

1st ESF Exploratory Workshop on Seismic Oceanography

(c) Data belonging to the EU project GO



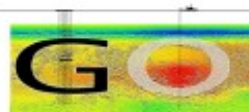
Begur, Girona (Spain), 18-21 November 2008

Convened by:

**Valenti Sallares ^①, Ramon Carbonell ^②, Richard Hobbs ^③,
Josep Lluís Pelegrí ^④, and Nuno Serra ^⑤**

-
- ^① Unitat de Tecnologia Marina, CMIMA-CSIC, Barcelona, ES
^② Institut de Ciències de la Terra Jaume Almera – CSIC, Barcelona, ES
^③ Department of Earth Sciences, University of Durham, UK
^④ Institut de Ciències del Mar, CMIMA-CSIC, Barcelona, ES
^⑤ Institut für Meereskunde, Universität Hamburg, DE
-

Co-sponsored by



ESF Exploratory Workshop on **Seismic Oceanography**

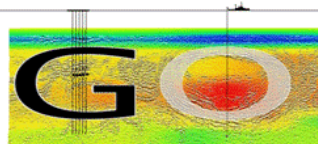
Begur, Girona (Spain), 18-21 November 2008

Convened by:

**Valenti Sallares ^①, Ramon Carbonell ^②, Richard Hobbs ^③,
Josep Lluís Pelegrí ^④, and Nuno Serra ^⑤**

-
- ^① Unitat de Tecnologia Marina, CMIMA-CSIC, Barcelona, ES
^② Institut de Ciències de la Terra Jaume Almera – CSIC, Barcelona, ES
^③ Department of Earth Sciences, University of Durham, UK
^④ Institut de Ciències del Mar, CMIMA-CSIC, Barcelona, ES
^⑤ Institut für Meereskunde, Universität Hamburg, DE
-

Co-sponsored by





The European Science Foundation (ESF) is an association of 77 Member Organisations devoted to scientific research in 30 European countries. The Mission of ESF is to provide a common platform for its Member Organisations in order to advance European research and to explore new directions for research at the European level. Through its activities, the ESF serves the needs of the European research community in a global context.

The main objectives of ESF for the years 2006-2010 as defined by its current *Strategic Plan* are to promote Science Strategy and Science Synergy, paving the way for initiatives across disciplinary and geographic boundaries in the European Research Area (ERA).

The Exploratory Workshops scheme is one of the key instruments of the Science Strategy “pillar”. Each year, ESF supports approximately 50 Exploratory Workshops across all scientific domains. The focus of the scheme is on workshops aiming to explore an emerging and/or innovative field of research or research infrastructure, also of interdisciplinary character. Workshops are expected to open up new directions in research or new domains. It is expected that a workshop will conclude with plans for specific follow-up research activities and/or collaborative actions or other specific outputs either within the frame of ESF (e.g. prepare the ground to develop a [Forward Look](#), a [Research Networking Programme](#) or a [EUROCORES](#) proposal; publication of a Policy Briefing...) or for submission to the EU 7th Framework Programme or to other European or international funding organisations.

European Science Foundation

1 quai Lezay Marnésia
BP 90015
67080 Strasbourg Cedex
France
Fax: +33 (0)3 88 37 05 32
<http://www.esf.org>

ESF Exploratory Workshops:

Nina Kancewicz-Hoffman
Scientific Coordinator

Valerie Allspach-Kiechel
Senior Administrator
Tel: +33 (0)3 88 76 71 36

Isabelle May
Administrator
Tel: +33 (0)3 88 76 71 46
Email: ew-office@esf.org
<http://www.esf.org/workshops>

Convenors

Valentí Sallarès
vsallares@cmima.csic.es
Tel: +34-932 309 623

Unitat de Tecnologia Marina - CMIMA - CSIC
Passeig Marítim de la Barceloneta, 37-49
08003 Barcelona, Spain.

Co-convenors

Ramon Carbonell
rcarbo@ija.csic.es
Tel: +34 971 172365

Institut de Ciències de la Terra Jaume Almera –
CSIC.
Lluís Solé i Sabarís, s/n
08028 Barcelona, Spain.

Richard Hobbs
r.w.hobbs@durham.ac.uk
Tel: + +44 (0)191 334 4295

NERC Advanced Research Fellow
Department of Earth Sciences, University of
Durham
South Road
Durham DH1 3LE, UK.

Josep Lluís Pelegrí
pelegri@icm.csic.es
Tel: +34-932 309 500

Institut de Ciències del Mar - CMIMA – CSIC
Passeig Marítim de la Barceloneta, 37-49
08003 Barcelona, Spain.

Nuno Serra
nserra@fc.ul.pt

Institut für Meereskunde Zentrum für Marine und
Atmosphärische
Wissenschaften
Universität Hamburg
Bundesstrasse, 53
20146 Hamburg, Germany.

Local committee

Berta Biescas Gorriz
biescas@cmima.csic.es

Unitat de Tecnologia Marina - CMIMA - CSIC
Passeig Marítim de la Barceloneta, 37-49
08003 Barcelona, Spain.

Mar Tapia Jiménez
mtapia@cmima.csic.es

Institut de Ciències del Mar - CMIMA – CSIC
Passeig Marítim de la Barceloneta, 37-49
08003 Barcelona, Spain.

Grant Buffet
gbuffer@ija.csci.es

Institut de Ciències de la Terra Jaume Almera –
CSIC.
Lluís Solé i Sabarís, s/n
08028 Barcelona, Spain

GENERAL PROGRAM

1st ESF EXPLORATORY WORKSHOP ON SEISMIC OCEANOGRAPHY

Parador d'Aiguablava, Begur (Spain)

November 19-21, 2008

Tuesday, November 18th

- 18:30** Shuttle from Barcelona airport to hotel Parador d'Aiguablava
- 17:00** Shuttle from Girona airport to hotel Parador d'Aiguablava
- 21:00** Dinner at the Parador

Wednesday, November 19th

- 8:00** **Welcome** speech by CSIC representative
- 8:10** ESF Presentation by ESF Rapporteur
- 8:20** Keynote introductory speech by W. Steven Holbrook
- 9:00** S1. Physical processes in oceanography (I)
- 10:20** Coffee break
- 10:50** S1. Physical processes in oceanography (I)
- 13:10** Lunch at the Parador
- 14:30** S2. Imaging and inversion of seismic data (I)
- 15:50** Coffee break
- 16:20** S2. Imaging and inversion of seismic data (I)
- 21:00** Dinner at Restaurant Mar i Vent

Thursday, November 20th

- 8:00** S3. Physical processes in oceanography (II)
- 10:00** Coffee break
- 10:30** S3. Physical processes in oceanography (II)
- 13:10** Lunch at the Parador
- 14:30** S4. Imaging and inversion of seismic data (II)
- 16:10** Coffee break
- 17:30** Visit Pals-Peratallada
- 21:00** Dinner at Restaurant Bonay (Peratallada)

Friday, November 21th

- 8:00** Open discussion
- 10:30** Coffe break
- 11:00** Draft of conclusions
- 13:00** **Goodbye**
- 13:10** Lunch at the Parador
- 14:00** Shuttle from the hotel to Barcelona/Girona airport

Saturday, November 22th

- 6:00** Shuttle from the hotel to Girona/Barcelona airport

SCIENTIFIC PROGRAM

1st ESF EXPLORATORY WORKSHOP ON SEISMIC OCEANOGRAPHY

Parador d'Aiguablava, Begur (Spain)

November 19-21, 2008

Wednesday, NOVEMBER 19th

ORAL: *Keynote (30'+10')*, *Other (15'+5')*

OPENING

- 8:00 WELCOME to the 1st ESF Exploratory Workshop on Seismic Oceanography
Juan José Dañobeitia (CSIC Representative, UTM Director)
- 8:10 Presentation of the European Science Foundation (ESF)
Isabel Ambar (ESF Rapporteur)
- 8:20 **S0.1. KEYNOTE SPEECH:** Five years of Seismic Oceanography: Successes, Challenges, and Future Directions.
W. Steven Holbrook

S1. PHYSICAL PROCESSES IN OCEANOGRAPHY (I)

Chair: *Nuno Serra*

- 9:00 **S1.1. KEYNOTE SPEECH:** Ocean processes that create seismic reflectors
Barry Ruddick
- 9:40 **S1.2.** T-S filaments generated by eddy stirring and seismic imagery
R. Ferrari
- 10:00 **S1.3.** Meddies: structure and evolution
L. Armi
- 10:20-10:50 **Posters & Coffee Break**
- 10:50 **S1.4.** Simulations of stratified turbulence surrounding Meddy structures
L. Hua
- 11:10 **S1.5.** Hydrodynamic, thermodynamic, and acoustic properties of large-amplitude internal waves
L. St. Laurent
- 11:30 **S1.6.** Spontaneous generation of Inertia-gravity waves by balanced flow in the ocean
A. Viúdez
- 11:50–13:10 **Open Discussion**

S2. IMAGING AND INVERSION OF SEISMIC DATA (I)

Chair: *Ramon Carbonell*

14:30 **S2.1. KEYNOTE SPEECH:** What does a seismic section represent?
Richard Hobbs

15:10 **S2.2.** Potential and limits of seismic methods to image oceans finestructure
V. Sallarès, B. Biescas, R. Carbonell, G. Buffet, J.L. Pelegrí, J.J. Dañobeitia

15:30 **S2.3.** Simulation of a seismic dataset over a model of a dynamic ocean
E. Vsemirnova, R. Hobbs and N. Serra

15:50-16:20 **Posters & Coffee Break**

16:20 **S2.4. KEYNOTE SPEECH:** Acoustic wave propagation and inversion of
physical parameters
Dirk Klaeschen

16:40 **S2.5.** Second-order CFS-PML algorithm for modelling seismic oceanography
experiments.
J. Kormann, B. Biescas, P. Cobo, V. Sallarès, R. Carbonell

