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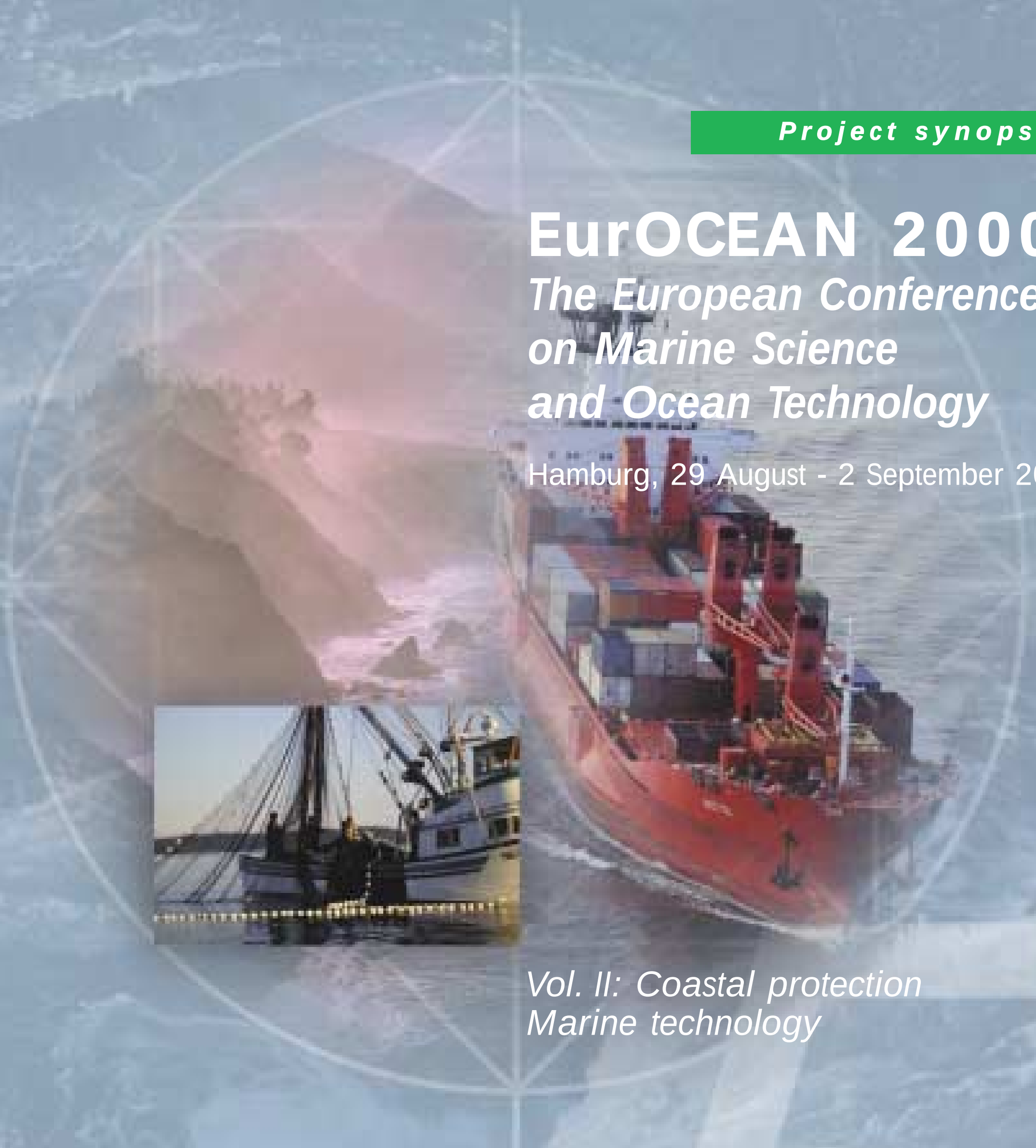
The European Conference on Marine Science and Ocean Technology

Hamburg, 29 August - 2 September 2000



Vol. II: Coastal protection
Marine technology

ENERGY, ENVIRONMENT
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Volume II

Coastal protection

II.1.1. Coastal processes and morphodynamics

TITLE: SURF AND SWASH ZONE MECHANICS : **SASME**

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SUMMARY

This MAST project started on 1 October 1997, and runs for 3 years. The total costs is estimated to be 2.895.000 ECU of which the EU contribution will be 1.810.000 ECU. The main aims of the project are described, and the work plan is summarized. No results are yet available from the project.

1. INTRODUCTION

The objective of the present project is to investigate the physical processes which take place in the surf zone on a coast with and without coastal structures.

The project shall lead to a significantly improved description of the cross-shore and longshore sediment transport, which mainly occurs within the surf zone.

The SASME project is divided into two interlinked parts:
I. Surf and swash zone hydrodynamics and sediment transport, and
II. Surf and swash zone morphology.

The surf and swash zone hydrodynamics and sediment transport will concentrate on the behaviour of breaking and broken waves, their generation of small and large scale turbulence, and the resulting sediment transport.

The morphological study focus on the bed behaviour in the surf/swash zone which includes bed-instabilities; formation of bars and their behaviour (like erosion and accretion in 2 horizontal dimensions; non-uniformities in the alongshore direction due to rip currents).

The far field impact of coastal structures is investigated: the effect of the modifications of wave, current and sediment transport fields by the structures. The project thus address important aspects of the function of the coastal structures. The project does not treat the three-dimensional near-field hydrodynamics and sediment transport around structures that are associated with local scour phenomena.

In terms of practical outcome, the project is expected to produce significant improvements in “medium” term modelling, which is necessary for the development of longer term prediction methods. In addition, improvements at a fundamental level will yield a basis for develop-ments of transport and mixing models for quantities other than sediments in the surf and swash zones, plus some results of wider significance, for example in relation to breaking waves in deep water and their significance for air-sea exchange and mixing.

2. DESCRIPTION OF THE INDIVIDUAL PROJECTS

SASME is divided into the following four main projects which each has a project leader and an assistant project leader. The 4 projects are:

- Project 1. Breaking/broken waves in surf/swash zone. Project leader: Rolf Deigaard, DTU.
- Project 2. Vertical structure of motion and associated sediment transport plus morphological modelling of coastal profiles. Project leader: B. Mutlu Sumer, DTU.
- Project 3. Horizontal structure of wave- and breaker-induced motion and area-modelling. Project leader: Jesper Damgaard, HR.
- Project 4. Structure-seabed interaction. Project leader: Dano Roelvink, DH.

Project 1: Breaking and broken waves in the surf and swash zone

Participants In the project: UPl, BrU, HR, DH, UUd, LWI, UCa, DHI, DTU.

This project deal with waves just before they break, the processes of wave breaking and the further propagation as broken waves to the limits of the run-up in the swash zone. The study treats plane as well as barred coasts and aspects of hydrodynamics and sediment transport. The research has included analysis of field data, analysis of physical processes, mathematical modelling and laboratory experiments.

Breaking and broken waves have been analysed from field data that have been made available for the project. The data are from locations in Germany: at the Baltic coast and at the North Sea coast (Sylt). The measurements have been specifically aimed at improving the physical understanding of breaking processes, energy dissipation and the transformation of wave energy across the coastal profile. Field work has been carried out in Spain to study infra gravity waves especially in pocket beaches.

The laboratory experiments include a study of accelerated flow in porous media at high Reynolds numbers. Flume experiments have been carried out on breaking waves over permeable and impermeable beds. Extensive experiments have been carried out on swash zone conditions for different breaker types and beach slopes. The measurements include among others surface elevations, run-up, the mean motion, turbulence intensity and the structure of the turbulence (length scales). The role of long waves for the dynamics of a surf zone has been investigated including the generation of long waves by a moving breakpoint. The interaction between breakpoint-generated and bound long waves has been investigated. Data has been available for plane and barred beaches. A theoretical study has been made on the generation of long waves from wave groups and the non-linear effect of long waves on short waves.

The effects of wave reflection on surf zone dynamics have been studied by experimental and theoretical investigations.

Boussinesq wave models for surf zone conditions have been verified against published data, including wave generated currents. Efficient 2DH models describing the vorticity generated by bores have been developed.

Sediment transport in surf beat and long waves has been studied by numerical models verified against published data, and by analysis of hydrodynamic data from flume experiments to determine zones of convergence and divergence. The theoretical study includes the effect of bound long waves outside the breaker zone, surf zone wave models that resolve the low frequency motion but averages out the short waves, and by phase resolving wave models.

The propagation of edge waves has been modelled for a plane beach with a shelf and a seawall to explain the formation of rhythmic morphology at a location in Spain. Work has continued with modelling of edge waves along a permeable barrier and resonance of a harbour under edge wave forcing.

Project 2: Vertical structure of motion and associated sediment transport, and morphological modelling of coastal profiles

The goal of the project is to study 3-D structures of wave-generated motions in the surf zone with focus on the large-scale vortices generated by plunging breakers, the turbulence generated by breaking and broken waves and the velocity distribution in wave-driven currents, and also to investigate morphological modelling of coastal profiles. Project 2 consists of two topics: (1) Vertical structure of wave- and breaker-induced motion and the associated sediment transport (Topics 1.2a - d); and (2) morphological modelling of the surf zone without structures (Topic 2.1a).

Topic 1.2a. Description of a plunging breaker. The work has been concentrated on two aspects: (1) DHI/ISVA has been developing a model for plunging breakers and to study the turbulent flow structures initiated by plunging breakers. (2) UEDIN in cooperation with ISVA has been doing PIV experiments of plunging breakers. The Volume of Fluid (VOF) method has been implemented in the general non-orthogonal Navier-Stokes solver in the DHI/ISVA work. Model results have been compared to PIV measurements performed by UEDIN under waves breaking on a 1:13.5 slope. The k- model has been used to model the turbulence, and applied to simulate periodic breaking waves. All PIV experiments have been completed at two laboratories, at UEDIN and at ISVA. Different dynamics of selected breaker types have been found. The comparison of the model results to measurements will be completed by the end of the project period.

Topic 1.2b. Wave- boundary-layer investigation under breaking waves. An experimental study (ISVA) is being undertaken to study the interaction between turbulence generated by wave breaking, and the turbulence generated in an oscillatory boundary layer. The experiments are carried out in an oscillating water tunnel, and the wave-breaking generated turbulence is simulated by placing a grid in the upper part of the tunnel. The externally generated turbulence affects the transition to turbulence in the bed boundary layer, the phase difference between the free stream velocity and the bed shear stress and the wave friction factor. In another study at

ISVA, turbulence under spilling breakers and broken waves has been investigated by wave flume experiments.

Topic 1.2c. Influence of breaking waves on sediment transport. The work undertaken by DHI/ISVA under Topic 1.2a (see above), constitutes a key element for this research. The sediment transport has been included in an advanced Navier-Stokes solver in two-dimensions. DHI/ISVA will continue the development of the free-surface method for breaking and broken waves. Also, comparison of the sediment transport rates to experimental results, and sensitivity analysis of for instance the fall velocity, will be made.

Topic 1.2d. Wave-induced currents. The objective is to develop a 3-D wave-driven current model. A start has been made in testing the 3D implementation against 2D (laboratory) cases. Furthermore the present implementation has been combined with a research version which has on-line sediment transport module included. The wave effects are implemented in a code that will also be used for morphological modelling of complex bathymetries. Testing of 3D implementation against 3D cases will be sought. The first comparisons have shown that especially the streaming effects are not yet included correctly. Research will focus on this aspect for the rest of the project period.

Topic 2.1a. Morphological modelling of the surf zone without structures. Two research groups have been working on this topic, namely DHI and DH. The work DHI undertakes basically deals with vertical structure of motion and associated sediment transport plus morphological modelling of coastal profiles. A mathematical model has been developed that describes the 3D distribution of the mean shear

stress, the time varying eddy viscosity, velocity profiles, suspended sediment concentrations and sediment transport. The sediment transport model has been extended to include irregular wave trains. A phase resolving model has been developed to simulate the morphological evolution of a cross-shore beach profile. The depth averaged-hydrodynamics are calculated from a wave model based on the Boussinesq equations. The Quasi 3D sediment transport model has been incorporated into a phase averaged morphological model for cross-shore profile evolution. The morphological model has been used to investigate the morphological development of beach profiles under the attack of obliquely incident waves. Regarding the DH study under this topic, the objective is to model the erosion/accretion of dry beaches in a morphodynamic area model.The principle idea is to extrapolate sediment transport from the last wet point to the highest dry point of a grid row or column, where transport is assumed to be a linear function of the height; in this way, profiles can uniformly shift in horizontal direction. A 1-D version of this approach has been successfully tested. Subsequently, a 2-D implementation has been carried out which has been tested successfully on the Keta Lagoon case.

Project 3. Horizontal structure of wave- and breaker-induced motion and area modelling.

Goal of the project: to investigate the hydrodynamics, sediment transport and morphodynamics in the surf and swash zone, with focus on the 2DH (two dimensions in the horizontal) view point. Most important results until now are as follows

- for a realistic longshore current, in presence of eddy viscosity, resonant triads, which can involve unstable and/or stable modes, can exist and a resonant triad, comprising 3 linearly stable modes derived from a linear stability analysis, can exhibit explosive instabilities.

- the nearshore circulation model SHORECIRC has been applied to study the infragravity wave response to the bathymetry and shortwave forcing. Specific attention has been paid to the generation of accurate boundary conditions for the bound incoming long wave.
- a linear model has been developed for the generation of long waves by obliquely incident grouped short waves on an along-shore uniform beach. Effects of set-up and longshore currents on the long wave response are taken into account.
- the development of rip channels has been simulated with a 2DH numerical coastal area model. The results for normal incidence exhibit significant scatter but compare relatively well with analytical results.
- experiments have been carried out on the circulation current over a longshore bar with a rip channel. The relation bewtween the water level, the wave conditions and the maximum velocity in the rip current has been investigated.
- the horizontal exchange of momentum in wave-driven currents and its importance for the velocity distribution has been invstigated. It is found that wave-current interaction can play an important role.
- survey data from the test site Rantum, Sylt, North Sea has been finalised, behavioural trends of morphologic changes, rip currents and current systems have been deducted.
- a simplified linear model for examining bar stability has now been developed. Results clearly indicate that a barred beach is less stable and will tend to exhibit instability.
- a stability analysis and the investigation into the initial formation of rip channels on a long, straight and uniform longshore bar has been performed with a numerical modelling system.
- the Coast3D test site of Egmond has been modelled using a 3D numerical modelling system.
- a systematic exploration of the linear instability with simple descriptions of sediment transport in case of oblique incidence has been achieved. Two behaviors are obtained depending of the

Project 4. Structure-seabed interaction

Goal of this project: This project aims at understanding, modelling and describing the effects of various coastal structures on the nearshore morphology. The project is divided into two topics:

- modelling of the far field morphological evolution around structures, and
- review of the experience on implementation of coastal structures.

The modelling applied to the role of structures will profit by developments and improvements carried out in other parts of SASME. The capabilities and limitations of the different modelling principles for different types of structures are analysed. The model results are used to analyse the flow, transport pattern and morphological development around the structures, to obtain a better understanding of the effect of the structures and of how a series of structures interacts.

The aim of the review study is to provide clear guidelines on the use of coastal structure in coastline protection programmes. These guidelines will be based on a review of existing experience with structures, and on the results of the detailed modelling of the effects of structures during the SASME project. The guidelines are recognised as one of the most important end products of SASME and will be published both in a detailed report and as a review paper.

Most important results until now:
WL | delft hydraulics (DH) has focused on the description of turbulence effects and 3D structure of
transport and resulting morphological changes around harbours and long breakwaters (lit [1]). It is also investigating the effect of beach nourishments. It will also do some depth-averaged runs for situations with groins for comparison with LNH's 3D approach

Danish Hydraulic Institute (DHI) looks at the morphological evolution around emerged and submerged offshore breakwaters with 2DH and quasi3D approaches (lit [2]), and investigates the effects of diffraction and directional spreading.

Laboratoire Nationale d' Hydraulique (LNH) investigates the effects of groins using a 3D approach (lit [3]).

Delft University of Technology (DUT) has looked into the effects of submerged breakwaters and is now investigating the equilibrium shape of natural bays and bays formed between offshore breakwaters, using a 2DH approach (lit [4]).

Together the partners span most types of structures. In a collaboration between all partners, the processes around these structures and the state of the art (including present improvements) of modelling these processes will be described in a review paper. A review paper on the practical use of structures and morphological design considerations is being prepared.

