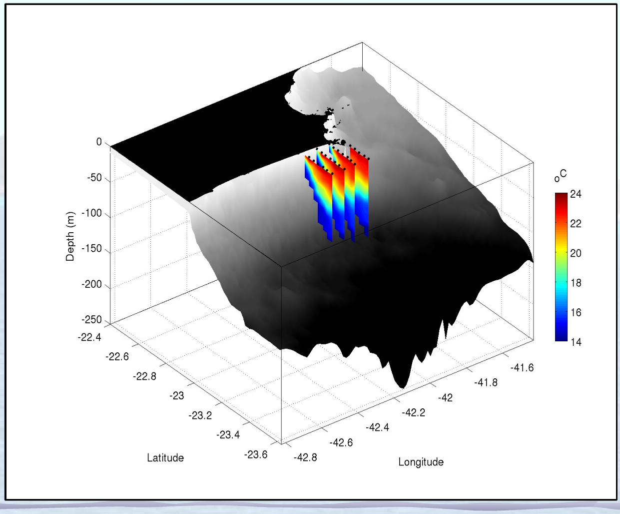




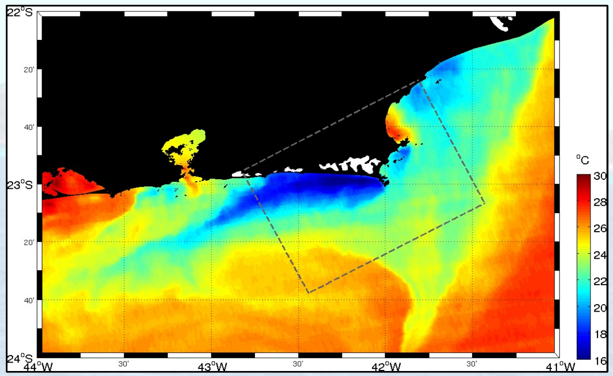
Collecting oceanographic data in the OAEx cruise



Collecting oceanographic data in the OAEx cruise



Collecting oceanographic data in the OAEx cruise



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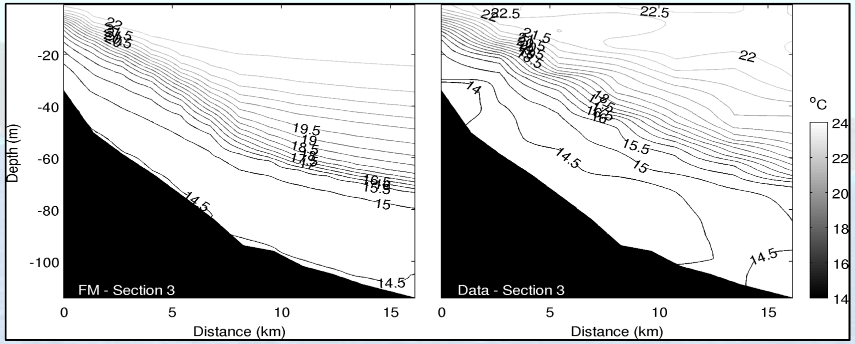


Contents

RESULTING PUBLICATIONS

N. MARTINS, L. CALADO, A.C. de PAULA and S.M. JESUS, "Classification of three-dimensional ocean features using three-dimensional empirical orthogonal functions", in Proc. 10th European Conference on Underwater Acoustics, Istanbul (Turkey), July, 2010.

O. Carrière, J.-P. Hermand, L. Calado, A. C. de Paula, and I. C. A. da Silveira, "Range-dependent acoustic tomography based on a feature model for monitoring the Cabo Frio upwelling (Brazil)", in Proceedings of OCEANS'10 IEEE Sydney Conference - Showcasing Advances in Marine Science and Engineering, pp. 1–7, Institute of Electrical and Electronics Engineers, IEEE, May 2010. doi: 10.1109/OCEANSSYD.2010.5603914.

RESULTING PUBLICATIONS

O. Carrière, J.-P. Hermand, L. Calado, A. C. de Paula, and I. C. A. da Silveira, "Feature-oriented acoustic tomography: Upwelling at Cabo Frio (Brazil)", in Proceedings of OCEANS'09 MTS/IEEE Biloxi Conference - Marine Technology for Our Future: Global and Local Challenges, pp. 1–8, Marine Technology Society, Institute of Electrical and Electronics Engineers, IEEE, Oct. 2009.

A. C. de Paula, L. Calado, and F. O. Marin. O Emprego de Modelos de Feições Oceanográficas em Apoio à Caracterização do Ambiente Acústico Marinho. VIII Encontro de Tecnolologia em Acústica Submarina (ETAS). Rio de Janeiro, 2009.

RESULTING PUBLICATIONS

W. B. Watanabe, R. M. Domingues, L. Calado, and L. M. Barreira. A influência da frente da ressurgência costeira na propagação do sinal acústico submarino e na probabilidade de detecção de alvos. IX Encontro de Tecnolologia em Acústica Submarina (ETAS). Arraial do Cabo, 2010.

ACKNOWLEDGEMENTS

Marinha do Brasil

EU - Marie Curie Actions

ULB

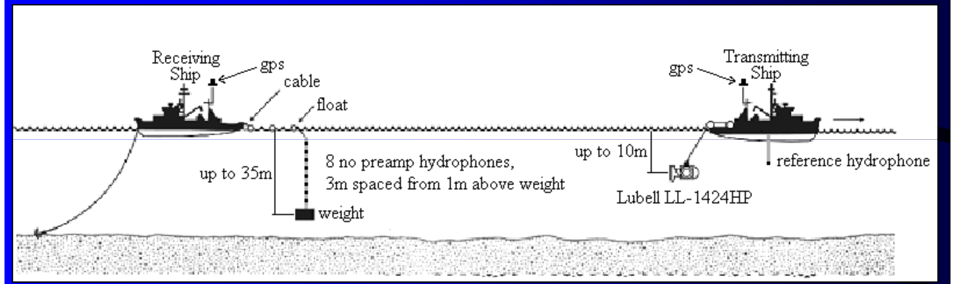
UAlg


2nd OAEx Workshop
LFMs Arrival
Patterns at OAEx'10
Barreira, LM; Xavier, FC; Simões, MVS; Diniz, CM.
Instituto de Estudos do Mar Almirante Paulo Moreira
27-28th June 2011
University of Algarve

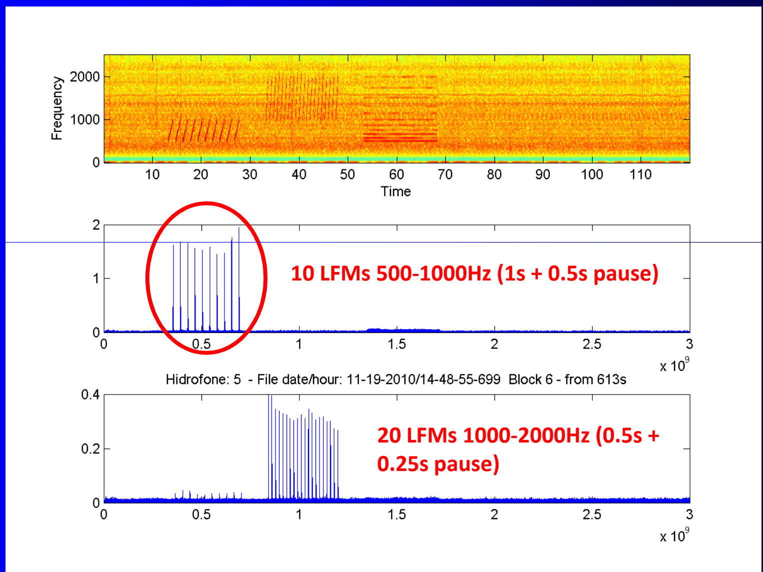
Summary

- Signal Received at each hydrophone
- Signal Received at the array
- Transects analyzed
- Comparison: Field Data x Bellhop
- Conclusion

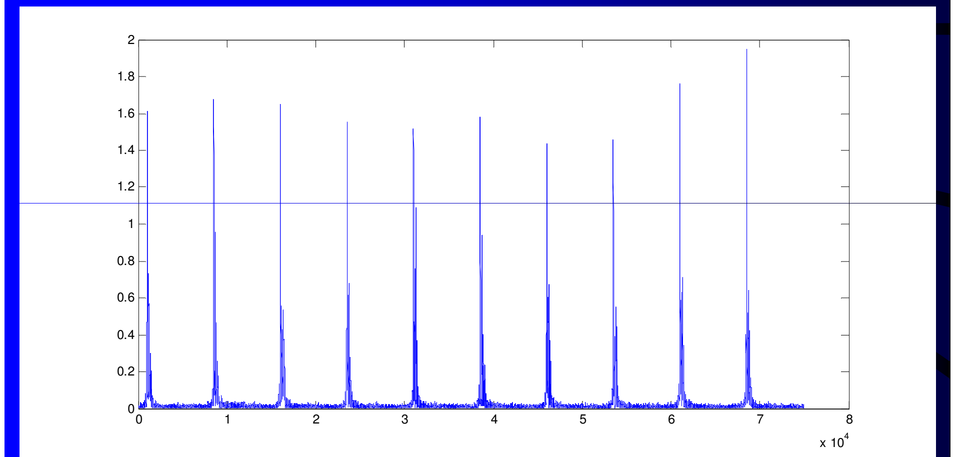
Signal Received at Each Hydrophone



Signal Received at Each Hydrophone



Signal Received at Each Hydrophone



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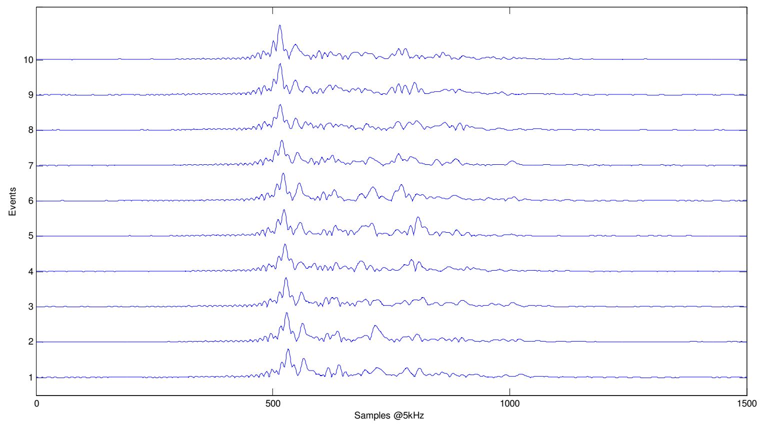
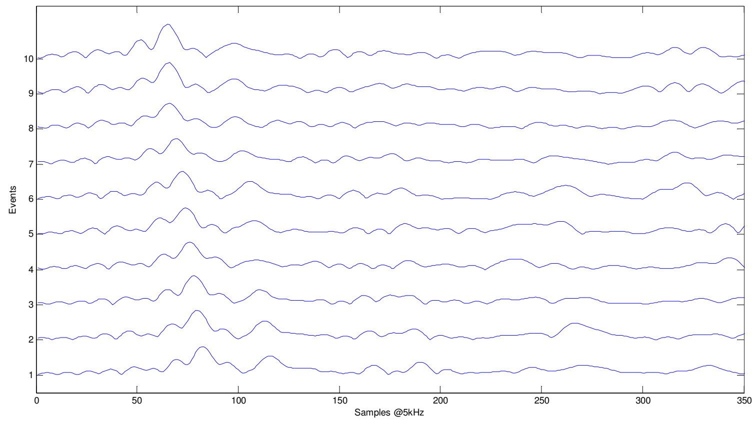


Signal Received at Each Hydrophone



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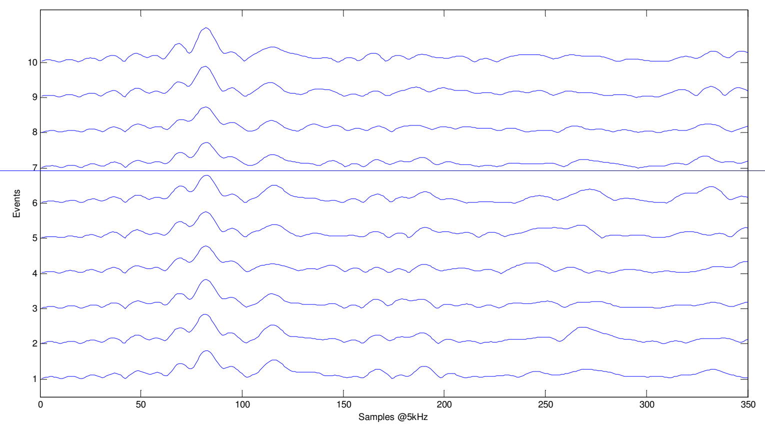
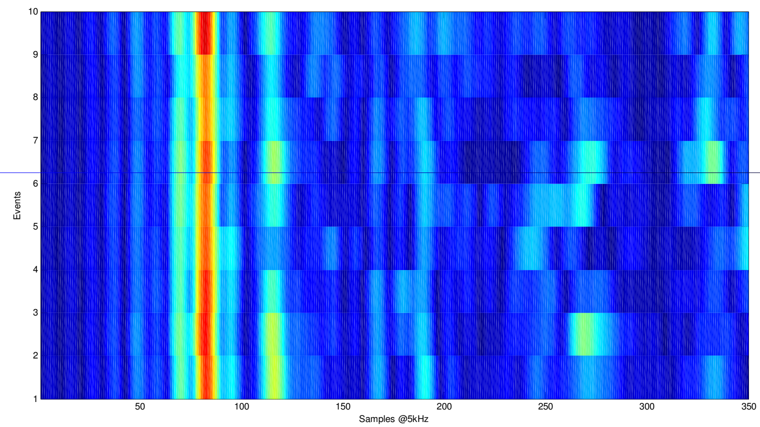
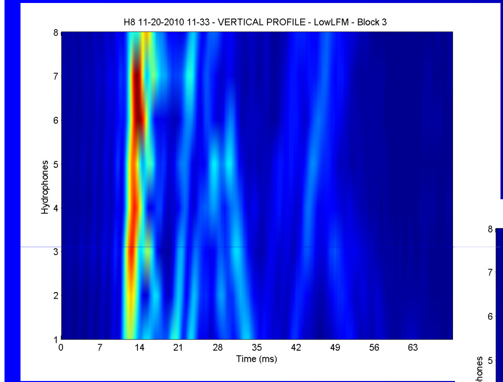
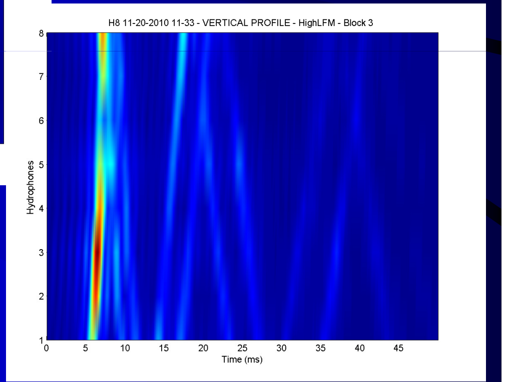


Signal Received at Each Hydrophone

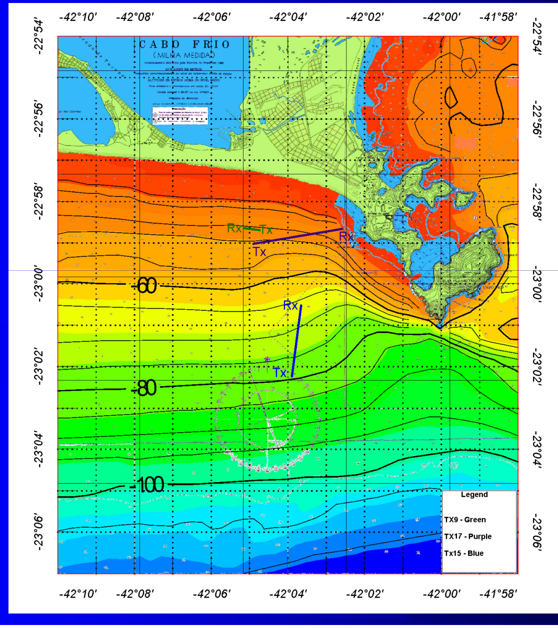


Signal Received at the Array



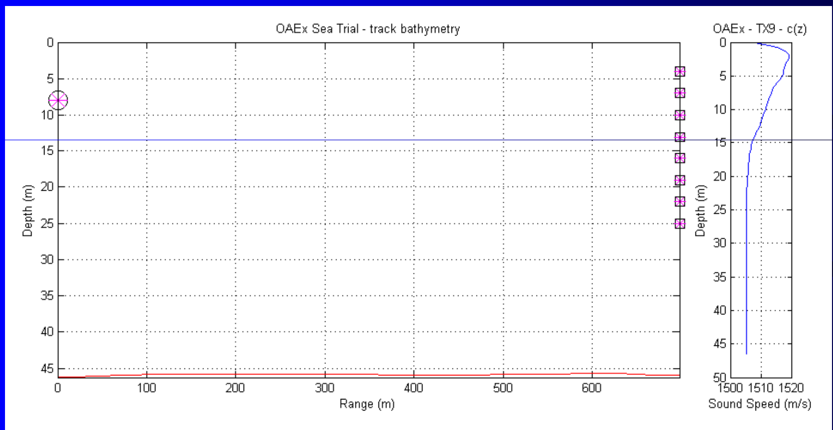


Transects Analyzed



Comparison: Field Data x Bellhop

TX9 (distance 700m)



Comparison: Field Data x Bellhop

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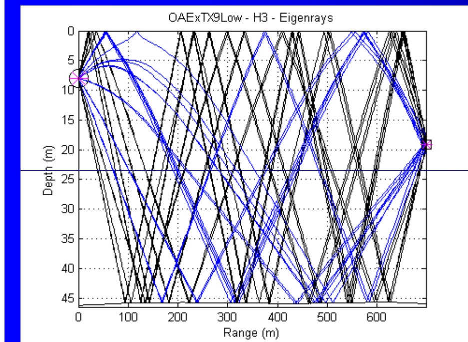

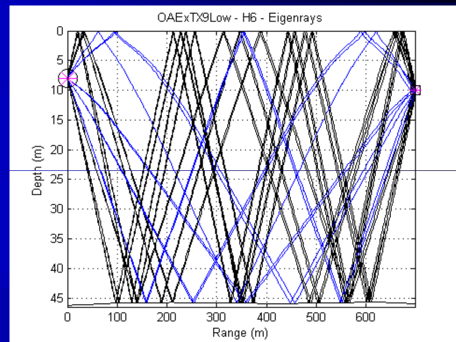

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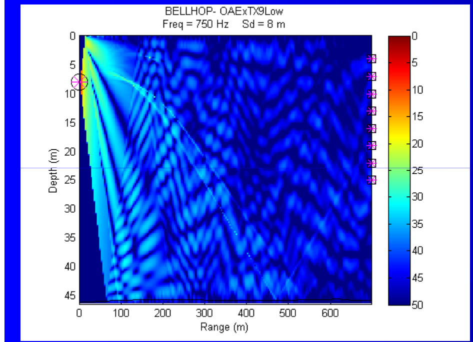