17:20 **S2.6.** Seismic processing and inversion methods in seismic oceanography –
latest results.
B. Papenberg and D. Klaeschen

17:40 **S2.7.** Two dimensional temperature profile in the Kuroshio Current using
fullwaveform inversion
T. Tsuji, S. Minato, T. Matsuoka, T. Noguchi, Y. Nakamura and Y. Fukao

18:00-19:30 **Open Discussion**

19:30 **Oral presentation of posters (5' each)**

Thursday, NOVEMBER 20th

S3. PHYSICAL PROCESSES IN OCEANOGRAPHY (II)

Chair: *Barry Ruddick*

- 8:00 **S3.1. KEYNOTE SPEECH:** Quantifying physical processes with seismic oceanography
Raymond W. Schmitt
- 8:40 **S3.2.** Understanding horizontal internal wave and turbulence spectra
J. M. Klymak and J. N. Moum
- 9:00 **S3.3.** Quantifying Ocean Mixing Processes Through Stochastic Heterogeneity Mapping
G. Buffet, R. Carbonell, B. Biescas, V. Sallarès
- 9:20 **S3.4.** Deep internal waves and vertical thermal structure affected by the passage of a Meddy in the open Canary Basin.
L. Gostiaux, and H. van Haren.
- 9:40 **S3.5.** The generation of Mediterranean water eddies: in situ observations and numerical simulations
N. Serra and I. Ambar
- 10:00-10:30 **Posters & Coffee Break**
- 10:30 **S3.6.** Analysis of the Yoyo-CTD at the Meddy's Edge.
G. Krahnemann, M. Vogt and P. Brandt
- 10:50 **S3.7.** Mesoscale to fine-scale structures related to the Mediterranean outflow water: a correlation of joint seismic reflection and physical oceanographic data acquired during the GO cruise.
E. Quentel, L. Aranda, M-A. Gutscher, X. carton, R. Hobbs, L. Géli, E. Cosquer and L. Hua.
- 11:10 **S3.8.** Gulf of Cadiz oceanography for comparison with seismic imaging.
J. Huthnance, I. Ambar, R. Alvarado, R. Hoobs, G. Krahnemann, P. Silva and E. Quentel

11:30-13:10 **Open Discussion**

S4. IMAGING AND INVERSION OF SEISMIC OCEANOGRAPHY DATA (II)

Chair: *Valentí Sallarès*

- 14:30 **S4.1.** Relative contribution of temperature and salinity to water column's acoustic reflectivity.
B. Biescas, V. Sallarès, G. Buffet, R. Carbonell
- 14:50 **S4.2.** Methods of measuring oceanic internal waves using seismic reflection data.
S. Jones

- 15:10* **S4.3.** Researches on internal waves spectra of northeastern South China Sea from one reflection seismic profile.
H. Song, C. Dong, B. Ruddick and L. Pinheiro.
- 15:30* **S4.5.** Detailed 2-D imaging of the Mediterranean Outflow and Meddies off W Iberia from Multichannel Seismic Data.
L. Pinheiro, H. Song, B. Ruddick, J. Dubert, I. Ambar, K. Mustafa.
- 15:50* **S4.6.** High resolution seismic images of the water structure obtained with a small volume source array
L. Géli, R. Hobbs, D. Klaeschen, E. Cosquer, B. Marsset, F. Klingelhoeffer F., C. Pappenberg
- 16:10-17:30* **Coffe Break & Open Discussion**

Friday, NOVEMBER 21th

FINAL DISCUSSION AND DRAFT OF CONCLUSIONS

Chair: *Richard Hobbs and W. Steven Holbrook*

8:00-10:30 **Open Discussion**

10:30-11:00 **Posters & Coffee Break**

11:00-13:00 **Draft of Conclusions**

13:00 **Goodbye**

POSTERS

Maximum dimensions: 90 cm wide x 100 cm high.

All posters can be up during the whole duration of the WS.

P1. Acoustic and chirp (3.5 kHz) gas detection within the submerged section of the North Anatolian Fault zone in the Sea of Marmara

L. Géli, P. Henry, T. Zitter, S. Dupré and the MarNaut Science Party.

P2. Seismic Processing and Inversion Methods in Seismic Oceanography? Latest results

C. Papenberg, D. Klaeschen

P3. To pick or not to pick: Accuracy and utility of sound speed models in processing seismic oceanography data

W. Fortin, W.S. Holbrook, and R. Schmitt

P4. Quantifying Turbulence Dissipation from Seismic Reflection Images

W.S. Holbrook, R. W. Schmitt, I. Fer, W. Fortin, and J. Klymak

P5. Velocity model inversion from seismic reflection stacked data using the Very Fast Simulated Annealing algorithm

B. Biescas, A. Ribodetti, V. Sallàres, R. Carbonell, C. Papenberg, D. Klaeschen

P6. Obtaining Seismic Images from Oceanographic Profiles using Morphing Techniques

L. Matias, I. Ambar, and P. Silva

P7. Exploring the fine-scale vertical variability of sound speed

F. Machín, J.L. Pelegrí, B. Biescas and V. Sallares

P8. Testing recovery of ocean properties using an emulation of internal wave surfaces

E. Vsemirnova, R. Hobbs and A. Bargagli

P9. First images from a 3D time-lapse seismic oceanography data set

T. M. Blacic, W. S. Holbrook and J. C. Seymour

P10. Seismic reflections within the water column south of South Africa: indications for the Agulhas Retroflection

G. Uenzelmann-Neben, D. Kläschen, G. Krahmman, T. Reston, M. Visbeck

P11. Thermohaline staircases viewed by contemporaneous seismic imaging

I. Ambar, R. Bezerra, L. Pinheiro, P. Silva, N. Salvao

P12. Seismic oceanography in Japan

Y. Nakamura, T. Noguchi, T. Tsuji

P13. Seismic Imaging Of The Southern Ocean

K. Sheen, N. White and R. Hobbs

P14. New Perspectives on the Physical Characterization of the Mediterranean Undercurrent

G. Buffett, B. Biescas, F. Machin, V. Sallàres, J. Pelegrí, R. Carbonell, D. Klaeschen, R. Hobbs

Abstracts

Five Years of Seismic Oceanography: Successes, Challenges, and Future Directions

W. Steven Holbrook (1), Raymond W. Schmitt (2), and Ilker Fer (3)

(1) University of Wyoming; (2) Woods Hole Oceanographic Institution; (3) Bergen University, Norway

Seismic oceanography has opened up new ways of visualizing thermohaline finestructure. Through reprocessing seismic reflection data with an emphasis on the water column, stunning images of fronts, eddies, water mass boundaries, and internal waves have been produced. These images have the potential to shed light on any process that creates, deforms, or disrupts oceanic finestructure. Five years after its inception as a discipline, seismic oceanography is entering a new and important stage of development. Early efforts to document the physical causes of the reflections and to catalog images in different oceanic environments is yielding to a need to extract useful, verifiable, quantitative information on physical oceanographic processes from the images. Here we review progress to date, and point to key areas of current and future research. Significant achievements so far include a basic understanding of the physical basis of the observed reflections (dominantly temperature fluctuations at the finestructure scale); discovery of the ubiquity of finestructure reflections in numerous data sets, including industry data; demonstration that reflector displacements provide a means of measuring internal-wave energy; and verification that temperature profiles can be estimated by waveform inversion of the seismic data. Promising areas of research include emerging techniques to quantify internal wave energy and turbulence dissipation from seismic images, the acquisition of industry SO data, the production of 3D and time-lapse images of finestructure, the development of improved techniques to invert for temperature structure from seismic reflections, the detection and quantification of moving targets (e.g., solitons) in the ocean, and continued research on best-practices for seismic data acquisition and processing. Principal challenges for the future include (1) acquisition of joint PO/seismic data sets in areas of targeted oceanographic processes, (2) merging synthetic and field seismic data with realistic, time-varying physical models of oceanic temperature/density structure, calculated at the dense horizontal and vertical spacing needed to simulate the seismic data, and (3) improved communication across the cultural divide separating seismologists and physical oceanographers. Meeting these challenges will require cross-disciplinary collaboration of the sort represented by this workshop.

S1. PHYSICAL PROCESSES IN OCEANOGRAPHY

Ocean processes that create seismic reflectors

A. Barry Ruddick(1) B. Raymond Schmitt(2)

(1) Dalhousie University, Canada (2) Woods Hole Oceanographic Institute, USA

The ocean is heated and made salty by evaporation in the tropics, cooled and freshened by precipitation at high latitudes, and forced by wind everywhere, creating a variety of water masses, stratifications, currents and fronts that transport heat poleward and moderate Earth's climate. The thermohaline and velocity variance cascades from forcing scales to dissipative scales of a few cm or less through a variety of physical phenomena. Seismic images outline the T-S structures of eddies, fronts, currents and other mesoscale features because the acoustic wavelengths match and directly image fine-scale (10s of m) ocean structures. Several processes are known to produce fine structure: internal waves, vortical modes, double-diffusion, thermohaline intrusions, and sheared along-isopycnal advection. We describe the physics of these processes, the scales, slopes, and other characteristics of the fine structure from each, and what we presently know of their relationship to larger-scale structures.

T-S filaments generated by eddy stirring and seismic imagery

R. Ferrari

MIT, Massachusetts Institute of Technology

The distributions of temperature (T), salinity (S), and potential vorticity (PV) in the ocean are the result of a balance between atmospheric forcing on planetary scales and mixing at molecular scales. While numerous studies focused on the transfer of variance from large- to meso-scales by geostrophic eddy stirring, less is known on the pathway of variance to sub-mesoscales all the way to dissipation. The real difficulty in studying the cascade at these small scales is the lack of observations. We show that seismic imagery might provide such observations and move the study of sub-mesoscale ocean turbulence forward.