SASME homepage with a lot of additional information: www.wldelft.nl/sasme/sasme.htm

TITLE : PREDICTION OF COHESIVE SEDIMENT TRANSPORT AND BED DYNAMICS IN ESTUARIES AND COASTAL ZONES WITH INTEGRATED NUMERICAL SIMULATION MODELS: **COSINUS**

CONTRACT N° : **MAS3 CT97-0082**

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PREDICTION OF COHESIVE SEDIMENT TRANSPORT AND BED DYNAMICS IN ESTUARIES AND COASTAL ZONES WITH INTEGRATED NUMERICAL SIMULATION MODELS

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INTRODUCTION

The management of coastal zones and estuaries requires accurate and detailed knowledge to cope with their problems such as wetland protection and restoration, maintenance of navigation channels, dredging and dredged material relocation, effects of construction works on siltation and turbidity levels, pollutant transport, etc. Development and application of this knowledge requires detailed mathematical models, amongst which full three-dimensional codes. This is becoming practically feasible in view of the current developments in soft- and hardware. The physical understanding and mathematical description or “modelling” of the processes however is still lagging behind, especially with respect to the presence of concentrated benthic (near-bed) suspension layers (CBS).

PROJECT METHODOLOGY

The state of the art knowledge on cohesive sediment transport shows that there is still a lack of experimental data on the role of flocculation and turbulence in the formation and erosion of mud beds and on the formation of CBS (concentrated benthic suspensions, or “fluid mud”). Therefore, an experimental programme has been set up to obtain these data. It consisted of field measurements in the Tamar estuary on floc formation and laboratory experiments on formation and erosion of mud beds and CBS, and the influence of floc structure and turbulence on these processes.

The data of the experimental programme, together with other relevant data from literature have been stored in a database, which at the end of the project will be accessible to the public.

Process modules have been developed and implemented into detailed 1D and 2D vertical models which solve the full hydrodynamic, turbulent energy and sediment mass conservation equations. Two different bed models, to be coupled to these hydrodynamic models have been developed as well (1DV point model). The data from the database have been used to calibrate and validate the process modules.

The process modules have been parameterised to obtain relatively simple formulations, which can be implemented into currently used 3D and 2DH engineering system models.

The performance of the improved system models has been tested by application of the models to a schematic estuary, for which a 2DV solution with the detailed research model is used as a reference. Various scenarios have been simulated. The models have also been applied to three real estuaries (Tamar, Loire and Weser). Data to set-up and calibrate the model applications are stored in the database. From the experience with the large-scale applications feed back has been produced towards the process module development and their parameterisations.

RESULTS

Sediment - turbulence interaction

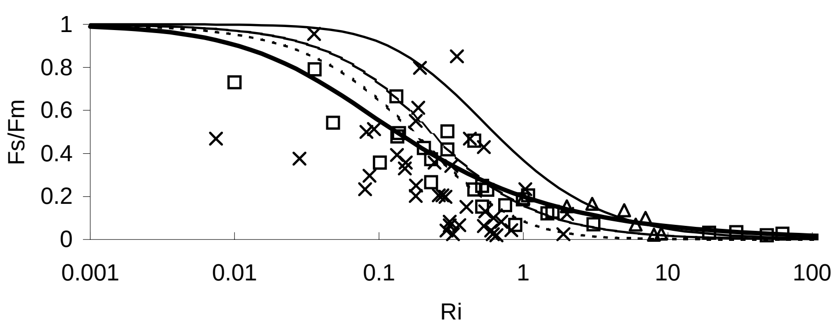
For the numerical modelling of sediment - turbulence interaction, the most commonly used engineering turbulence models have been used, i.e. the Prandtl mixing length (PML) and the k-ε model.

Suspended sediment particles cause damping of turbulent energy in the flow. Traditionally, this effect is parameterised by the use of semi-empirical damping functions, which are applied to correct the turbulent eddy viscosity (in the PML model) and the sediment mixing coefficient (or eddy diffusivity) for neutral conditions. The k-ε model includes the buoyancy effect explicitly but still needs the damping functions in the bed boundary conditions and the buoyancy term. Data on turbulence damping in stratified flows from the literature have been reanalysed, together with numerical data generated with the k-ε model. Based on these results and on theoretical considerations, new damping functions have been proposed and tested.

High density gradients at the bed result in an apparent reduction of the bottom roughness with consequently higher transport and erosion rates than expected when the model would not account for these buoyancy effects in the bed boundary conditions. A new bottom boundary treatment method has been proposed, which yields the correct bed shear stress.

When a flowing suspension decelerates during a tidal cycle, hindered settling may lead to the formation of a two-layer stratified flow with a distinct density interface, the lutocline. Turbulence can be completely suppressed at this interface, as a result of which no sediment can be suspended in the upper layer, increasing the amount of sediment in the lower layer further. Hence a snow-ball effect occurs resulting in a collapse of the turbulence field and the vertical concentration profile. Under certain conditions this interface becomes unstable, resulting in internal waves which generate new turbulence and mixing across the lutocline. It has been proposed to model this turbulence generation in a parameterised form as an additional eddy viscosity. An experimental and theoretical study was carried out to establish the effects of non-locally produced turbulence on the mixing

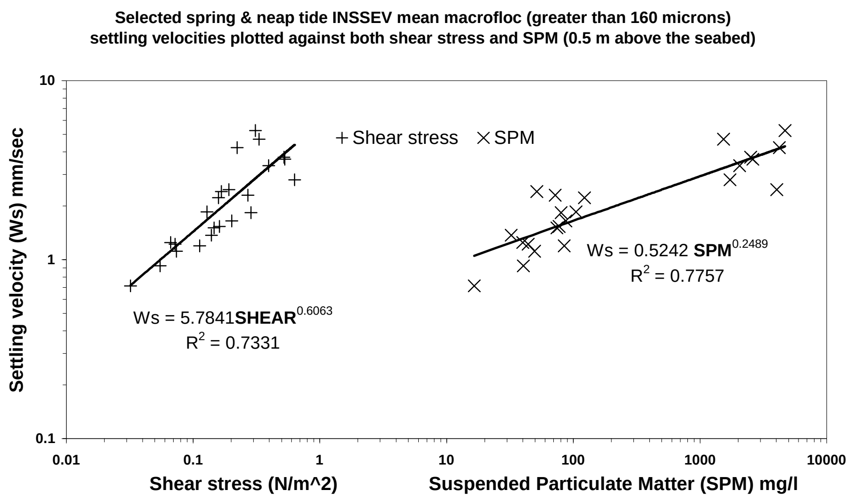
Ratio of the mixing to the momentum damping function (or normalised inverse Schmidt number) as a function of the gradient Richardson number (symbols = various data from the literature, fine line = Munk & Anderson (1948), dashed line = Ellison (1956), dotted line = Kranenburg (1999), thick line = new proposal)



processes of CBS. This is particularly relevant in case of spatially confined occurrences of CBS/fluid mud, as often encountered in nature.

Flocculation

Because, as far as cohesive suspensions are concerned, laboratory experiments cannot scale the turbulent properties of natural flows adequately, field measurements were obtained of floc characteristics. The measurements were taken in September 1998 in the upper reaches of the Tamar Estuary, and covered the neap and spring tide conditions. In that location the turbidity maximum is well developed and suspension concentrations of order g/l are present. The aim of the experiment was to measure floc size and settling velocity and their dependence on salinity, concentration and turbulent shear.
Two stations about 1km apart in the centre of the channel were deployed simultaneously. At both stations frequent profiles of velocity, salinity, temperature, and suspended sediment concentration were obtained, and Owen tube measurements of settling velocity were taken. At the lower station profiles of floc size were taken with a Lasentec P-100 system (Law et al., 1997), and near bed measurements of floc size, settling velocity, and effective density obtained with the INSSEV instrument (Fennessy et al., 1994). Also turbulence parameters were measured with miniature electromagnetic flowmeters above and below the INSSEV. At the upper station a LISST laser diffraction particle sizer was deployed, video measurement of floc size and settling velocities were observed within Owen tube samples. Additionally, samples were taken for laboratory analysis of the carbohydrate and chlorophyll a contents and CHN ratios.



Suspended near bed sediment concentrations ranged from 16 mg/l on a neap tide to 7 g/l on a spring tide. Maximum velocities were 0.5 and 1.5 m/s, respectively. Typical spring tide shear stresses were 0.68 N/m^2 at the level of the INSSEV. The number of flocs per INSSEV sample varied between 14 and 1150. Floc sizes up to 600 microns were observed. Examination of the settling velocity spectra of the flocs has indicated that the settling velocity Ws can be represented in simple linear correlation by: $Ws = 5.784\ (Shear)^{0.606}$ and $Ws = 0.524\ (SPM)^{0.249}$, where Ws is in mm/s, shear is in N/m^2 and SPM in mg/l. Also the ratio of macroflocs to microflocs separated at a size of 160 microns was observed to increase with both increasing concentration and shear stress. This suggests that the influence of concentration on aggregation is greater than that of shear on floc break-up. The biochemical results suggest that high carbohydrate levels acts as an adhesive assisting the production of the larger faster settling macroflocs formed during low concentrations at neap tides. It also appears that the faster settling macroflocs can selectively scavenge the very small microflocs at a rate faster than that for the medium sized flocs. Lower organic and chlorophyll-a content sediment is eroded from the bed at spring tides, reducing the contents observed at neap tides.

A 3D flocculation model in an Eulerian frame, describing turbulence induced aggregation and floc break-up, has been developed. The flocs are described as self-similar fractal entities. The model is calibrated against experimental data reported in the literature and deployed to describe the processes in the turbidity maximum on the Ems estuary (The Netherlands). Observed variations in vertical concentration distributions could be predicted only when both flocculation and sediment-induced buoyancy effects are taken into account.

CBS dynamics

In 2D models, the modelling of entrainment is important. From flume experiments is has been found that

- due to generation of turbulence in the lower, dense CBS layer, material from the upper, less dense and less turbulent layer is entrained into the lower layer, which thickened accordingly.
- the entrainment velocity appears to be constant in time, which is consistent with theory.
- a freshly deposited CBS behaves as a viscous fluid
- A relationship of the form $E \sim 1/Ri^*$ was found, in which E is the dimensionless entrainment rate and Ri^* the overall Richardson number.

From grid tank experiments the formation of CBS layers reaching an equilibrium thickness was observed for different concentration conditions. The time averaged sediment concentration appears to be uniform in the CBS layer for all concentrations. The turbulent kinetic energy decreases with increasing distance from the grid. No decay of turbulent kinetic energy was found for sediment concentrations up to 200 g/l. The flux Richardson number below the lutocline varies by more than two orders of magnitude when the variations of the settling velocity versus the concentration was taken into account.

Bed dynamics

Extensive settling column experiments have been used to develop and verify numerical models of the consolidation process. The relationship between the properties of the settling flocs, the deposition rates and the properties of the deposited bed (in particular the consolidating density profile and strength development) have been investigated. Using in situ measurements the critical shear stress for erosion has been related to other properties.

A 1DV sedimentation-consolidation model, solving the classical Gibson equation in an Eulerian frame, has been deployed to simulate the hindered settling and consolidation process in an annular flume. Material functions and strength evolution are described using fractal theory. The model has been extended to include the effects of sand-mud mixtures in the case of small sand fractions.

A 2DV bed dynamics model based on the generalised Biot theory, extended to deal with extremely large deformations and corresponding density changes, has been developed to study the strength development in cohesive sediment beds during consolidation, fluidisation and

liquefaction (e.g. induced by wave action). The model allows the implementation of more realistic constitutive rheological equations (i.e. stress – strain relationships).
With regard to deposition/ erosion the use of a new empirical stress – density relationship has been proposed which accounts for the fact that no strength is developed below the gelling point of the mud. The erosion rate parameter is proposed to be a function of the bed surface density. For deposition the total settling flux is considered, i.e. no critical stress for deposition. In order to distinguish between the settling sediment, which attaches to the bed and the deposited sediment which remains mobile and can readily be entrained, the erosion law has been generalised.

Applied modelling

The goal of the "Applied Modelling" was to provide results using numerical models, including the knowledge resulting from the theoretical aspects of the project. For this purpose, various test cases have been defined, in order to test and validate the new formulations, and to compare the different numerical models. The final goal is to apply the models to the cases of real estuaries, to show their capability to reproduce actual cohesive sediment phenomena.
The first test case is a one-dimensional vertical case, designed to compare the models regarding vertical processes, and particularly the modelling of turbulence damping by suspended sediment. Several sets of conditions for hydrodynamics and sediment have been tested. The computed results show that stratification and saturation effects are very sensitive to the choice of damping functions. It appears, looking at the viscosity and diffusivity profiles, that the influence of the shear velocity at the bottom is an important parameter to make correct sediment transport predictions. However, theoretical work has shown that the shear velocity is not correctly estimated by traditional methods when sediment is involved. Therefore a new formulation has been proposed.
Experimental and theoretical studies of flocculation processes have produced new information, which has been used to develop parameterisations of the sediment settling velocity. Several approaches exist, which have been implemented in the one-dimensional model. Comparisons and sensitivity tests have been carried out. On the other hand, the effects of entrainment of bed materials, resulting from the instability of the lutocline, have also been examined. A parameterisation has been established, which has been tested in the numerical models.
Similarly, the results of detailed studies of bed properties have been used to consider parameterised representations of the bed. There are two main aspects to this: consolidation of bed deposits and erosion. The model developed for consolidation is a variant of the Gibson equation based on a fractal representation of the floc structure (Winterwerp, 1999). It has been tested in the one-dimensional model. Resistance of the bed to erosion is a crucial parameter in the modelling of cohesive sediment transport, but less well understood. Based on experimental results and theory new formulations have been proposed and incorporated in the model parameterisation.
Simulations have been carried out with a second test case, a schematic estuary, considered as a two-dimensional vertical model. The results will prove the ability of the parameterisation developed to represent correctly the cohesive sediment processes when including advection and realistic estuarine processes, such as unsteady tidal hydrodynamic forcing, river discharges, and stratification due to salinity.
Finally, simulations have been carried out in the cases of three different real estuaries: the Weser, the Tamar, and the Loire estuaries. To validate the model results, these are compared with extensive experimental data from the three estuaries, partly collected during the project. The comparison between the models results and these experimental data show that it is now possible to predict cohesive sediment processes correctly in real estuaries.
All data have been stored in a data base, which is accessible to the public.

CONCLUSIONS

The objective of the research programme was to establish well validated physical and mathematical descriptions of the behaviour and fate of concentrated near-bed suspensions (CBS or «fluid mud») and their interaction with the water and the sediment bed.
An experimental programme has been set up to obtain missing data on floc formation, the formation of mud beds and CBS and the influence of floc structure and turbulence on these processes.
Different processes have been studied in detail: turbulence damping in sediment laden flow; turbulence production due to internal waves in concentrated suspensions; flocculation; generation, properties and entrainment of CBS; bed strength development and erosion of mud beds.
The detailed process models have been parameterised to obtain relatively simple formulations which can be plugged in into currently used 3D and 2DH engineering system models.
The performance of the improved system models has been tested by application of the models to a schematic estuary for which 2DV solutions with the detailed research models were used as a reference.
The models have been applied and tested in three real estuaries (Tamar in U.K., Loire in France and Weser in Germany).
All data have been stored in a data base, which is accessible to the public.
It is felt that great progress has been made in the physically based description of cohesive sediment dynamics with respect a.o. to the formulation of turbulence damping functions; the modelling of the rheology of CBS, incl. consolidation; the modelling of flocculation and the modelling of erosion and entrainment of CBS.
Engineering software tools have been improved to enable better predictions of mud dynamics for the benefit of estuarine an coastal managers.

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Several papers will be presented at the INTERCOH 2000 conference, Delft September 4 – 8, 2000. The conference will coincide with the closure of the COSINUS project. Besides individual papers, joint papers describing the achievements within the different tasks will be presented. Most of the scientific progress achieved within COSINUS will thus be published in the proceedings of INTERCOH 2000.

More detailed information can also be found on the COSINUS internet site:
http://sun-hydr-01.bwk.kuleuven.ac.be/COSINUS/cosinus.html

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TITLE : COASTAL STUDY OF THREE-DIMENSIONAL SAND TRANSPORT PROCESSES AND MORPHODYNAMICS : **COAST-3D**

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COASTAL STUDY OF THREE-DIMENSIONAL SAND TRANSPORT PROCESSES AND MORPHODYNAMICS (PROJECT COAST3D)

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SUMMARY

The COAST3D project has made measurements of waves, currents, sediment transport and seabed/beach evolution at sites at Egmond in the Netherlands in 1998, and at Teignmouth, south Devon, UK, in 1999. The resulting data are being used to derive new understanding of coastal hydrodynamic and sediment dynamic processes, to test computational models of morphological evolution, and will lead to tools for coastal zone management.

INTRODUCTION

A great deal of research has been devoted in recent years to modelling and measurements of waves, sediment transport and morphodynamic evolution on coastlines that are notionally straight and uniform, and these are now reasonably well understood. However, many of the coastlines that are of importance in practical applications do not conform to this ideal, but either have imposed non-uniformities such as headlands, river mouths, and manmade structures, or they spontaneously depart from two-dimensionality due to morphological non-uniformities such as rip-channels leading to dissected breaker bars.