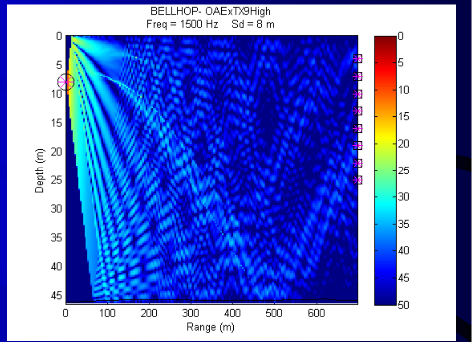

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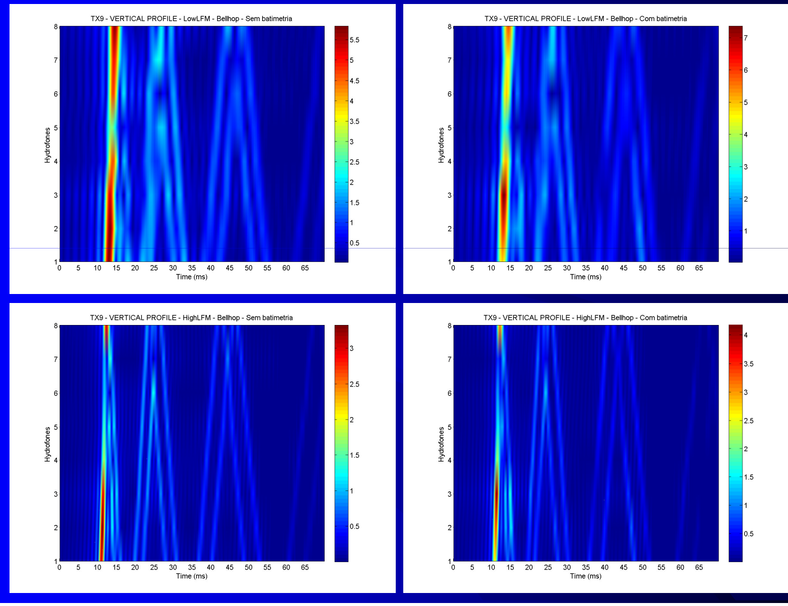
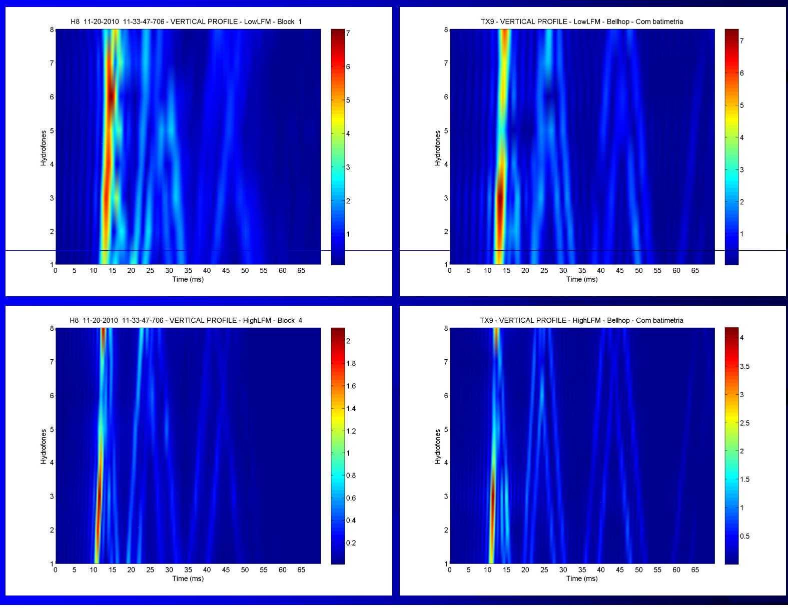


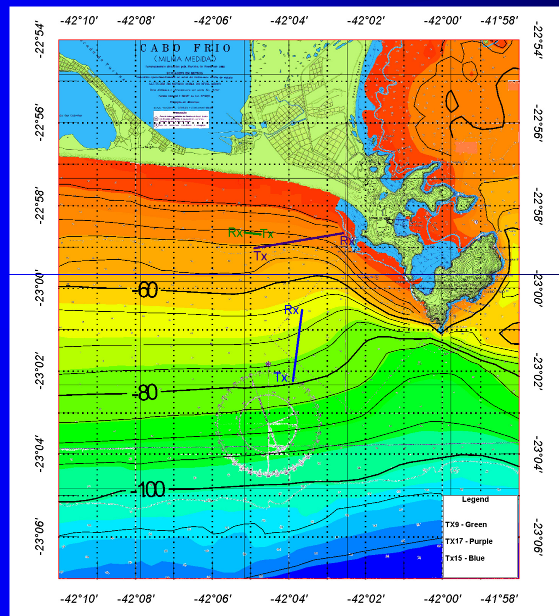
Comparison: Field Data x Bellhop

TX9



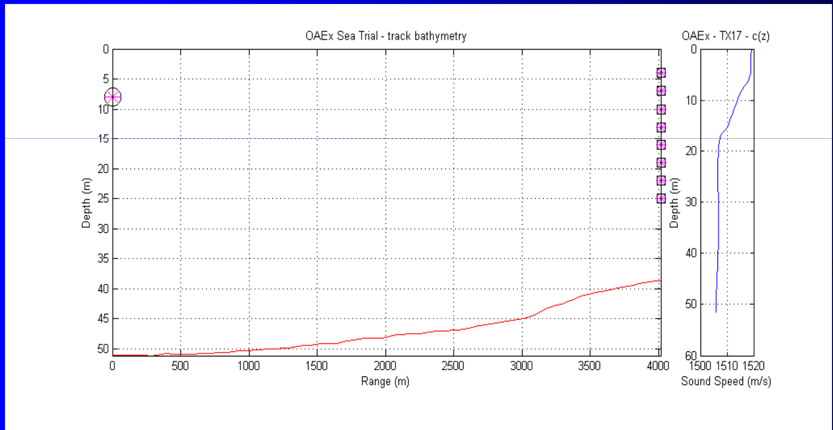
Transects Analyzed

TX17



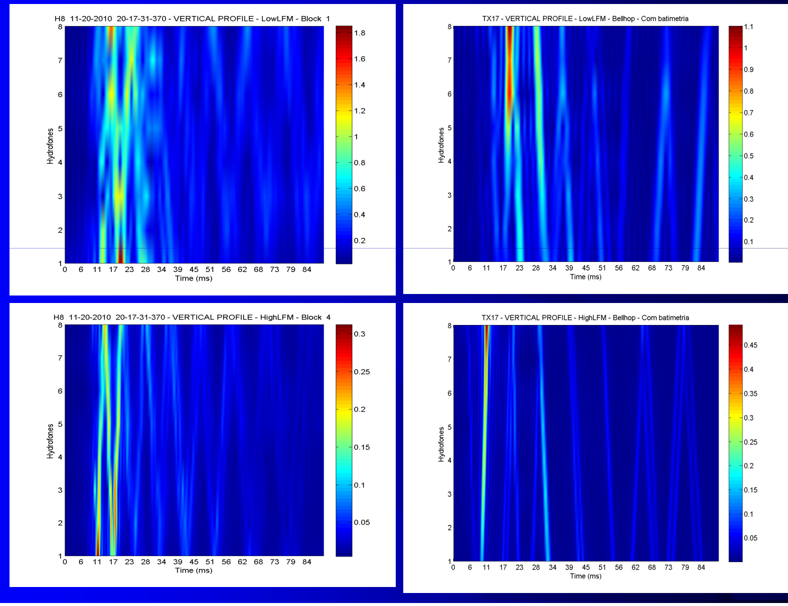
Comparison: Field Data x Bellhop

TX17 (distance 4000m)



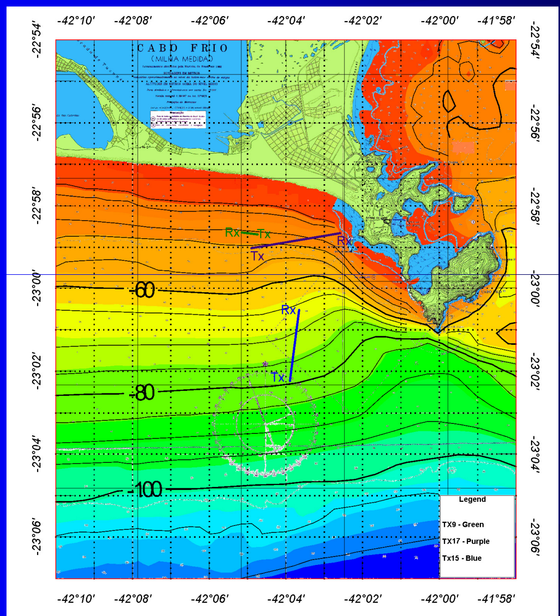
Comparison: Field Data x Bellhop

TX17



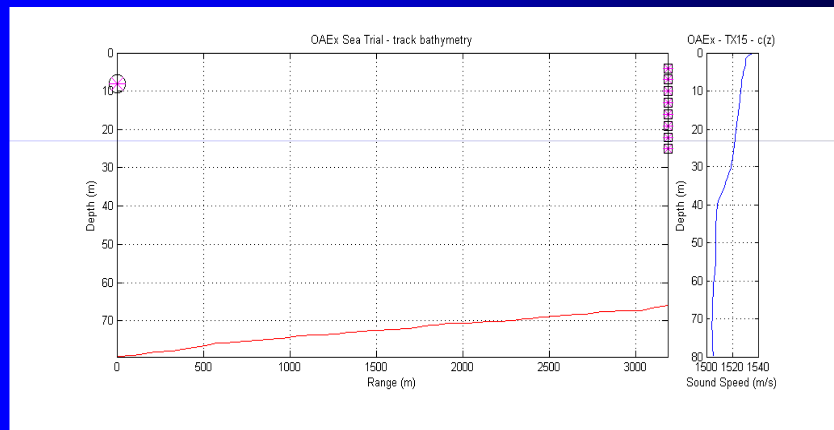
Transects Analyzed

TX15



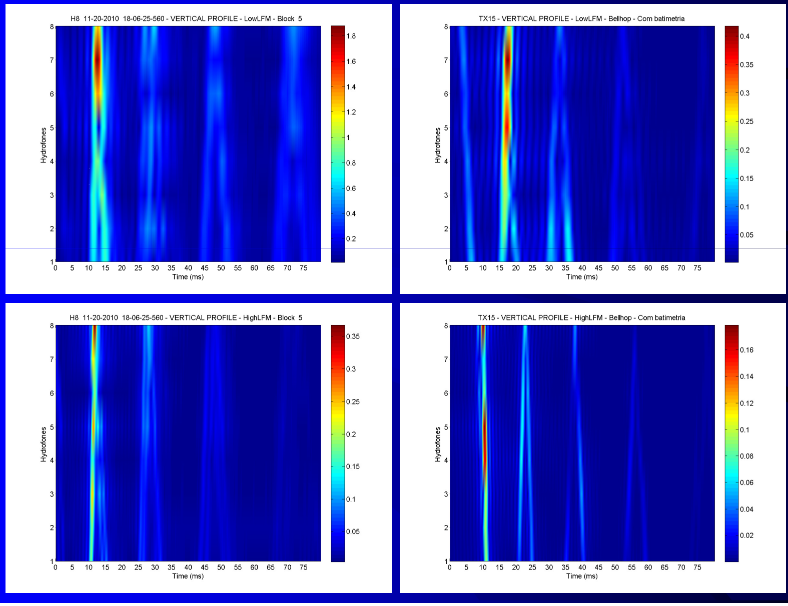
Comparison: Field Data x Bellhop

TX15 (distance 3200m)



Comparison: Field Data x Bellhop

TX15



Conclusion

- LFMs arrival pattern well defined from the vertical array for distances up to 4000m.
- Observed signal dilation of about 70ms in both bands.
- Bellhop with good agreement for short distances (<1000m).
- For longer distances model should be adjusted.
- Time-varying nature of the channel cannot be properly handled by the model.
- SSP and bottom properties considered range independent.
- Inversion can yield SSP and bottom properties effective fields.

OAEx sea trial Communications signals:

Some Preliminary Observations and guidelines for future Work

Salman Ijaz Siddiqui, António J. Silva, Sérgio M. Jesus.

SIPLAB, ISR-Lisbon, University of Algarve, Portugal

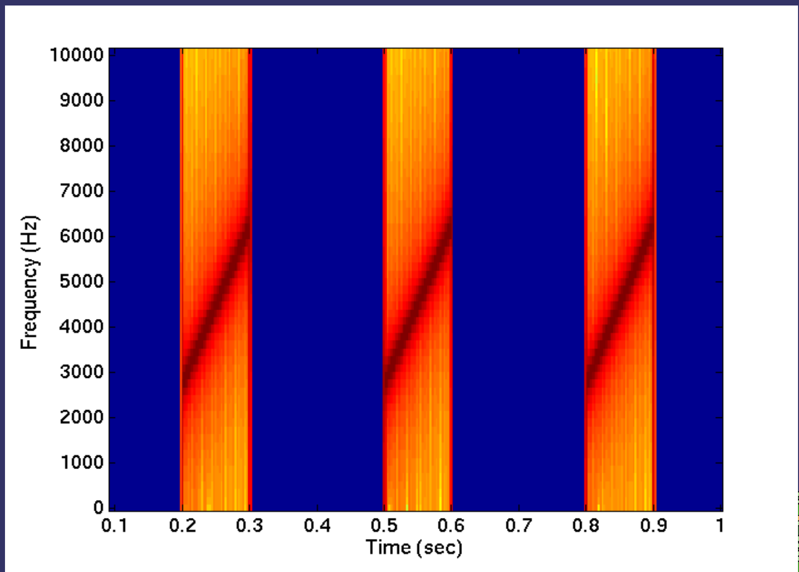
Outline

- Transmitted Signals Waveforms
- Received Signals Waveforms
- Preliminary Results
- Simulations
- Guidelines for future Work in Brazil

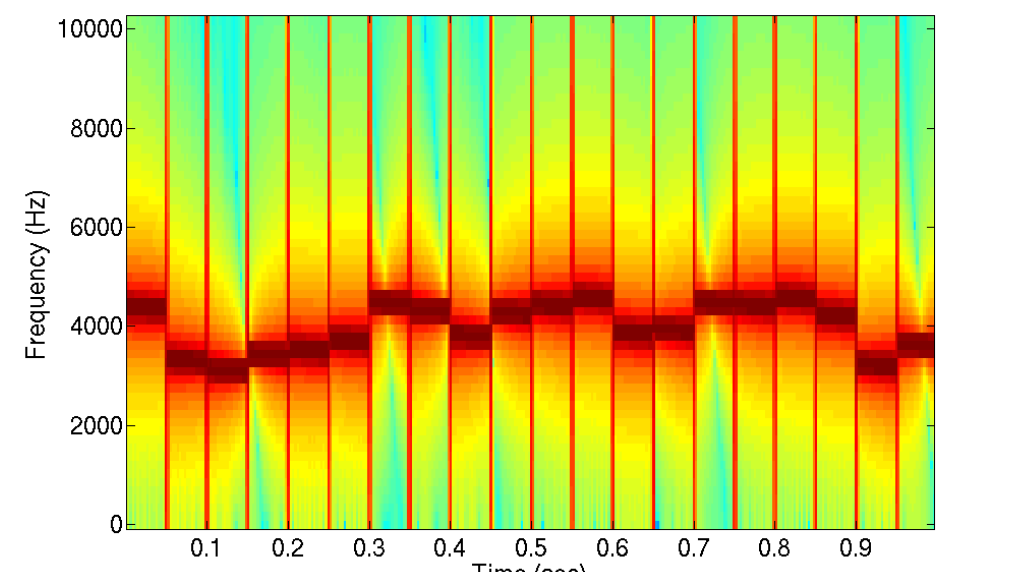
Transmitted Signals Specifications

Code	Type	Duration (sec)	Band Separation (Hz)	Start Stop Frequency (KHz)	Silence at the end (sec)	Repetition rate (sec
LFM	LFM	0.1	-	2.64-3.75	0.2	0.3
Code_A	FSK	0.05	50	3.0-4.6	-	-
Code_B	FSK	0.01	20	3.0-5.5	-	-

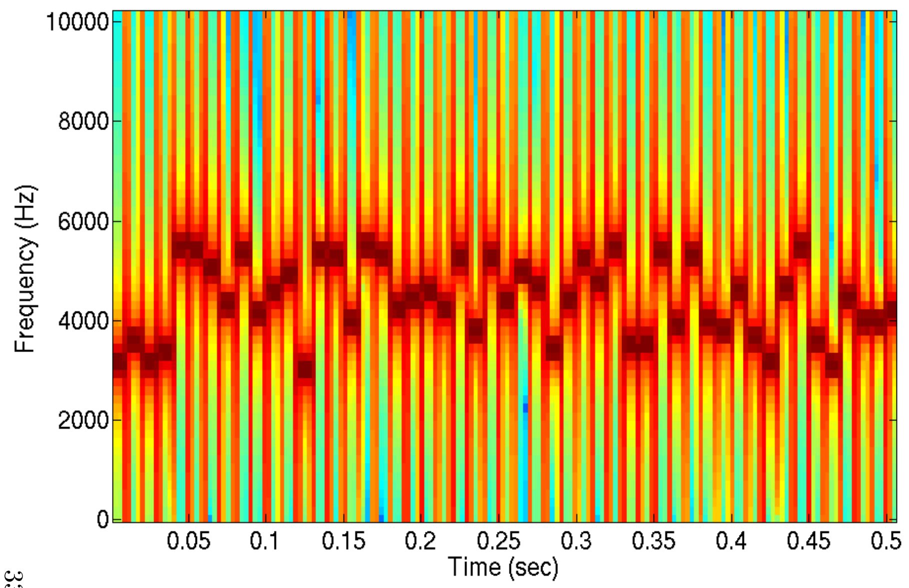
Transmitted Signals Waveforms



Code A



Code B

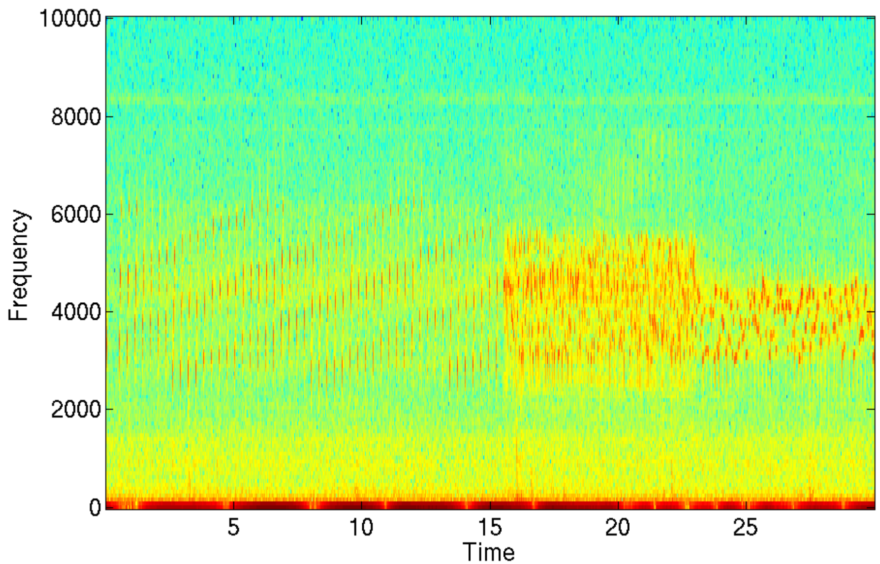


Received Signals

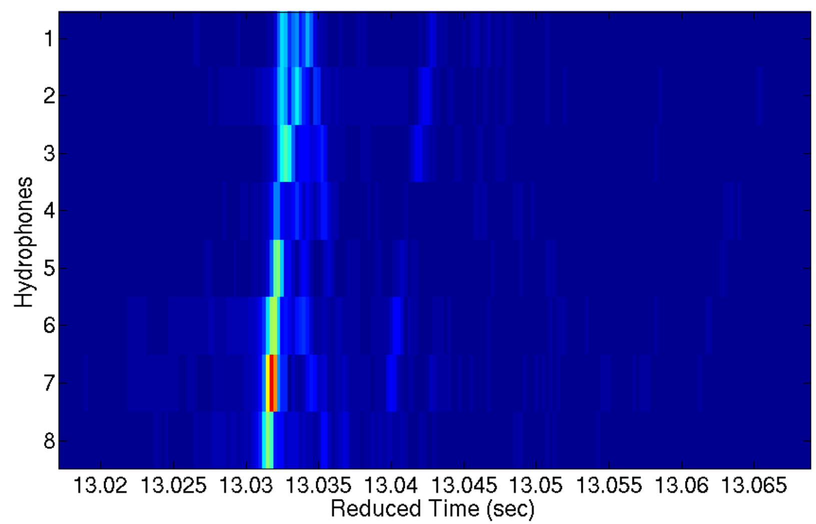
- Two Transmissions on first day (19-11-2010)
- Two Transmissions on second day (20-11-2010)

- Low Amplitude of the received signals
- High source receiver range at the start

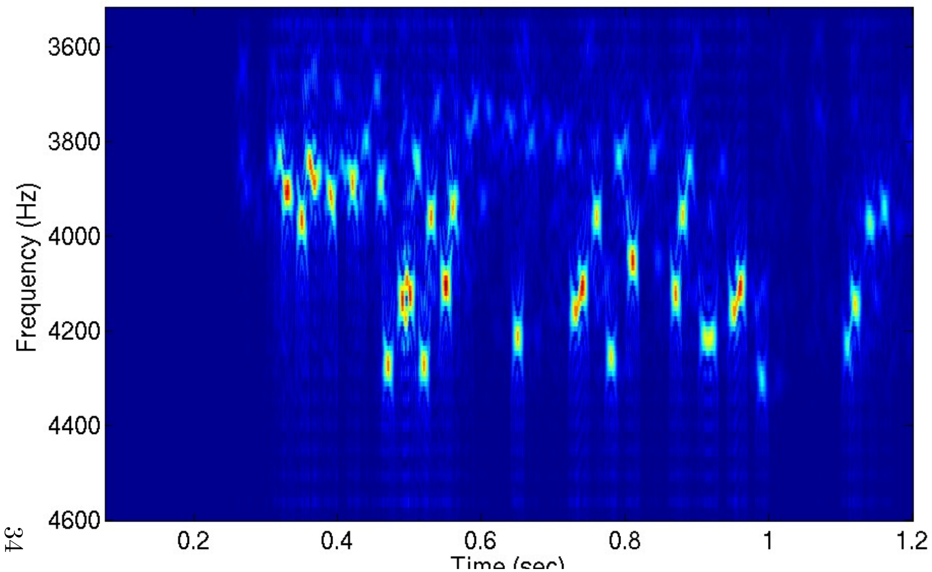
Received Signals
11:44 AM, 19-11-2010



Impulse Responses
11:44 AM, 19-11-2010



Received FSK signals



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Doppler Analysis

Guidelines for future work

- Use Passive time Reversal to exploit the spatial diversity in FSK signals.
- Use FSK signals to update the channel estimates.