In this talk, we discuss the cascade of tracer variance below the mesoscales with a combination of T-S observations from the North Atlantic Tracer Release Experiment and idealized numerical models with a resolution of $O(1)$ km in the horizontal and $O(10)$ m in the vertical. We find that stirring by geostrophic eddies drives a cascade of T-S variance to small horizontal scales along isopycnals, as suggested

by McVean and Woods. The resulting variability is characterized by large isopycnal T-S excursions. These T-S structures are typically referred to as the permanent thermohaline finescale structure, in contrast to the reversible T-S fluctuations associated with internal wave heaving. Moving beyond previous investigations, we show that the lateral eddy stirring is accompanied by vertical shear that tilts the T-S filaments in the vertical producing a cascade of thermohaline variance to small vertical scales. Most importantly, the filaments develop a characteristic aspect ratio of N/f (where N and f are the buoyancy and inertial frequencies). We provide preliminary evidence that seismic imagery support our predictions. We finally show that the coupling between the horizontal and vertical cascades of tracer variance has profound implications for the overall T-S budgets of the ocean.

Meddies: structure and evolution

L. Armi

Institute of Geophysics and Planetary Physics. Scripps Institution of Oceanography.
 University of California at San Diego. La Jolla, California 92093-0225

With seismic oceanography, detail structure of meddies has now been imaged at unprecedented resolution! In the core, which is in near solid body like rotation, layers extend undisturbed for tens of kilometers. In contrast, in the sheared region from the velocity maximum at the boundary of the core to the ambient fluid, the layering is not coherent. The plane of the imaging transect when cutting through the core produces images of structures that have spread coherently over the lifetime of the meddy. Since the meddy decays primarily through isopycnal mixing processes in the sheared region exterior to the velocity maximum of the rotating core, the plane of imaging cuts many of these sheared structures which are presumably only coherent over large distances in the azimuthal direction. Historical data will be reviewed in light of the recently obtained seismic images. Other flow structures of the deep ocean may also be suitable for seismic imaging, in particular mixed layers formed by bottom mixing at sea mounts and on continental slopes.

Simulations of stratified turbulence surrounding Meddy structures

L. Hua

IFREMER, Brest, France.

The spatial characteristics of the ominous "pancake"-like temperature structures surrounding the GO Meddy have been studied using spectral, wavelet and structure functions analysis. The depths of the pancake-like layering unambiguously coincide with potential energy spectra in $k_h^{-5/3}$, -- where k_h is the horizontal wavenumber --, reminiscent of non-rotating stratified turbulence results.

Using very high resolution simulations on the Earth Simulator (Yokohama), with grid sizes down to 100m in the horizontal and 3m in the vertical, of an idealized Meddy structure, we have been able to reproduce the pancake-like layering surrounding the Meddy. Moreover potential and kinetic energy with $k_h^{-5/3}$ inertial ranges have been simulated. A rationale is proposed for the formation mechanism of the layering and we discuss the influence of rotation on stratified turbulence properties.

Hydrodynamic, thermodynamic, and acoustic properties of large-amplitude internal waves.

Louis St. Laurent

Florida State University

Large-amplitude internal waves are a common occurrence in the oceans. They are particularly prevalent in deep regional seas, where the combination of tides, topography, and stratification leads to particularly large-amplitude waves. In the case of the South China and Indonesian Seas, waves with displacement amplitudes exceeding 100 m are common. These waves are nonlinear, often conforming to dynamics of the KdV family of equations. Wave steepness often approaches 1 in 10 (rise over run), and propagation speeds for soliton-like pulses reach 3 m/s in deep water. These waves have considerable hydro- and thermodynamic impacts on the upper ocean, in both deep water where they disrupt the thermocline, and in shallow water where the waves breakdown down into long trains of high-frequency internal waves with considerable turbulence levels.

I will present a discussion of the properties of these waves, including direct examples drawn from recent observations in the South China Sea. I will describe results from mid- and high-frequency acoustic studies, as well as results from my own measurements of microstructure and turbulence. These waves may be the most dissipative physical process occurring in the open ocean away from the influence of boundary layer effects. These waves would be an excellent subject for future seismic oceanographic studies.

Spontaneous generation of Inertia-gravity waves by balanced flow in the ocean

A. Viúdez

Institut de Ciències del Mar, Barcelona, Spain.

High-resolution three-dimensional numerical experiments show that initially balanced (void of waves) geophysical flows, static and inertially stable, generate spiral patterns of small amplitude inertia-gravity waves (IGWs). The spiral wave patterns are due to the spontaneous generation of IGW packets emitted from fluid volumes (the IGW sources) experiencing large local changes of potential vorticity. The IGW packets spread away from the vortical flow and cause spiral wave patterns of the same sense of spiralling, cyclonic or anticyclonic, as the moving IGW sources. The spiral patterns are noticeable in the vertical velocity at deep layers, away from the large amplitude balanced vertical velocity. The generation of the spiral wave patterns is illustrated through several examples: the single ellipsoidal vortex (cyclone and anticyclone), the merging of two spherical vortices, the dipole, and the anticyclonic shear instability. Though it is very probably that these waves had been already partially identified from conventional low spatial resolution oceanographic data, their existence lack a complete observational proof. It is however possible that high spatial resolution seismic data could be a good observational technique to prove the existence of these waves in the ocean.

S2. IMAGING AND INVERSION OF SEISMIC DATA

What does a seismic section represent

R. W. Hobbs

Department of Earth Sciences, University of Durham, South Road, Durham DH1 3LE, UK

The seismic trace is formed by the convolution of seismic source function with the impedance structure in the water column. This sounds simple but in reality the process maybe very complex. In this presentation I will cover the issues of seismic acquisition and their consequences for imaging the structure of the water column. Of principal importance is the source function and tuning of the bandwidth of the seismic data. Low frequencies show the larger gradient zones in the water temperature/salinity whereas higher frequencies reveal the fine structure of the boundaries. Additional complexity is caused by the 3D structure and/or water movement which may distort the image. These have fundamental consequences for estimating power spectra/correlation lengths in both the horizontal and vertical directions.

Examples will be shown using constrained models and real data collected during the G0 experiment.

Potential and limits of seismic methods to image oceans finestructure

V. Sallares (1), B. Biescas (1), R. Carbonell (2), G. Buffet (2), J.L. Pelegrí (3), J.J. Dañobeitia (1)

(1) Marine Technology Unit-CSIC, Barcelona, Spain; (2) Institute of Earth Sciences "Jaume Almera"-CSIC, Barcelona, Spain; (3) Institute of Marine Sciences-CSIC, Barcelona, Spain

Seismic oceanography is slowly becoming a popular tool to investigate the internal structure of the water column. The principle of this technique is that seismic energy is partially reflected at the boundaries between water masses with contrasting temperature (and salinity), then recorded and processed to provide continuous images of these boundaries. Numerous papers have recently appeared showing the potential of seismic oceanography to image the oceans' finestructure with unprecedented lateral resolution (~10 m), the spatial coincidence of seismic reflectivity and temperature/salinity contrasts, and the correlation between seismic reflections and internal wave spectra. Despite the relatively large amount of work, little has been published concerning the existing issues to adapt seismic systems to oceanographic research. As part of the European funded G0 Project (www.dur.ac.uk/eu.go) as well as Spanish funded Geocean project we present here a set of basic synthetic tests to illustrate the relative significance of different parameters for imaging the oceanic finestructure using seismic methods. The parameters considered include the frequency content and energy of the source wavelet, the ambient noise level, as well as the shooting rate, signal redundancy and fold. We show that powerful (>200 dB re 1 μ Pa), low-frequency (20-60 Hz) sources such as those commonly used in deep seismic soundings (DSS) are very well-

suited to image also the oceans finestructure at all depth ranges. The reason for this is twofold: on one hand, the acoustic impedance associated to intra-oceanic boundaries is two orders of magnitude smaller than those associated to geological boundaries ($10^{-3}/10^{-1}$), so it is crucial to use energetic sources to overcome ambient noise regardless of the target proximity. On the other hand, the structures developed by double diffusion, in contrast to the geological ones, do not show abrupt impedance contrasts but rather smooth gradients within layers of several tens of meters! So the dominant wavelength of common DSS sources (~25-75 m) is suitable to image them. In addition, we show that for a given system layout one can define the optimal shooting rate that gives the best possible signal-to-noise ratio by taking advantage of system redundancy but at the same time allowing background seismic noise due to repeated shooting to mitigate.

Simulation of a seismic dataset over a model of the dynamic ocean

E. Vsemirnova (1), R. Hobbs (1) and N. Serra (2)

(1) Earth Sciences Department, Durham University, Durham DH1 3LE, United Kingdom,
 (2) Institute of Oceanography, University of Hamburg, Hamburg 20146, Germany

The GO project experiment examined the ability of the seismic method to image the Mediterranean Outflow water in the Gulf of Cadiz (April - May 2007). A combined dataset with simultaneous and co-located seismic and oceanographic data was successful but raised the question of what, if any, are the effects of relative movement of the water and vessel during acquisition. To resolve this issue we have computed a synthetic seismic dataset over a dynamic model of the ocean. The model is of a two-dimensional dam-break experiment, in which warm dense water is allowed to spill over a sill from reservoir basin into a receiving stratified environment. Between 600 and 1000m deep the plume becomes neutrally buoyant. This model mimics the penetration of the Mediterranean Water plume in the Gulf of Cadiz and the associated mixing and entrainment processes. The initial conditions in the reservoir and receiving basins derived from temperature and salinity casts.

As in the case of combined seismic and oceanographic data sets, we are faced with the same issues of how to reconcile the conventional modelling scale for regional oceanography with the scale required for modelling seismic wave propagation.