These types of coastline are being addressed by the COAST3D project, a collaborative project co-funded by the European Commission's MAST-III programme and national sources, running from October 1997 to March 2001. A consortium of 11 partners from five EU states (UK, Netherlands, France, Spain and Belgium) is undertaking the project, which has the following objectives:

- to improve understanding of the physics of coastal sand transport and morphodynamics
- to remedy the present lack of validation data of sand transport and morphology suitable for testing numerical models of coastal processes at two contrasting sites
- to test a representative sample of numerical models for predicting coastal sand transport and morphodynamics against this data
- to deliver validated modelling tools, and methodologies for their use, in a form suitable for coastal zone management

FURTHER DETAILS OF THE AIMS AND METHODOLOGY OF THE PROJECT WERE GIVEN BY SOULSBY (1998A,B).

METHODOLOGY

This is being achieved by making field measurements purpose-designed for numerical model evaluation, with adequate boundary conditions and a dense horizontal array of measurement points, in conditions typical of the European coastline. Previous coastal experiments in Europe and elsewhere have placed their main emphasis on hydrodynamics; an innovative feature of the present project is that the emphasis throughout is on sand transport and morphodynamics. Another distinctive feature is that the focus is on non-uniform (3D) coasts, rather than on the relatively well understood (but possibly unrealistic) uniform 2D case.

Four field experiments have been successfully performed, resulting in large amounts of high quality data on water-levels, currents, waves, sediment transport and bathymetric changes. The first two experiments took place at Egmond-aan-Zee on a quasi-2D sandy stretch of the Dutch coast, with a pilot and main experiments in spring and autumn 1998 respectively (Ruessink, 1999a,b). Although the coastline and bathymetric contours appear on charts to be nearly straight, on direct inspection it is seen that there is a natural three-dimensionality produced by rip-channels intersecting a bar system that has a major effect on the hydrodynamics and sediment dynamics of the coast. The site is regarded as "2.5–dimensional" as a result of these sedimentary non-uniformities, and the departures from 2-dimensionality are an important aspect of this experiment.

The second two experiments took place at Teignmouth on the south coast of England in spring and autumn 1999, where a rocky headland and a river mouth provide a strong three-dimensionality to the coastline and bathymetry, which in turn result in complex patterns of flow and waves. A complicated re-curving spit adjacent to the river mouth, and a series of offshore sandbanks, are very active morphodynamically. This site, which additionally has a wide range of grain-sizes, stretches the capabilities of present day coastal morphodynamic numerical models to their limits, and provides a very exacting test of these and future models.

The data from these experiments will provide new understanding of coastal physical processes, which are valuable for coastal management both directly, and through the improvement of hydrodynamic and morphodynamic numerical models. Numerical modellers are working interactively with the experimenters, at the planning, experiment, and evaluation phases. Very successful "Modellers' Weeks" were held at both sites during the experiments, when the project's modellers, supplemented by others from outside the project, ran their models together at the site they were modelling.

RESULTS

The data from the experiments is currently (May 2000) being analysed. A number of interesting results are already apparent. At the notionally uniform site at Egmond, analysis of the bathymetric changes during the autumn experiment revealed that the bed changes associated with the along-shore non-uniformity were actually greater than those associated with along-shore uniform behaviour, so that an assumption of 2D behaviour would not be appropriate. A side-scan sonar survey revealed a surprisingly complex distribution of rippled areas, smooth areas, and more irregular bed features (Lankneus et al, 1999). The wave and current driving forces at the site were analysed by Pullen (1999).

Coastal Profile models have so far only been run for a pre-existing data-set with significant morphology changes, and the pilot experiment at Egmond, when there was very little morphological change. Their predictions of wave-heights, set-up and long-shore currents showed large differences between models. Results of the modelling for the Egmond site were described by Elias (1999), Elsayed (1999), O'Connor and Nicholson (1999), Sierra et al (1998, 1999), Tomé et al (1998), Walstra et al (1999), and Weerakoon (1998). Next they will be run with the main experiment data, when large changes in morphology occurred. As well as making runs with single transects, tests will be made to investigate whether such models give better results if they are run in a long-shore averaged fashion. Coastal Area models run for the Egmond site predicted circulation cells and rip systems.

At the complex Teignmouth site the current-meter data show large pulses as vortices are produced at the edge of the jet emerging from the estuary mouth. Some of the Coastal Area models are also able to predict such vortices, with at least qualitatively the right features. Detailed measurements in the swash-zone show that this is a very active area, advecting up and down the beach with the tidal rise and fall. Ripple profiles taken acoustically in the strong estuarine outflow and inflow show a rapid migration and reversal of asymmetry. Sidescan surveys at both sites show a remarkably complex pattern of bedforms, not all of which are easily explained. The autumn experiments at both sites encountered storms that produced large changes in the bathymetry which the morphological models will endeavour to simulate.

CZM TOOLS

An important aspect of the consortium is that national regulatory authorities from UK (Environment Agency, in conjunction with MAFF) and NL (RIKZ/Rijkswaterstaat) are partners, to ensure that the project is focused on practical tools for Coastal Zone Management (CZM). The means by which results from the project can be made use of in CZM applications were addressed from the outset of the project. It has been found to be by no means straightforward: there is a gap between the problem-driven requirements of CZ Managers and the science-driven goals of the researchers. All partners are keen to find methods of bridging this gap. To aid this, a questionnaire has been prepared by the CZM Tools Group and distributed to all the consortium partners, requesting them to answer a number of questions that relate to CZM in terms of the results that their data analysis and/or modelling will provide. Their responses are currently being analysed.

The COAST3D project will provide the following products, some freely available and some available commercially:

- **Data-sets:** (CD-ROM), from the two contrasting coastal sites, available publicly in October 2001
- **Reports and papers:** on coastal processes, morphological models, and innovative instrumentation
- **CZM tools and guidelines:** a report describing WHEN to use WHAT tools and HOW to use these tools, illustrated by case studies at Egmond and Teignmouth
- **Models:** improved, validated, morphodynamic numerical models
- **Instruments:** innovative instrumentation and systems for measuring bathymetry, waves and sediment transport

DISCUSSION

The COAST3D project has achieved a great deal in its first two and a half years. Four major field campaigns have been successfully completed, two on the coast of the Netherlands and two on the south English coast. These have resulted in a very large amount of high quality data, some of which have already been incorporated into a data-bank following stringent quality and consistency checks (Vermetten, 1999), and the rest will follow imminently. Numerical modellers have gathered at both the sites to participate in "Modellers' Weeks", boosted by modellers external to the project. The work done in these events, together with a much larger effort when back at base, has made good use of the data to test, intercompare and improve the models' capabilities for predicting the distributions and evolution of waves, water-levels, currents, sediment transport and bed morphology at the two sites. The data is also being used by the experimenters to derive a better understanding of the processes involved, which can subsequently be used to develop the numerical models further, as well as providing important information in its own right. The results from the data and the modelling, together with an assessment of the new monitoring techniques used, are being pulled together into a form that is of direct use for coastal zone management.

The project is now past the "high-risk" stage of the field campaigns. We are now, in its final year, into the most interesting part of the project, when the analysis and interpretation of the data, the main model testing, the publication of the results, and their digestion into CZM Tools take place. All these activities are being undertaken interactively between the partners, facilitated by meetings and email correspondence.

ACKNOWLEDGEMENTS

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ALGARVE INLET PROJECT: (INDIA)

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SUMMARY

The INDIA Project is a multi-disciplinary research study of interacting coastal processes in the Barra Nova Inlet within the Ria Formosa National Park in the Algarve Region of Portugal. Some twenty international research teams have combined to study the newly (1997) created Barra Nova Inlet using state-of-the-art field equipment and a range of aerodynamic, hydrodynamic and morphodynamic computer results. Measurements taken by the field teams during an intensive campaign between January - March 1999 are presently being analysed. Particular results as of May 2000 are presented.

1. INTRODUCTION

Cliff/land erosion in areas of rapidly changing coastline orientation or adjacent to low-lying coastal areas often leads to the formation of quiet lagoon areas separated from the sea by low-height spits/peninsulas and islands. The tidal inlets between the islands are dynamic and move in the direction of dominant longshore sediment movement unless prevented by engineering works. Navigation through natural inlets is often difficult due to the presence of complex patterns of flood and ebb bars as well as the interaction of tidal flows with coastal waves. Interactions can also occur between inlets as the back-lagoon drainage paths over-lengthen and new inlets are produced and old inlets are blocked by wave action. Lagoon circulations also change as a consequence of inlet change and affect lagoon use.

The INDIA Project brings together multi-disciplinary research teams from some 20 research institutes in Europe and around the world to study interactive coastal processes in a natural dynamic tidal inlet located in the Ria Formosa National Park in the Algarve region of Portugal. Research advice has been provided by SME's, Bullen & Partners (UK) and Halcrows (UK). The Project started on the 1st November 1997 and lasts for three years. Final Project results will be presented for scientists/engineers and end-users at a special three-day INDIA workshop to be held between 25-27th September 2000 at the University of the Algarve (UALG), Faro, Portugal as part of the 3rd Symposium on the Atlantic Iberian Margin (see also www.ualg.pt/ciacomar/Simp). Further Project details are given below as well as on the Project's Web site (http://www.pol.ac.uk/india/INDIA.html).

2. OBJECTIVES

A threefold approach is used in the Project to obtain increased understanding of complex processes. Direct field observations have been made in the vicinity of the Barra Nova Inlet, a newly-dredged (June 1997) inlet through the Ancão peninsula at Faro in the Algarve, Portugal. Use has been made of a large range of remote sensing equipment, including acoustic, radar and video systems, with much of the equipment being deployed during an intensive field campaign between January - March 1999: video records have continued from a tower up to January 2000, when observations were stopped due to erosion of the tower supports. In addition, a range of one-, two-, and three-dimensional computer models of flow, water level and seabed changes have been used to extend the spatial and temporal distribution of coastal parameters. Data from other international studies, particularly in Holland and America is being studied to integrate the field site into a wider context. Details of Project organisation, work plan, equipment and models have been given in earlier publications, see Section 6.

3. RESULTS

Partners are currently analysing the large quantity of field data that was successfully collected during the 1999 field campaign and which is currently being assembled into a Project Database by BODC. In addition, data is being used to check and calibrate models.

- Analysis of satellite photographs by UALG and lagoon modelling by HIDROMOD show that the deterioration of the original Ancão Inlet, which was some 5km to the east of the Barra Nova, is at the expense of the rapid widening of the Barra Nova Inlet.
- The geometry of the Barra Nova Inlet has been shown by LU to have developed in width at an exponential rate to reach equilibrium values after some 18 months. GPS and bathymetric observation by UALG show that individual storms have had a much greater impact on changes in width than in inlet depth. Video tower analysis by UP confirms that up to 60m of vegetated dunes were lost downcoast from Isle de Barreta in a single storm event. There has also been 90m of erosion over the seven-month period from December 1998 to July 1999. The corresponding movement of the Inlet channel was 55m towards Barreta.
- Examination of historic bathymetric charts and satellite photographs by UALG suggests a twenty year cycle for the new Inlet, based on evidence of the earlier Ancão Inlet, with a yearly alongshore movement of some 100m while modelling longshore sediment movement by LU using computer hindcasts of wave information by IST suggests that some 80% of such movement occurs during the winter months of November to April with south easterly movements of nearly 30m/month.

- Historic bathymetric chart analysis by WHOI and SOES for a 300 year period suggests that the number of inlets in the Ria Formosa system may be increasing over time while computer modelling of the lagoon system by WHOI shows that the lagoon can be divided into three largely separate hydrodynamic cells. Lagoon modelling by HIDROMOD and LU shows that the Barra Nova Inlet is ebb dominant, which will assist longshore easterly movement by wave action, and that more tidal water is drawn to the Inlet from the western part of the lagoon than from channels to the east.
- Analysis of recent hydrographic charts by UALG and computer modelling by HIDROMOD and LU shows that the erosion that has occurred on the inside of the Peninsula de Ancão near the Barra Nova Inlet is a consequence of the re-direction of tidal flow in the lagoon by the opening of the new Inlet.
- Use of models of aeolian sand transport by LERG has shown that significant sand movement from the beach dunes to the lagoon only occurs during high storm events (1-2 per year) and that transport is very sensitive to the state of the dune vegetation.
- Use of bathymetric surveys of the Ancão beaches combined with fluorescent tracer studies by UB and UALG has shown that the easterly moving longshore sand transport is trapped by the Barra Nova's ebb shoal, which has also received material from the eroded area on the lagoon side of the Peninsula de Ancão. Sediment transport calculations by UB using engineering formulae show realistic comparison with sediment movement on the ebb shoal system as determined by tracer studies.
- Computer modelling of sediment movements in the Barra Nova vicinity by KU and LU show a complex pattern of deposition on ebb and flood shoals and rapid erosion of beach-size sand from the Inlet channel. The nett ebb loss of sand through the inlet is confirmed by LU computations of bedload sediment movements, which represents the dominant mode of transport until major cliff erosion of medium-sized sand on the downcoast Ile de Barreta occurs, which computer modelling suggests disperses rapidly to the ebb and flood shoal areas. The effect of wave action in the inlet cross-section has been shown by LU to reduce the nett ebb loss of sand.
- Computer modelling of flow patterns through the Barra Nova Inlet by KU, LNEC and LU show the presence of tide and wave-induced gyre-circulations in the Inlet flow cross-section on both flood (Ancão side) and ebb (Barreta side) phases of the tide.
- Computer modelling of wave transformations from offshore to the Inlet by LU, KU, LNEC, IMAR show major reduction in wave heights (60-70%) due to depth limitations and refraction in the Inlet.
- Computer modelling of tidal currents by KU and LU together with CCMS-POL barge observations show maximum ebb tidal currents of between 2.5-3.5 m/s through the Inlet with lower values (some 60-75%) on flood tides. The models also show good agreement with surface currents measured by JCU's COSRAD radar system.
- Direct calculations of sediment transport by CCMS-POL based on measurement of ripple migrations in the Inlet from a jack-up barge using sonar shows good comparisons with engineering transport equations, while prediction of bed form sizes by LU's engineering bedform model shows similar values to CCMS-POL's measurements: features not predicated by existing engineering equations used for design purposes.
- Much of the Project's remote sensing equipment has been found to produce reliable results during storm conditions: BLISS (UP), STABLE (CCMS-POL) bed tripods offshore; S4 current meters (UB) inshore; automatic tracer vehicles in the inter-tidal zone (UB, UALG); the use (CCMS-POL) of a jack-up barge (SEACORE Ltd) in the Inlet itself; X-Band radar (CCMS-POL) on the barge for waves as well as ECM's , SONTEK ADVs and ADCPs

(CCMS-POL, USC) and bed sonar elevation monitors (SSS, CCMS-POL); and both OSCR and COSRAD (JCU) radar systems for surface currents.

4. DISCUSSIONS AND CONCLUSIONS

The development and working of the Barra Nova Inlet and the lagoon system is now partially understood. New and unique data has been obtained from the field site. Computer modelling confirms the accuracy of the data collected and also records new features of the coastal processes, which could not have been obtained totally from field studies. Project data will be valuable in the study of other inlet systems.

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TITLE : SEDIMENT TRANSPORT MODELLING IN MARINE COASTAL ENVIRONMENTS **(SEDMOC)**

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SEDIMENT TRANSPORT MODELLING IN MARINE COASTASL CONDITIONS

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INTRODUCTION

The state of the marine environment is a matter of concern for several countries within the European Union. An important aspect of this is the future evolution of the coastline, where uncertainty arises both from the morphological impacts of human interference (e.g. beach nourishment and coastal protection schemes), and also the expected future rise in sea-level and associated climatic variations. These changes may gradually alter patterns of waves and currents and, hence, the sediment transport pathways in coastal areas. In the medium- and long-term, such changes may profoundly influence the stability of the shoreline itself, with all that this entails for the security and livelihoods of the large proportion of the population living near the coast.

The practical solution of real-life, coastal engineering problems in the short- and medium-term necessarily involves site-specific studies, often including the acquisition of field data. However, great expense is involved in carrying out field studies and, in recent years, increasing emphasis has been placed on the development of computer-based, coastal sediment transport and morphological modelling systems. Such models are generally capable of representing the surface waves and currents in a coastal area with considerable accuracy. However, the same claim cannot be made for their prediction of net sediment transport rates, due largely to our presently incomplete understanding of detailed transport processes.

OBJECTIVES

The general objective of the present project sedmoc (sedmoc = sediment transport modelling in marine coastal environments) is to fill gaps in our existing knowledge of transport processes of non-cohesive sediments in the marine coastal environment.
The objectives of the project are summarized, as:

- To increase knowledge of the physical processes involved in transport of non-cohesive sediment (sand) under the influence of waves and currents;
- To develop improved predictive mathematical models for the quantitative description of sediment transport processes, which achieve accuracy within a factor of ±2 throughout the physical parameter ranges of importance in coastal engineering practice and
- To deliver simplified sand transport models for use in coastal morphological models and in coastal engineering practice.