Thank You !

Low frequency Geoacoustic Modelling in Shallow Water Sediment Environments

Ross Chapman

University of Victoria, BC, Canada

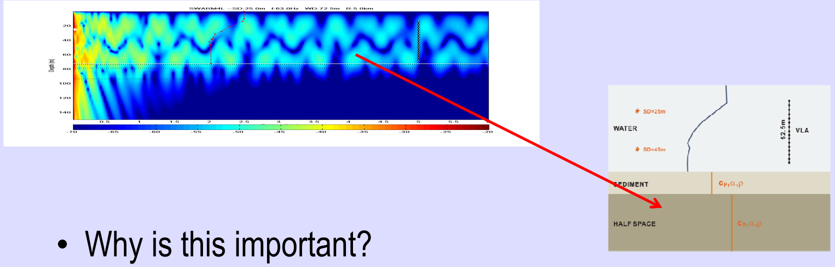
Work supported by ONR Ocean Acoustics

Outline

- Background of geoacoustic inversion
  - what is an inverse method?
  - what are the objectives?
  - what type of data are used in inversions?
  - how does geology interact with acoustics in present day inverse methods?
- Example applied to shallow water acoustics
  - SW06 experiment on New Jersey Shelf

Geoacoustic Modelling:

- Characterize the structure and properties of the ocean bottom from measurements of the acoustic field in the water
- This is an inverse problem….field ⟶ bottom properties



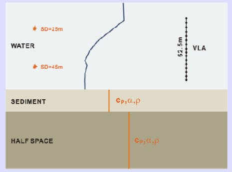
- Why is this important?
  - what is the impact of the ocean bottom on TL in the ocean?
  - what properties of the bottom are important?

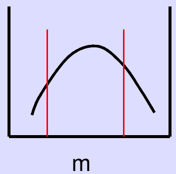
Inversion: where did it come from?

- Roots go back to Neil Frazer (Science, 1990) (with honourable mention to George Frisk (1988))
  - MFP: field measurements and accurate propagation models
  - Efficient search algorithm….simulated annealing
  - Geoacoustic 'Perfect Storm': combined physics of sound propagation with signal processing
- 1990's: geoacoustic inversion as an optimization problem
  - prior geophysical model of the bottom
  - comparison modelled response with field data
  - efficient search algorithm
- Many efficient methods developed, tested and implemented:
  - Gerstoft (Saga); Knobles and Westwood;…. Benchmark workshops (1997)……

20 years later:

- Inversion is an Estimation process:
  - infer parameters of a physical model of the ocean bottom from the information about the model in the data





- Fundamental paradigm shift:
  - inversion involves providing the user with:
    model parameter estimate (mean; most probable)
    + estimate of uncertainty (confidence limits)

Acoustic data: what type of data are used?

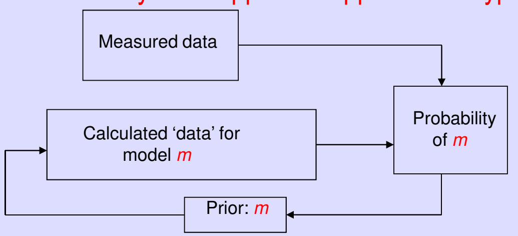
- Pressure field: primary observable
  - CW; Broadband (LFM; shots; airgun…
  - Noise (Siderius; Gerstoft…..
- Observables derived from the acoustic pressure
  - reflection coefficient (Holland…
  - horizontal wavenumber (Frisk, Becker…
  - time-frequency: modal dispersion (Miller, Potty, Zhou..
  - acoustic travel time (Jiang….
  - others…*all involve some type of signal processing on the pressure field data*

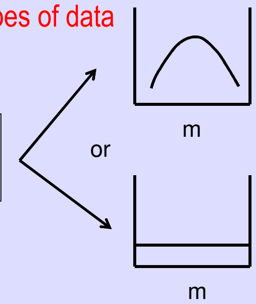
Inversion approaches

- Linear or linearized:
  - perturbative methods (Frisk; Rajan; Lynch; Becker…
  - provide measure of error
  - apply well to some types of data
    - e.g. travel time, horizontal wavenumber
- Non-linear methods:
  - assess a multi-dimensional model parameter space
    - prior model from 'ground truth' information
  - require an efficient 'navigation' method
  - provide measure of error
  - not sensitive to starting model

Implementation

- Bayesian approach: (formalized by Dosso (2002))
  - allows input of local geology (prior knowledge of model)
  - results are provided as probability of models in the search space: 1-d or 2-d marginal distributions
  - inversion tells whether data has any information about prior model
  - Bayesian approach applies to all types of data





Warning: Data errors in geoacoustic inversions

- Bayesian inversion compares measurement and model in terms of a likelihood function:

$$L = \exp[-E(m,d)]$$

$$E(m,d) = \tfrac{1}{2}(d - d(m))^T C_d^{-1}(d - d(m))$$

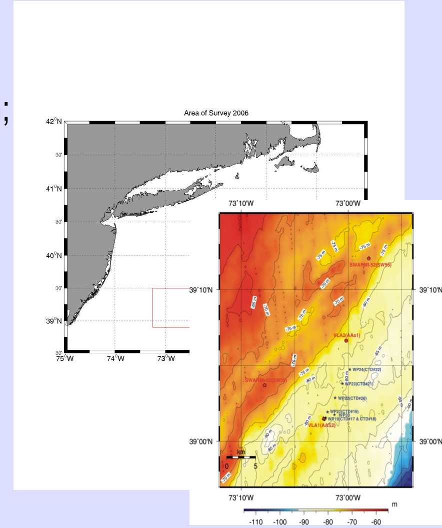
- $d - d(m)$ is interpreted as 'noise in the inversion i.e. experimental and 'theory' errors
- distribution is not known
- data error Covariance C may not be diagonal

Example of geoacoustic inversion

- Data from ONR Shallow Water '06 experiment
  - two sites of different sediment geology
  - short range experiments at each site
  - mid-frequency 1.5 – 4.5 kHz sweeps
  - use acoustic travel time data at vertical and horizontal arrays
  - estimate local geoacoustic properties
- Develop prior geoacoustic model from
  - local knowledge of environment (ground truth
  - the experimental data itself

Prior Geological knowledge of NJ Shelf

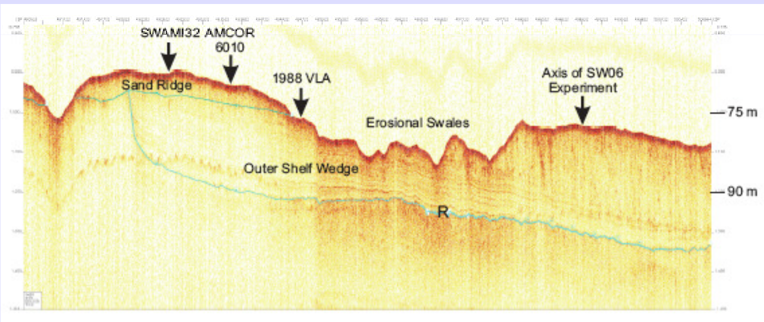
- Many investigations:
  - Mayer; Kraft; Goff; Austin; Turgut; AMCOR; Geoclutter……
- Methods:
  - Physical samples:
    - Sediment grab samples
    - in situ probes
    - Sediment cores
  - Remote sensing
    - Chirp sonar profiles



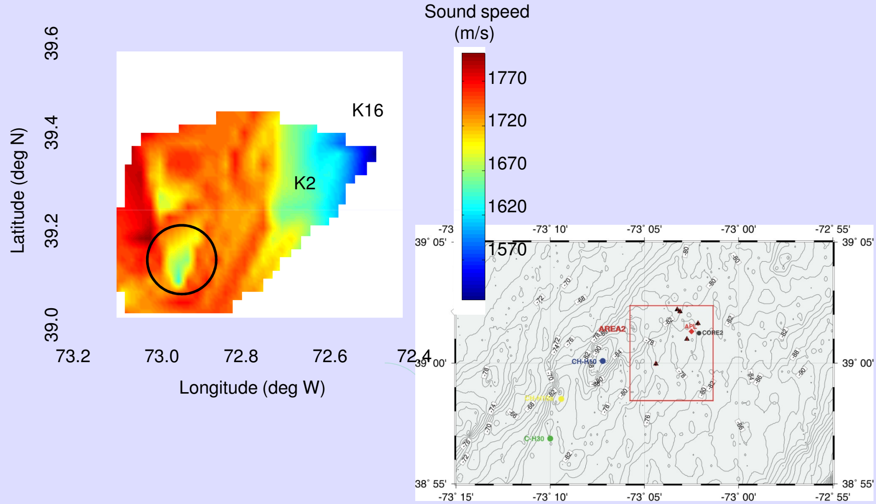
Chirp sonar travel time sections

Sand ridge - medium course to coarse sand
1. Grain sizes ~ 0.8-1.5 phi
2. Low-frequency sound speed ratio ~ 1.11- 1.14, sound speeds 1650-1710

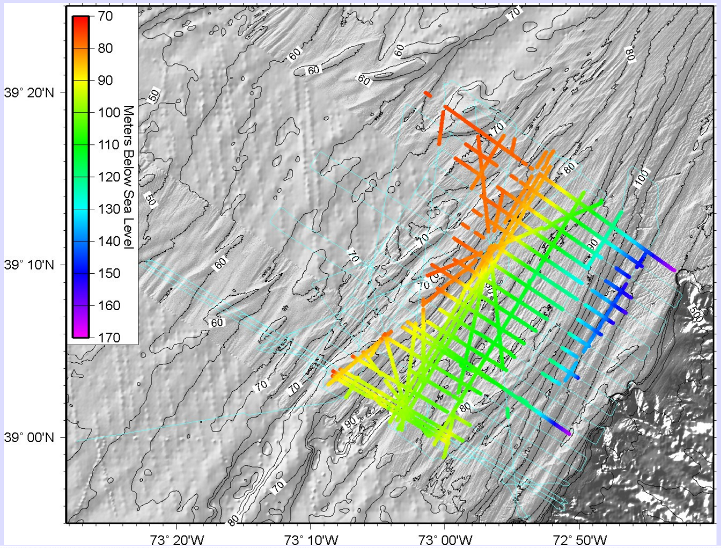
Outer shelf wedge (Medium sand - clay mixture)
1. Grain sizes ~3+ phi
2. Sound speed ratio ~ 1.06-1.08, sound speeds 1580-1610 m/s



Sea floor sound speed map



map of R reflector (2-way travel time)



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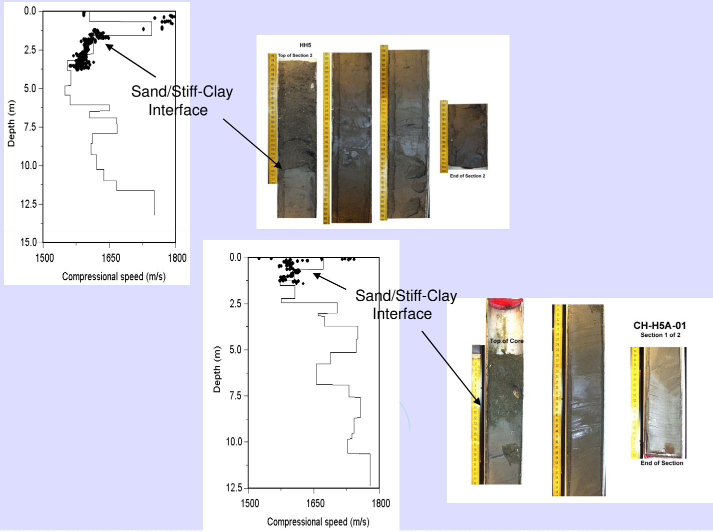
Sediment cores: outer shelf



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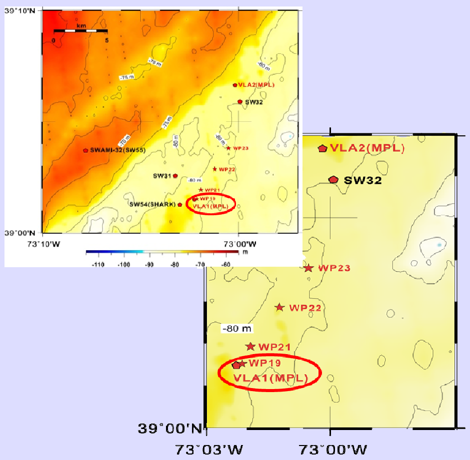
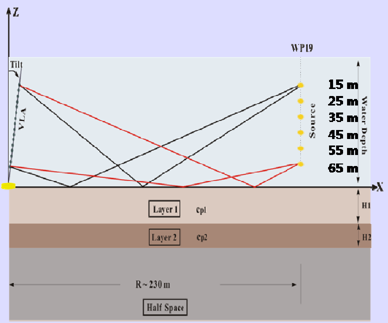
Outer shelf wedge site (Moray)





- Water depth ~ 79m
- Range ~ 230m
- Source depth: 15-65m in 10m steps
- Receiver depth: 14.25-70.5m @ 3.75m
- LFM sweep: 1.5-4.5 kHz

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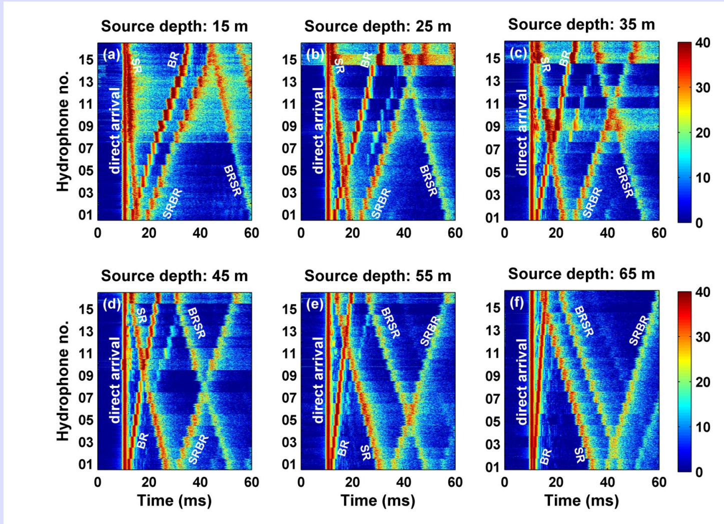
Broadband acoustic data: 1.5 – 4.5 kHz



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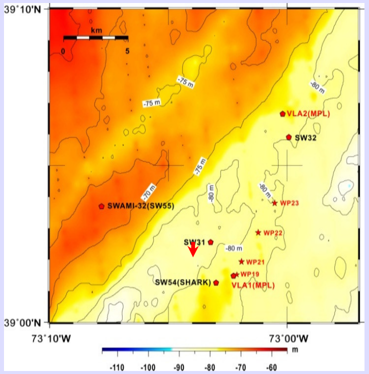
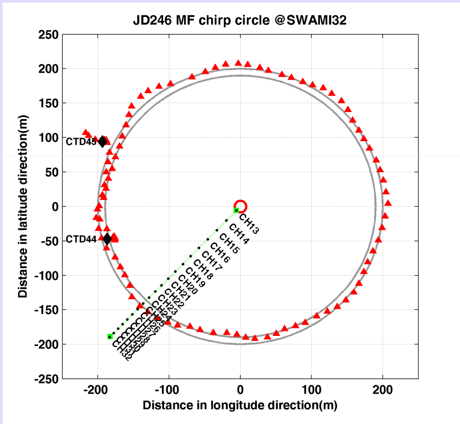
Sand wedge site (SWAMI32)





SWAMI32 site:

ARL's L-shape array

- VLA – 10 hydrophones
- HLA – 20 hydrophones

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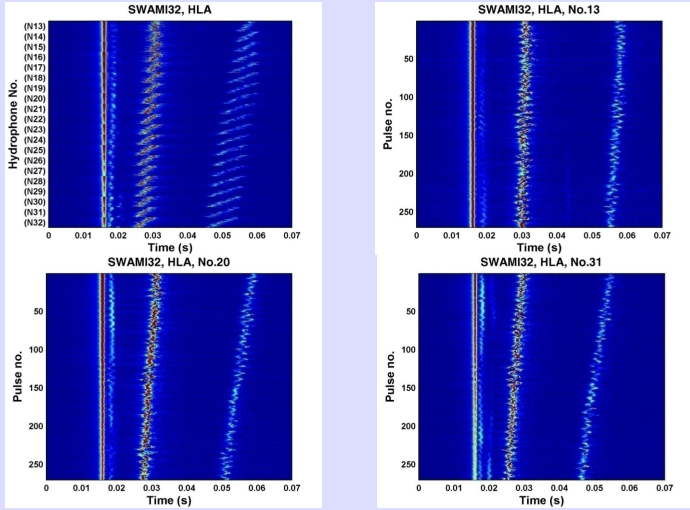
Acoustic data on horizontal array



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Bayesian travel time inversion:

Bayes' rule: $P(\mathbf{m}|\mathbf{d}) = \dfrac{P(\mathbf{d}|\mathbf{m})P(\mathbf{m})}{P(\mathbf{d})}$ ⇨ $P(\mathbf{m}|\mathbf{d}) \propto L(\mathbf{m})P(\mathbf{m}),$

$$\mathbf{L}(\mathbf{m}) \propto \prod_{L=1}^{N_L} \exp\left[-\frac{1}{2}(\Delta t_L - \Delta T_L(\mathbf{m}))^{\mathrm{T}} C_L^{-1} (\Delta t_L - \Delta T_L(\mathbf{m}))\right]$$

Relative travel times:

- time difference between sea floor and sub-bottom paths
- invert single layer geoacoustic model
  - sediment layer thickness and sound speed

Data error covariance matrix estimation:

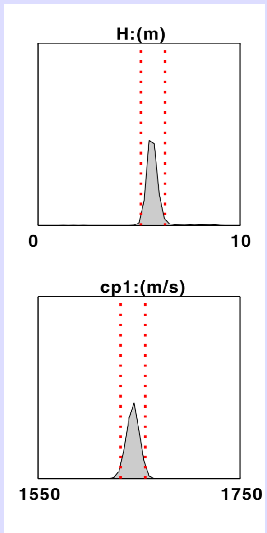
- from multiple pings

Sampling algorithm:

- MCMC of Metropolis Gibbs sampling

Chapman Faro OAEx workshop

Inversion results for SWAMI32 site:



Layer thickness:
[3.92 5.10 5.98] m

Recall from 'Ground truth':

- medium course to coarse sand
- Grain sizes ~ 0.8-1.5 phi
- sound speeds 1650-1710

Sound speed:
[1623 1652 1681] m/s

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Short range geoacoustic inversions:

- Travel time inversions
  - Outer shelf wedge site:
    - sound speed 1600 m/s ± 30 m/s
    - average over 20-m depth to R-reflector
  - Sand wedge site
    - sound speed 1650 m/s ± 30 m/s
    - average over 5 m sand layer

Summary:

- Geoacoustic modelling is an inverse problem

- Geoacoustic inversion is an estimation process
  - provide model parameter estimate and its uncertainty
  - Bayesian approach applies to any type of acoustic data

- What's in the future?
  - Model selection: can this be done in the inversion?
  - What other types of data are useful?
    - particle velocity
  - applications of inverse methods at higher frequencies

  - Is Bayesian approach the only way?

Acknowledgements

• Just about everyone in the room who has contributed to the development of geoacoustic inversion

• Special thanks to Neil, Evan, David, Mae, Stan and Alex, and
• all my graduate students who took my simple suggestions to higher levels

Thanks!

Acoustic inversion with broadband MFP for seabed characterization in OAEx'10 experiment

Lussac P. Maia(1), **Lucia Artusi**(2), **Carlos E. Parente**(3), **Jean-Pierre Hermand**(4)

(1) Centro de Apoio a Sistemas Operativos (CASOP), Ilha de Mocanguê, s/n, Niterói/RJ, Brazil
(2) Instituto de Estudos do Mar Almirante Paulo Moreira (IEAPM), r. Kioto, 253, Arraial do Cabo/RJ, Brazil
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(4) Université libre de Bruxelles (U.L.B.), Av. Franklin D. Roosevelt, 50 CP 194/5, 1050 Brussels, Belgium

2nd Ocean Acoustic Exploration Meeting
Faro, Portugal – June, 2011

*Work presented in the 4th Underwater Acoustics Measurements Conference (4thUAM), June, 2011, Greece.