The ocean model covered a 30 hour interval and produced a snapshot of the water structure (temperature, salinity) and derived every 15 minutes on a 2D section 250km wide by 2 km deep with a horizontal and vertical grid size of 160 x 2 m respectively. However, for the seismic simulation, based on the acquisition used during the GO experiment - 40 m shot spacing with a 20 s shot interval, corresponding to a ship speed over the ground of close to 4 knots. Hence to model the seismic response, we require a snapshot every 20 seconds and, to avoid serious spatial aliasing problems, a horizontal and vertical grid size of 20 x 4 m respectively. We approached this interpolation issue in four steps; firstly we windowed the original model data in time and space centred on the time and location of the seismic shots to be modelled; secondly we interpolated in time using a cubic-spline to give a time slice every 20 seconds; we then used a second cubic-spline interpolation in the horizontal spatial domain to resample from 160 to 20 m; finally we converted the data to a format compatible with a phase-screen modelling

program to compute the seismic shot response. Synthetic data were computed for the ship travelling with and against the water flow. Also an idealised dataset over a stationary water model and for a stationary receiver/VSP. Processing of the data reveals how the reflectivity is closely related to the gradient of the impedance and water motion does matter in estimation of horizontal spectra.

Acoustic wave propagation and inversion of physical parameters

D. Klaeschen (1), C. Papenberg (1)

(1) IFM-GEOMAR, Kiel, Germany

Seismic reflection data images boundaries between the water masses with different physical properties. Special imaging and inversion techniques are needed to quantify physical properties across the boundaries.

To solve the non-linear inverse problem of acoustic waves a decomposition of absolute velocity and velocity contrast is needed. The traditional migration/inversion is decomposing the process into a determination of the macro-model (migration velocity analysis) followed by a quantitative (amplitude preserving) migration and amplitude versus angle-inversion.

A full waveform inversion minimize the differences (residuals) between observed and calculated data by modeling the physical parameters of the measurement. A non-linear behavior can be solved by an iteratively application of the linearized inversion procedure. Important aspects of the waveform inversion is the accuracy of the starting model, especially if the low frequency components of seismic data frequency bandwidth are missing or non presence of reflections. It has been shown that an computational efficient 1D full waveform inversion can recover the velocity depth profile in great detail as soon the limitations of an one dimensional structure are full filled (Woods et al.,2007).

The 2D full waveform inversion does not have so much model limitations, but requires a good starting model located in the neighbourhood of the global minimum. Because of the high computational cost calculating 2D-synthetic seismic data, the inversion is formulated in the frequency domain and as an iterative descent method (Hicks and Pratt, 2001). To avoid a convergence into a local minimum special strategies are needed like sequential frequency inversion from low to high frequencies with gradient preconditioning.

Common for all inversions is that they can recover the velocity contrast more accurate than the absolute velocity values. Further a good knowledge of the source signature is needed as well as broad frequency band data. Data examples and different seismic inversion strategies are explained and discussed.

Hicks, G.J., and Pratt, R.G., 2001, Reflection waveform inversion using local descent methods: Estimating attenuation and velocity over a gas-sand deposit: *Geophysics*, 66, no. 2, 598-612.

Warren, T.W., Holbrook, W.S., Sen, M.K., and Stoffa, P.L., 2008, Full waveform inversion of reflection seismic data for ocean temperature profiles: *Geophysical Research Letters*, Vol. 35, L04608, doi:10.1029/2007GL032359.

Second-order CFS-PML algorithm for modelling seismic oceanography experiments

J. Kormann (1), B. Biescas (2), P. Cobo (1), V. Sallares (2), R. Carbonell (3)

(1) Instituto de Acústica, CSIC. (2) UTM, CSIC. (3) Instituto Jaime Almera, CSIC

In the last decades, a constant effort was applied to afford efficient exploration tools for oceanographers. One example is the recent effort made to adapt seismic exploration tools to image the internal structure of the water column. The results prove that it is an efficient tool for visualizing ocean structures such as Meddies and thermohaline intrusions. These images are not only snapshots of the water reflectivity but contain also indirect information on physical properties such as temperature and salinity contrasts with the resolution of the source's wavelength. To extract this information it is necessary however to adapt seismic tomography methods specifically to oceanographic data, this in turn requiring accurate modelling of the seismic wave propagation within the water column. Since acoustic wave equation must satisfy the Sommerfeld condition at infinity, modelling acoustic wave propagation in a limited computational area needs the introduction of special absorbing conditions at the boundaries. Seismic oceanography experiments involve propagation at very grazing angles and require high numerical precision numerical models. Therefore, the Perfectly Matched Layers (PML) represent an interesting alternative to deal with both constrains. Thus, the aim of this work is to present a new Complex Frequency Shifted-PML formulation especially derived for the acoustic wave equation, providing very low boundary reflections at grazing angles incidence, better absorption at low frequencies, and ensuring stability at long time computations. In the second part of this communication, a comparison between synthetic and experimental data will be presented for a small stacked section measured during the GO Survey in the Gulf of Cadiz.

Seismic Processing and Inversion Methods in Seismic Oceanography - Latest results

C. Papenberg (1), D. Klaeschen (1)

(1) IFM-GEOMAR, Kiel, Germany

During the European funded GO Project (www.dur.ac.uk/eu.go), seismic data as well as hydrographic data were recorded simultaneously. These contemporaneous measurements optimize inversion procedures and provide the necessary calibration of the results. Data examples and traditional seismic inversion strategies are discussed. In particular, how to combine the high vertical and low lateral resolution hydrographic data with high lateral and low vertical resolution seismic data. Here we present the latest processing and inversion results on the GO project data.

Thermohaline finestructure and temperature distribution across the Kuroshio Current

Takeshi Tsuji (1), Shohei Minato (1), Toshifumi Matsuoka(1), Takashi Noguchi (1),
 Yasuyuki Nakamura (2), Yoshio Fukao (3)

(1) Kyoto University, (2) University of Tokyo, (3) Japan Agency for Marine-Earth
 Science and Technology

To reveal thermohaline finestructure and temperature distribution across the Kuroshio Current axis, we analyzed and interpreted several seismic reflection data acquired over a wide range of the Kuroshio Current area, southwest Japan. The Kuroshio Current locates above the Nankai accretionary prism (plate convergent margin). Because seismogenic thrusts within the Nankai accretionary prism cause great earthquakes, many reflection seismic surveys have been operated (Tsuji et al., 2005; Nakamura et al., 2006). In the processed seismic profiles, the strong reflections exist above ~900m and they are slightly dipping toward the Kuroshio Current axis. For a quantitative estimation of temperature/salinity variation in finestructures, furthermore, full waveform inversion for seismic velocity estimation was performed. This approach must be suitable to estimate of high-resolution velocity structures (e.g., Wood et al., 2008). In this study, we adopted Simulated Annealing (SA) method for velocity inversion. As a forward modeling that reconstruct pseudo-shot data from model parameters, we adopted ray tracing based method. The two-dimensional velocity structures obtained via full waveform inversion demonstrate that the velocity (temperature) boundary is dipping toward the current axis, and the location of velocity contrast is consistent with finestructure reflections.

S3. PHYSICAL PROCESSES IN OCEANOGRAPHY

Quantifying Physical Processes With Seismic Oceanography

R. W. Schmitt (1) and B. Ruddick (2)

(1) Woods Hole Oceanographic Institution (2) Dalhousie University

Seismic Oceanography provides detailed information on the morphology of finescale sound speed variations in the water column. This is new data for the physical oceanographer, we have no comparable tools for imaging the internal finestructure at such close horizontal resolution over the whole water column. Here we review recent attempts to extract quantitative information on oceanic processes from multi-channel seismic reflection profiling.

Two general approaches can be identified:

1. Visualization of how fine-scale phenomena link to larger scale phenomena ? i.e., how do internal waves relate to, for example, eddies? How do intrusions interact with currents? These are difficult but important questions about the cascade of energy and variance from large scales to the dissipation scales.
2. Quantitative interpretation of reflectors in terms of physical quantities. This requires some minimal knowledge of the actual in-situ conditions or strong assumptions about the ocean. Efforts have concentrated on assessing internal wave energetics, generation mechanisms and dissipation rates.

Examples of the use of seismic oceanography in the analysis of internal wave energetics and dissipation, estimating the strength of geostrophic currents and the intensity of thermohaline staircases will be discussed. In all cases, the amount of supporting physical information has been limited and sometimes strong assumptions about the state of the ocean are necessary. Seismic oceanography should contribute to understanding of the ?sub-grid-scale? oceanic mixing processes that must be parameterized for accurate oceanic models.

Understanding horizontal internal wave and turbulence spectra

J. M. Klymak (1), J. N. Moum (2)

(1) Univ.of Victoria, (2) Oregon State Univ.

At scales of a few kilometers to centimeters ocean motions are dominated by internal waves and turbulence. A great deal of literature is available on how these phenomena look from vertical profilers, but few measurements have looked at their horizontal characteristics, which are more useful for seismic applications. Here we will review our findings using Marlin, a horizontally towed turbulence profiler, and demonstrate how horizontal measurements can often be a better indicator of turbulence levels than vertical measurements.

Quantifying Ocean Mixing Processes Through Stochastic Heterogeneity Mapping

Buffett, G.G.(1), C. Hurich(2), R. Carbonell (1), B. Biescas(3), V. Sallares(3), D. Klaschen(4)

(1) Institut de Ciències de la Terra Jaume Almera - C. Lluís Solé Sabaris s/n. Barcelona. E-08028 (SPAIN). TEL: +34 93 409 54 10. FAX:(+34) 93 411 00 12 (2) Department of Earth Sciences, Memorial University of Newfoundland, Prince Phillip Drive, St. John's, Newfoundland, Canada (3) Centre Mediterrani D'Investigacions Marines i Ambientals - Passeig Marítim de la Barceloneta, 37-49. E-08003 Barcelona (Spain) (4) Leibniz-Institute of Marine Sciences, IFM-GEOMAR, West Shore Campus, Duesternbrooker Weg 20, D-24105 Kiel, Germany

Stochastic heterogeneity mapping based on the band-limited Von Karman function is applied to stacked, migrated seismic data allowing the extraction of several stochastic parameters that may elucidate ocean mixing processes. In particular, the Von Karman method enables extraction from the reflectivity field: 1) the power spectrum, a combined estimate of amplitude and coherence in the analysis window, 2) correlation length, an estimator of the maximum length for which the event distribution described by a power law, and 3) the Hurst number, which is the exponent of the power law and is directly related to the fractal dimension, a measure of how completely a fractal fills space. With the extraction of these parameters we aim to quantify various scale mixing processes in ocean. Curiously, a single scaling law derived from percolation theory asserts that Hurst numbers between 0 and 0.5 are indicative of sub-diffusive behavior and Hurst numbers between 0.5 and 1 indicate super-diffusive behavior. Moreover, double-diffusion regimes are represented by a Hurst number of 0.25. Low Hurst numbers represent a rich range of scale lengths and, accordingly correspond to well-mixed regimes. Preliminary analysis of 60 seismic profiles acquired in April-May, 2007 show that zones corresponding to particular water masses display varying degrees of diffusive behavior. We believe that this method of analysis can address multi-scale mixing processes in the ocean from seismic data alone.