To this end, detailed physical process models of differing complexity are being improved, intercompared and validated in relation to experimental data from the laboratory and the field; new laboratory experiments are being performed to investigate physical parameter ranges in which uncertainty presently exists; and existing field data are being analysed to ensure that the

project is focussed on relevant practical problems. The detailed process studies will provide great scope for innovative work, and will help to reduce the present high degree of empiricism in the field of sediment transport. The core work of the project involves simplification of the theoretical and experimental results in order to produce engineering sediment transport predictors, based on sound physical arguments. Emphasis is being placed on strategies for the practical application of the results in conditions which may include, for example, a spectrum of irregular waves combined with a current profile over an irregularly undulating bed comprising a mixture of sediments, and practical approaches are being developed to predict sediment transport in the long-term for given 'wave climate' statistics.
Thus, the project (April 1998 to April 2001) has a general character, not focussing on a particular set of physical conditions or on a pre-defined geographical site, and the deliverables will be applicable in a variety of coastal environments, including wave- or current-dominated, offshore or nearshore areas.

RESEARCH TOPICS

The research has been focussed on local sand transport modelling in the coastal zone and may be summarized in terms of the following **topics**:

- **Flat bed sediment transport processes and modelling**
  Bed load transport in the sheet flow regimes for steady and unsteady flow (due to waves); formulation of bottom boundary conditions and sediment mixing coefficient in wave boundary layers; effects of sediment size gradation and sediment-induced stratification, turbulence damping, hindered settling, etc.;

- **Rippled bed sediment transport processes and modelling**
  Sediment transport above rippled beds for steady and unsteady flow (due to waves); formulation of bottom boundary conditions and sediment mixing coefficient for suspension layer (including convective entrainment, vortex shedding), effects of sediment size gradation; effect of sloping beds; prediction of sand ripple formation and effective hydraulic roughness of rippled beds;

- **Engineering sand transport modelling**
  Application of sophisticated research models in practical situations, development of practical integrated sand transport models (via simplification of research model results), intercomparison and validation of practical transport models.

METHODOLOGY

A balance has been established between 'basic research of physical processes', including experimental research and mathematical modelling, and the 'development of practical engineering formulations' through the composition of the research team which includes leading European experts in (i) experimental sediment transport research (laboratory/field), (ii) theoretical - fluid/sediment mechanics, and (iii) engineering field applications.
For the achievement of the overall objectives the research and development programme has been organized into three task groups, which will act as cross-topic working units, namely:

- **Process Research: experimental research (Task 1)** Increasing knowledge of the physical processes involved in the transport of non-cohesive sediment (sand) under the influence of waves and currents;
  - — analysis of sediment transport mechanisms using existing laboratory and field datasets;
  - — new experimental research in laboratory facilities;
  - — updating an existing database (MAST-I/II) with validated laboratory and field data;
- **Product Development: mathematical modelling (Task 2)** Developing improved, soundly-based, predictive mathematical models for the quantitative description of sediment transport processes;
  - — improvement of existing mathematical models of local sediment transport;
  - — validation of mathematical modelling systems using pre-selected datasets;
- **Practical Application: engineering formulations (Task 3)** Delivering simplified engineering sand transport models, and new sediment transport formulae, for implementation in coastal morphological modelling systems;
  - — development of engineering sand transport formulations for use in real-sea conditions, based on the new theoretical and experimental work;
  - — intercomparison and validation of sand transport formulations over parameter ranges of engineering importance.

RESULTS

An important result of the project is the production of new datasets for calibration and validation of the mathematical models used in the SEDMOC project. New datasets are presented below.

Flat bed regime:

oscillatory sheet flow / suspension

three uniform grain-sizes by Univ. of Twente and Delft Hydraulics, The Netherlands

iregular waves sheet flow by NTNU, Norway

graded sediments

Oscillatory sheet flow by University of Twente and Delft Hydraulics, The Netherlands

bed slope influence on sediment transport

Oscillatory flows in SCRIPPS wave tunnel by University of Twente, The Netherlands

Rippled bed regime:

wave-induced sediment transport above rippled beds

Deltaflume experiments with regular / irregular waves and two sand sizes by Delft Hydraulics, The Netherlands and Proudman Oceanographic Laboratory, England

graded sediments

Waves over rippled beds by Delft University of Technology, The Netherlands

bed slope influence on sediment transport

Steady flow / duct experiments by HR Wallingford, England

ripple migration

Wave flume data by University of Genova and Catania, Italy

Modelling results for the flat bed regime

One of the main tasks in the SEDMOC project is the development of local (i.e. point) sediment transport models under waves and currents in the high energy regime of flat bed (sheet flow) conditions. The presently existing models generally rely on the assumption that the transport is dominated by the horizontal oscillatory boundary layer flow near the sea bed. The models vary in complexity from analytical (similarity theory) and numerical mixing length models, to direct 3D-simulations and two-phase flow models.

The experimental data needed for further model improvements have been mainly selected from existing datasets from experiments in the oscillating water tunnel of WL/Delft Hydraulics. Recent experimental work on oscillatory sheet flows shows that especially the processes inside the sheet flow layer generally dominate the transport process in oscillatory sheet / suspension flows.

However, most of the present boundary layer models are based on the assumption of a fixed-bed, neglecting most of the mobile bed effects, such as the vertical oscillatory motion of the bed, high-concentration effects in the sheet flow layer and vertical advection mechanisms in the sheet flow and suspension layer. An important part of the SEDMOC project is therefore aimed at the development of improved sheet flow process descriptions. Despite these shortcomings on a process level, it appears that, as long as the sediment size is not too fine (0.2 mm or coarser), the measured net transport rates can be predicted with a reasonable accuracy with the present 1DV modelling approaches. Recent experiments with finer sand (0.13 mm, waves and waves + currents) revealed strong time-lag effects during the wave cycle of a deviating nature, which in some asymmetric wave cases (2^{nd}-order Stokes) even led to negative net transport rates (against the wave 'propagation'). In this phase of the SEDMOC project it is still unclear how well the present 1DV models perform in these conditions. Some indications exist that the time-lag effects are greatly underestimated and net transport rates do not become negative.

During the first year of SEDMOC a number of 1DV model improvements have been proposed and implemented which are related to i) a better representation of the sheet flow layer processes, including the transition to suspension (IMAR, UCNW, DUT/UT), ii) the representation of advective sediment entrainment (UCNW, DHI) iii) graded sediment sizes (IMAR, UCNW). DUT and UT have demonstrated the consistent behaviour of calibrated parameters of a 1DV mixing-length model (bed roughness height, turbulent mixing) related to the thickness of the layer with high concentrations near the bed. The newly implemented model improvements shows encouraging improvements, however, further model development and validation is still clearly required.

Fundamental modelling studies have been carried out by the University of Genova and EDF. Using 3D direct numerical flow simulation, the University of Genova has revealed the influence of the height of roughness elements on the transition from laminar to turbulent oscillatory flows (objective: improved turbulent closure schemes). EDF has extended its two-phase (steady)flow model to permeable bed conditions. Considerable improvements have been obatined in simulating Lyn's (steady) flow experiments (mean concentration and velocity profiles).

Delft Hydraulics has started the development of a general 1DV model framework for the representation of wave+current induced transport processes, including vertical orbital velocities, undertow and boundary layer streaming. A first model validation with Klopman's flume experiments has shown promising results.

Modelling results for rippled bed regime

Innovative research modelling work on rippled beds has been started in Year 1. Research models of differing complexity have been under development in Task Group 2. Research models have been developed by four institutes (DTU, SINTEF, UGe and UCNW). In addition, IMAR's model can be used for rippled as well as plane beds, and DHI's STP model can also be used for ripples (though it was developed primarily for plane beds). In Year 1, DTU has completed modelling work on roughness and friction above vortex ripples using a k-ω turbulence model, and has made systematic comparisons of the (mean) drag coefficient for wave+current flows and for currents alone. This model has been used also to make morphological calculations to predict the profiles of fully developed vortex ripples. At SINTEF a model has been developed of (mainly) steady flow above undulating beds, based on the Reynolds equations and standard closures for the turbulence and sediments. This model also performs morphological calculations. A feature of importance suggested by the solution is the possible role of suspended sediments in suppressing flow separation above the lee slopes of bedforms. At UGe in Year 1, computer code to perform a 3D direct numerical simulation of the oscillatory flow over fixed ripples has been developed and validated. This model will be used to study sediment dynamics using a Lagrangian approach. Also at UGe a study of the ripple formation process has been completed using a linear stability analysis, with emphasis on the role of near-bed drift currents, and the resulting migration of ripples. These latter results have been compared successfully with preliminary experimental data from the University of Catania. Finally, at UCNW, a new model for wave+current flows above rippled beds has been developed. Unlike the models above, this is a simplified 1DV model in which vortex shedding is represented in the near-bed layer by an analytical eddy viscosity formulation. The near-bed solution is coupled with a standard turbulence model in the outer layer. This model will be further validated in Year 2.

As in the case of the flat-bed research models, it is still under discussion how best to use the rippled-bed models in practical applications, and how the results should be systematised for this purpose.

Engineering model results

As a good starting point, an intercomparison exercise with field data proposed by HR has been carried out in order to assess the reliability of existing engineering models and methods. The results showed an unexpectedly large discrepancy between the different model predictions and the data applied. The intercomparison exercise was joined by DUT, DH, IMAR, UCNW and LNH.

Existing models and methods need to be improved in order to achieve the overall objective of the project which is to make sediment transport rate predictions within a factor 2. This has been started for example by DH, which has extended its engineering model (TRANSPOR) based on existing field data sets and large scale experiments, in order to include the effect of the wave-related suspended transport. The work by IMAR can also be mentioned, which has extended the Dibajnia and Watanabe formula, in order to improve sediment transport rate predictions for finer sand.

A framework for a new engineering formula has been proposed jointly by HR and UCNW based on the parameterization of their own model results. It was decided at the first stage to run improved models for a given set of input parameters and to produce graphs which could be used later on to fit the different coefficients of the proposed framework.

An exploitation plan for the results of the project has been completed by EDF. A web page and leaflets has been prepared by DUT. A questionnaire has been sent out by DHI to target/user groups: national and regional coastal and sea authorities, harbour/port authorities, consulting engineering firms (coastal engineers), European hydraulic laboratories, universities: faculties of civil engineering (hydraulic engineering), physical geography, oceanography, geology, consultants within dredging firms, offshore oil industry, contractors. Responses showed that a new sediment transport formula would be very useful to morphological modellers.

II.1.2. Methods for monitoring, forecasting and management of shelf seas and coastal zones

TITLE: **COASTAL REGION LONG-TERM MEASUREMENTS FOR COLOUR REMOTE SENSING DEVELOPMENT & VALIDATION: COLORS**

CONTRACT N^{o}: **MAS3-CT97-0154**

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COASTAL REGION LONG-TERM MEASUREMENTS FOR COLOUR REMOTE SENSING DEVELOPMENT AND VALIDATION (COLORS): PROJECT STATUS

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ABSTRACT

COLORS is the first attempt to create a long-term European network program for the development and validation of water colour remote sensing in coastal zones and shelf seas.
COLORS, by the end of year 2000, is aimed to complete the following activities:
i. Extensive long-term measurements over three selected sites, located in different coastal/shelf areas (Adriatic Sea, English Channel, North Sea) representative of the main European water types.
ii. Analysis, interpretation and processing of the data acquired, aimed at deriving bio-geo-physical marine and atmospheric parameters. These are then used to develop robust marine and atmospheric algorithms accounting for site and season specific influences.
iii. Application of the ensuing algorithms and techniques on available satellite data. The resulting data products are validated in order to assess the full potential of operational optical remote sensing in European coastal waters.

1. INTRODUCTION

Observations of marine optical properties from satellites, offer a unique means to obtain synoptic information on the constituents in the marine environment. Advanced satellite ocean colour sensors (i.e. the already launched MOS, SeaWiFS and MODIS and the forthcoming MERIS) have been designed to support climate and environmental studies on global scales. However the exploitation of ocean colours data in the European coastal zones, requires extensive development of methodologies based on comprehensive atmospheric and marine data. COLORS is aimed at ensuring a major data collection and exploitation program for the assessment of algorithms and methods for the operational use of satellite colour data in the European coastal/shelf water.

2. OBJECTIVES AND METHODOLOGY

The main objective of COLORS is to establish a European network of three differing sites, at which a systematic program of long-term measurements in water and in the atmosphere is carried out. The sites, which provide a cross section of the European coastal waters, are: Adriatic Sea, English Channel, North Sea.

All three sites are equipped with identical instrumental packages and special attention is given to sensor intercalibrations to ensure comparability of the data collected at the different locations.

By the end of 2000 COLORS is expected to provide:

- series of optical and bio-geo-chemical measurements of the major types of European coastal atmospheres and waters;
- bio-optical and atmospheric models and algorithms for coastal and shelf sea areas, developed and assessed using the measurements collected;
- assessment of methods for the interpretation of satellite remotely sensed data of European seas, based upon the new bio-optical and atmospheric models and algorithms.

The flow schematic diagram of COLORS activities is given in figure 1.

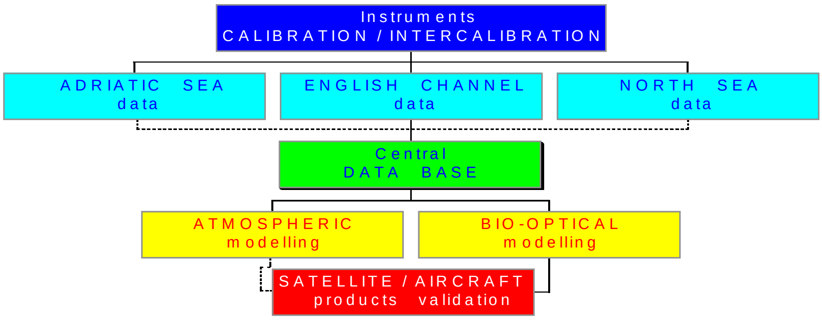

Figure 1. Flow of the COLORS activities

2.1 Optical and bio-geo-chemical measurements

The three measurement sites have been chosen to ensure that the main water types dominating European coastal/shelf waters, are considered.

- *A site off Venice in the Northern Adriatic Sea* (Lat. 45°18‘50”N, Lon. 12°30’30”E). The site is representative of the marine features of the entire Adriatic Sea and is located in a transition region which is characterized by oceanic or coastal aerosols and Case-1 or Case-2 waters, depending on prevailing winds and currents. Both marine and atmospheric measurements are taken from an oceanographic tower.
- *The area around the island of Helgoland* (Lat. 54°N, Lon. 09°E) in the North Sea. The site is characterized by maritime and coastal aerosol and Case-2 water with very high concentration of suspended matter and yellow substances from the Elbe river. The marine measurements are performed from a research vessel. The atmospheric measurements are taken from the island of Helgoland.
- *A long term mooring site off Plymouth* (Lat. 50°13’N, Lon. 04°05’W) *in the English Channel*. The site is mostly characterized by maritime aerosol and oceanic waters. However according to changes in direction of prevailing winds and currents, the site can be

characterized by coastal aerosol and Case-2 water. A ship ensures the collection of marine measurements. The atmospheric measurements are taken from Rame Head .

An important objective of the project is the production of a large quantity of statistically representative, high quality oceanic and atmospheric data. To satisfy this requirement significant efforts are put in:

- *the calibration and intercalibration of instruments***,** to ensure the highest possible accuracy in the conversion of measurements to geo-physical units and to make data sets from different sites fully comparable;
- *the development of processing methods for data quality assurance* to avoid archival of measurements affected by errors.

Collected data are stored at local archives at each measurement site and successively processed and archived at a central data base.

To satisfy the requirements of the COLORS objectives, the integrated program comprises a combination of field and laboratory measurements carried out at frequencies ensuring seasonal characterization of sites.

The field measurements are:

(d-i)	*Subsurface upwelling radiance and downwelling irradiance*
(d-ii)	*Above water downward irradiance*
(d-iii)	*Direct sun irradiance*
(d-iv)	*Sky radiance*
(d-v)	*Water attenuation and absorption*
(d-vi)	*Water temperature and salinity*
(d-vii)	*Atmospheric pressure, humidity and temperature*
(d-iii)	*Wind speed and direction*

The laboratory measurements, providing site-specific data complementary to the field measurements, include:

(i-i)	*High Pressure Liquid Chromatography (HPLC) for phytoplankton-pigments*
(i-ii)	*In-vivo absorption spectra for pigments*
(i-iii)	*Absorption spectra of filtered water for dissolved material*
(i-iv)	*Gravimetric filter analysis for total suspended matter and organic/inorganic fractions.*

All the measurement sites use almost identical instruments and measurement methodologies. This ensures the compatibility and mutual comparability of the data-sets from the different sites.

2.2 Bio-optical and atmospheric models and algorithms for coastal/shelf areas

The accuracy of water parameters obtained from the remote sensing of ocean colour is, to a great extent, determined by:

- the accuracy of the data used in the atmospheric correction process (i.e. the removal of atmospheric contribution from the remotely sensed radiance);

- the accuracy of relationships between water reflectance and, particulate and dissolved matter.