Outline

Acoustic inversion with broadband MFP for seabed characterization in OAEx'10 experiment

Lussac P. Maia[1], **Lucia Artusi**[2], **Carlos E. Parente**[3], **Jean-Pierre Hermand**[4]

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Outline

Outline

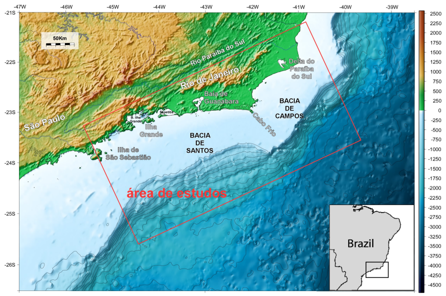
Introduction

- Acoustic inversion techniques: characterization of the seabed or the marine environment;
- Several methods, *e.g.*: Bartlett MFP, MBMF, FD-MBMF, MMP, ... -(domain, objective function, sampling/type of signal);
- This work: results of broadband MFP inversion – incoherent-in-frequency linear processor;
- Data: Ocean Acoustic Exploration 2010 experiment (OAEx'10), off the south-east coast of Brazil;

Introduction

It was used:

- Broadband signal;
- 8-hydrophones vert. array;
- Nearby isobath of 40-m, range-independent;
- Normal modes model;
- Bartlett MFP and a GA for global optimization;
- Site with previous cores and seismic assessment (ground truth).



Ocean Acoustic Exploration 2010 (OAEx'10) experiment, off the southeast coast of Brazil.

Outline

Objectives

- Show the general characteristcs of the OAEx'10 experiment;
- Review briefly some theory: show the processing applied in this work;
- Present the results & conclusions of the broadband MFP inversion with those acoustical pressure data.

(Run #1 – Core9 site)

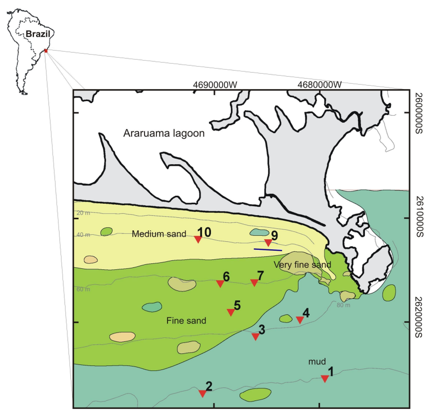
Outline

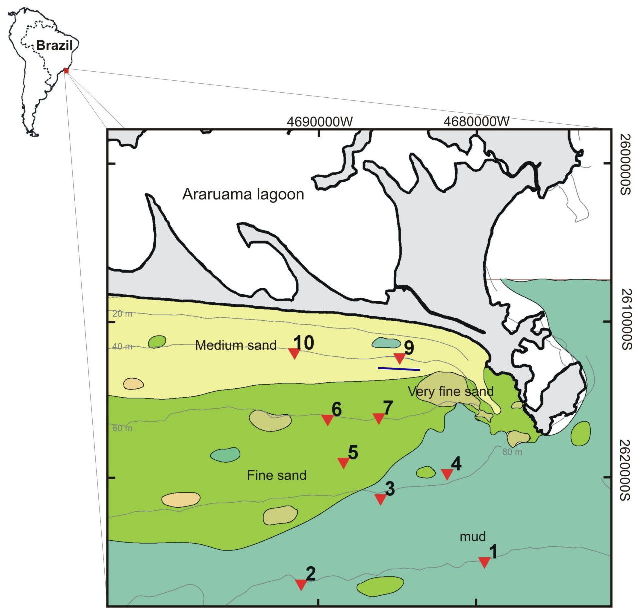
OAEx'10 Experiment

- November 19-22, 2010 - off the coast of Arraial do Cabo/RJ, continental shelf in southeast of Brazil;
- Others data collected: CTD, pressure gauge, GPS, echo sounding (source ship), early seismic profiles and core samples;
- Acoustic measurements: near core number 9, short S-R transect (700-m), sparse 8-hydrophones array;
- Source: set to max. range cable (10-m depth), multitone signals, sequences repeated every minute during 10 minutes;

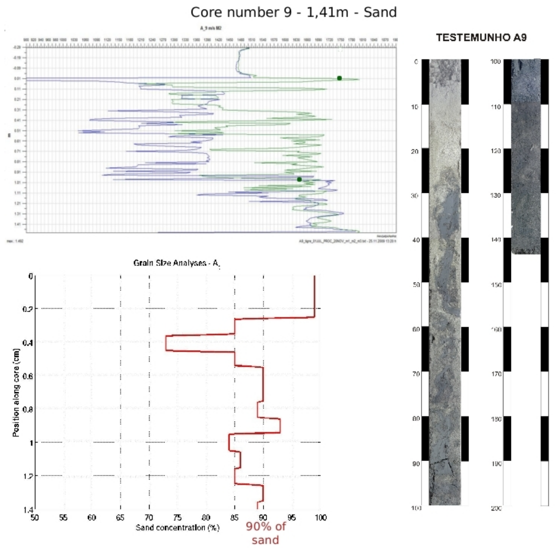
OAEx'10 Experiment – Site & ground truth

- Red triangles: core positions (number 9 is over the 40-m isobath);
- Blue line: acoustic run transect.





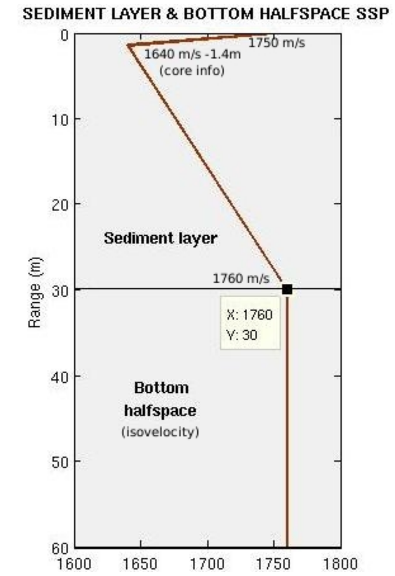
Transect, approx. 47–48-m depth, 700-m, near core#9 site.



Information from previous seabed assessment: Sand, C-sed near to 1750m/s, rho 1.6 g/cm^3, sediments layer between 10 and 40m.

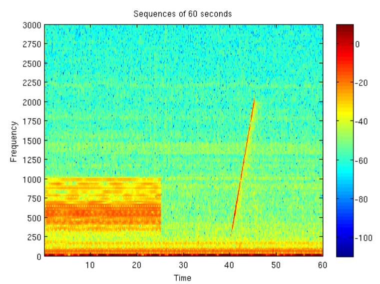
Sediment & bottom ssp model:

- Search of *a priori* sound speed profile in sediments over isovelocity bottom halfspace;
- Aspect kept;
- Lower point in sediment – 1720 to 1780 m/s;
- Isovelocity in bottom – 1730 to 1790 m/s;

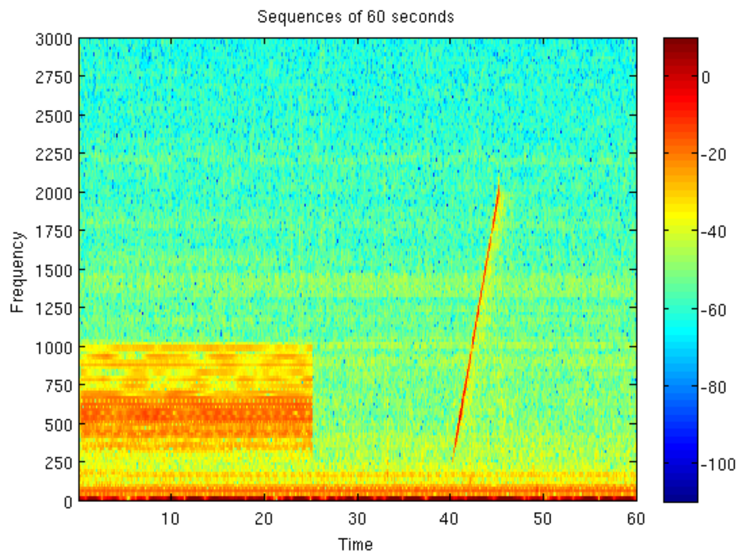


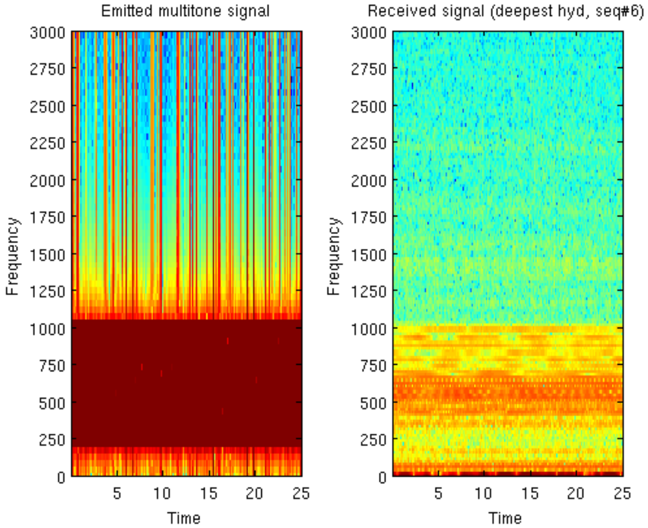
OAEx'10 Experiment – Signal

Sequences: each full sequence is composed by one CW multitone signal (250 Hz to 1000 Hz) followed by one LFM signal (250 Hz to 2000 Hz);



Sequence of CW and LFM signals emitted every minute, during 10 minutes. Spectrogram of the acoustic data recorded on the deepest hydrophone during the 6th sequence.

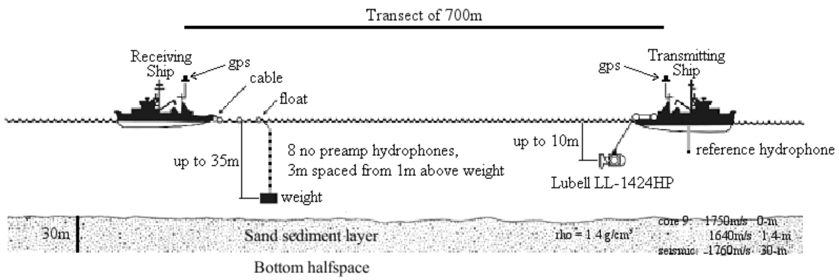




Multitone signal: emmited by the source (left) and received in the deepest hydrophone (right).

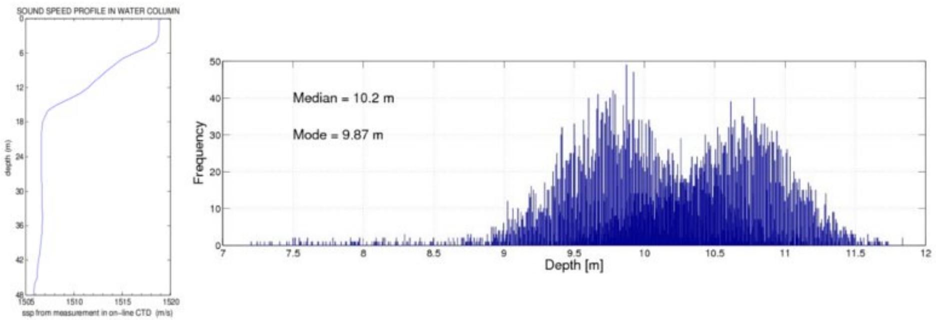
OAEx'10 Experiment – Geometries

- Receivers: Acoustic Array consisting of eight hydrophones 3-m equally and vertically spaced;
- Top array element was set to 4-m depth;
- Environment between the source and receivers: approx. 47–48-m depth, 700-m, range-independent;
- Sediment layer (10–40m) over bottom halfspace.



OAEx'10 experiment. The sketch shows positions and configurations for ships and equipments during the acoustic measurements on the core#9 site.

OAEx'10 Experiment – Support data



Water sound speed profile collected from CTD just before the acoustic measurements on core#9 site (left). Histogram of the hydrostatic pressure data collected from pressure gauge positioned joint to the source (*one day before) in November 19, 2010 (right).

Outline

Processor

- Bartlett MFP coherent-in-space and incoherent-in-frequency processor applied to sparse CW signals;
- Range-independent shallow water waveguide – normal modes model for solution of the wave equation with those boundary conditions for create the predict fields;
- Multidimensional problem (12) – huge search space – genetic algorithm.

Processor – Foward models and optimizations

- Solve wave equation for that ocean waveguide (after crit. angle):

  Helmholtz cil.coord.: $\left[k^2 + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{\partial^2}{\partial z^2}\right]\Psi(r,z) = P_\omega \frac{\delta(r)\delta(z-z_s)}{2\pi r}$

- Normal modes model solution

  e.g. for Pekeris:

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

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

- Huge search space: strong statistics – G.A. 4500 calls for 40 populations

  SNAP, SAGA, 8cores, compiled in Hydra U.L.B. cluster.

Processor – Bartlett MFP

- Considering a shallow water environment parameterized by a model vector **m**, the processor used is:

$$\phi(\mathbf{m}) = \sum_{i=1}^{F}\sum_{j=1}^{H}\left(R_{jj,i} - d_{ij}^{\dagger}(\mathbf{m})\sum_{l=1}^{H} R_{jl,i}d_{il}(\mathbf{m})\right)$$

Where:

$d_{ij}(\mathbf{m})$ – [predicted data for the i^{th}frequency and j^{th} hydrophone];

$R_{jl,i} = p_{ij}p_{il}^{\dagger}$ – [Estimated correlation matrix of the observed acoustic data];
*Used mean of 25 matrix from segments of the signal.

p_{ij} – [observed data for the i^{th}frequency and j^{th} hydrophone];

The † symbol stands for the conjugate transpose.

- Bayesian inference: results in terms of probability distributions;
- Environmental *a priori* information and S-R geometry reflects in the *a priori* distribution $\rho(\mathbf{m})$ – The results of the inversion procedure reflects in the *a posteriori* distribution $\sigma(\mathbf{m};\mathbf{d})$;
- Relation: $\sigma(\mathbf{m};\mathbf{p}) = \Lambda(\mathbf{m};\mathbf{p})\rho(\mathbf{m})$

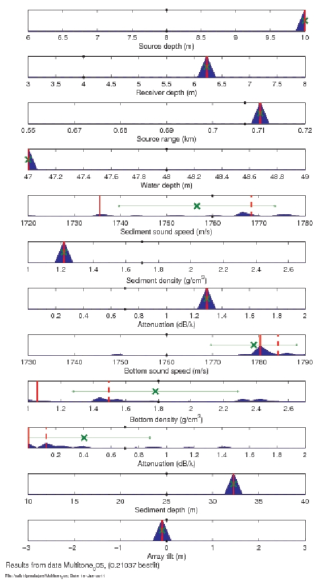
Where the $\Lambda(\mathbf{m};\mathbf{p})$ is the likelihood function.

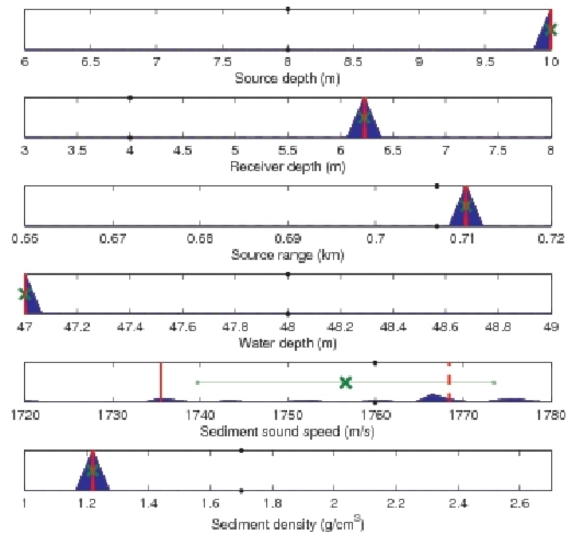
Outline

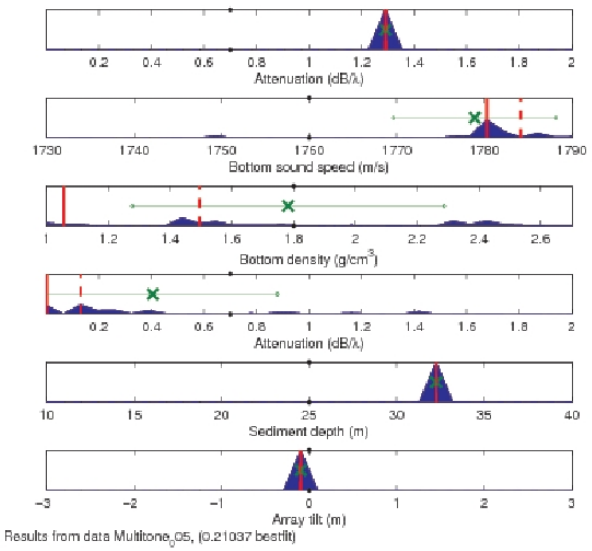
Results reached in this acoustic run of the experiment

Results - *e.g.* for ping # 5: One-dimensional marginal a posteriori probability distributions (PPD) for each inverted parameter (blue surface);

Maximum a posteriori (red solid line) – maximum likelihood (red dashed line) – mean and standard deviation of the distributions (green cross and line,resp.).



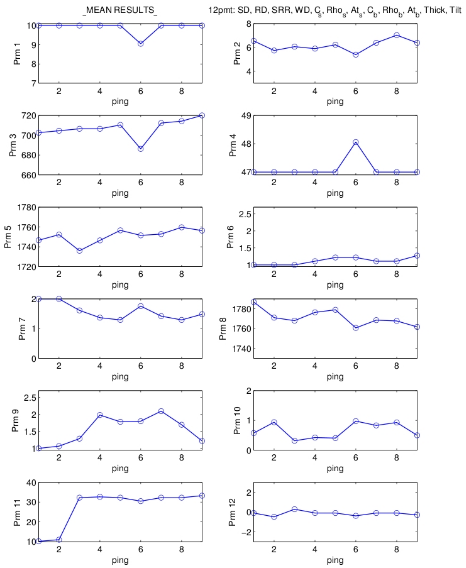




Results – Analysis of stability

Evolution of the mean marginal PPD results for the 9 processed multitone signals.

The vertical axis limits correspond to the search ranges in the optimization algorithm.



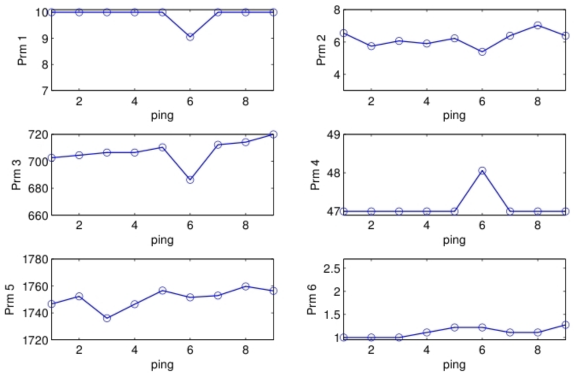


Figure: From 1 to 6: Source depth (m), Receiver depth (m), S-R range (m), Water depth (m), C-sediments (m/s), Rho-sediments (g/cm^3).

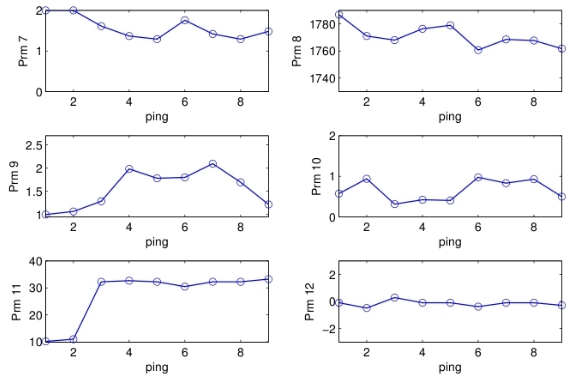
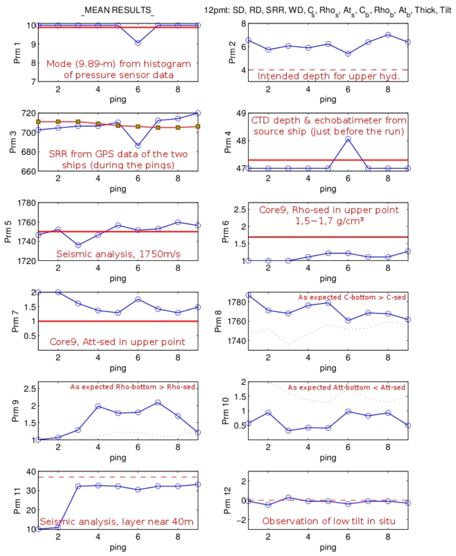


Figure: From 7 to 12: Att-sediments (dB/λ), C-bottom (m/s), Rho-bottom (g/cm^3), Att-bottom (dB/λ), Thickness sed-layer (m), Array tilt (m).