Deep internal waves and vertical thermal structure affected by the passage of a Meddy in the open Canary Basin

L. Gostiaux (1), H. van Haren (2)

(1) Coriolis Platform, LEGI-CNRS, Grenoble, France; (2) Royal NIOZ, Texel, Netherlands

Accurate (<1 mK) temperature sensors have been stiffly moored at ~1450 m in the open Canary Basin for 1.5 years while sampling at a rate of 1 Hz. This unique set of measurements shows simultaneously very short period motions associated to high frequency internal waves at the small-scale buoyancy frequency, as well as long

term variations of the temperature background, which consists of steps that are strongly affected by the passage of a meddy in winter 2007. The present open ocean w-spectrum continuum is not flat, as in previous near-surface observations, but linearly increases to a peak at $\sim 0.7N$. Isothermal smoothing reveals details of coherent vertical internal wave displacements and incoherent motions. By subtracting vertical coherent motions, the interleaving dynamics of alternatively homogeneous and strongly stratified layers can be studied. The upper and lower boundaries of these layers are supposed to be strong reflectors for high frequency seismic signals. As measurements were performed from a single mooring line, triggering questions on the horizontal scales associated to these intrusions remain.

The generation of Mediterranean Water eddies: in situ observations and numerical simulations

N. Serra (1,2) and I. Ambar (2)

(1) Institut für Meereskunde, University of Hamburg, Germany, (2) Instituto de Oceanografia, University of Lisbon, Portugal

Mediterranean Water (MW) eddies (Meddies) transport MW in an almost undiluted form into the interior of the North Atlantic, being a significant mechanism of southward heat and salt transport and acting to maintain the Atlantic large-scale mid-depth salinity tongue. Some of the mechanisms promoting the meddy decay are small scale in nature thus being difficult to study with conventional oceanographic measurements, mainly lacking detailed horizontal resolution. A new research tool is emerging in the field of Physical Oceanography with the use of the Multichannel Seismic method, which is in the way of allowing synoptic studies of small-scale processes.

A high-resolution three-dimensional regional model of the spreading of MW in the Gulf of Cadiz is here presented. The simulations are used to show particular features of the MW Undercurrent variability and the major sites and mechanisms of Meddy generation. In situ measurements are presented to validate the model results. The large temporal and spatial variability reproduced in the simulations emphasizes the difficulties of interpreting seismic measurements, like those recently acquired in the frame of the European Union funded project "Geophysical Oceanography - GO".

Analyses of the Yoyo-CTD at the Meddy's Edge

G. Krahnmann (1), M. Vogt (1), P. Brandt (1)

(1) IFM-GEOMAR, Kiel, Germany

Within the G0 experiment a 12 hour long CTD Yoyo station was carried out at the edge of a Meddy. During the Yoyo station the depth interval from 500 to 1500m was surveyed 17 times in downward and 17 times in upward direction. In addition to the high quality salinity and temperature measurements ocean currents were observed from the CTD rosette.

We analyze the data with respect to the thermohaline properties within intrusive structures found in the observations. As such intrusions are highly reflective to seismic sound we compare their temporal development at the Yoyo station with the spatial image of the surrounding seismic survey.

Mesoscale to fine-scale structures related to the Mediterranean Outflow Water: A correlation of joint seismic reflection and physical oceanographic data acquired during the G0 cruise

E. Quentel(1,2), L. Aranda(1,2), M.-A. Gutscher(1,2), X. Carton(1,3), R. Hobbs(4),
 L. Géli(5), E. Cosquer(5) and L. Hua(5)

(1) Université Européenne de Bretagne, Brest, France, (2) Laboratoire Domaines Océaniques, UMR 6538 UBO-CNRS-IUEM, Plouzané, France, (3) Laboratoire de Physique des Océans, UMR 6523 UBO-CNRS-IFREMER, France, (4) University of Durham, United Kingdom, (5) IFREMER - Centre de Brest - Technopole Brest-Iroise - B.P. 70 - 29280 Plouzané, France

During the G0 cruise (HMS Discovery) in April 2007, 2000 km of seismic reflection profiles were acquired synchronously with collocated oceanographic data (500 XBT and 40 CTD) in the Gulf of Cadiz (www.dur.ac.uk/eu.go). To investigate the seismic response of water boundary layers related to the warm, saline Mediterranean Outflow Water (MOW), three types of seismic sources were used: a high-resolution (HR - 117 cu in, 15-350 Hz), low-resolution (LR - 2000 cu in, 10-60 Hz) and medium resolution source (MR - 10-60 Hz and 20-120 Hz). The expected vertical resolution is 2.5, 15 and 7.5 m respectively. The horizontal resolution of the continuous seismic profiles (10m) is much higher than that of oceanographic data, which is typically 10km.

Here, we examine the spectra of seismic reflectivity and of oceanographic profiles and analyse histograms to determine the characteristic vertical and horizontal

scales of the structures imaged by both methods on the continental slope and in a Meddy.

Similar structures are observed at the boundaries between water masses with the different sources at high spatial resolution. In particular, a Meddy seen in the LR and MR profiles presents strong, laterally continuous (about 10 km) reflectors. The low-frequency source offers better images of the deep boundary of the Meddy. The HR source reveals more fine-scale structures with horizontal scales on the order of 10 km, and a thickness of 20 m : in the mixed layer, these reflectors are due to the temperature (and thus density) gradient, while above the Meddy, the gradient of sound velocity is more marked, and is influenced by salinity.

Gulf of Cadiz oceanography for comparison with seismic imaging

J. Huthnance(1), I. Ambar(2), R. Alvarado Bustos(1), R. Hobbs(3), G. Krahnemann(4),
 P. Silva(2) and E. Quentel(5)

(1) Proudman Oceanographic Laboratory, Liverpool, UK, (2) Instituto de Oceanografia, Universidade de Lisboa, Lisbon, Portugal, (3) Department of Earth Sciences, University of Durham, Durham, UK, (4) IFM-GEOMAR, Kiel, Germany, (5) Domaines Oceaniques, Université de Bretagne Occidentale, Plouzane, France

The GO project (European Union-NEST-Adventure funding; www.dur.ac.uk/eu.go) aims to assess the potential of seismic imaging of the water column. A dedicated experiment (April-May 2007, Gulf of Cadiz) looked at varying Mediterranean Water (MW) flow along and down the continental slope. The distinctive MW thermohaline properties provide strong reflections from seismic sounding. We aim to relate water properties to mixing and hence (e.g.) to tides, internal waves, eddies.

Physical oceanography results derive from 500 XBT casts, typical spacing 2km, and moorings: three ADCPs and three temperature strings in line on the north-eastern margin of Portimão Canyon (water depths 740-980 m); a fourth ADCP offset ~6 km from the line in 1015 m depth. Additionally there was CTD and LADCP profiling on an IFM-Geomar research cruise, closely following the seismic sections.

We examine the structures observed on the principal line through the moorings (five repeated surveys), and compare with the contemporary seismic data that also show boundaries in water characteristics. The mooring data and profiles are analysed for a bottom boundary layer, for tides, for internal wave spectra in comparison with the Garrett-Munk spectrum, for small-scale structure to estimate diffusivity and mixing.

S4. IMAGING AND INVERSION OF SEISMIC OCEANOGRAPHY DATA

Relative contribution of temperature and salinity to water column's acoustic reflectivity

B. Biescas(1), V. Sallàres(1), G. Buffet(2), R. Carbonell(2)

(1) 1.Unitat de Tecnologia Marina, Consejo Superior de Investigaciones Científicas, Passeig Marítim de la Barceloneta, 37-49, 08003-Barcelona, Spain, (2) 1.Institut of Earth Sciences "Jaume Almera", Consejo Superior de Investigaciones Científicas, Lluís Solé i Sabarís, s/n, 08028-Barcelona, Spain.

At present day it is commonly accepted that the water column's reflectivity at the frequency range of deep seismic sources (20-80 Hz) is the expression of the acoustic impedance associated to fine-scale (scale of ~101 m) oceanic structures created by double-diffusive mixing, internal waves, or thermohaline intrusions. One of the main challenges of seismic oceanography lies on the interpretation of the reflectivity in terms of physical parameters such as sound velocity, density, temperature or salinity; more concretely trying to quantify the vertical variation of these physical properties based on seismic data. Most attempts made to date focus on the derivation of sound velocity perturbations with respect to a background velocity model using different inversion techniques. These models generally assume that the contribution of density contrasts to acoustic impedance is negligible as compared to sound velocity ones. In the same manner, it is assumed that salinity contrasts are small enough as compared to the temperature ones (~one order of magnitude), making possible to translate sound velocity variations into temperature ones using any existing empirical relationship. However, to our knowledge no systematic approach has been made to date to actually quantify the contribution of these parameters. In this work we make an attempt to do so by calculating the partial derivatives of sound velocity and density with respect to temperature and salinity using UNESCO empirical relationships, incorporating the expression into Zoeppritz equations of reflection coefficients, and applying the resulting expressions to real, high resolution, temperature and salinity data acquired during the GO cruise in the Gulf of Cadiz. The results show that while the contribution of density is generally less than 10% of that of velocity; that of salinity can be as high as 30-40% with respect to temperature, especially in the regions prone to mixing such as the boundary zones of meddies and other Mediterranean water features. It is also noteworthy that the relative contribution varies between the top and bottom boundaries, the salinity contribution being more significant in the upper boundary zone.