Although a basic parameterisation is available, simultaneous extended in-situ marine and atmospheric optical and bio-geo-chemical measurements have been available only rare in European coastal areas. Using the data collected at the three sites, the project is undertaking the development and validation of atmospheric algorithms for the parameterisation of atmospheric optical thickness and phase function, and the development and validation of bio-optical algorithms for water particulate and dissolved matter. The ultimate goal is to develop atmospheric and marine algorithms applicable in European waters.

2.3 Assessment of methods for the interpretation of remotely sensed data

Inversion of remote sensing data (i.e. the retrieval of atmospheric and marine geophysical products) relies on modelling the radiative transfer processes in the atmosphere-surface-water system. The project is assessing some of the radiative transfer models commonly used for marine colour applications using the in-situ data collected at the various measurement sites. Methods for deriving quantitative information from remote sensing data taken over coastal regions are also addressed. The mapping capabilities of colour sensors for pigments, total suspended matter and aerosol are currently validated with sample SeaWiFS imagery.

3. PRELIMINARY RESULTS

In the period December 1 – April 30, COLORS has ensured the:

1. development of common measurement protocols;
2. development of common data formats;
3. execution of almost 50 (total) measurement campaigns at the three measurement sites;
4. execution of 6 (total) intercomparison exercises for in-water and atmospheric instruments;
5. development of a central data base for data and results;
6. submission to the central data base of ~50% of the collected data in the common data format;
7. development of codes for quality assurance and processing of atmospheric and marine data;
8. processing of all the submitted data;
9. intercomparison of different marine/atmospheric algorithms and radiative transfer codes;
10. development of new atmospheric/marine algorithms for remote sensing data exploitation.

Detailed description of project achievements is given in the Second COLORS annual report (SAI-JRC, December 1999) and in specific papers and presentations at conferences (see §4).

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TITLE : OPERATIONAL MODELLING FOR COASTAL ZONE MANAGEMENT : **OPCOM**

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INFORMATION SOURCES AND DECISION SUPPORT TOOLS FOR COASTAL ZONE MANAGEMENT : FUTURE PROSPECTS AND CURRENT LIMITATIONS FOR CONSULTING LOCAL OPERATIONAL MODELS

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INTRODUCTION

European coasts are unique in a very real economic sense as sites for port and harbour facilities but they are also rich and diverse ecosystems. The combination of freshwater and salt water in coastal estuaries creates some of the most productive and richest habitats on earth. Furthermore the coasts are highly valued and greatly attractive as sites for resorts and as vacation destinations.

The existing different interests comprising sustainable protection and the economic use of the coastal and shelf environments require the long-term predictive capability of coastal zone evolution. An important prerequisite are general improvements of forecast ability of operational systems.

In the framework of the OPCOM project methods and techniques for continuous monitoring and operational forecasting for coastal waters were applied based upon existing operational model systems. These models could provide important improvements to the current state of affairs in continuous monitoring, operational forecasting, and integrated coastal management (including risk assessment), in short: helping to protect our precious coastal environment.

PROJECT METHODOLOGY AND TASKS

The primary objective of the OPCOM project (Operational Modelling for Coastal Zone Management) is to improve methods and techniques for continuous monitoring and operational forecasting in coastal waters by using already existing operational model and monitoring infrastructure to address needs and quality standards of interested first users. The individual technical and scientific tasks of the project may be outlined as:

- A. Site-specific investigations on coastal management aspects to define user requirements: Improvement of coastal management and monitoring practice by analysing operational data and model results and defining user requirements on model and monitoring systems in four OPCOM key pilot studies for different hydrographic regimes and coastal management objectives.

- ❑ B. Model investigations on operational aspects and forecast ability: Improvement of operational and pre-operational coastal zone models regarding forecast-ability, field data assimilation, and long-term stability and reliability in continuous operation.
- ❑ C. Integration of modelling, coastal monitoring, and user specifications: Goal is a dedicated database structure as basic operational forecast segment of coastal zone management information systems also suitable for GOOS (Global Ocean Observation System) purposes.

There are many different hydrographic situations and coastal management problems relevant in European waters. OPCOM intends to address a wide range of this spectrum. Thereby it is convenient to pay special attention to suitable areas where a profound infrastructure of in-situ data acquisition and validated model systems of coastal circulation and transport already exist (e.g. Nöhren and Duwe [6]). Especially the problems of pollutant transport (or the environmental impact assessment based on transport forecasts in general) are of great importance and need a thorough modelling technique (Post [7], Duwe and Pfeiffer [1]). Within OPCOM the following geographical areas were investigated:

- Bay of Marennes-Oléron (French Atlantic Coast)
- Elbe estuary (German North Sea Coast)
- Tagus estuary (Portuguese Atlantic Coast)
- Archipelago Sea and Luodonjärvi Lake (Bothnian Sea)

Starting with the MAST-project OPCOM in late 1997 the main goals were already defined. Especially these goals and the planned approach to reach them were reasons enough for the EU to fund this project. The highlights were:

- Four highly interesting target areas with first users eager to test the new OPCOM-products to find solutions for their problems.
- A number of different model approaches were proposed for the application on a wide range of hydrodynamic modelling and forecasting tasks.
- Optimisation of model codes and algorithms to make models faster and more reliable.

Specific local experiences from the OPCOM project are described in Freissinet et al. (2000), Lauri et al. (2000), and Neves et al. (2000). These activities were also directed towards

- User defined requirements for operational models for the coastal management.
- New approaches to improve the reliability of coastal operational models.
- How to reproduce the coastal variability to improve operational model approaches.

Main objective in these local applications was how to help to protect the coastal environment by means of e.g. expert systems for traffic guidance, sewage outlet control, environmental monitoring of salinity variations on oyster banks, and nutrient transport between islands in a non-tidal sea.

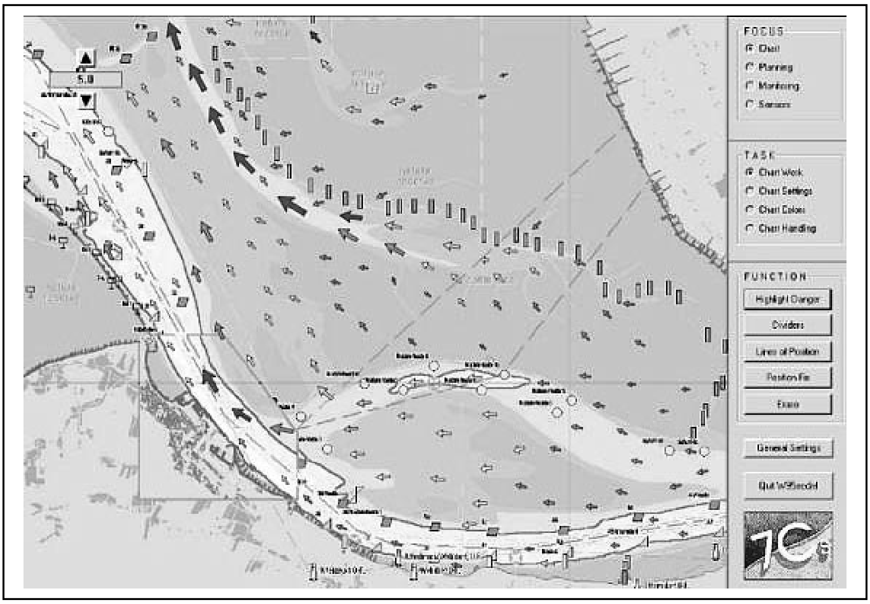

Fig. 1: Screen-shot of a combination of hydrodynamic model and navigational support information on an electronic sea chart of the outer Elbe estuary near Cuxhaven: A local operational model as decision support tool for CZM.

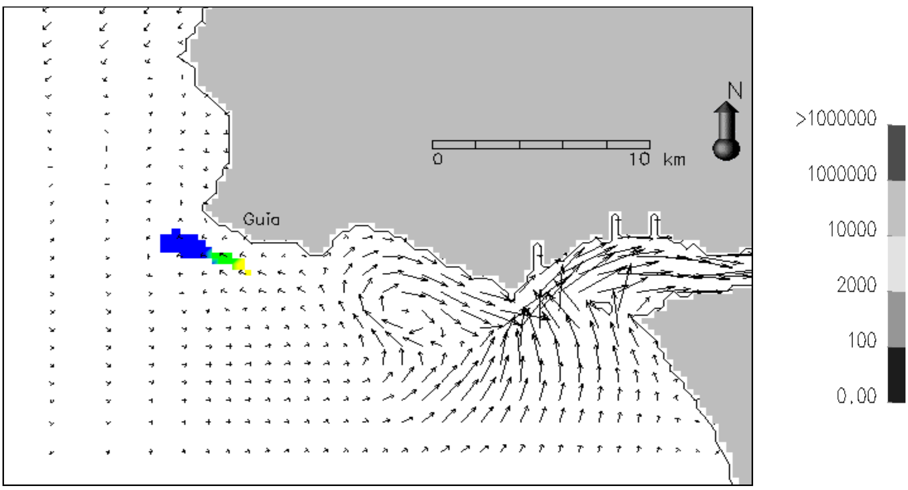

Fig. 2: Coliform concentration ≈3 hours after low water (Outfall flow 7.5 m^3/s; Coliform 10000 / 100 ml = 10000000/ m^3). Units in coliforms/100 ml: A local operational model as information source for CZM.

GENERAL RECOMMENDATIONS

OPCOM project experiences showed that existing local monitoring practice in connection with coastal zone management can be assisted and considerably optimised (even in an economic sense) by consulting small-scale operational models. Here special attention has to be paid on modelling strategies and sampling design. Some very important remarks can be given by drawing experiences both from within the OPCOM project and from the already functioning operational networks.

- By matching relevant information 'from both sides of the shoreline' only a comprehensive account of changes and impacts in coastal zones can be achieved. Here a local hydrographic model can be an efficient tool, which could even be extended in future by ecological modules or the connection with a river basin model of the corresponding catchment area.
- Readily available model information can be used very intelligently to optimise location or sampling rates of field stations that are costly to be operated and maintained. Moreover dedicated interpretations of model results can be very informative to improve future strategies of measurement and monitoring activities.
- The continuous check of field measurement registrations, with the corresponding model results, could be used very efficiently to look at data quality and, accordingly, lead to swift reactions in case of quality deterioration or malfunctions.

The described avenues of progress through operating smaller-scale local models will have to be defined more clearly and tailored to specific individual demands in a case-by-case manner. Here the requirements and resources of the local users become overwhelmingly important.

As example might be presented an operational model system as decision support tool applied to the tidal estuary of the Elbe river and the dynamically complex port region of the City of Hamburg. The numerical model can be used for navigational support by integrating the results in a pilots positioning system. It is designed to become an integral part of the complex port logistics. Within a vessel traffic information system the integrated operational hydrodynamic module provides now- and forecasts of the dynamical situation with high accuracy and in high spatial and temporal resolution. These comprise e.g. current speed and direction and water-levels which can be target-related incorporated into the electronic sea chart display (ECDIS, established by 7Cs, Hamburg, see fig. 1) both on board and ashore. Generally this application of a local numerical model system has mainly two different kinds of users: the navigational authorities which are mostly interested in the spatial distribution of parameters and pilots who are keen to know the temporal development of parameters on a defined route.

A further example of a local operational model acting as information basis for CZM is a combined hydrodynamic-ecological model of the Tagus estuary which is used for the prediction of coliform concentrations in the vicinity of a major submarine outflow. In figure 2 a characteristic information is shown which is being used to monitor the situation providing essential additional insights complementing the expensive field data acquisition activities.

CONCLUSION

Generally there are quite a number of different objectives of CZM (coastal zone management) where local operational models could be used to its advantage. These include

- Long-term routine monitoring and assessment activities in coastal waters to complement existing field measurements and observations. High-resolving model information can provide a far more consistent picture than single point time series or accidental observations. This is also true for models in connection with the vast amount of data from ferry box operations.
- Future planning activities and necessary assistance in decision support by providing impact assessment information. The very existence of an operational system could help to avoid considerable efforts and costs for the set-up and qualification of another version of consulting tool (preventing the everlasting reinvention of the wheel).
- Needs of short-term information provision like nowadays weather forecasts. Such applications could include early warning systems (pollution control or hazardous surge predictions) and on-line nowcast information on current and wave conditions. However, especially the necessary on-line data flow from field stations and larger-scale hydrographic and meteorological models prove to be essential and (in most cases) very expensive.

There are however strong handicaps in exploiting fully the advantages of routinely running operational models. These are essentially a lack of long-term technical and financial support from the local administrative network engaged in CZM and the diffuse definition of a 'coastal manager'.

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TITLE: A USER-FRIENDLY TOOL FOR THE EVALUATION OF WAVE CONDITIONS AT ANY EUROPEAN COASTAL LOCATION : **EUROWAVES**

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EUROWAVES - A USER FRIENDLY TOOL FOR THE EVALUATION OF WAVE CONDITIONS AT ANY EUROPEAN COASTAL LOCATION

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INTRODUCTION

In the absence of long term wave data collected at a coastal site of interest, the calculation of wave statistics at a coastal site requires various data sets to be assembled, including temporally and spatially long term representative directional wave data offshore of the site, as well as bathymetric and coastline data. Further, a suitable wave model is required, which is capable of modelling the transfer of the offshore conditions to the site, incorporating the relevant shallow water wave phenomena. EUROWAVES simplifies the modelling of wave conditions in coastal waters by integrating the following under a single software package for all European waters:

- High quality long term wave data offshore of all European coasts derived from the integration of wave model data from operational and hindcast runs of the WAM model at the European Centre for Medium-Range Weather Forecasts (ECMWF), together with high precision satellite altimeter data and buoy data from 13 European countries.
- European-wide bathymetric data from US Navy's Digital Bathymetric Data Base (DBDB-V)
- European-wide coastline data from the GMT High Resolution Coastline Database (GMT-HRCD).
- Two shallow water wave models: SWAN (Simulating Waves Nearshore), a state-of-the-art third generation wave model and VENICE, a traditional backward ray-tracing model.
- Sophisticated offshore and nearshore wave statistics toolboxes.
- A geographic module allowing the user to easily zoom in to the area of interest on geographic maps, displaying bathymetry and coastline, together with tools to assist the user in setting up the wave model grid.

In addition, in recognition that the user may have access to more accurate wave and/or bathymetric data, EUROWAVES also provides facilities for user input.

The EUROWAVES project runs to November 2000. In this paper we primarily aim to give an overview of the capabilities of the EUROWAVES software package (a full PC demonstration will be given at the EUROWAVES stand). Fuller details of EUROWAVES development may be found, for example, in Barstow et al. (2000). More information about the project, including an on-line demo, is available from the project Web Site (http://www.oceanor.no/eurowaves)

EUROWAVES OVERVIEW

A quick illustrated guide to the EUROWAVES toolbox, which runs under Matlab on a PC, is given in this section.

Zoom to target area and wave data selection

The user of the EUROWAVES software package has all the information he or she needs to evaluate the wave conditions anywhere along the coasts of Europe and surrounding areas; i.e., the Atlantic coastlines, the North Sea, the Barents Sea, the Atlantic islands (Azores, Canaries, Iceland, Faeroes etc.), the entire Baltic, Mediterranean and Black Seas. Given a target area or location at which the user requires wave information, the EUROWAVES geographic zooming tool (Figure 1) allows the user quickly to select the area of interest using click and drag on the red rectangle (bottom screen on Figure 1). The offshore data points at which wave data are available are indicated by the red dots. Nominally, the data comprise 6 hourly time series, for 1992 to 1999, of significant wave height, period and direction for wind sea and swell separately. It is easy for the user to import his own data (say, in the case where in-situ measurements are available) and use these instead of the data provided. On the maps tools are available showing the lat/lon coordinates of the position of the mouse, and other geographic tools are available, such as the calculation of the great circle distance between two points selected by the mouse.

Wave statistics

At this stage, the user may wish to inspect the supplied offshore statistics. There are many different statistics available, including

- Univariate probability density functions for Hs, Tm, Tp, θ (histograms, tables and analytic models)

- Mean monthly values for Hs, Tm, Tp, θ (plots or tables)

- Bivariate probability density functions for Hs, Tm, Tp, θ (histograms, tables and analytic models)

(available for wind sea, swell and overall parameters). A few examples are given for a grid point off north west Crete in Figure 2.

Offshore to Nearshore (OtN) transformation

EUROWAVES is equipped with two shallow water wave models for carrying out the OtN transformation. VENICE is a backward ray tracing model, which can relatively quickly transform a many year offshore time series to a coastal location. However, being a simple model, it does not incorporate all the important shallow water effects (refraction and bottom friction are included). Nevertheless, at deeper water target points or in order to give a quick first estimate of wave conditions, this may be a perfectly acceptable approach. In SWAN, on the other hand, the wave evolution is performed on a grid, and most relevant processes are included as sources and sinks in the basic governing equations.