Results – Comparison with ground truth & support data



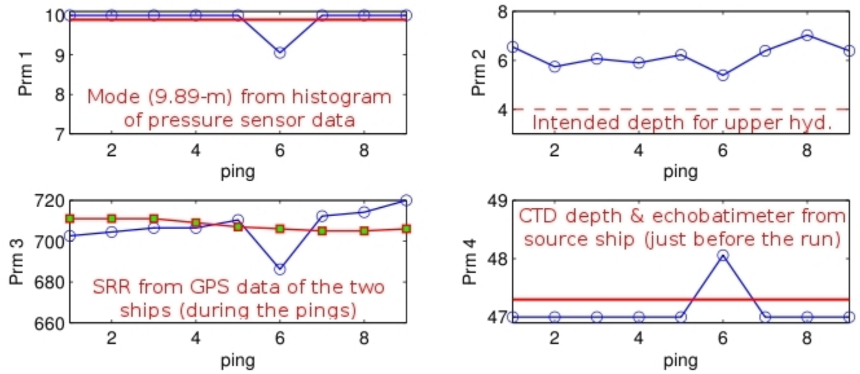


Figure: From 1 to 4: Source depth (m), Receiver depth (m), S-R range (m), Water depth (m).

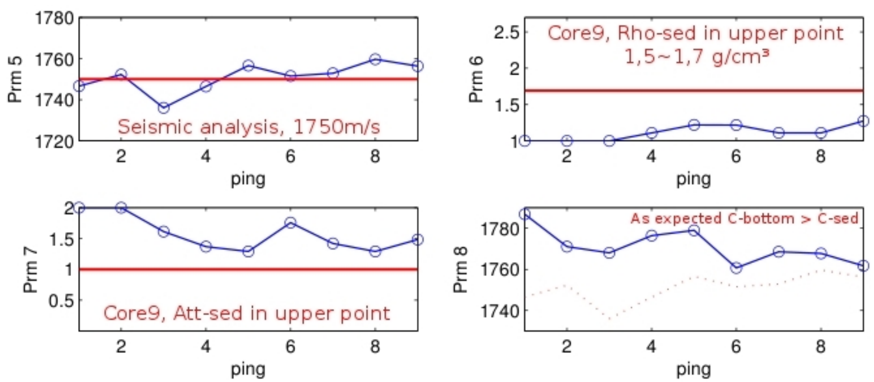


Figure: From 5 to 8: , C-sediments (m/s), Rho-sediments (g/cm^3), Att-sediments (dB/λ), C-bottom (m/s).

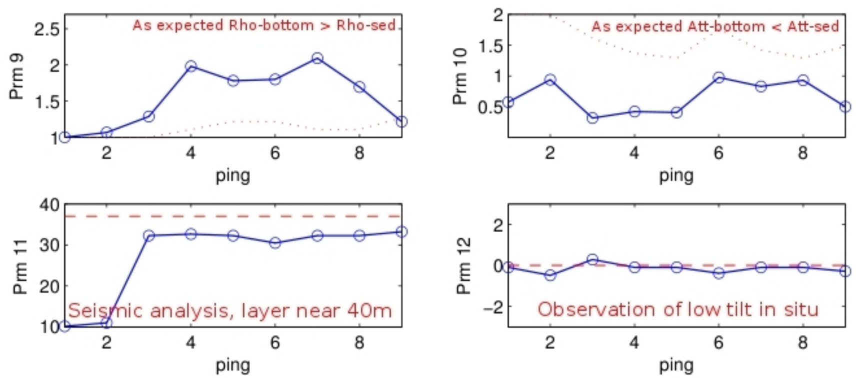


Figure: From 9 to 12: Rho-bottom (g/cm^3), Att-bottom (dB/λ), Thickness sed-layer (m), Array tilt (m).

Outline

Conclusions

- In general, the inverted geoacoustic parameters showed higher instability with respect to the geometric parameters;
  [- short propagation range;
  - a weaker interaction with the seabottom;
  - greater complexity involved in the resolution of seabed characterization problem.]
- Results consistent with the earlier seismic and core assessment;
- Some interference can be seen in the instant of the ping number 6;

Conclusions

- In spite of this, the inversion still provides a reasonable estimation of the physical parameters in the area of the experiment;
- It confirmes the ability of the broadband Bartlett MFP approach to invert efficiently multitone signals recorded on hydrophone array using a coherent-in-space processor.

Thanks!

OAEx

Noise Cavitation Experiments

Carlos Eduardo Parente

Luiz Gallisa

Kleber Pessek

Benevides Colella Xavier

Antonio Hugo S Chaves

Noise cavitation experiments

- **INTRODUCTION**
- **AIMS**
- **EXPERIMENTATIONS**
- **RESULTS**
- **CONCLUSION AND FUTURE WORKS**

INTRODUCTION

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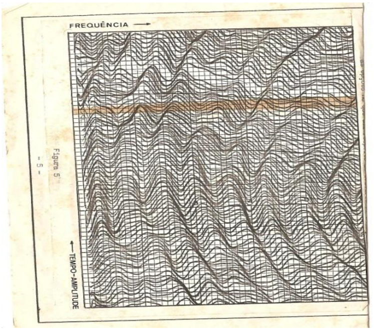
INTRODUCTION

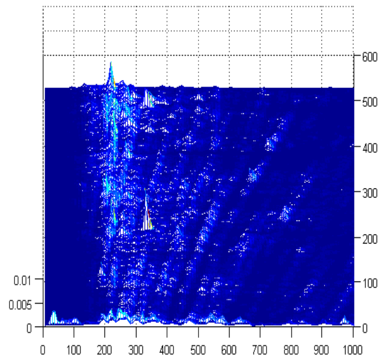
- MAIN PROBLEM – ESTIMATE SOURCE
 DISTANCE IN PASSIVE MODE
- IMPROVE THE DETECTION DISTANCE
- SIMPLIFIED CALCULUS



- Database – shallow waters – below frequency 1Khz
- (cavitation noise).
- 1978_ first images
- BETA INVARIANT – CHUPROV

AIMS

- Understand how beta invariant affect the modal propagation in one area.
- Estimate distances
- Improve detection distance for nowadays systems
- Allow a rapid and precise calculus of detection limit
- Cavitation broadband noise model



EXPERIMENTS

OAEx 10

PESQUISEX 11

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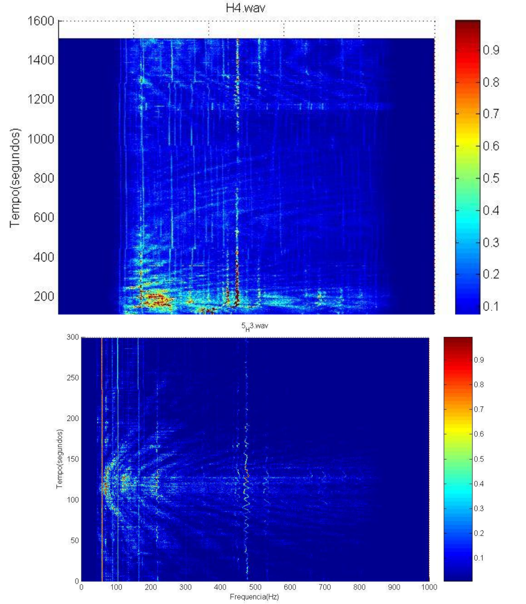
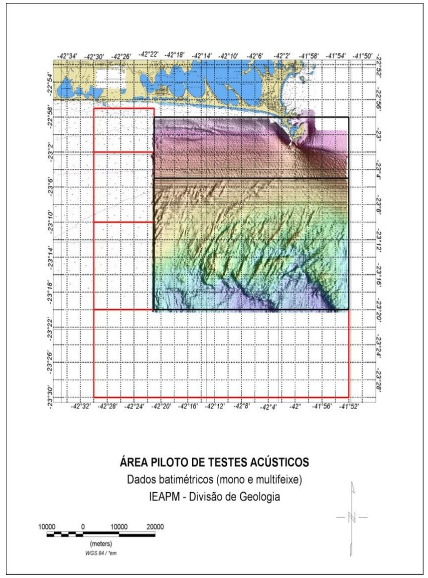
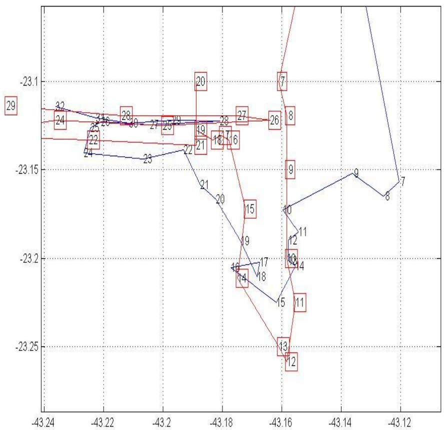
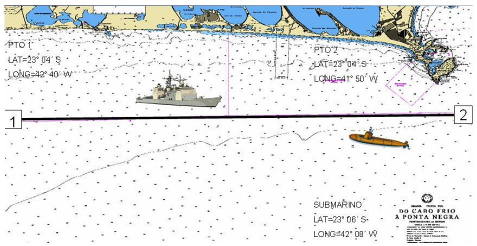
OAEX 10

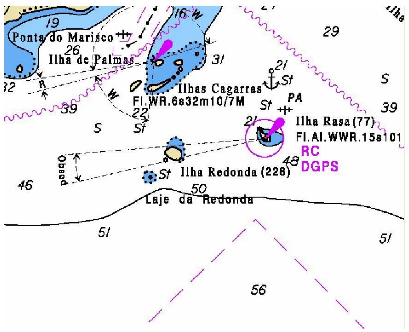




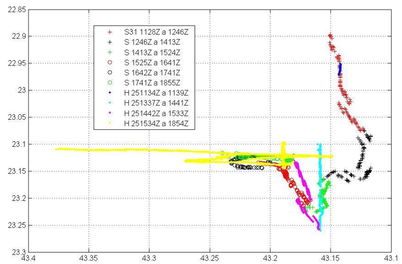
Pesquisex 11

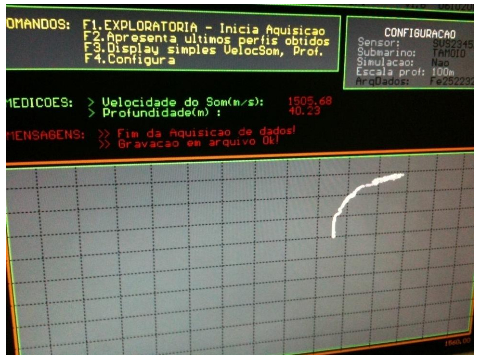


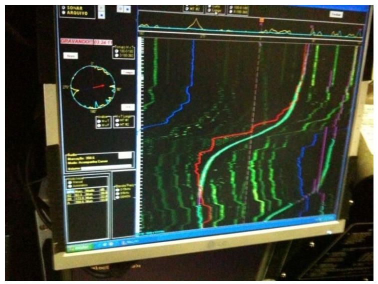




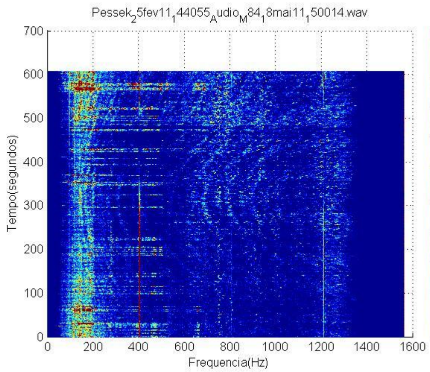
PESQUISEX 11

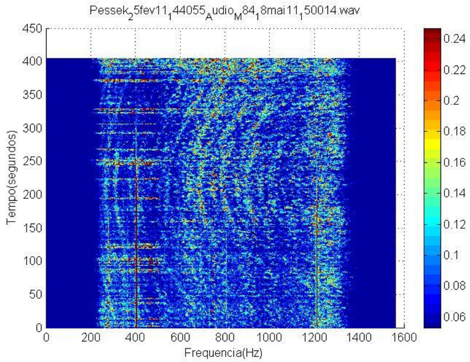






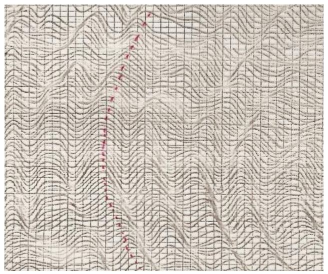
Pesquisex 11

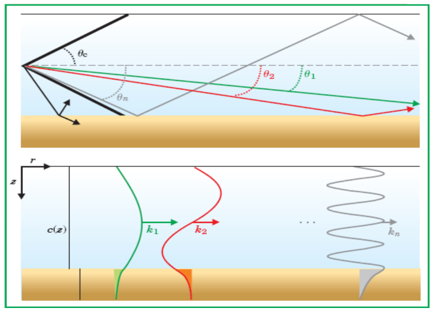




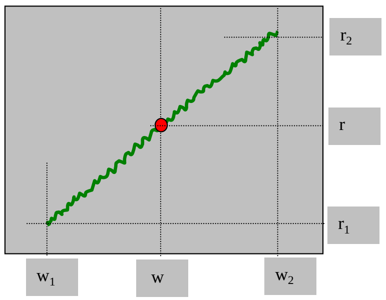
RESULTS

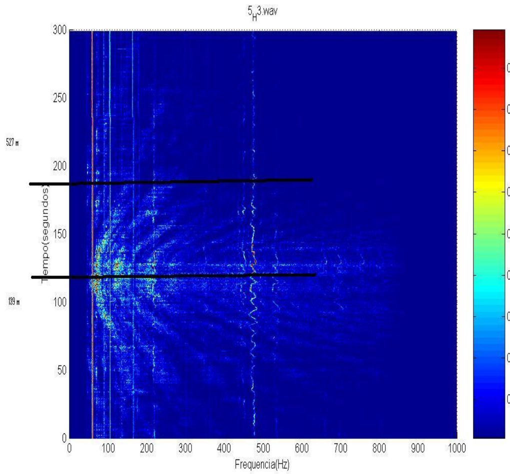
Oaex10

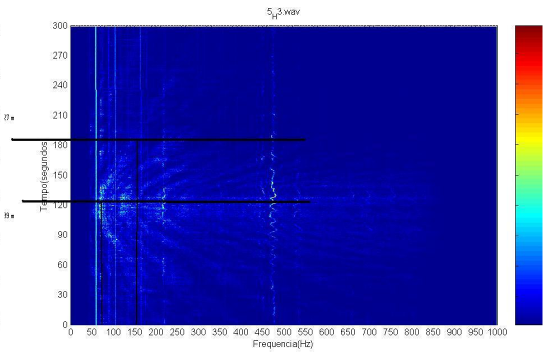




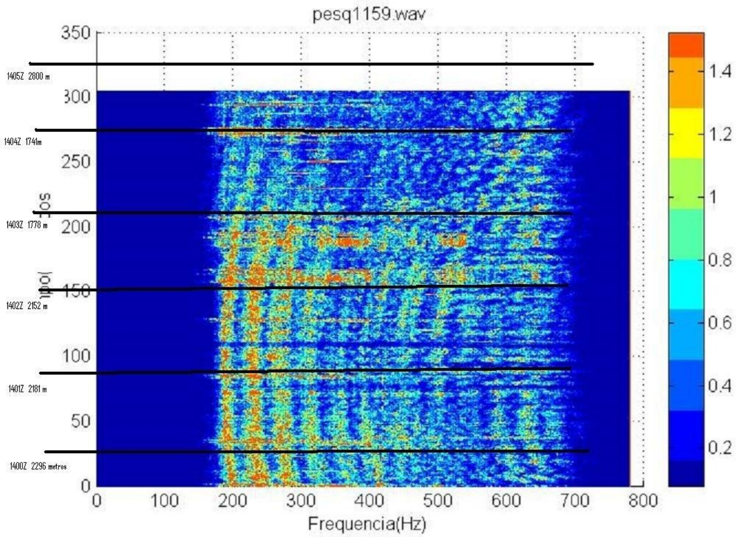
$$\beta = \frac{r}{\omega}\frac{d\omega}{dr}$$







Pesquisex11



CONCLUSION AND FUTURE WORKS

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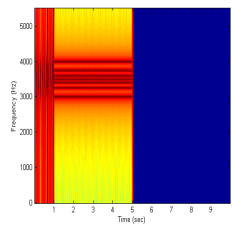
CONCLUSION AND FUTURE WORKS

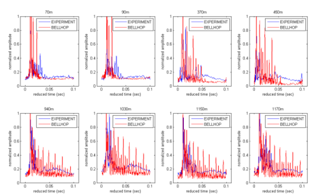
- Inicial estimation os Beta in diferent areas and experiments
- Find a simplified calculus to execute instead a graphic solution
- Search to solve Operational Condition in Shallow Waters for the Submarine.

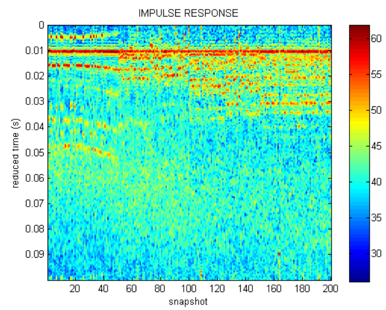
OAEX11

Oaex 10 – calculo IR semelhante ao feito em 09, data check and simplified inversion

Signal processing - noise cavitation experiments







END


Instituto de Estudos do Mar
Almirante Paulo Moreira - IEAPM
BELLHOP TRANSMISSION
LOSS PERFORMANCE
EVALUATION FROM FIELD
DATA OF OAEx'10
EXPERIMENT
Departamento de Oceanografia
GRUPO DE ACÚSTICA

Summary

- Objective
- Methodology
- Results
- Conclusions
- Future Work

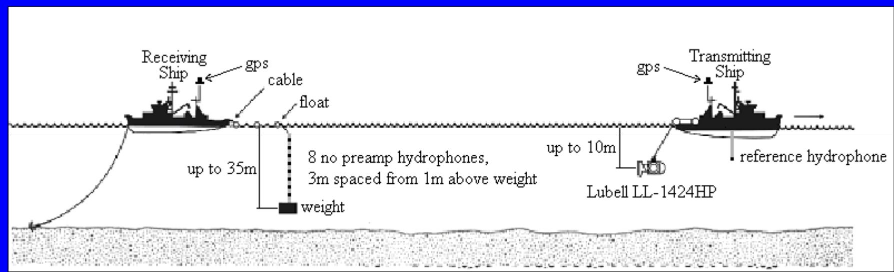
Objective

Evaluate the Bellhop Transmission Loss model using data from the OAEx'10 sea trial.