Methods of measuring oceanic internal waves using seismic reflection data

Stephen M. Jones, Robert J.J. Hardy, David Hardy, Ciaran Sutton

Trinity College Dublin

The Southern Ocean is the most inaccessible and under-sampled ocean in the world. It nevertheless contains water masses which are essential components of the global thermohaline circulation and controls the water mass exchange between the major ocean basins through the Antarctic Circumpolar Current.

Here we present a series of seismic images of the water column from a region in the southwest Atlantic using legacy seismic reflection datasets shot in the 1990s. The seismic surveys follow the northern part of the Antarctic Circumpolar Current as it veers northward after exiting Drake Passage, loops around the Falkland Trough and enters the Argentinian Basin, largely following the Sub Antarctic Front route. Finestructure imaged in the data occurs dominantly in the boundary layer between Antarctic Intermediate Water and underlying Upper Circumpolar Deep Water, and correlates well with hydrographic interpretations. Structures such as dipping bands of heterogeneous water and eddies characterized by homogeneous cores and strong reflective inter-leaving edges are seen in the vicinity of ocean fronts. Further to the north, interesting thermohaline structures associated with the intrusion of North Atlantic Deep Water into the region have been captured. Seasonal variations in the time of data acquisition and the subsequent differences in the acoustic images provide interesting insights into the temporal variability of the water masses. Processing techniques such as prestack depth migration have been performed on much of the data in order to investigate longer wavelength acoustic velocity variations.

Turbulent mixing in this part of the Southern Ocean is known to be remarkably intense and widespread and thought to contribute significantly to driving the upward transport of water closing the ocean's meridional overturning circulation. The deformation of thermohaline finestructure by such mixing and the ambient internal wavefield results in small undulations along seismic reflection horizons. Spectral analysis of these sinusoidal displacements has been used to extract quantitative information on internal wave energy and turbulent dissipation rates.

Researches on internal wave spectra of northeastern South China Sea from one reflection seismic profile

Haibin Song(1) Chongzhi Dong(1) Barry Ruddick(2) Luis Pinheiro(3)

1) Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029, China, (2)Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada, (3)Departamento de Geociências and CESAM, Universidade de Aveiro, 3800 Aveiro, Portugal.

Northeastern margin of South China Sea(SCS) is known as a wonderful internal wave experiment field. The internal waves in this region are considered as from Bashi strait or shelf-slope edge. But by now there are less quantified studies of the internal waves in northeastern SCS. This paper shows first time that thermohaline fine structures and internal waves develop vigorously in the area from seismic imaging. It also presents the calculated horizontal and vertical wave number spectra of internal waves.

Results from the processing of a multi-channel seismic profile that extends from the continental slope of northeastern SCS to Bashi strait reveal the vertical and lateral variations of the thermohaline structure in the water column in this area with a high detail along a continuous 463 km long section. They image the developed internal waves in different regions, including slope, abyssal basin, Hungchun Ridge and Luzon Volcanic arc and their lateral variations. Horizontal wave number spectra of Internal waves are calculated from digitized undulation reflection events of different depth range in four sections and compared with Garrett-Munk tow spectrum of oceanic internal wave displacements (GM76 spectrum).

The results show internal wave spectra of 150m~250m in these four regions match the theoretical GM 76 spectrum, with the slope of -2. But the average spectra of all depth reflectors in four regions have much larger slope, they are around -2.6~-3.5. It can be interpreted that GM76 spectrum describing open ocean internal waves may not be fitted with shallow zones such as northeastern SCC slope, Hungchun Ridge and Luzon Volcanic arc. While the spectra of abyssal basin of northeastern SCS more than 3000 meters deep are also different from GM76 spectrum. As a marginal sea, South China Sea seems to have different characteristics of internal wave spectra from open ocean, such as high long-wavelength energy, low short-wavelength energy and larger slope. Vertical wave number spectra of internal waves above abyssal basin are also computed by a correlation method from 54 reflectors with different depth.

The meso- and fine-scale features of the water column from seismic imaging may be important for further researches on water mixing process, especially the water exchange of Kuroshio and SCS in the area. Internal waves develop mainly in the upper slope, Hungchun Ridge and Luzon Volcanic arc and it indicates that submarine topography influence the formation and evolution of the internal waves.

Detailed 2-D imaging of the Mediterranean Outflow and Meddies off W Iberia from Multichannel Seismic Data

Luis Menezes Pinheiro (1), Haibin Song (2), Barry Ruddick (3), Jesus Dubert (4),
 Isabel Ambar (5), K. Mustafa (1)

(1) Departamento de Geociências and CESAM, Universidade de Aveiro, (2) Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 100029, China, (3) Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada, (4) Departamento de Física and CESAM, Universidade de Aveiro, 3800 Aveiro, Portugal, (5) Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa

Reprocessing of a 326-km long multichannel seismic line acquired in the Tagus Abyssal Plain off W Iberia in 1991 allowed detailed imaging of the thermohaline structure of several mesoscale features within the water column. The interpretation was supported by subsurface float measurements, Sea Level Anomaly (SLA) Maps and Sea Surface Temperature (SST) images contemporaneous with acquisition of the seismic data. Clear images were obtained of the reflective patterns associated with one previously known and one newly discovered meddy, one cyclone, the upper and lower cores of the Mediterranean Undercurrent, and the interface of the high-salinity tongue of the Mediterranean Water with the North Atlantic Central Water. These reveal a complexity and a detail of the lateral variations of the thermohaline structure not easily observed by conventional physical oceanography tools.

The mesoscale structures were imaged via reflections from oceanic fine structures of scale 30 m or less. We compare the characteristics of observed reflectors with known mechanisms of fine structure production. Most of the observed reflectors are consistent with internal waves and thermohaline intrusions as previously hypothesized. We postulate a new mechanism to explain the formation of the steeply sloping reflectors that outline the meddy and other features, involving frontogenetic isopycnal advection, formation of thermohaline intrusions, and tilting of the intrusive layers by mesoscale shear flows. The imaging technique therefore shows the relationship between mesoscale features and the fine scale oceanographic phenomena associated with mixing, including steeply-sloped structures that would otherwise not be tracked using CTD profiles alone.

High resolution seismic images of the water structure obtained with a small volume source array

L. Géli (1), R. Hobbs (2), D. Klaeschen (3), E. Cosquer (1), B. Marsset (1), F. Klingelhoeffer F. (1), C. Pappenberg (3)

(1) Ifremer, (2) University of Durham, (3) IFM-GEOMAR

The GO calibration experiment (April 2007) was designed to seismically image the internal structure of the Mediterranean Outflow Water (MOW) at different scales, from internal waves (of characteristic size of 10 to 1000 m) to meddies (50 to 100 km). To image the smaller scale structures, a small volume (117 cu3), high resolution source was used, based on SODERA mini-GI guns with two air chambers fired in succession to damp primary bubble oscillation. The two sub-arrays of 3 airguns each were towed at 1.5 meters bsl, to give frequencies from 15 Hz up to 350 Hz. The reflection data were recorded on a 600-m long streamer with 72 traces (group length 6.25 m). Shots were fired every 10 s with a ship's speed of ~5 knots. The data were binned with a horizontal resolution of 6.25 m (distance between CDPs). The expected vertical resolution, here defined as the quarter of the dominant signal wavelength, is 2.5 m. The stack seismic sections show reflectors within the water column between 500 and 800 m bsl that are related to the MOW. This interpretation is consistent with oceanographic profiles from XBTs/XCTDs and there is excellent correlation between seismic reflectors and discontinuities in vertical temperature gradients. The compact size of the system not only documents the short spatial variability (< 50m) but also short temporal variability (< 4 h) on repeated sections.

Posters

Acoustic and chirp (3.5 kHz) gas detection within the submerged section of the North Anatolian Fault zone in the Sea of Marmara

L. Géli (1), P. Henry (2), T. Zitter (2), S. Dupré (3) and the MarNaut Science Party

(1) Ifremer, (2) Collège de France / CEREGE, (3) Geosciences Azur

Associations between fluid expulsion sites on continental margins (generally called cold seeps) and active fault systems have been recognized for some time. It is also known that earthquakes influence gas emissions at cold seeps, and precursor gas emissions have been observed]. In the Gulf of Izmit at the eastern end of the Sea of Marmara, expulsion of gas through seafloor fault ruptures was observed after the 1999 Kocaeli earthquake on the North Anatolian Fault using 3.5 kHz seismic data. However, detailed studies often conclude that spatial relationships between cold seeps and presumably permeable faults are complex or, worse, absent. We here present data from acoustic and chirp surveys and Nautilie submersible dives over the whole Sea of Marmara showing that, at least in some settings, distribution of gas seeps may provide indications of fault activity and even help identify buried structures.

Vertical Seismic Profiling (VSP) in Seismic Oceanography - a proof of concept

C. Papenberg (1), D. Klaeschen (1)

(1) IFM-GEOMAR, Kiel, Germany

As part of the European funded GO Project the concept of vertical seismic profiling was tested for being a tool to image water mass boundaries in 3D. Water bodies with different temperature have different acoustic velocity (and density). Seismic methods designed for imaging the subsurface can thus map out the boundaries between water masses and map mixing processes at meso-scale with unprecedented horizontal resolution. In addition to conventional surface streamer geometry, a new approach of vertical seismic profiling (VSP) has been developed. Following standard VSP techniques (walkaway- and offset-VSP) a first approach using 2 ships has been tested to collect 3D-seismic data of different water masses. Seismic migration produces a pseudo 3D image of the water structure which, when combined with 2D seismic profiles and oceanographic data, could give detailed information on the lateral extent of boundaries involved in the mixing process. Here we present the results of this experiment and discuss the concept of vertical seismic profiling as a tool for future studies in seismic oceanography.