EUROWAVES incorporates an easy to use gridding routine. An initial computational area is selected by the user and a default grid is set up automatically (a nested grid is used by SWAN). However, the user may easily make changes to the grid. The user next selects the target point of interest. Default formulations of the bottom friction may be overriden by the user if better local information is available. It is also possible to impose an increase in the water depth, associated, for example, with a storm surge. Having chosen the grid, the target point and the offshore boundary points (Figure 3), one can choose either to run a time series (as provided in the EUROWAVES data base or input by the user) or to make a single run, in which case the user is asked to specify the wind and wave conditions at the selected boundary points. In the latter case, having performed the run, the output can be inspected as a contour plot over the whole area (Figure 4; also for Venice, which is run for all grid points to construct a wave field) or as a directional wave spectrum at the target location (Figure 5). In the case of a time series run, the long term wave data at the target point can be analysed by the nearshore statistics module (the presentations are similar to the offshore ones, Figure 2)

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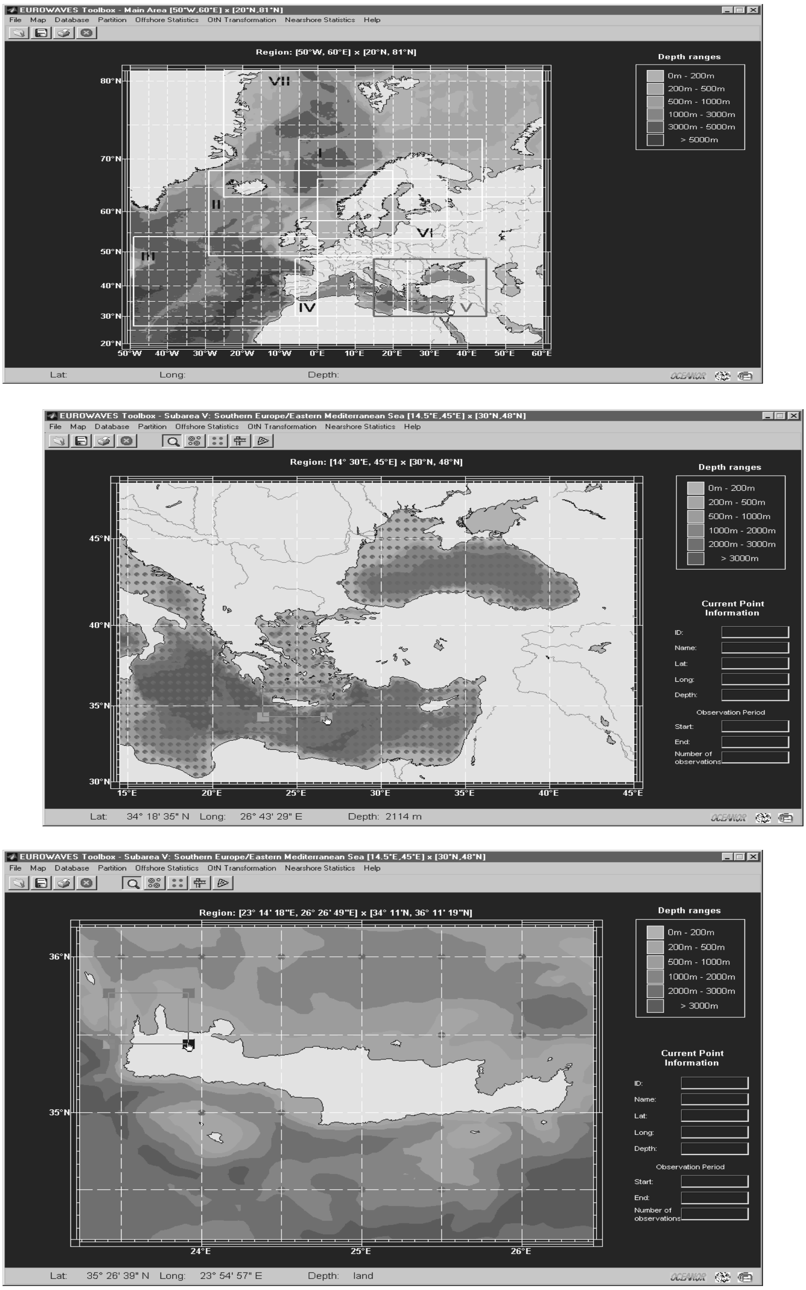


Figure 1 An example of the EUROWAVES progressive zooming facility. In this case, the target area was the north western corner of Crete. At each level, the bathymetry is shown. The red dots indicate all the data points at which wave data are available. The red rectangle illustrates how the zooming is carried out (using the mouse, click and drag).

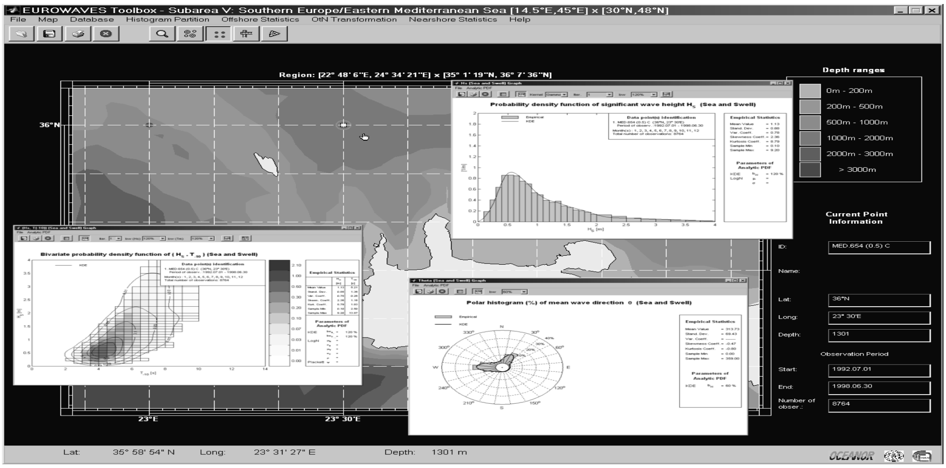


Figure 2 Examples of presentations of wave statistics for a grid point (circled) off north west Crete. Both univariate, bivariate and directional polar plots are shown.

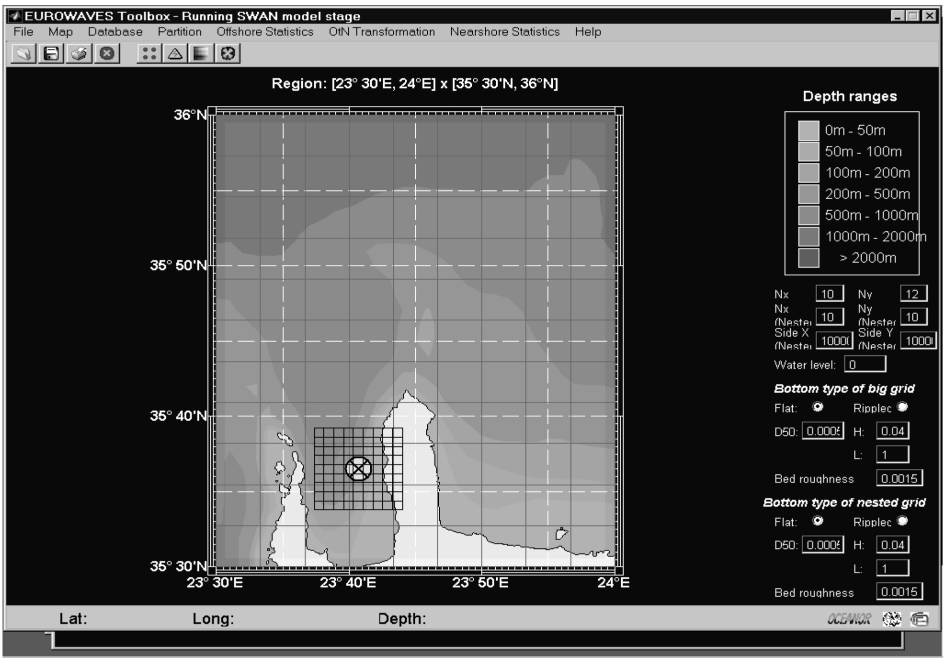


Figure 3 Example of screen after the selection of grids for a run of the SWAN model. On the right hand side is the menu enabling the grid size and the bottom friction to be altered.

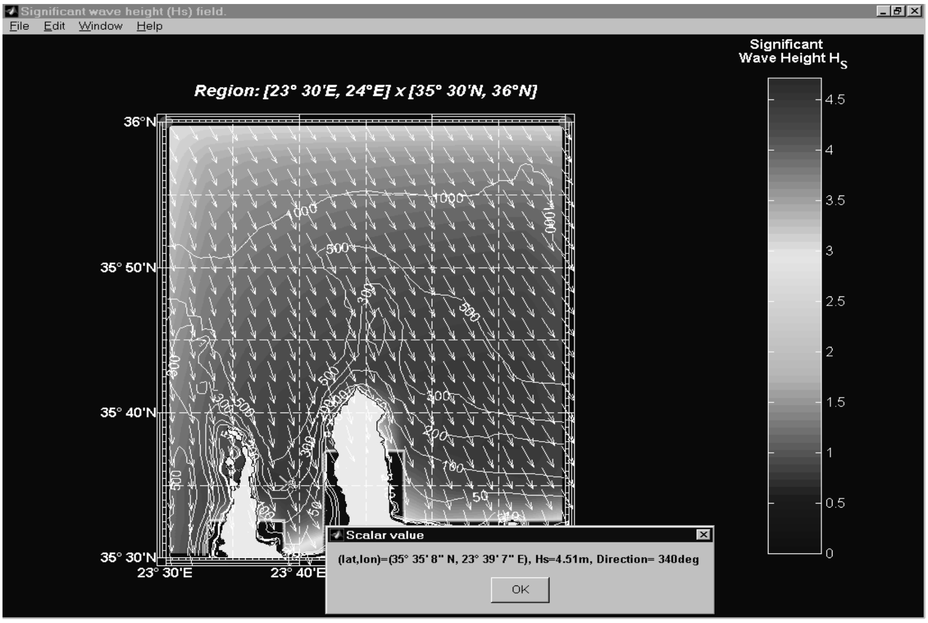
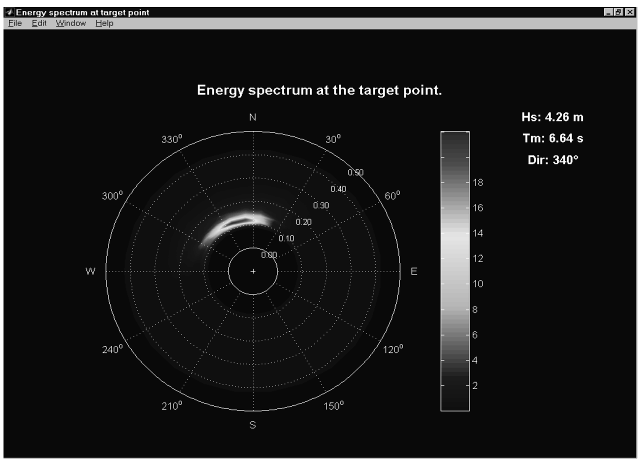


Figure 4 Example output field for significant wave height under wave growth conditions on the north west coast of Crete. Clicking on any point of the plot provides the user with information on the local wave height and direction as can be seen.

Figure 5 Output directional wave spectrum at the target point in addition to overall wave parameters.



TITLE : EUROPEAN RADAR OCEAN SENSING
EuroROSE

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EUROPEAN RADAR OCEAN SENSING

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INTRODUCTION

Human activities and their environmental consequences to the coastal zones of the world require new and enhanced understanding of the physical processes in the coastal waters as well as in the atmosphere. Wind, wave and current systems are known to be highly complex and transient in many coastal areas, and even course resolution information on these phenomena is difficult and expensive to obtain.

An important goal of the Global Ocean Observing System (GOOS) is the development of operational tools for those actors which are in charge of safety and regulation for coastal marine operations and constructions, as well as for the protection of the marine environment. Among such actors are Vessel Traffic Services (VTS) operators, harbour managers, coastal and waterways managers and marine environmental protection organisations. These actors are in a rapid development process due to general increase in traffic density and the new loads of environmental protection duties. In the following VTS is used as an example. VTS management tools are an integrated concept embracing vessel and cargo data, seafloor, safety, and rescue undertakings. In the context of this project, the governing met-ocean conditions (winds, waves, water levels and currents) are considered because they affect the safety, manoeuvrability, and operational performances of ships. Furthermore, the requirements for such information are not limited to the actual location, but are needed for a fairly extensive area surrounding the focus point. This is due to the existence of strong spatial variability within the area, as well as to the propagating nature of ocean phenomena (such as eddies).

Nowadays, different in-situ sensors (e.g. buoys) providing point measurements are used to monitor the sea. In addition model forecast information is normally provided on coarse grids (about 5 km) and updated every 3h or 6h. A finer temporal and spatial resolution is demanded for harbours with a shallow or narrow approach channel. For example, a crude oil tanker that cannot stop or change course within the last hours before reaching a harbour needs the environmental parameters on space and time scales of a few hundred meters and one to two hours, respectively.

From the 1960's, ground-based radar sensors and fine-mesh numerical models have been developed and tested in parts of the world. They provide the spatial coverage in a coastal area and resolve the variability of environmental parameters in necessary space and time scales (Guddal, 1995; Graber et al. 1998). Therefore the European Radar Ocean Sensing (EuroROSE) project has the objective to demonstrate the benefit of a combination of ground-based radar and numerical models, in an operational service to Vessel Traffic Services.

The three years project has been started in September 1998. Further details of the project are available via its homepage: http://ifmaxp1.ifm.uni-hamburg.de/EuroROSE/index.html

PROJECT METHODOLOGY

The EuroROSE tool consists of four basic elements:

1. The high frequency radar system (WERA) (Gurgel, and Antonischki, 1997), which provides gridded coverage of wave spectra (Wyatt, 1997 and 1999) and currents (Essen et al, 1999) over a range from 2 - 40 km off shore and a resolution between 0.5 - 2 km.
2. Navigational X-band radar system (WaMoS) (Reichert et al, 1998; Nieto Borge, et al, 1999), which provide near field wave spectra and surface current averages for significant sub-areas (about 1 km) within a range from 0.5 - 10 km.
3. High-resolution numerical models (about 500 m) simulating and predicting waves, currents and water levels (Roed, 1996) in an area of about 40x40 km^2. These models are combined with assimilation systems (Evensen, 1994) for the spatial radar sensed data to improve their initial fields for the prediction of the following hours.
4. An interface, which presents the nowcast and forecast sea state information to the operators in a user friendly way within real time.

The project is organised in 4 phases:

1. Set-up and preparation of the four basic EuroROSE elements.
2. Installation of real time data transfer utilities between the elements
3. Application of the full system in operational mode co-ordinated with the Vessel Traffic Services in field experiments in Norway and Spain.
4. Validation of the data obtained during the field experiments and assessment of the added value in terms of forecast skill obtained by combining the different data sources.

RESULTS FROM THE FEDJE EXPERIMENT

Phase 1 and 2 of the project have been finished and the first of the field experiments was successfully carried out from February 15th to March 31st 2000. The target site was the VTS Centre at the Fedje Island on the western coast of Norway, serving supertanker navigation to and from two nearby crude oil terminals. Initial discussions with the VTS operators led to the conclusion to focus mainly on current patterns and their variations at the ship entrance south of the VTS station.

Fig. 1 shows a surface current field measured by the WERA HF-radar. Circles north and south of the shipping channel between the islands of Fedje and Lyngoy mark the dual antenna sites. The typical northward directed coastal currents as well as the outflow between the islands are clearly visible. Fig. 2 gives an example of a wave map obtained from the same radar.

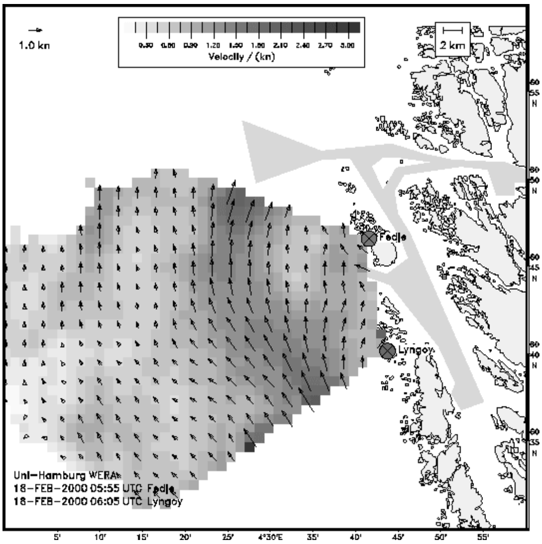


Figure1: WERA current field.