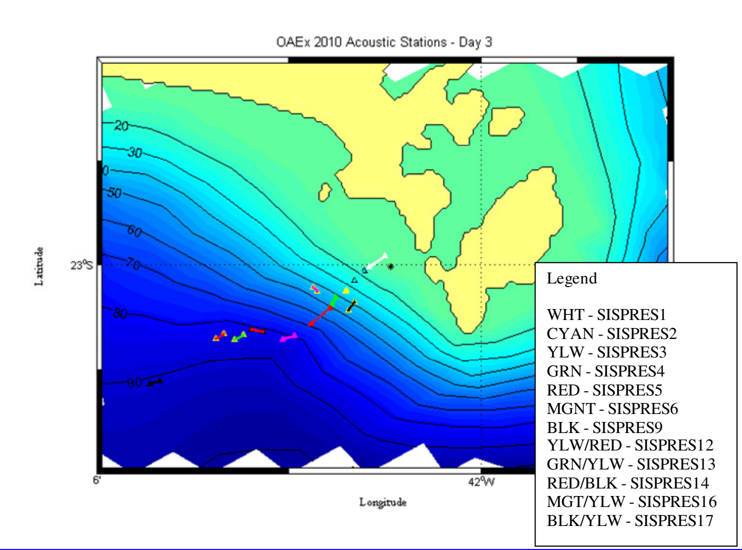
Summary

- Objective
- Methodology
- Results
- Conclusions
- Future Work

Methodology

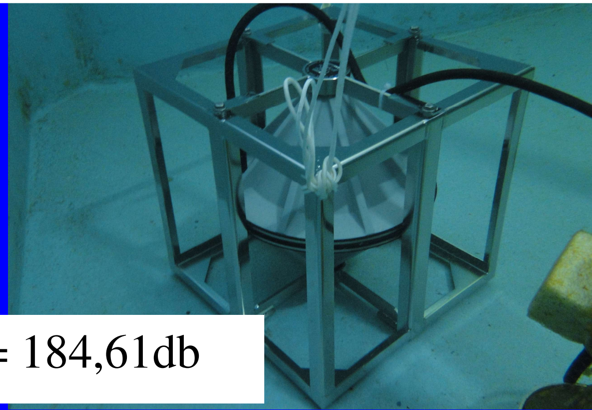


Methodology



Methodology

Frequency Khz	Transmit Voltage Volts	Transmit Current amps	Real Power watts	Z Magnitude ohms	Phase (Z) deg	SPL dB// dB//uPa	TVR dB// uPa/volt	TCR uPa/amp
1.00	80.09	7.92	349.50	10.11	-56.59	190.90	152.82	172.92
3.50	79.69	25.11	1961.84	3.17	-11.37	188.32	150.30	160.33

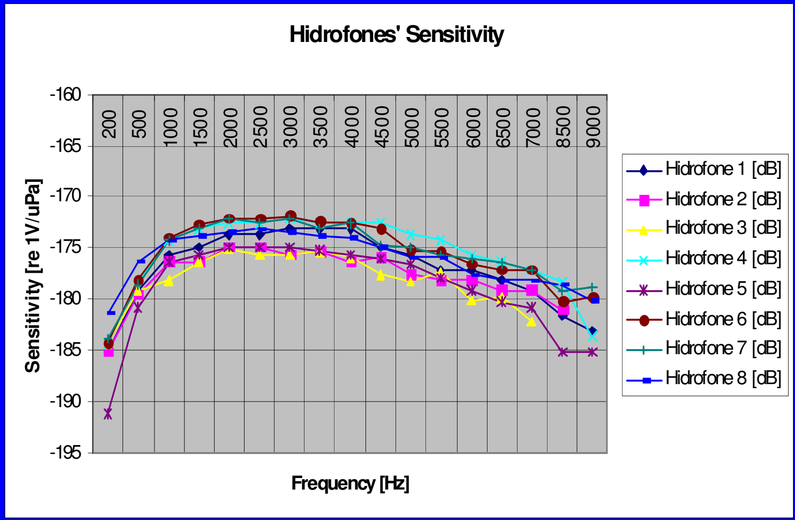


$SL_{dB} = 184{,}61\text{db}$

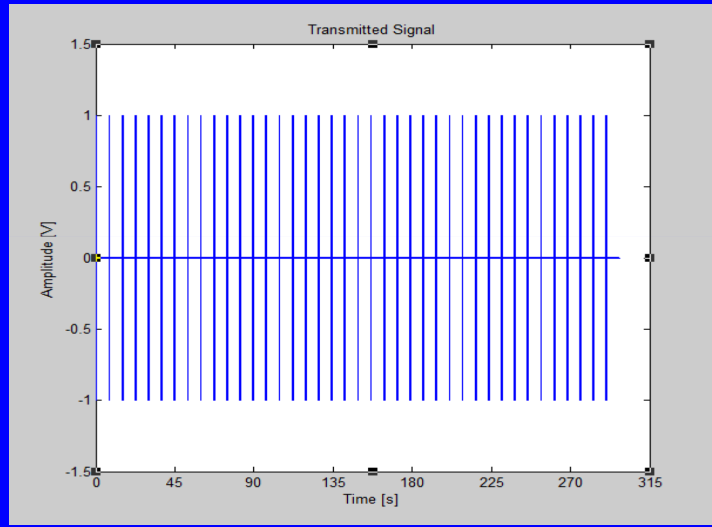
Methodology

Methodology

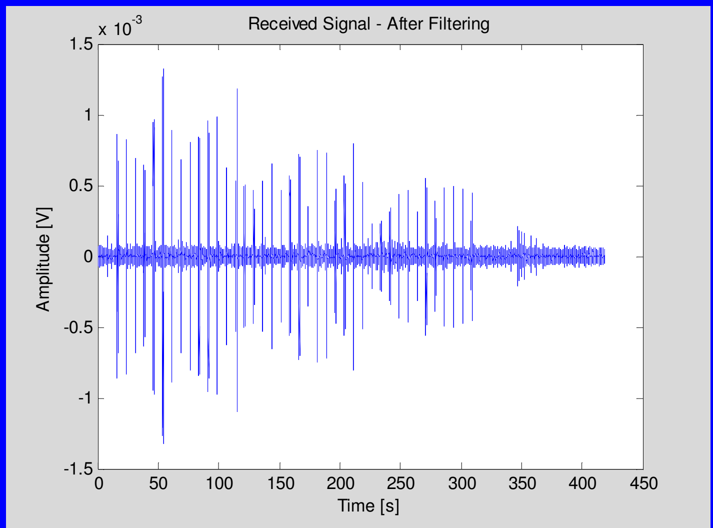
Methodology



Methodology



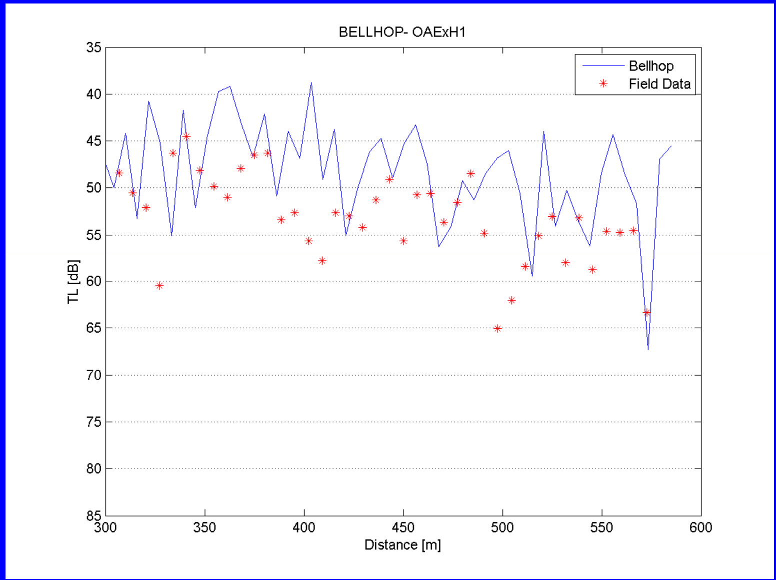
Methodology



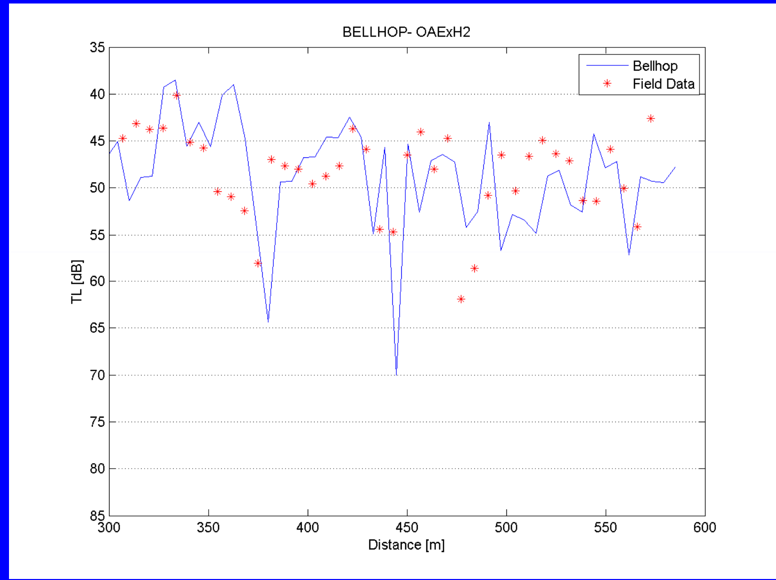
Summary

- Objective
- Methodology
- Results
- Conclusions
- Future Work

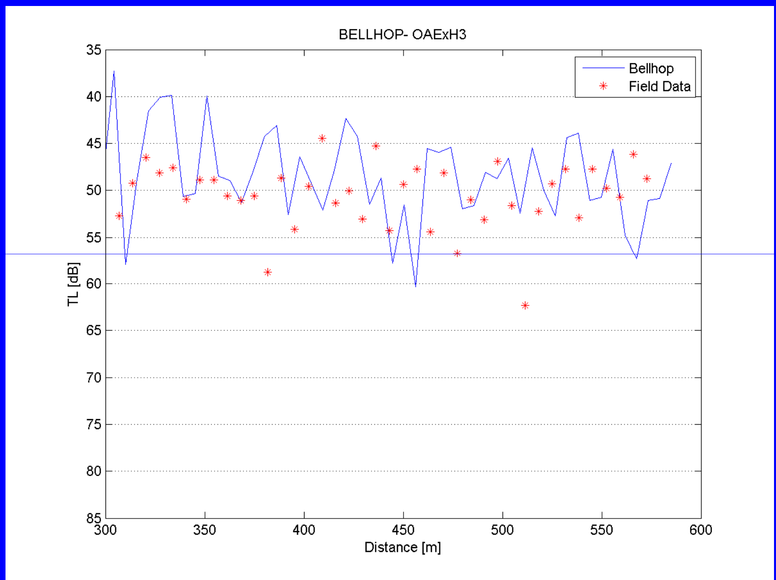
Results - Hydrophone 1



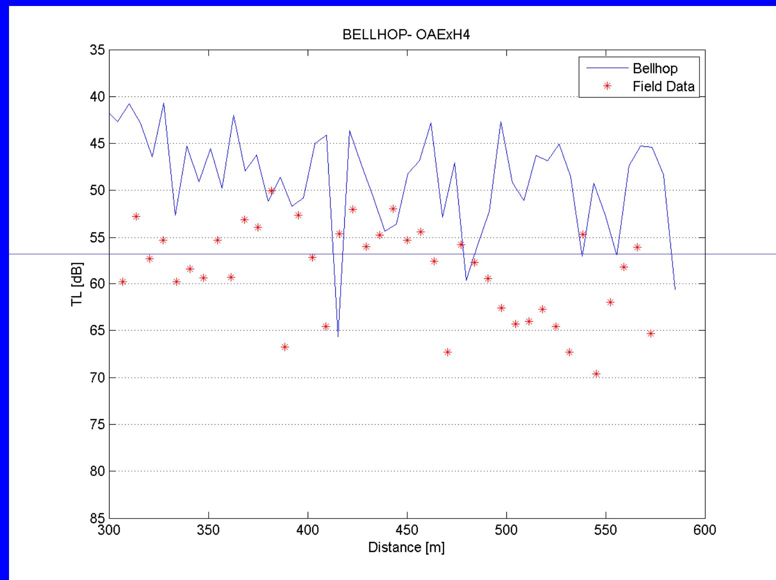
Results - Hydrophone 2



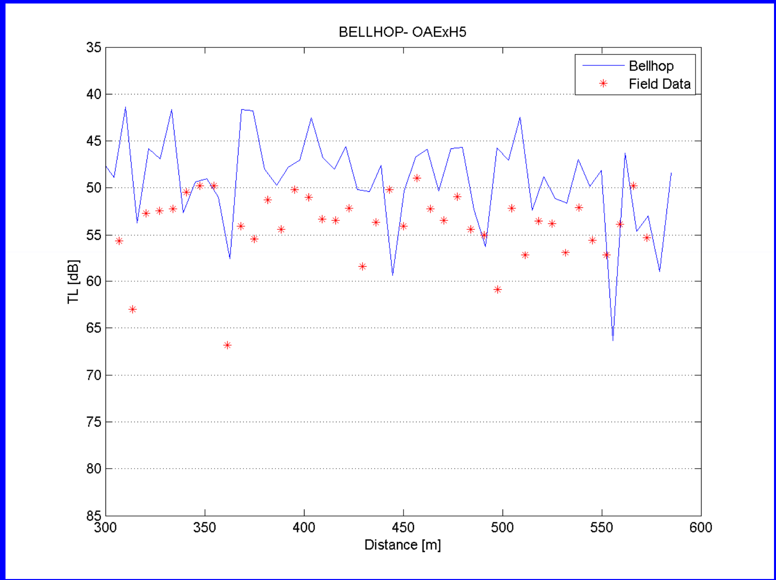
Results - Hydrophone 3



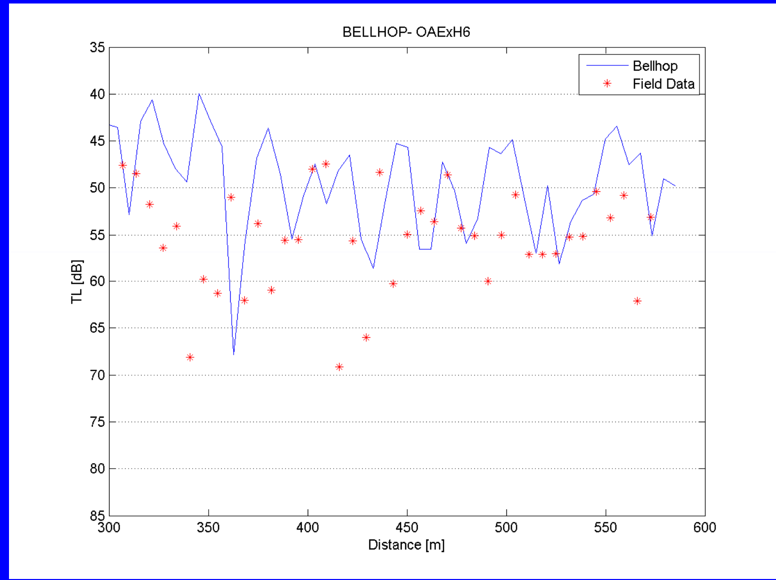
Results - Hydrophone 4



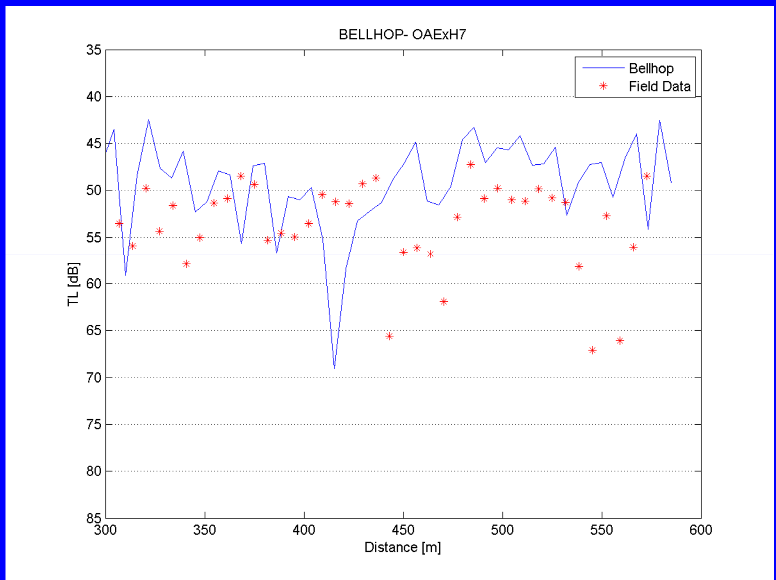
Results - Hydrophone 5



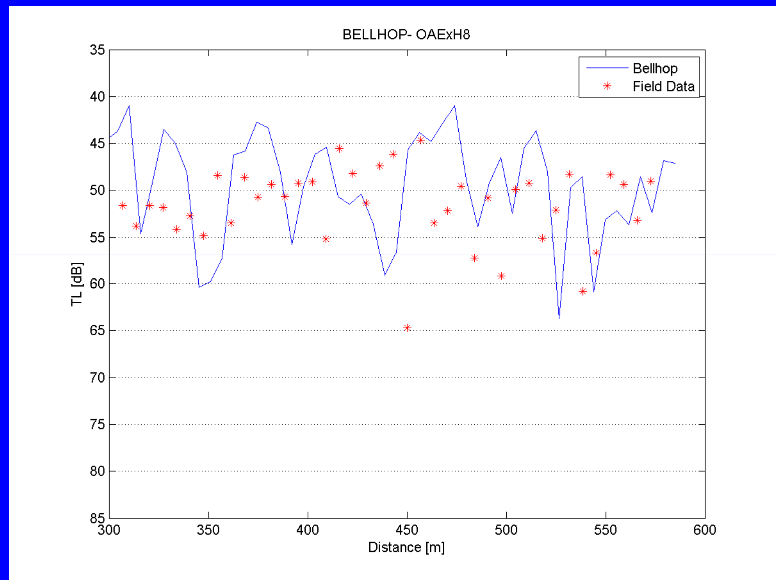
Results - Hydrophone 6



Results - Hydrophone 7



Results - Hydrophone 8



Summary

- Objective
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Conclusions

- ***Array's hydrophones successfully calibrated;***
- ***Good agreement between the experimental and Bellhop modeled data, considering the low distance variation and high frequency issues.***

Summary

- Objective
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Future Works

- ***Enhance experimental data with more distance variation;***
- ***Evaluation of the transmission loss from field data using wavelets;***
- ***Advance in the use of Bellhop model by adjusting its parameters based on the TL experimental data;***
- ***Implement other models such as Parabolic Equation .***

THANK YOU

QUESTIONS?

OAEx
Workshop

(June 28 2011)

NUMERICAL MODELING OF SIGNAL PROPAGATION IN THE CONDITIONS OF THE OAEx'10 EXPERIMENT

General Overview

- The OAEx'10 experiment
  - Site bathymetry
  - Acoustic source and array
  - Mean sound speed profile
- KRAKEN calculations
  - Normal modes
  - Transmissions loss calculations
- Bellhop calculations
  - Ray spreading for different source depths
  - Eigenrays and arrivals
  - Transmission loss for different source apertures
  - Impulse response
- Conclusions

Modeling signal propagation in the OAEx'10 experiment

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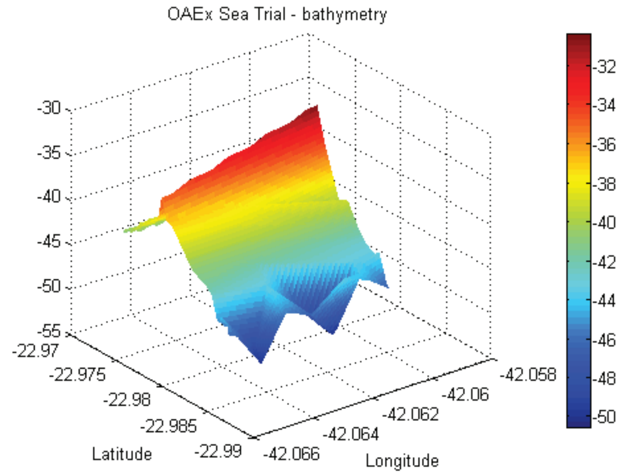
OAEx'10 bathymetry

Range ≈ 1500 m

OAEx'10 bathymetry



Characteristics (IEAPM):

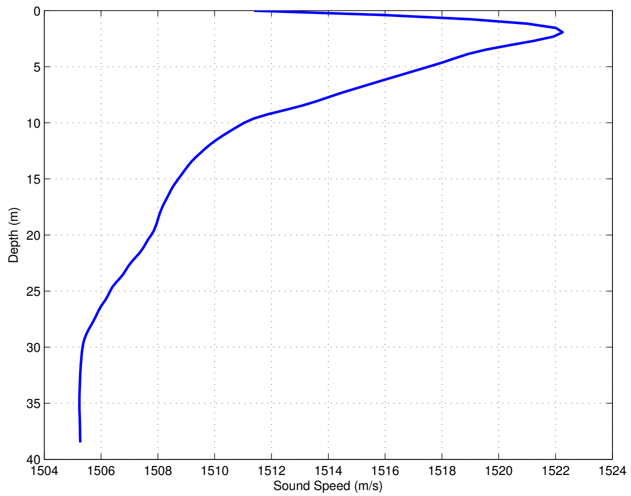
ρ	(g/cm^3)	≈	1,9
c_p	(m/s)	≈	1626
α_p	(dB/λ)	≈	0,8

OAEx'10 acoustic source and array

Lubel source

Hydrophone array

OAEx'10 mean sound speed profile



KRAKEN calculations

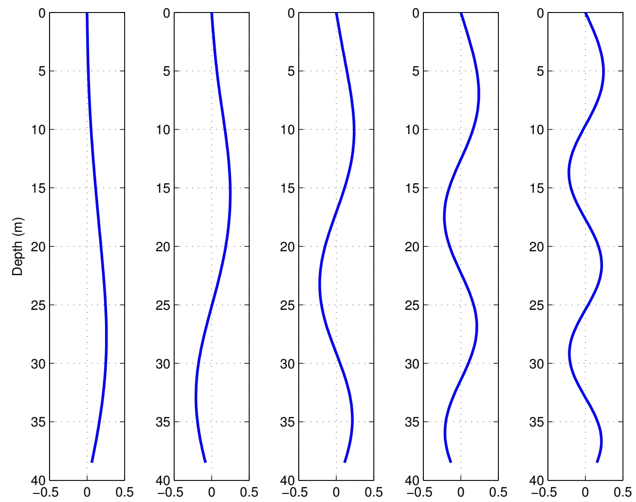
Normal mode expansion of acoustic pressure

$$P(r,z) = S(\omega)\frac{e^{i\pi/4}}{\rho(z_s)\sqrt{8\pi r}}\sum_{m=1}^{M} u_m(z_s)u_m(z)\frac{e^{ik_m r}}{\sqrt{k_m}}$$

where $u_m(z)$ are the acoustic modes and z_s is the source position.