To pick or not to pick: Accuracy and utility of sound speed models in processing seismic oceanography data

W. Fortin (1), W.S. Holbrook (1), and R. Schmitt (2)

(1) University of Wyoming, (2) Woods Hole Oceanographic Institution

In order to extract meaningful oceanographic data from seismic images, it is important that reflections in the water column be clear. The clarity of the reflections relies on the sound speed model used in the processing. Here, we present three seismic images produced with different sound speed profiles to determine the accuracy and utility of different sound speed models. We used three methods to produce these images; the first was produced using a careful handpicked sound speed profile, picking a profile every 156.25 meters. The second sound speed profile was created from information obtained by expendable instruments launched concurrently with the collection of the seismic data, densely spaced expendable bathythermographs. Finally, the third used a constant sound speed for the entire water column. Seismic images produced by the first two methods are compared to determine which method produces a clearer image. To determine each method's strengths and weaknesses, a difference plot of the two final seismic images was produced. The third seismic image, constructed by a constant sound speed profile, is compared to the first two methods to show how significant the benefits of a detailed sound speed model are. Consideration is also given to the constant sound speed model regarding its utility in processing existing seismic data sets; a large number of existing seismic data sets need to be quickly processed and examined in order to find interesting oceanographic features and a simple sound speed model could enable this type of work.

Quantifying Turbulence Dissipation from Seismic Reflection Images

W. Steven Holbrook (1), Raymond W. Schmitt (2), and Ilker Fer (3), Will Fortin (1), and Jody Klymak (4)

(1) University of Wyoming; (2) Woods Hole Oceanographic Institution; (3) Bergen University, Norway; (4) Victoria University, Canada

A principal challenge for seismic oceanography is the development of methods that derive useful, important dynamical quantities from seismic reflection images of the ocean. Intuition suggests that reflection images should be particularly amenable to study of ocean mixing processes; existing papers show that reflector displacements provide a measure of internal wave energy consistent with the Garrett-Munk wavefield, and internal wave energy is thought to be a primary driver of turbulence in the ocean. Here we show that turbulence dissipation (and, through the Osborn-Cox relationship, vertical diffusivity, $K-\rho$) can be estimated from seismic reflection images. The basis of our methodology is the model proposed by

Klymak and Moum (2007) relating horizontal slope spectra to turbulence dissipation (via a Batchelor spectrum). Klymak and Moum showed that turbulence can have a signature that extends to surprisingly long horizontal wavelengths, up to several hundred meters - wavelengths easily quantified by tracked seismic reflectors. We show synthetic seismic images of a turbulent ocean that demonstrate the feasibility of the method, then apply the method to real seismic data. Horizontal slope spectra from seismic images show a clear turbulence slope and provide estimates of vertical diffusivity in the expected range ($\sim 10^{-5}$ - 10^{-4} m²/s). A preliminary comparison of K-rho derived from seismic data to that derived from 10-m shear measured on a coincident XCP shows a promising correlation. These results suggest that seismic oceanography may provide a tool to remotely quantify mixing processes in the ocean.

Velocity model inversion from seismic reflection stacked data using the Very Fast Simulated Annealing algorithm

B. Biescas(1), A. Ribodetti(2), V. Sallàres(1), R. Carbonell(3), C. Papenberg(4),
 D. Klaeschen(4)

(1) Marine Technology Unit-CSIC, (2) Geosciences Azur IRD Observatoire
 Océanologique de Villefranche sur mer, (3) Earth Science Institut Jaume Almera-
 CSIC, IFM-Geomar

The Very Fast Simulated Annealing (VFSA) is a random-search technique that has been applied to several multiparameter optimization problems, including those of geophysical inversion (i.e. Agudelo,2005). We have used an inversion code based on this algorithm to find a model of sound velocities in the ocean water layer from seismic amplitude reflection data. The code uses three inputs, a migrated stacked seismic section, an initial velocity model and the source wavelet. The migrated stacked section must be previously calibrated to ensure that we introduce true amplitudes to the code. The initial velocity model is calculated from the oceanographic probes dropped simultaneously to the seismic data acquisition. The inverse problem is solved trace by trace, with an independent procedure of one trace and the next. The VFSA uses a random number generator to calculate random changes in the control variable, i.e. sound velocity. The 1D velocity profiles, randomly perturbed, are convolved with the source wavelet. The convolved traces are subsequently compared with the migrated ones by the VFSA algorithm that accept or reject the model. If it is rejected it is again perturbed and introduce in the loop. The model space is discretized in a matrix and each accepted model has associated a number of visits of each cell. The final model will be that corresponding to the most visited cells. We present here a very preliminary results of this inversion method applied to data acquired in the European Project GO (line GO-LR-12).

Obtaining Seismic Images from Oceanographic Profiles using Morphing Techniques

Luis Manuel Matias (1), Isabel Ambar (2) and Patrícia Silva (2)

(1) Centro Geofisica Universidade Lisboa/Instituto D. Luis, (2) Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa

It is now well established that the thermohaline structure of the water column in the oceans can be imaged by standard multichannel seismic methods. The concept has been proved by a number of cruises where coincident seismic and oceanographic data was acquired. However, data has shown that there is not a one-to-one relationship between the seismic traces and the synthetics computed from the impedance reflectivity derived from the physical oceanographic data. One of the possible explanations for the discrepancies is the contribution of salinity variations that are not accounted by the procedures used to estimate the thermohaline structure from XBT profiles, where CTD data is not available.

The discrepancies between oceanographic and seismic images are more serious when we go from single traces to the 2D images. In fact, background impedance images are derived from sparse oceanographic profiles, with 1 km or 2 km spacing, while the horizontal resolution of the seismic images is more than 100x higher. If the impedance images are converted to seismic profiles by convolution of an adequate wavelet the profiles obtained are not realistic, rendering the comparison of both datasets more difficult. This problem shows that the standard interpolation methods applied to oceanographic data are not able to derive realistic models of the thermohaline structure of the water column. New interpolation schemes are required in order to preserve the strong lateral correlation of some density and temperature heterogeneities over long distances that are recognized in the seismic images of the water column.

In April/May 2007 the GO project (www.dur.ac.uk/eu.go) undertook a combined cruise with comprehensive oceanographic and seismic systems ensuring simultaneous collection of both data-types, including high-resolution seismic reflection data and the first ocean vertical seismic profile. In this work we use the XBT's and CTD's data to derive the best relationships between salinity, temperature and depth that were shown to be area dependant. Next, we apply a new horizontal correlation scheme, which resembles the morphing techniques applied to images, to the salinity and temperature fields in order to interpolate them to 100-m horizontal spacing. From these two 2D fields we compute the seismic impedance and derive seismic images by convolution with a simple ricker wavelet. We compare the results with the recorded GO-LR-01 seismic line. We may see that the synthetic profile is much more seismic-like and that some continuous heterogeneities imaged on the seismic line were well reproduced on the synthetic one.

Exploring the fine-scale vertical variability of sound speed

F. Machín(1), J.L. Pelegrí(1), B. Biescas(2) and V. Sallarès(2)

(1) Institut de Ciències del Mar, Barcelona, Spain; (2) Unitat de Tecnologia Marina, Barcelona, Spain.

The vertical distribution of $\rho \partial v / \partial z$ and $v \partial \rho / \partial z$, where v is sound speed and ρ is water density, is examined along two hydrographic sections, to investigate the origin of seismic reflections. Both sections, a meridional one from the Equator to Iceland and a zonal one across the Gulf of Cádiz, display substantial transitions between different water masses. The results show that $\rho \partial v / \partial z$ is much larger than $v \partial \rho / \partial z$, so we explore in more detail the vertical distribution of sound speed. These vertical profiles are adjusted using a polynomial function expressed in terms of salinity, temperature and depth, with the coefficients changing smoothly from one station to another. This procedure permits us to explore the vertical distribution of the sound speed variability, which is eventually related to water masses and mixing processes along the hydrographic sections.

Testing recovery of ocean properties using an emulation of internal wave surfaces

E. Vsemirnova (1), R. Hobbs (1) and A Bargagli (2)

(1) Earth Sciences Department, Durham University, Durham DH1 3LE, United Kingdom,
 (2) ENEA Casaccia, Rome 00060, Italy

The Garrett-Munk (GM) model gives a consistent description of the internal wavefield which agrees with observations for open ocean. To simulate the GM spectrum of oceanic internal wave displacements we created a von Karman power spectrum in the wavenumber domain applying a random phase with uniform distribution between 0 and 2π and transforming to the spatial domain. The statistical parameters of random medium, such as Hurst numbers and correlation lengths are chosen to make the spectrum fit the GM. The seismic response for a set of interfaces with assigned soundspeed and density, derived using the program "WAVE" to compute soundspeed realisations, gave images similar to those obtained during the GO cruise for open ocean. Picking events from the stack gives the resulting horizontal wavenumber spectrum well matching to the initial GM-like spectrum which we used as a basis of the model as we would expect. However, the recovery is sensitive to source frequency content and the vertical and horizontal correlation distances used for the model with the higher source frequencies giving a more robust result. The match in spectral content of the seismic data with the original GM-like spectrum is further improved by migration.

First images from a 3D time-lapse seismic oceanography data set

T. M. Blacic (1), W. S. Holbrook (1) and J. C. Seymour (2)

(1) University of Wyoming, (2) Exxon Mobil

We present 2D image slices from a unique 3D multichannel seismic data set made available for seismic oceanographic analysis by Exxon Mobil. The data consist of two 8-cable, two-source 3D swaths in the Gulf of Mexico separated by an interval of two days with XBT casts for both swaths. This industry data may be the first of its kind with coincident seismic and water temperature measurements and represents an important step towards increasing cooperation and data sharing with the oil industry. Preliminary 2D processing reveals strong laterally continuous reflectors throughout the upper ~1500 m as well as a few weaker but still distinct reflectors as deep as ~2400 m. At least one prominent sloping feature is imaged over several cables allowing an estimate of its 3D extent to be made. We also compare an image made using only one of the two airgun source arrays to one using both sources in order to illustrate the affect of increasing the seismic fold of the data on the resulting image.