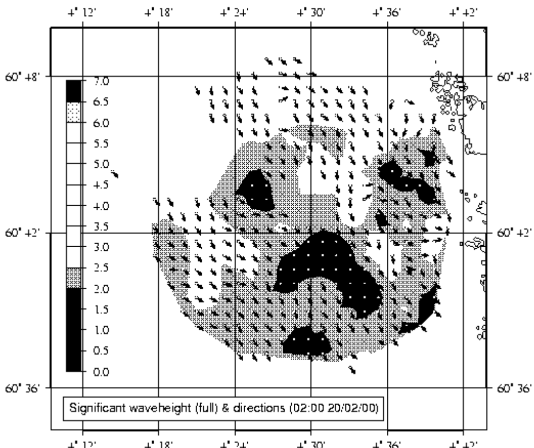


Figure 2 :Significant wave height and wave direction from the WERA HF radar

Two WaMoS X-band radar were installed for closer monitoring of the current and wave conditions in the narrowest and most critical part of the entrance channel. Fig.3 presents a very good comparison of the significant wave heights measured by the WaMoS radar and a buoy located outside of the entrance channel.

Measurements were taken every 20 minutes and processed in real time. The data were transferred to Norwegian Meteorological Office to become assimilated into the appropriate numerical model fields. Consequently, at the VTS operations central measurements were presented with a delay less than 15 minutes. Updated model fields with a forecasting range of 6 hours were presented each new hour with a delay of 20 minutes. Fig. 4 shows a model current field as it was presented on the interface to the VTS operators. These currents are characteristic for the 10 m surface layer which is the most dangerous current for the passing ships. The corresponding wave heights and directions are presented in Fig 5, which indicates the shoaling of waves in front of the Fedje Island.

To achieve the real time data flow a communication system was generated. The complexity of this system is presented in Fig. 6, showing the various locations and computers involved.

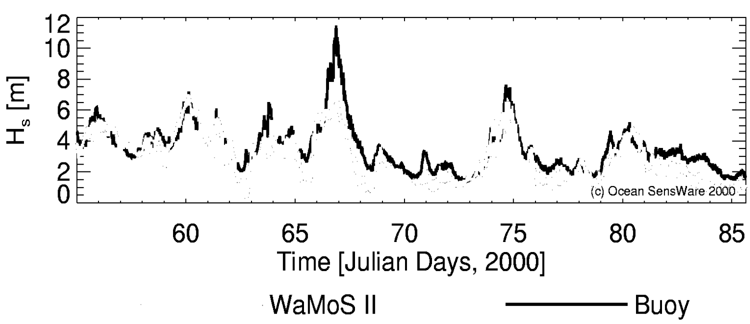
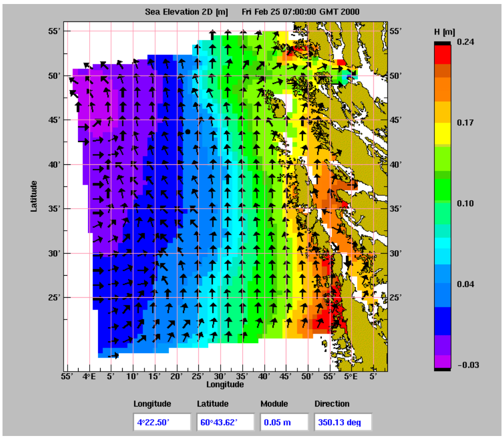


Fig.3 Significant wave height measured by WaMoS and Wave buoy



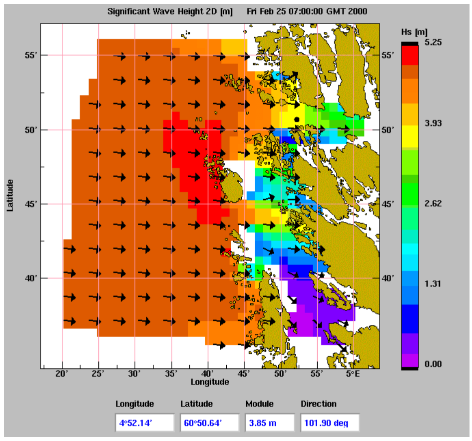


Figure 4: Model currents field as displayed in the VTS control centre.

Figure 5: Same as Fig.4, but wave height and direction field.

A special field campaign was organised to collect data for subsequent validation of the EuroROSE products. For a period of 10 days the research vessel Hakon Mosby operated in the area and in-situ data were gathered. For the duration of the experiment an Acoustic Doppler Current Profiler (ADCP) and a directional wave rider buoy (see Fig. 3) was deployed in front of the entrance channel. The data return rate was very close to 100%.

Except for minor interruptions due to breaks in public electrical power supply the Fedje field experiment was operationally successful from its first day. The VTS officers and ship pilots enthusiastically received the measurement data and model products. It was particularly encouraging that long life experienced pilots confirmed the major features of the coastal currents: a prevailing jet-shaped current going northwards about 10 km offshore from the island, sometimes with significant changes in its position and strength. Temporarily, the current was interrupted by propagating eddies which changed the direction up to 180 degrees.

CONCLUSION

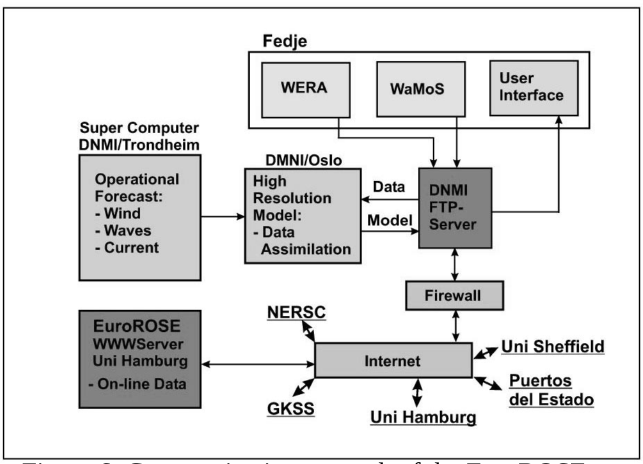


Figure 6: Communication network of the EuroROSE Fedje field experiment

The Fedje field experiment has proven that the EuroROSE concept is feasible, even if a detailed analysis has not been carried out, yet.

HF and X-band radar have demonstrated their potential in operational coastal oceanographic monitoring. The combination with numerical models generates detailed information about the sea-state, which never can be achieved by a conventional oceanographic data collection system. Displaying the sea-state information in maps has proven to be very helpful to the VTS operators and the ship pilots to ensure save passage to the narrow entrance channel supervised by the Fedje VTS.

The choice of the shown sea – state parameter and the layout of the display were discussed in detail with the VTS operators before and during the experiment. This guaranteed that they accepted the operational products from the first day on.

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TITLE : PREPARATION AND INTEGRATION OF ANALYSIS TOOLS TOWARDS OPERATIONAL FORECAST OF NUTRIENTS IN ESTUARIES OF EUROPEAN RIVERS : **PIONEER**

CONTRACT N° : **MAS3CT980170 + IC20CT980110**

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THE PIONEER PROJECT AS AN EXAMPLE OF OPERATIONAL ANALYSIS

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INTRODUCTION

After decades of successful research into the understanding of processes the coastal environment and the development of quasi-realistic dynamical models, the overall scope of coastal research is beginning to focus on applications. **Systems analysis** helps to comprehend the coast as one environment, and allows the reconstruction of past developments as well as the construction of plausible scenarios of possible future developments. **Operational analysis** provides governmental and commercial users with low-cost, real time information about the detailed state and near-future evolution of the coastal seas. Finally, understanding of the **social dynamics** responsible for the political decision process is mandatory for facilitating the rational use of natural science knowledge in managing the coast. The European project "Preparation and Integration of Analysis Tools towards Operational Forecast of Nutrients in Estuaries of European Rivers" (PIONEER) is an attempt to implement operational analysis in coastal zone management. In the project a prototypical marine integrated monitoring system is built which merges low-cost specific observational measures with routine general monitoring data and quasi-realistic models. This system will deliver low-cost, real-time spatially disaggregated distributions of nutrients in coastal waters. The system will be set up for the test cases Lower Odra, Odra Lagoon and Ebro Delta. PIONEER is funded within the 4th EC framework programme MAST III (Projekt) and coordinated by GKSS research center Geesthacht. The general concept of the PIONEER project is outlined in this article.

THE PIONEER APPROACH

The main tasks of coastal environmental research are the generation of knowledge about the state of the environmental system and its change, and about the dynamical functioning of this systems and its sensitivity against anthropogenic modifications. To the former we refer as **operational analysis**, and to the latter as **systems analysis**.

Operational Analysis

Information about the physical, chemical and biological state of the coastal zone is needed for averting and managing dangerous situations such as storm surges optimizing the use of resources, such as in ship routing. To meet these needs, information must be **obtained** robustly, routinely and economically, subjected to **quality control** measures, **collected** from various sources, **merged** with information from other platforms (like remotely sensed data, weather forecasting), **analyzed** with the help of dynamical or empirical models (“objective analysis”, “data assimilation”) and **conveyed** to end users in a suitable format.

Systems Analysis

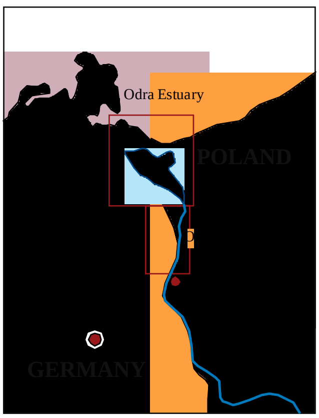
The dynamical description of the coastal “system”, comprising the sea, the rivers and its hinterland, the coastal land, the regional atmosphere, the morphology, fluxes of matter, and human action, is needed for

1. the planning of the use and modification of the coastal environment, like dredging rivers, use of lead in gasoline and the like.
2. the assessment of long-term changes of the coastal seas, like the accumulation of heavy metals of changing statistics of extremes.

To meet these needs, **quasi-realistic models** of the physics, chemistry and biology of the components have to be coupled together, and exposed to past and plausible future human pressure. Past states and changes need to be reconstructed, and scenarios for possible future developments must be constructed with such **holistic** models.

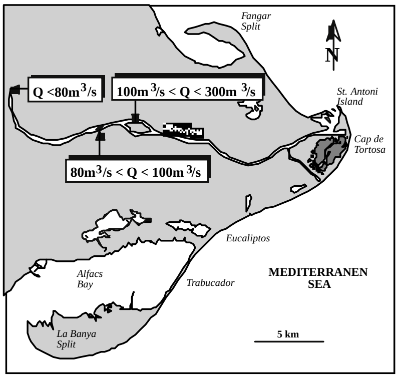
The Test Areas

As test areas have been chosen the **Lower Odra**, the **Odra Lagoon** and the **Ebro Delta** (see maps).The **Odra Lagoon** straddles the German-Polish border. Its surface covers about 600 km^2, its average depth is 5 m so that its volume is about $3{*}10^{9\,m3}$.



Fresh water enters the Lagoon from several rivers, with the Odra being the most important. Intermittently salt water intrudes in small amounts through the three narrow entries to the Baltic Sea. Such intrusions are caused by water levels differences between the Baltic Sea and the Lagoon. Plankton and cyanobacteria blooms take place in summer. In the past years a tendency towards lower concentrations of phosphate was observed, whereas nitrate concentrations are not declining. The nutrient and oxygen conditions are determined by processes in the Lagoon and its sediment as well as by imports and exports from the Baltic Sea and the rivers. Important processes in the nutrient cycle are resuspension and sedimentation of nutrient carrying particulate matter, which responds sensitively to short term weather fluctuations.

The **Ebro** river is the most important river in Spain. It is 928 km long and drains 85,550 km^2. The small tidal range favours the formation of a salt wedge in the estuary.



Salt wegde position depending on the river discharge

Due to a variety of anthropogenic causes, its discharge has decreased by as much as 29% in the 20th century. Among these causes are the construction of dams, and an increasing irrigation of farm land. The diminishing discharge has had an impact on the extension of the salt wedge, which extends about 5kminto the river when the discharge is between 300 and 400 m^3, but 32 km when the discharge is only 100 m^3 (see Figure). The sediment load has been significantly reduced as well because of the dams. Together with the sinking of the Delta due to soil compaction and subsidence, this strongly reduced influx of sediment load makes the Delta suffering from an overall loss of sediment.

Human activities, like domestic consumption, industries, agriculture and cooling of nuclear power stations have caused increased levels of nutrients and organic matter in the Ebro in the past. For instance, the averaged orthophosphates concentrations increased from 0.2 mg/l in the 60's to 0.9 mg/l by the end of 80's, while the nitrates grew from 3 mg/l to 9 mg/l in the same period.

Tasks

The PIONEER project is organised in a series of tasks. In the first phase the tools and data to run the operational simulations will be set up. In the second phase these tools will be applied, tested and assessed by users.

a) Setup of analysis tools: Existing models of the hydrodynamics, of suspended sediment transport and of nutrient are integrated into coupled models which are calibrated to the Odra and Ebro estuarine regions. Geostatistical data analysis (Wackernagel, 1995) and data assimilation techniques (Evensen, 1997; Robinson et al., 1998) for a consistent inter- and extrapolation of limited observational evidence are devised.
b) Setup of data base: To combine meteorological, hydrographical, and water quality parameters for operational forecasting a data base will be set. The data base comprises historical field data and field data measured during the project period.
c) Preparation of models and data sets for operational simulations: Two main sets of data will be analysed. First, “historical” data collected in previous campaigns as well as routine observations and analysis, like satellite imagery and weather analysis, are brought together; these data are used to set up and improve the numerical models and assimilation tools. Second, during selected time intervals during the project time, the project partners will collect new and independent data in a quasi-operational manner and combine these with routine observations by governmental agencies.
d) Operational simulations: The developed analysis and data management tools will be integrated and applied to assess scenarios of possible future developments of changing nutrient loads in the considered rivers.
e) Assessment and validation of methods and results: The dependencies of the model forecast on data quality and the skill of the assimilation schemes are validated and assessed.
f) Dissemination and exploitation: Three symposia combined with the half annual project meetings at the three different demonstration sites will be held in order to involve the potential end users in the developing phase of the pre-operational forecasting tool.

Data Analysis

The basic idea of advanced data analysis scheme is to consider two equations; the *state space equation* describes the temporal evolution of the unobservable, spatially distributed *state variable*; the other equation is the *observation equation*, which relates the low-dimensional *vector of observables* to the continuous state space variable. In general, both equations feature noise terms, mimicking the uncertainty related to observation errors, errors in transfer functions and the neglect of specified processes. In the PIONEER application the state variable is a (vector of) nutrient concentration(s) determined locally with automated devices.The determination of the spatial distribution at a given time ("synoptic") can not be done instrumentally. Additionally other variables such as the discharge of the rivers, satellite imagery, or the wind responsible for the rate of resuspension may be observed locally, and form the vector of observables.
Formally, the *state space equation* may be written as

(1) $\Theta_{t+1} = D(\Theta_t) + \varepsilon_t$

with the state variable Θ_t, the dynamics D and a stochastic term ε_t representing a variety of neglected processes. The *observation equation* is given as

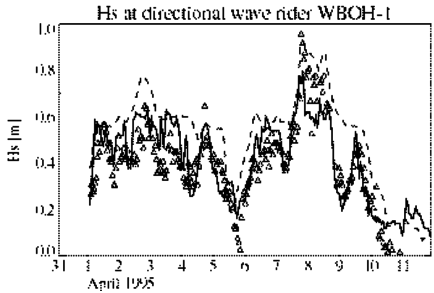
(2) $\theta_t = O(\Theta_t) + \delta_t$

with the observational uncertainty δ_t and a mapping O of the state variable Θ_t on the (vector of) observable(s) θ_t. In general, the mapping O is not invertible, as a continuum of state variables Θ_t will often be consistent with a specific observation θ_t. Note that both equations 0,0 are stochastic equations.
The state variable Θ_t is never completely known as it is unobservable. Only estimates are available and some knowledge about the range of uncertainty. Therefore, the determination of a future state Θ_{t+1} by integrating the state space equation 0 forward in time may return estimates which are in conflict with the actual observational evidence θ_t. Thus, the problem of specifying Θ_t is to solve the systems of equations 0-0 consecutively. At any given time, it is assumed that an estimate of Θ_t as well as a vector of observations θ_t is available. An estimate of the state variable Θ_{t+1} at time t+1 is obtained by optimally exploiting the dynamical knowledge encoded in the state space equation and in the empirical knowledge available through the observation equation. Formally:

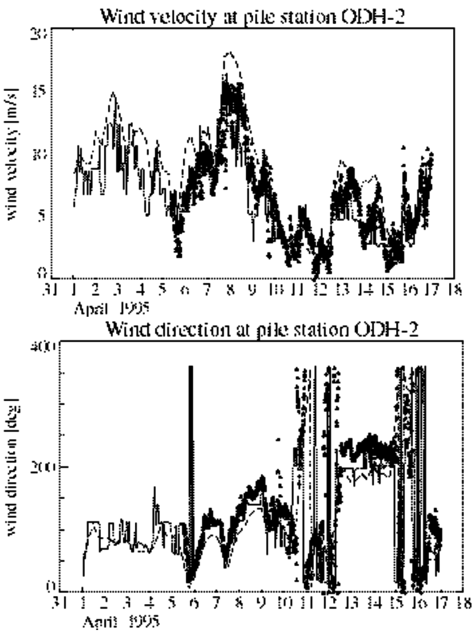
(3) $\Theta_{t+1} = \alpha D(\Theta_t) + (1-\alpha)K(\theta_t)$

with an operator K which in general accounts for the observation process O, the previous state Θ_t and the range of uncertainties δ_t and ε_t. The most general formalism for implementing 0 is that of the Kalman filter (Jones, 1985, Honerkamp, 1994).
In PIONEER a number of different approaches with different levels of sophistication to solve 0-0 are pursued.
The simplest approach is based on straight forward spatial interpolation. In that case the observables θ_t are point observations of the continuous state variable Θ_t.. No forward integration,. i.e. prediction, is attempted. Thus no equation 0 is utilized, and only the observation equation 0 is inverted.
A more sophisticated version operates with the observable θ_t = *local wind* and a table relating the local wind to a spatial wind distribution calculated with the regional atmospheric model GESIMA (Kapitza and Eppel, 1992; Eppel et al., 1997). This wind distribution is part of the state variable Θ_t, an other part is the spatial distribution of wave statistics. The dynamics D is a wave model (Schneggenburger et al., 1997), simulating the response of the wave field to the wind forcing.
The success of this exercise is displayed in the following diagram (from Wolf et al., in prep.). It shows as triangles the observations of wind speed and wind direction as recorded for about two weeks by one of the piles shown above. Additionally, significant wave height is available from a wave rider buoy in the Lagoon. In case of the wind direction and velocity, the dashed

line is the 6-hourly operational analysis provided by the German Weather Service, whereas the solid line is the one-hourly best guess taken from a GESIMA simulation selected according to the observed wind at an other pile some 15 km away. The dashed and solid lines in the diagram with the significant wave height represent the response of the wave model to the two types of wind fields, the 6-hourly German Weather Service analyses and the 1-hourly GESIMA estimates. Seemingly, the German Weather Service analyses tend to overestimate the wind velocity and it fails to exhibit temporal detail. This wind and wave analysis scheme will play an important role in the system to be set up for the Odra Lagoon as wind and wave mixing are first order processes in the determination of the nutrient state of the Lagoon.