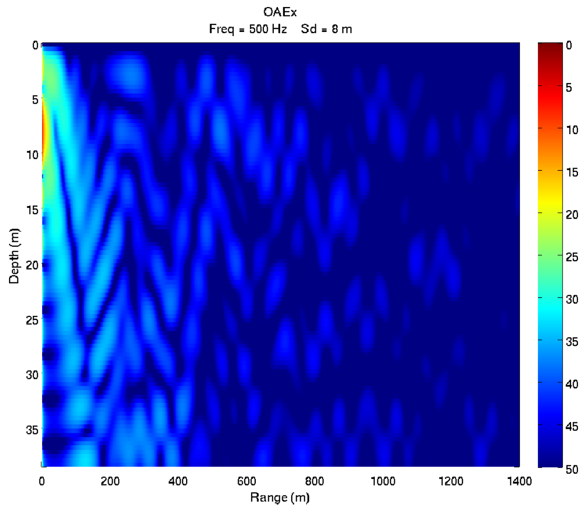
KRAKEN calculations

Acoustic modes @ 500 Hz:



KRAKEN calculations

Transmission loss @ 500 Hz



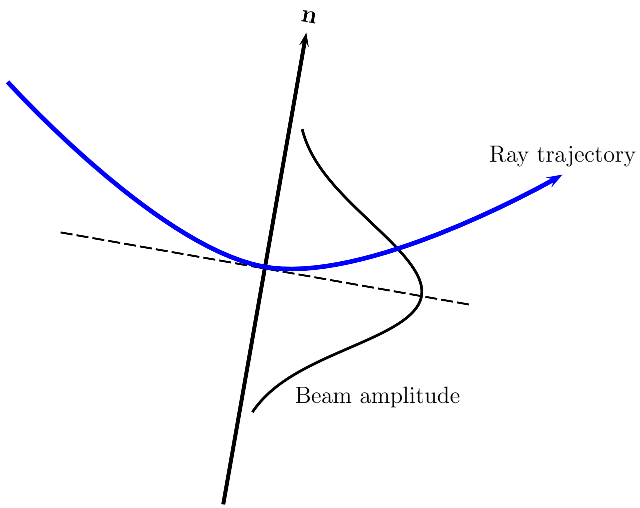
Bellhop calculations

Gaussian beams

Acoustic pressure along a ray:

$$P(s,n) = \frac{1}{4\pi}\sqrt{\frac{c(s)}{c(0)}\frac{\cos\theta(0)}{q_\perp(s)q(s)}}\ \exp\left[-i\omega\left(\tau(s)+\frac{1}{2}\frac{p(s)}{q(s)}n^2\right)\right]$$

where s is the ray arclenght and n is the ray normal.



Eikonal equations ("Kinematics" of ray tracing):

The trajectories that minimize $\tau(s)$ can be obtained solving the system

$$\frac{dr}{ds} = c(s)\sigma_r(s) \; , \quad \frac{d\sigma_r}{ds} = -\frac{1}{c^2}\frac{\partial c}{\partial r} \; ,$$

$$\frac{dz}{ds} = c(s)\sigma_z(s) \; , \quad \frac{d\sigma_z}{ds} = -\frac{1}{c^2}\frac{\partial c}{\partial z} \; .$$

"Dynamic" equations:

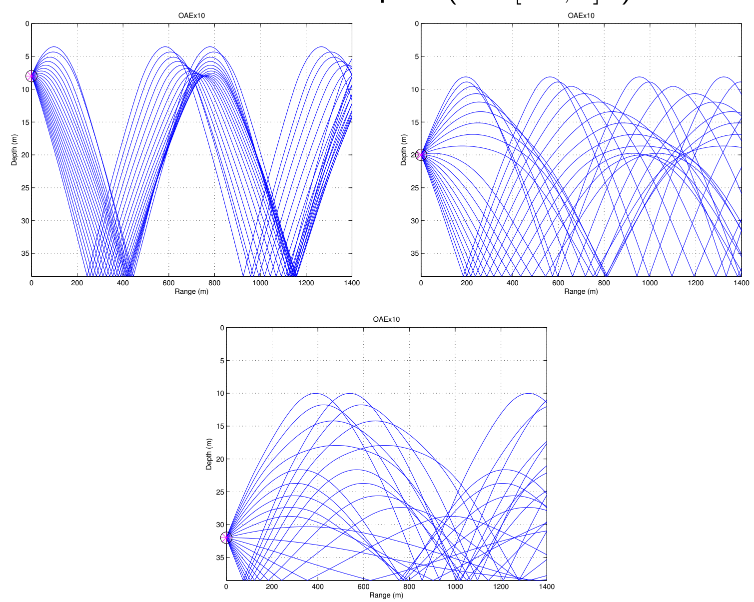
The beam influence depends on the parameters p and q, which are solutions of the system

$$\frac{dq}{ds} = c(s)p(s) \quad , \quad \frac{dp}{ds} = -\frac{c_{nn}}{c^2}q(s) \; .$$

where

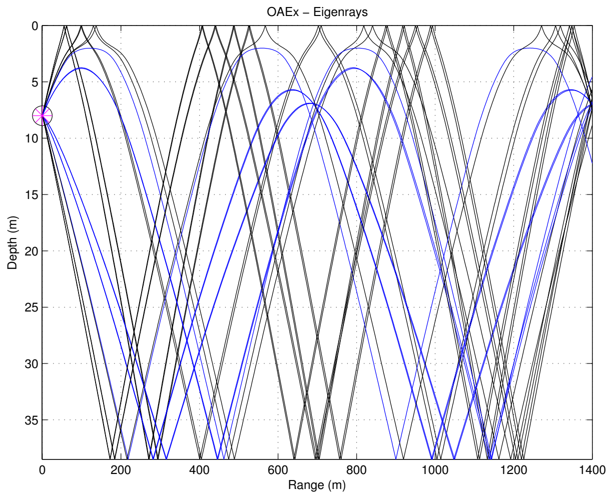
$$c_{nn} = \left(\frac{dr}{dn}\right)^2 c_{rr} + 2\left(\frac{dr}{dn}\right)\left(\frac{dz}{dn}\right) c_{rz} + \left(\frac{dz}{dn}\right)^2 c_{zz} \; .$$

Different source depths ($\theta \in [-5, 5]\,^\circ$)



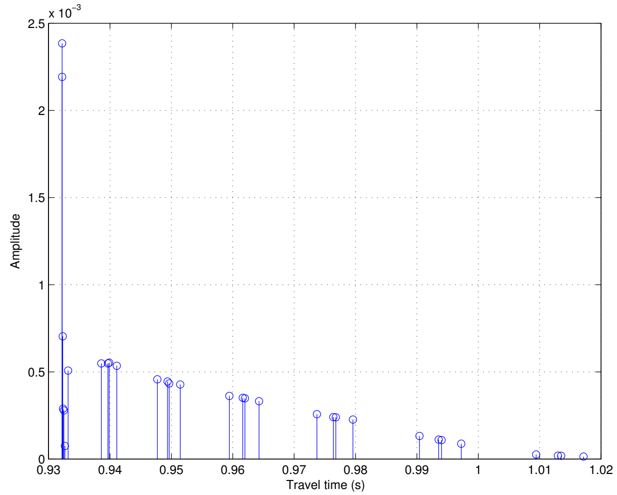
Bellhop calculations

Eigenrays



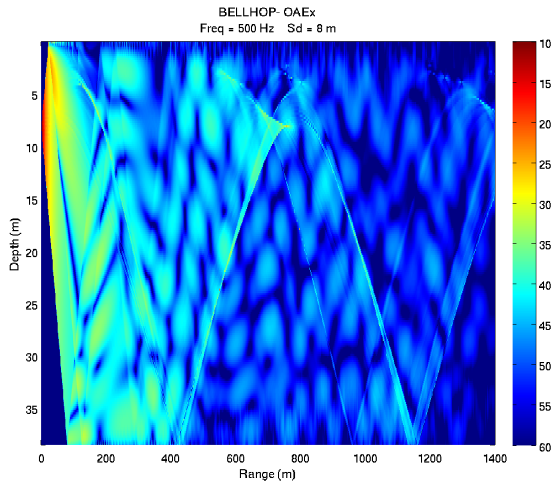
Bellhop calculations

Arrivals



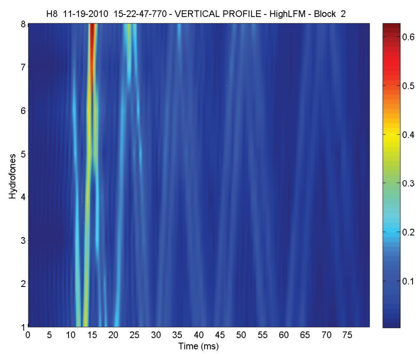
Bellhop calculations

Coherent Transmission Loss

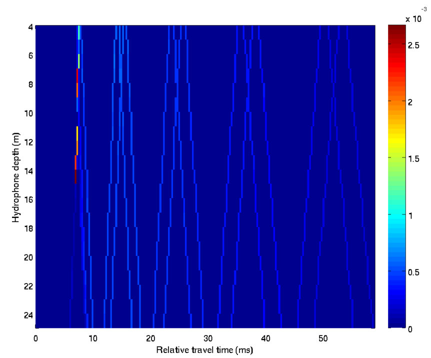


Bellhop calculations

Impulse response:



Real



Modeled

Conclusions

- There is a remarkable good agreement between real data and model predictions despite the improvised nature of assumptions regarding waveguide geometry.
- Acoustic models complement perfectly each other pointing to particularities of signal propagation (like the excitation of higher order modes) that could be missed by relying on a single model.
- A further review of environmental data is higly recommended in order to improve model accuracy.
- The environmental complexity of the waveguide deserves the development of further predictions using models, which rely on different approximations (like, for instance, the parabolic equation).

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OBRIGADO PELA VOSSA ATENÇÃO

Bayesian sonar performance prediction perspectives for Cabo Frio

N. Martins[1] and L. Calado[2]

SEVENTH FRAMEWORK PROGRAMME

[1]Institute for Systems and Robotics
University of Algarve, SiPLAB
Portugal

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

II OAEx Workshop, June 2011

Sonar —passive sonar equation

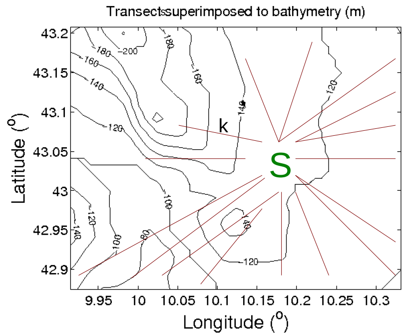
Transmission loss ↑ · Directivity index ↑

$$SL - TL - NL + DI = DT$$

↓ Source level · ↓ Noise level · ↓ Detection threshold

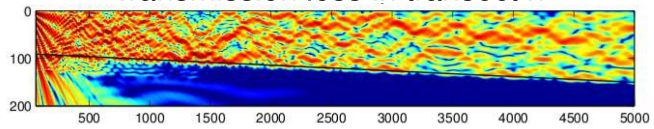
Acoustic prediction

At present time t_P, determine the acoustic field at future time t_F, in a given area



S: acoustic source

Transmission loss in transect *k*

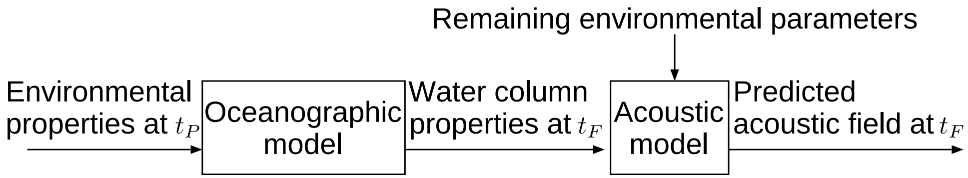


Acoustic field = ?

Physics, data and models

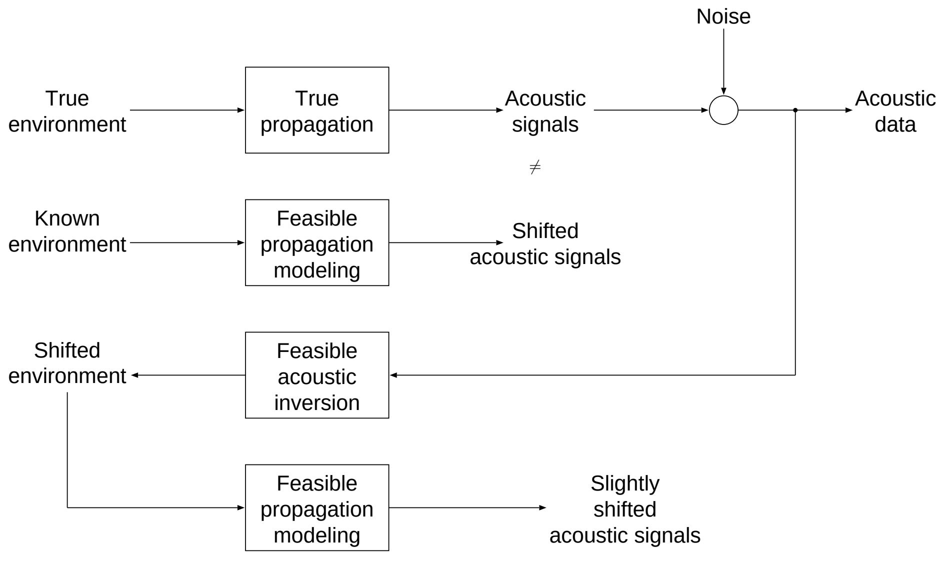
- Physics
  - Environment evolves with time
  - Acoustic propagation = function(environmental properties)
- Data
  - Oceanographic: water column temperature, ocean floor samples, nautical charts, etc.
  - Acoustic: hydrophone array system(s)
- Models
  - Environmental: oceanographic prediction system
  - Acoustic: ray tracing, normal-mode, parabolic equation, etc.

Standard acoustic prediction cell



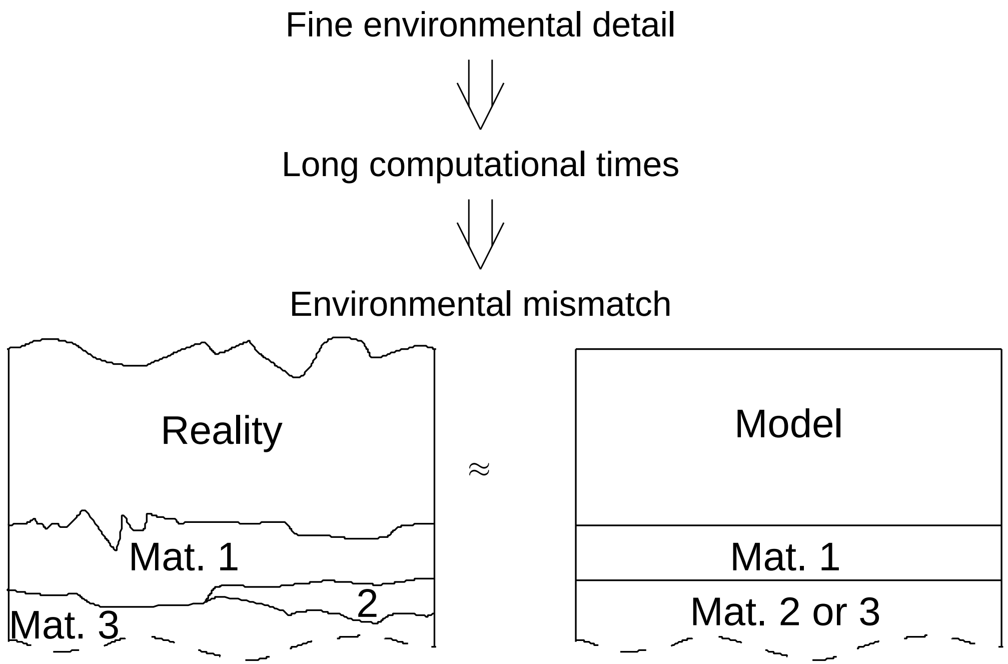
Strong point: computational speed

Real forward and inverse acoustic modeling

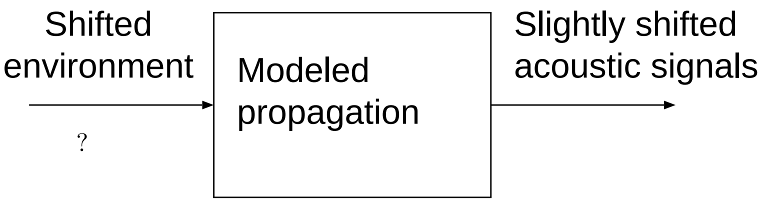


Present time

Modeling is just an approximation!



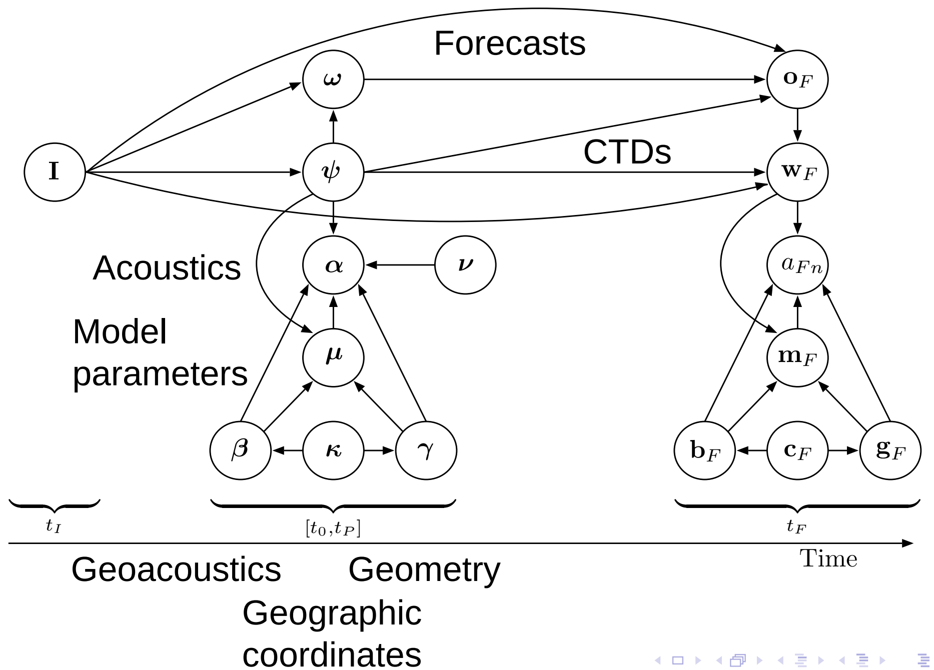
Motivation



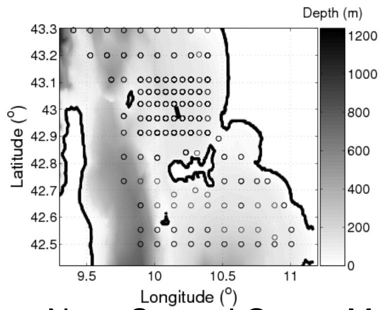
Future time

Learn shifts from forecasts/measures, w/ past data

An ocean of information



Application example: MREA'03 data set



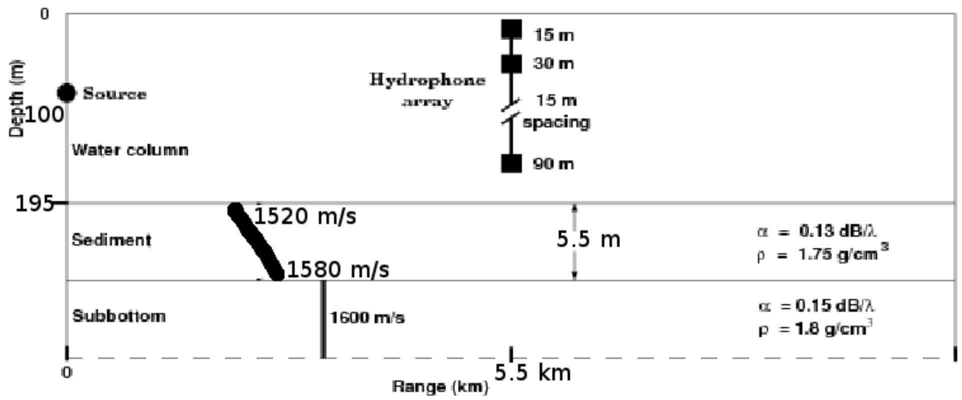
CTD casts in the MREA'03 sea trial - Elba Island
(142 × 87.9 km)

Acoustic field simulations: Julian day (JD) 151–175

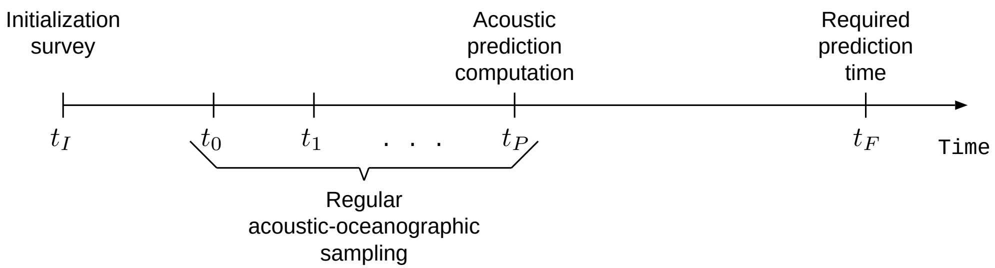
- Navy Coastal Ocean Model (NCOM)[1]
- SACLANTCEN normal-mode acous. prop. model (SNAP)[2] and SNAP w/ adiabatic approximation (ground truth acoustics)

[1] Martin P., "Description of the Navy Coastal Ocean Model version 1.0", ...
[2] F.B. Jensen and M.C. Ferla,"SNAP: The SACLANTCEN normal-mode acoustic propagation model", SM-121, SACLANT...