Seismic reflections within the water column south of South Africa: indications for the Agulhas Retroflection

Gabriele Uenzelmann-Neben (1), Dirk Kläschen (2), Gerd Krahnemann (2), Tim Reston (3), Martin Visbeck (2)

(1) Alfred-Wegener-Institute for Polar and Marine Research, Bermerhaven, Germany,
 (2) IfM-GEOMAR Leibniz Institut für Meereswissenschaften, Kiel, Germany, (3)
 University of Birmingham, Birmingham, UK

With the publication of Holbrook et al. (2003) the field of seismic oceanography experienced a major momentum. Several authors since then (Nandi et al., 2004; Holbrook and Fer, 2005; Paramo and Holbrook, 2005) could show that those reflections within the water column correspond to thin layers with strong vertical temperature gradients. Those reflections hence represent a chance to trace those temperature gradients over large distances.

Weak seismic reflections within the water column south of South Africa gave rise to the question whether here traces of the Agulhas Current or Agulhas Retroflection can be observed. A careful reprocessing of the data led to the imaging of fields of reflections pointing towards a 135 km broad and about 1000 m deep reaching well stratified area with strong reflection amplitudes and several weaker reflections extending down to at least 1500 m water depth over the whole area of investigation. To image both the boundaries between the water masses as reflections and the different properties of the long wavelength velocity variations in depth special imaging techniques like prestack depth migration analysis were performed. Further, the temperature gradients from the short wavelength properties as velocity and density contrasts were determined by a two step inversion of acoustic amplitude

versus angle analysis to better quantify the variations of the water masses of the Agulhas Current.

References:

- Holbrook, W.S., and I. Fer, Ocean internal wave spectra inferred from seismic reflection transects, 2005, *Geophys. Res. Lett.*, 32, L15604, doi:10.1029/2005GL023733.
- Nandi, P., W.S. Holbrook, S. Pearse, P. Paramo, and R.W. Schmitt, 2004, Seismic reflection imaging of Norwegian Sea water mass boundaries, *Geophys. Res. Lett.*, 31, L23311, doi:10.1029/2004GL021325.
- Páramo, P., and W. S. Holbrook, 2005, Temperature contrasts in the water column inferred from amplitude-versus-offset analysis of acoustic reflections, *Geophys. Res. Lett.*, v. 32, L24611, doi:10.1029/2005GL024533.

Thermohaline staircases viewed by contemporaneous seismic imaging

Isabel Ambar (1), Ronaldo Bezerra (2), Luís Menezes Pinheiro (2), Patrícia Silva (1), Nádia Salvação (1)

(1) Instituto de Oceanografia, Faculdade de Ciências da Universidade de Lisboa

The Geophysical Oceanography (GO) project (funded under the European Union NEST initiative) main objective is to assess the potential of seismic imaging of the water column for understanding physical processes of the ocean interior. In the frame of this project, an intensive observational campaign in the Gulf of Cadiz took place in April-May 2007, during which a few lines off Cape St. Vincent were surveyed using both seismic and hydrographic profiling. The presence of the two main cores of the Mediterranean Water (MW) was detected in the hydrographic sections through the temperature and salinity maxima centered at about 800 m and 1200 m.

When the temperature (and salinity?) profiles were analysed in detail, there was evidence, in some of the offshoremost stations, of a step structure just beneath the MW layer, between 1200 m and 1500 m. Thermohaline staircases - a succession of fine structure steps in the vertical profiles of temperature and salinity instead of a continuous trace - have been reported in the ocean at sites where water mass intrusions with relatively higher salinity and temperature induce large scale vertical gradients in the interfaces with the surrounding water masses. These features result from small scale instabilities created by double diffusion processes acting at the boundary of warm and salty water over less salty and colder water (formation of salt fingers at the boundary) or the inverse case (formation of diffusive layers at the boundary).

The GO dataset provides a unique opportunity to analyze the direct effect of thermohaline staircases on the seismic profiles since previous correspondence reported by Schmidt et al. (2005) was based on the comparison of observed and synthetic seismic sections based on hydrographic data which were non-simultaneous (acquired with a time difference of 13 years) and located several hundred of miles away.

Here we report results from the GO project showing that the seismic method can indeed image double-diffusive staircases, based on XBT data acquired contemporaneously with the seismic data. After obtaining the salinity profiles

corresponding to the XBT profiles using Käse et al. (1996) method, acoustic impedance (density times sound velocity) and reflection coefficients were calculated and synthetic seismograms generated. The comparison of the observed and synthetic seismic sections confirm the potential of this method to investigate in detail thermohaline staircases with a high spatial resolution not easily obtainable with CTD/XBT data.

Seismic oceanography in Japan

Y. Nakamura (1), T. Noguchi, T. Tsuji

(1) Ocean Res. Inst., Univ. Tokyo, (2) Graduate School of Eng. Kyoto Univ.

The Kuroshio current, which is one of the major warm currents in the Pacific Ocean, flows from south to east of Japan. Oceanic finestructure is well developed around Japan due to the mixing of the warmer Kuroshio water and colder other water masses like Oyashio, thus the area around Japan is a suitable field for seismic oceanography. We started seismic oceanography studies at 2004 using a legacy 3D seismic data set obtained south off Japan, and since then we have conducted two research cruises dedicated for seismic oceanography. We simultaneously carried out simple seismic reflection, using single air gun and a short streamer cable, and physical oceanographic observations with XCTD, XBT and XCP. We could detect the seismic reflectors which could be linked to the thermohaline finestructure even we used very small sounding source and short receiver array compared with previous studies. We introduce results of seismic oceanography studies in Japan.

Seismic Imaging Of The Southern Ocean

A. Katy Sheen, B. Nicky White and C. Richard Hobbs

University of Cambridge, University of Cambridge, University of Durham

The Southern Ocean is the most inaccessible and under-sampled ocean in the world. It nevertheless contains water masses which are essential components of the global thermohaline circulation and controls the water mass exchange between the major ocean basins through the Antarctic Circumpolar Current.

Here we present a series of seismic images of the water column from a region in the southwest Atlantic using legacy seismic reflection datasets shot in the 1990s. The seismic surveys follow the northern part of the Antarctic Circumpolar Current as it veers northward after exiting Drake Passage, loops around the Falkland Trough and enters the Argentinian Basin, largely following the Sub Antarctic Front route. Finestructure imaged in the data occurs dominantly in the boundary layer between Antarctic Intermediate Water and underlying Upper Circumpolar Deep Water, and correlates well with hydrographic interpretations. Structures such as dipping bands of heterogeneous water and eddies characterized by homogeneous cores and strong reflective inter-leaving edges are seen in the vicinity of ocean fronts. Further to the north, interesting thermohaline structures associated with the intrusion of

North Atlantic Deep Water into the region have been captured. Seasonal variations in the time of data acquisition and the subsequent differences in the acoustic images provide interesting insights into the temporal variability of the water masses. Processing techniques such as prestack depth migration have been performed on much of the data in order to investigate longer wavelength acoustic velocity variations.

Turbulent mixing in this part of the Southern Ocean is known to be remarkably intense and widespread and thought to contribute significantly to driving the upward transport of water closing the ocean's meridional overturning circulation. The deformation of thermohaline finestructure by such mixing and the ambient internal wavefield results in small undulations along seismic reflection horizons. Spectral analysis of these sinusoidal displacements has been used to extract quantitative information on internal wave energy and turbulent dissipation rates.

New Perspectives on the Physical Characterization of the Mediterranean Undercurrent

G. Buffett(1), B. Biescas(2), F. Machin(2), V. Sallàres(2), J. Pelegrí(2), R. Carbonell(1), D. Klaschen(3), R. Hobbs(4)

(1) Institute of Earth Sciences "Jaume Almera", (2) Centre Mediterrani d'Investigacions Marines i Ambientals, (3) IFM-GEOMAR, Dynamics of the Ocean Floor, Wischhofstr. 1-3, 24148 Kiel, Germany, (4) Department of Earth Sciences, University of Durham, South Road, DURHAM DH1 3LE, United Kingdom

Seismic reflection profiling is applied to study large scale thermohaline structures and ocean current circulation in the Gulf of Cadiz and western Iberian coast coinciding with the path of the Mediterranean Undercurrent. Data are corroborated against historical oceanographic data (CTD casts). Water masses of different temperature and salinity are stratified and separated by thin boundary layers. Conventional oceanographic techniques have been able to image these boundaries, however only at sparse horizontal intervals. The multi-channel seismic reflection method, provides a horizontal resolution approximately two orders of magnitude higher than CTD casting.

Seismic waves travel through fluids as pressure waves that reflect from fluid interfaces according to the magnitude of acoustic impedance boundaries (the product of density and sound speed). When a wave front impinges upon an acoustic impedance boundary there is partial transmission and partial reflection depending on the ratio of density and sound speed above and below the boundary. At any given pressure, temperature and salinity are the two dominant factors influencing density and sound speed in the ocean. However, the precise contribution from each is not well known and may vary considerably in different regions or in different mixing regimes.

Stacked seismic sections are presented coinciding with the path of the Mediterranean Undercurrent. The images clearly show strong lateral stratification, Meddies and evidence of turbulent entrainment from the observation of differing seismic reflectivity and horizontal coherency variations. Data are corroborated against co-located oceanographic data that show decreasing salinity downstream. We conclude that the seismic reflectivity and coherency patterns observed proceeding downstream illustrate increasing salt dilution that is brought on by turbulent entrainment.