Acoustic propagation transect



Simulation parameters



Acoustic prediction time line

- Mismatch: EOF representation (3 EOFs (87% of the variance) for 465 profiles)
- Frequencies: 10 tones in [540–900] Hz ($1.7 < \lambda < 2.8$ [m])
- 50 time samples in $[t_0, \ldots, t_F]$
- Use the information up to time $t_P = t_{25}$, to predict for the posterior times
- Step: 12 h

Acoustic propagation model parameters

- Water column SSP 1st EOF coefficient
- Water column SSP 2nd EOF coefficient
- Water column SSP 3rd EOF coefficient
- Sediment comp. speed at water-sediment interface
- Sediment comp. speed at sediment-subbottom interface
- Sediment thickness
- Subbottom comp. speed

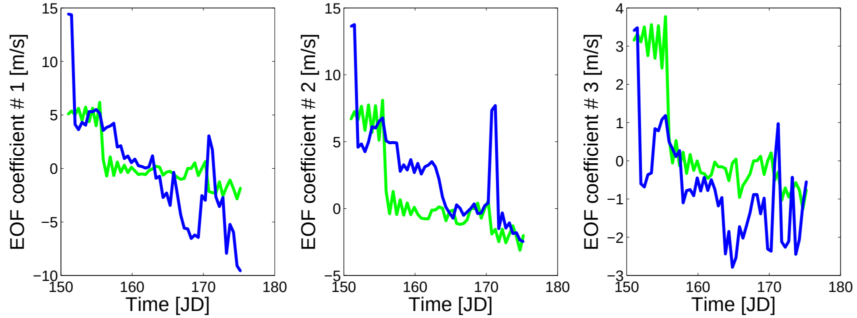
PDF to estimate

$$p(a_{Fn}|\mathbf{c},\mathbf{g},\mathbf{o}_F) \;=\; (\cdot)\int \underbrace{p(a_{Fn}|\mathbf{m}_F)}_{\text{Information about the future acoustic field}}\;\underbrace{p(\mathbf{m}_F|\mathbf{c},\mathbf{g},\mathbf{o}_F)}_{\text{Information about the future propagation model parameters}}\;\mathrm{d}\mathbf{m}_F$$

Information about the future acoustic field

Information about the future propagation model parameters

Water column measures vs. forecasts



Measure   Forecast

PDF approximations

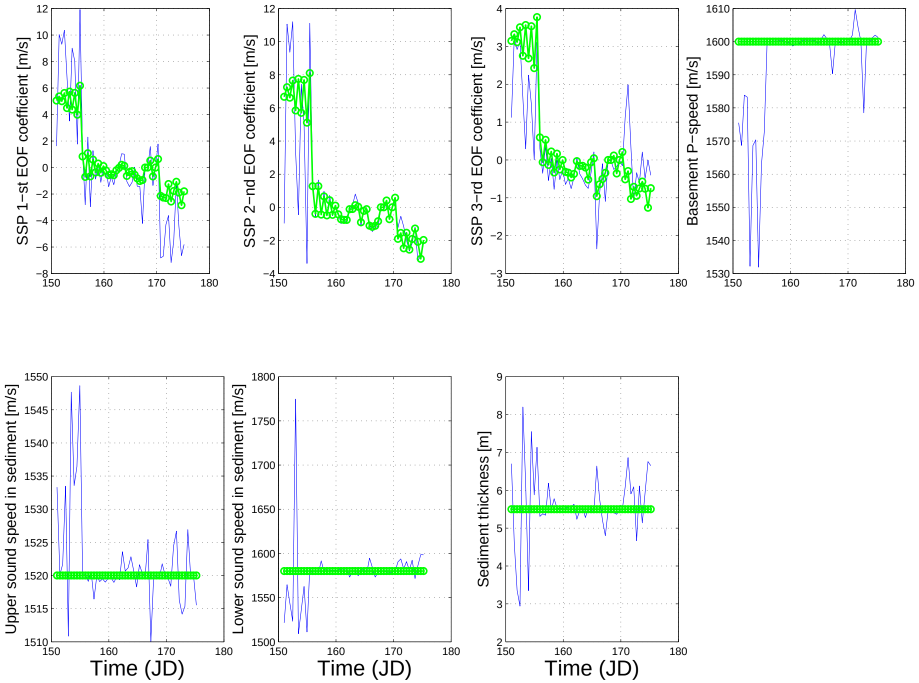
- Vector to scalar: $p(\mathbf{m}_F|\mathbf{c},\mathbf{g},\mathbf{o}_F) \approx \prod_{q=1}^{7} p(m_q|\mathbf{c},\mathbf{g},\mathbf{o}_F)$
- Homologous quantities:

$p(m_{w1}|\mathbf{c},\mathbf{g},\mathbf{o}_F) \approx p(m_{w1}|o_1)$, the same for other EOFs

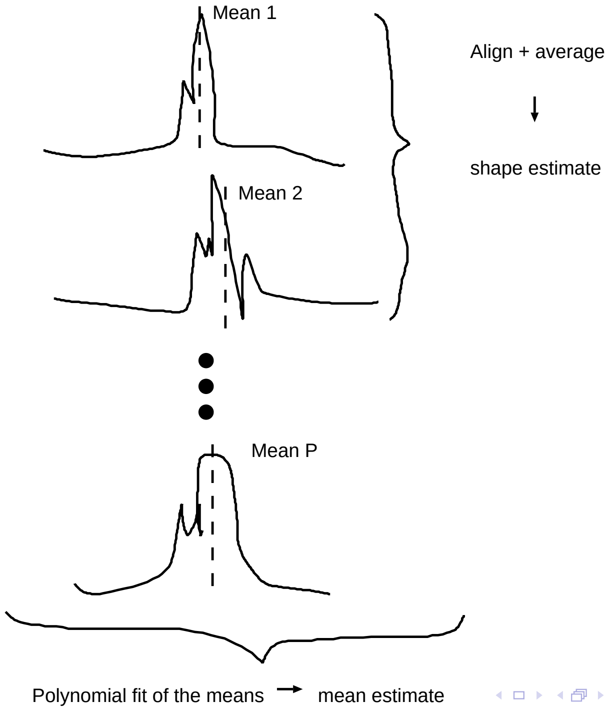
$p(m_p|\mathbf{c},\mathbf{g},\mathbf{o}_F) \approx p(m_p|\mathbf{c})$, the same for other seafloor params.

- No acoustic model parameters realizations: $p(m_{w1}|o_1) \approx p(m_{w1}|\mathbf{a}_p)$, etc.

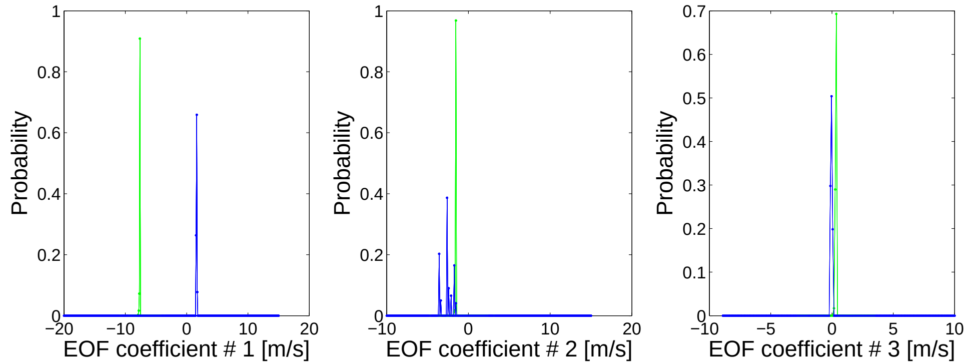
Acoustic inversion results



p(future propagation model parameters | other)



Future environmental posterior densities estimates



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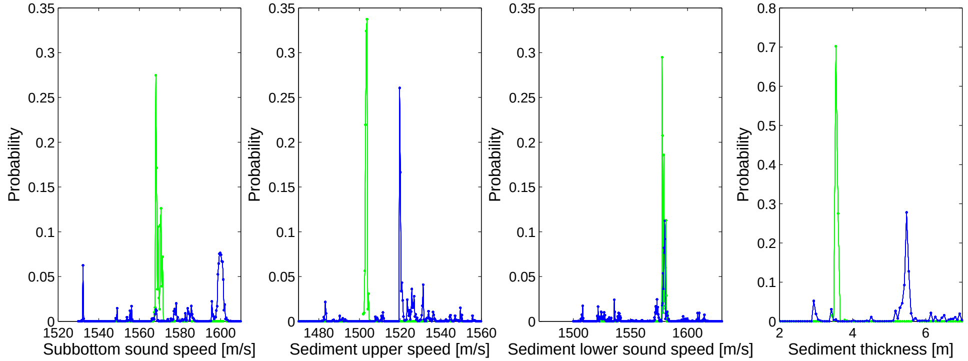
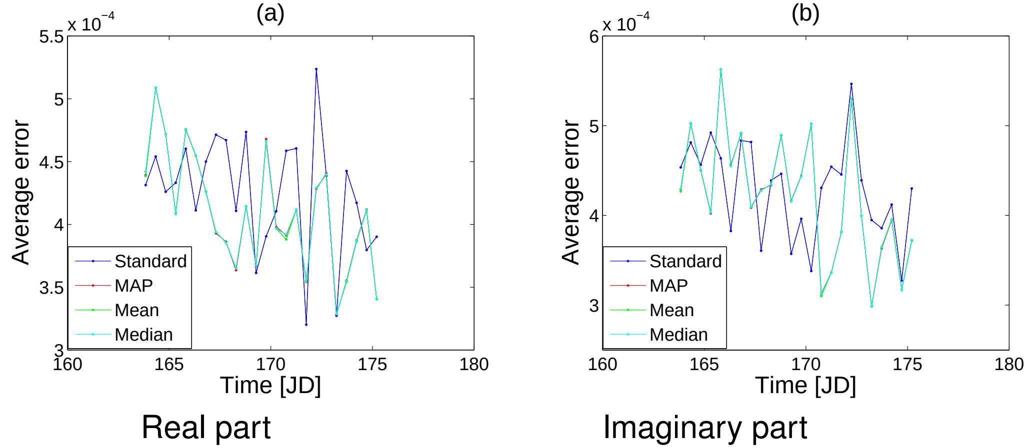
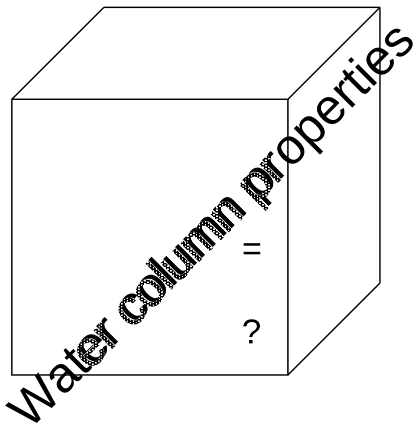


Acoustic field estimate error



Problem: to determine instantaneous three-dimensional water column properties (sound speed or temperature field, etc.)



Applications: oceanography, oceanic engineering, sonar performance prediction, biology, etc.

3D EOF parametrization

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

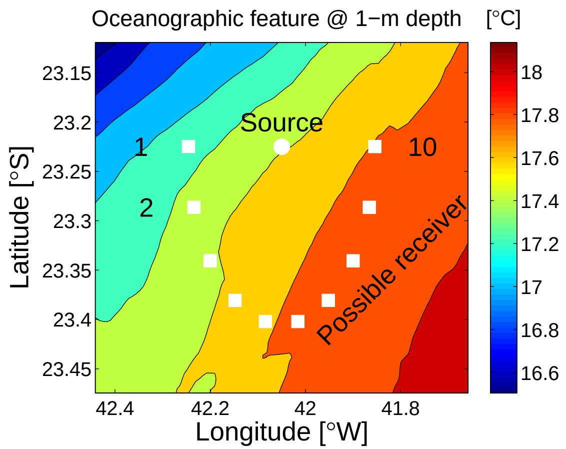
$\bar{c}(x,\ y,\ z)$: average 3D sound speed field

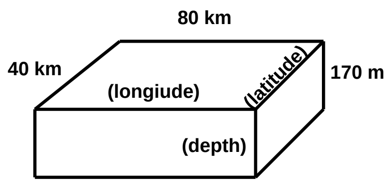
α_k: coefficients

$E\hat{O}F_k(x,\ y,\ z)$: 3D k-th EOF estimate (Latitude-, longitude- and depth-dependent) α_k is representative of the full 3D space. $\Rightarrow$ an estimate of the coefficients obtained w/ data from any region inside the volume allows to estimate the field in the whole volume

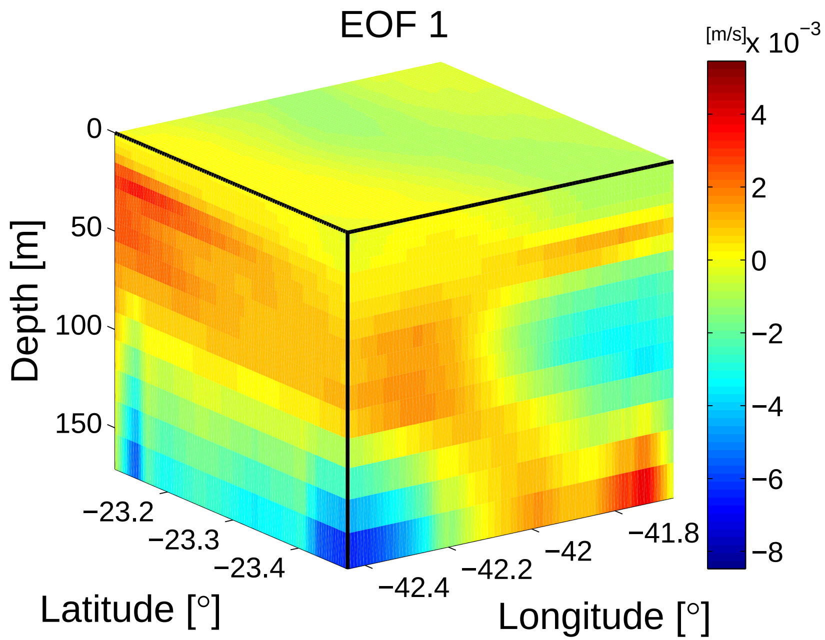
Test case: feature horizontal section + acoustics

Feature to estimate: 31st December ROMS model output



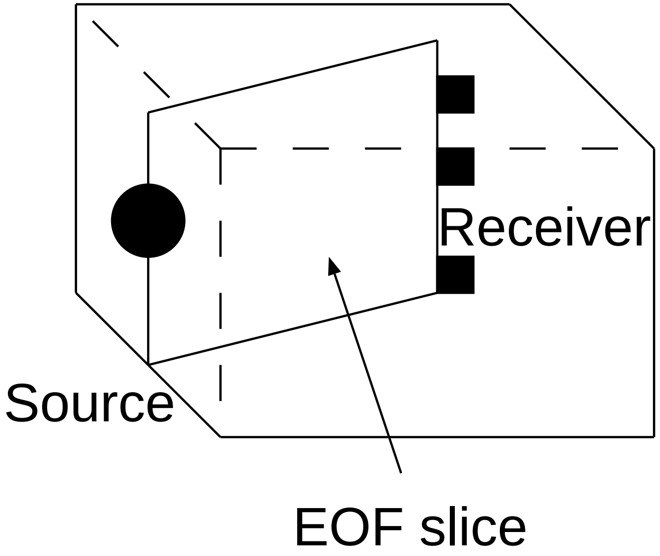


Test case: 3D EOF plots



Up to 8

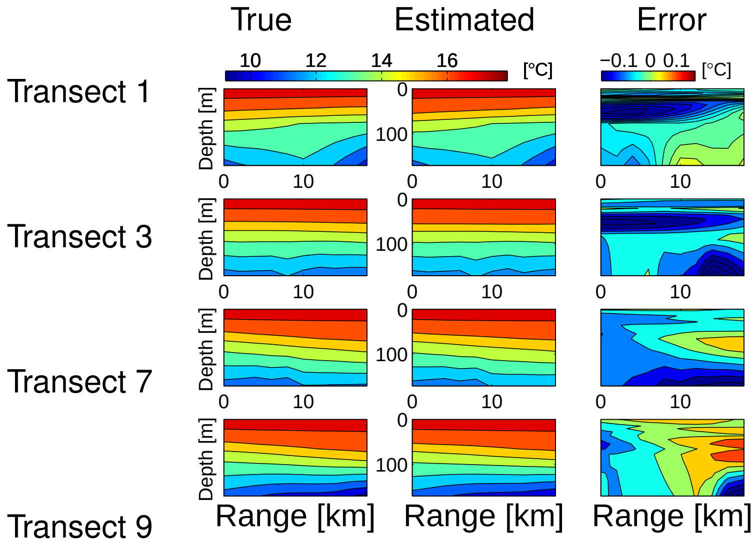
Test case: EOFs in acoustic inversion



Source: 20-m depth
Receiver: 1–46 m 10 hydrophone array
20-km range

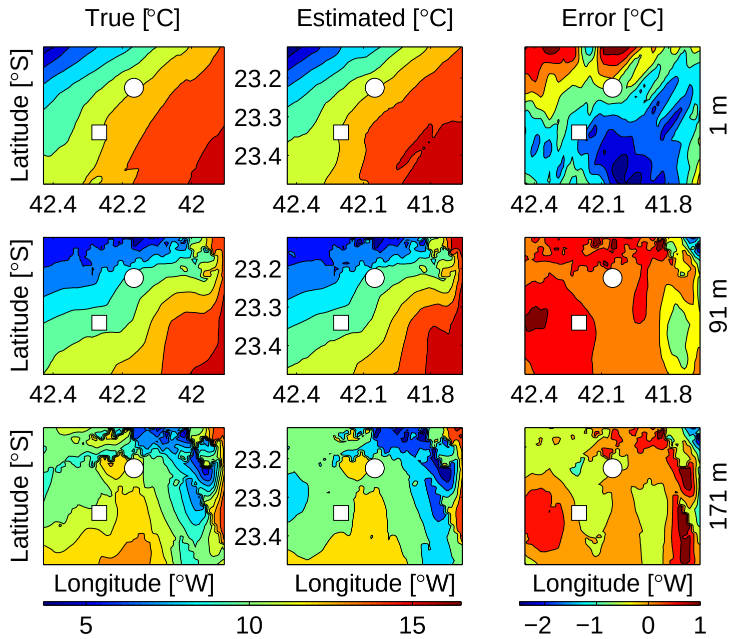
500 and 1000 Hz

Test case: estimates of the acoustically observed slices (vertical view)



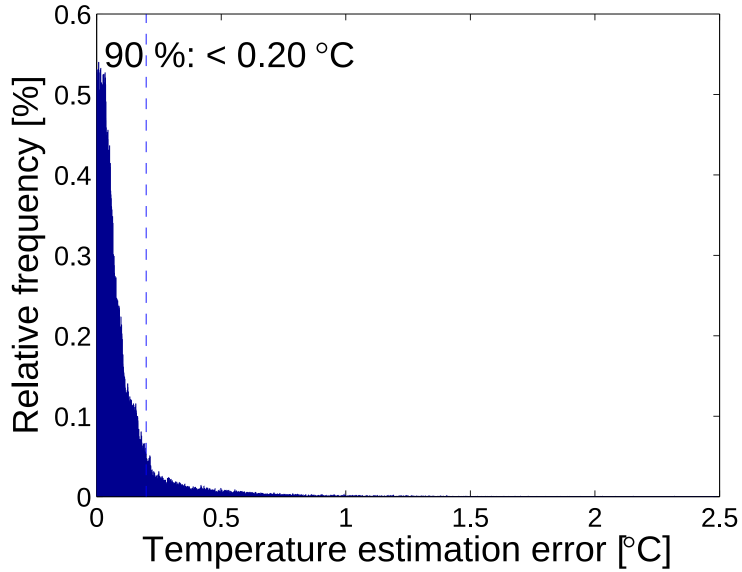
Test case: Transect 3

Latitude × longitude view, constant depths



Test case: Acoustic inversion results

Ocean volume estimation error statistics



Future work

- Synchronize

  Measures | Forecasts | Inversion outcomes (Bellhop, SAGA, etc.)

  in space and time
- Predict the acoustic signals in selected transects, using the appropriate Bayesian network
- Solve the sonar equation

Further: use 3D EOFs

Thank you