Significant wave height in April 1995 recorded by a wave rider buoy in the Odra Lagoon. Triangles: in-situ observations; dashed: wave model results forced with the smoothed 6-hourly analyses of the German Weather Service; solid: the same, but with the use of the best guesses derived from GESIMA simulations, conditioned upon wind observations (T.-Wolff, et al. In press).



Wind velocities and directions in April 1995 at a pile in the Odra Lagoon. Triangles: in-situ observations; dashed: smoothed 6-hourly analyses of the German Weather Service; solid: best guesses derived from GESIMA simulations, conditioned upon wind observations at another pile some 15 km away. From T.-Wolf, pers. comm.

5. CONCLUSION

Presently, coastal research is undergoing a paradigmatic change; while in then past emphasis was placed on the study of processes, now the insight gained in the past is asked to be implemented in system analyses and schemes for synoptic analyses of the environmental state. After many years of fundamental research, applications are coming to the forefront. Such applications are related to the management of the coast, be it in terms of political decisions about to the utilization of the coast, or in terms of routine decisions in shipping, offshore operations and the like. Since these applications have immediate implications of the public arena, the transfer of natural science knowledge is competing with alternative socially and culturally constructed views of the coast. Thus, the rationale use of such knowledge needs the guidance from social and cultural sciences.

PIONEER is an attempt to set up such low-cost routine analysis and forecast system, aimed at the monitoring of water quality in coastal seas. The basic idea is to combine routinely available information, for instance from tide gauges, weather forecasts, satellite imagery, with specific, low costs instruments, which are processes in data-driven model simulations of advanced geostatistical schemes. The challenges of a project like PIONEER are to bring together different sources of information (in situ, satellites; problem or site specific information versus general monitoring data) and to convey the results to users.

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MEDITERRANEAN FORECASTING SYSTEM PILOT PROJECT FIRST RESULTS

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ABSTRACT

The first two years of the Mediterranean Forecasting System Pilot Project (1998-2001) are being completed and every week a ten days forecast is released on the Web (http://www.cineca.it/mfspp). This is realized with a networking of Near Real Time observing and modeling centers started within the project and working operationally from January 2000. The network consists of:

1) three data centers that provide in situ and satellite data for initialization of model forecasts. The observations are released with a time delay of maximum a day through the internet and GTS;
2) a central modeling and data assimilation center which executes the forecasts;
3) a coastal modeling facility center which coordinates the nesting of regional and shelf scale models into the basin wide forecasts;
4) an ecosystem modeling facility center which coordinates the implementation of ecosystem modeling test sites in shelf areas.

INTRODUCTION

In the past five years, EuroGOOS (Woods et al., 1996) has promoted the formation of a Mediterranean Test Case Task Team (MTCTT). This is composed of representatives of all European and non-European countries bordering the Mediterranean Sea, together with several other European and non-EU countries. The MTCTT involves directly a large number of Mediterranean scientists with an exchange of expertise in order to: 1) build a cost-effective basin wide multi-platform, multi-use monitoring system; 2) build capacity in local centers to model the shelf areas with state of the art hydrodynamic and ecosystem modeling; 3) create a network between all the nations bordering the Mediterranean Sea and other European countries which will freely share observational data and model results in order to build a ocean forecasting local user community.

The MTCTT has elaborated a Mediterranean Forecasting System Science and Strategic Plan (Pinardi and Flemming, 1998) that describes the rationale and the strategy of implementation of marine environmental predictions in the Mediterranean Sea.

The overall Mediterranean ocean Forecasting System goal can be synthesized as follows:

Scientific

To explore, model and quantify the potential predictability of the ecosystem fluctuations at the level of primary producers from the overall basin scale to the coastal/shelf areas and for the time scales of weeks to months through the development and implementation of an automatic monitoring and a nowcasting/forecasting modeling system, the latter called the Mediterranean Forecasting System as a whole.

Pre-operational

To demonstrate the feasibility of a Mediterranean basin operational system for predictions of currents and biochemical parameters in the overall basin and coastal/shelf areas and to develop interfaces to user communities for dissemination of forecast results.

The first phase of implementation of the MFS is contained in the Mediterranean Forecasting System Pilot Project (MFSPP). In the following we will discuss the results and products of the first 18 months of the Project.

THE MULTIPLATFORM MONITORING SYSTEM

The elements of the monitoring system developed and implemented in MFSPP are a Voluntary Observing Ship (VOS) network, a multi-purpose moored buoy and satellite data analysis in near real time.

The VOS network is composed of seven tracks (see Fig. 1) repeated approximately every fifteen days with XBT data collection at 12 nm resolution. These sampling parameters were decided based upon a compromise between resources available and the knowledge of the internal Rossby radius of deformation and the large-scale structure of the basin gyres. These sampling requirements are typical of semi-enclosed seas and they are not really met by the conventional open ocean VOS system technology. Thus the system is semi-automatic, with on-board research personnel but satellite data communication for release of data in real time. The actual seven tracks implemented in the Mediterranean are working with a GTS (Global Telecommunication System using the ARGOS satellite communication channels) data telemetry system which transmit decimated profiles in the first 700 meters of the water column. Due to the steep gradients in the shallow thermocline, 15 points instead of the traditional 12 were selected as decimation points. A land based data collection center (http://estaxp.santateresa.enea.it/www/ec/new/mfs2.htm) re-collects the data from the GTS and makes them available in near real time through the Internet to the forecasting center and to the global users. Decimated profiles will be available every two days while the full 1-meter resolution profiles are updated every two weeks.

A buoy system, called Mediterranean Multisensor Moored Array (M3A), was deployed in the Cretan Sea (see Fig. 1). This mooring system has a large surface buoy which allows the measurement of air-sea interaction parameters and surface waves. The subsurface is sampled by a set of three moorings, one connected to the surface buoy, with fixed position sensors in the first 500 meters. The second and third mooring are subsurface. Lines two and three are located at a distance of about 1 km away from the central mooring: line two mooring site consists of an upward looking

ADCP and line three mooring consists of fixed position sensors located in the first 100 meters (the euphotic zone). The fixed position sensors are CTDs irregularly spaced in vertical, oxygen and turbidity sensors with the addition of chlorophyll (fluorescence), PAR and nitrate sensors in certain positions. The air-sea interaction parameters and the subsurface measurements are subsampled every hour and sent through GSM link to the receiving land station, which releases the data in near real time and quality control them. Data are put on the web within a day delay. These data will be initially used for validation of the Ocean General Circulation Model (OGCM) and calibration of the one dimensional ecosystem model for this near shelf area.

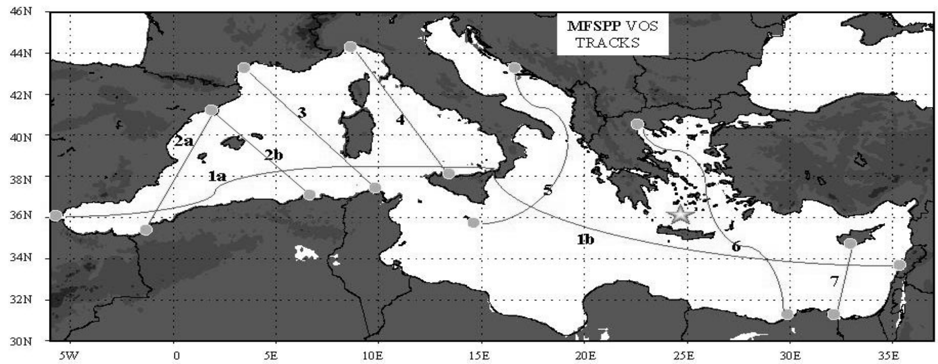

Fig. 1: The seven tracks of the VOS XBT system in the Mediterranean Sea. The star indicates the position of the M3A buoy

The near real time analysis of satellite sea surface height anomalies and sea surface temperatures is ensured on the internet for the entire Mediterranean Sea with a two days time delay. The sea level anomalies are given both along satellite tracks (satellites are Topex Poseidon and ERS-2) and mapped on the model regular grid. The sea surface temperature is given as a weekly mean of night passes over the Mediterranean with values interpolated into the model grid.

The data management system organizes multiple levels of quality control procedures and provides the near real time dissemination to the research community via WWW and ftp communication systems. The initial quality control system consists only of the detection of extreme outliers with respect to climatology for all the near real time data sets. In fact it is believed that the final quality control is made by the assimilation system which will feedback possible reasons of data rejection to the observing data collection centers. For climate studies, the full resolution VOS-XBT profiles, the M3A and satellite data are archived in conventional historical data banks. The Web system used in the project has been found to be working adequately making it possible to release a ten days forecast with a maximum delay of two days with respect to the actual start day of the forecast (nowcast). Furthermore, it is the system that allows the research community to fast communicate with the data acquisition systems and it can generate easily multiple users of the data itself as recommended by Molinari (1999).

OCEAN MODELLING FOR FORECASTING AT THE BASIN SCALE AND IN THE SHELF AREAS

The past ten years the Mediterranean research community has developed a suite of OGCM and regional models capable of simulating the seasonal and interannual variability of the basin currents with good accuracy (Korres et al., 2000). The forecasting OGCM is at 1/8 X 1/8-degree resolution and 31 vertical levels and the assimilation/forecasting system is composed of four parts:

1. The first consists of an assimilation engine partially developed in the project (DeMey and Benkiran, 2000) which uses a reduced order Optimal Interpolation scheme with empirical orthogonal functions used to project in an assimilation subspace. The assimilation engine is used for both sea level anomalies and XBT with multivariate empirical functions. In practice, sea level anomaly is assimilated to give the first guess for the successive multivariate assimilation of temperature profiles from XBT. Thus the two data sets are assimilated sequentially. Both sea level anomaly and temperature profiles assimilation is multivariate but the sequential assimilation allows the usage of different empirical orthogonal functions that are optimized for the two different data sets.
2. The second is a software interface between the atmospheric forcing parameters and the OGCM. This interface allows to drive the ocean model every week from the previous week forecasting day (J0-7) to the present week starting forecast day (J0) with atmospheric analyses (hindcast mode). Then the same interface couples the OGCM with ten days deterministic forecast surface parameters from the ECMWF (European Center for Medium range Weather Forecast, forecast mode). The sea surface temperature data from satellite are used in the hindcast run to correct the surface heat fluxes by means of a flux correction term
3. The third part is a software interface between the observed data and the assimilation engine, to feed the observations in the appropriate format to the model.
4. The fourth part is a post processing interface that translates the model forecast to image products for Web publication and dissemination of information.

The whole system is represented schematically in Fig.2

The OGCM simulations are also used to initialize regional and shelf models that receive boundary fields at different time frequencies. The downscaling brings the OGCM 12.5 km resolution fields down to 1-2 km resolution in the shelf areas. This is at the base of the coastal forecasting system of the next phase, where the initialization of the regional and shelf models will crucially depend upon the OGCM dynamical fields. The Mediterranean Sea shelf area is narrow and the general circulation can determine a large portion of the coastal hydrodynamics variability. Thus two and three fold nesting is necessary to develop the future experiments of near real time forecasting in the coastal areas.

Finally, ecosystem models are also implemented and validated during MFSPP at several coastal test sites. The aim is to calibrate the ecosystem model parameters in a one dimensional set up since it has been found that this is useful to understand non generic model parameters. In the next phase, it is hoped to start the simulations of the ecosystem variability with a fully coupled 3-D ecosystem model based upon the shelf models developed in MFSPP.

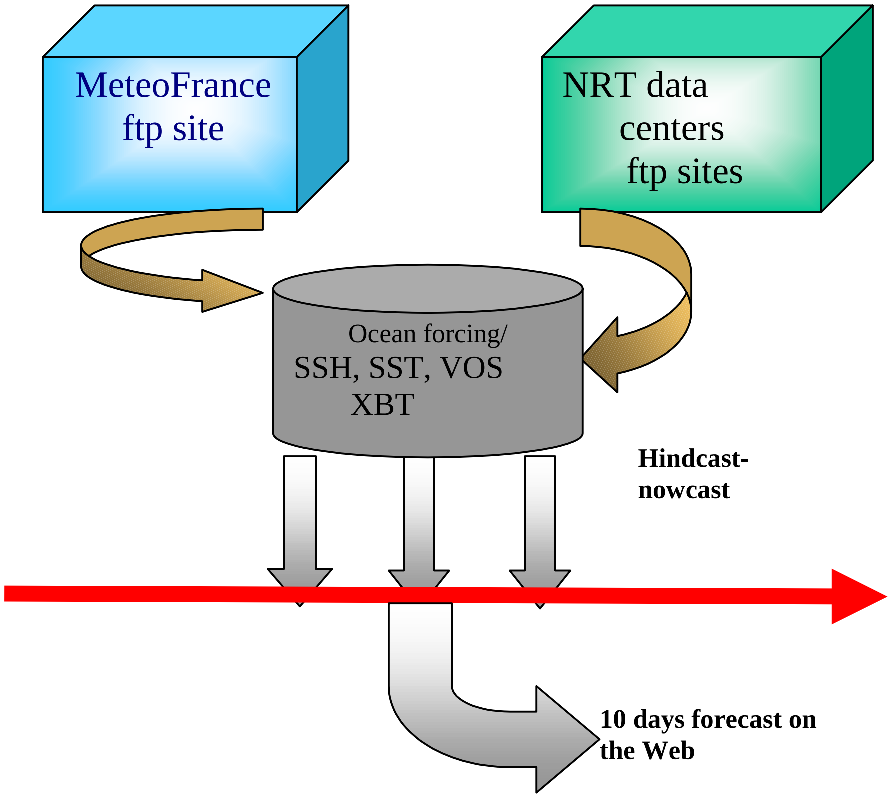

Fig. 2: The schematic of the Forecasting system interfaces and network

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TITLE: ASSESSMENT OF ANTIFOULING AGENTS IN COASTAL ENVIRONMENTS : **ACE**

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ASSESSMENT OF ANTIFOULING AGENTS IN COASTAL ENVIRONMENTS (ACE)

MAS3-CT98-0178 (February 1999 – February 2002)

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SUMMARY

In 1989 the European Community introduced a directive to restrict the use of TBT-based antifouling paints on boats under 25m. This, in combination with other National and International legislation, has provoked paint manufacturers and chemical companies to develop and vend a range of agents for new antifouling paints for the "small boat" market and as an addition to TBT-based formulations to enhance efficacy for larger vessels.

Examples of the types of compounds being used or promoted include: 2,3,5,6-tetrachloro-4-(methyl sulphonyl) pyridine; 2-methylthio-4-tertiary-butylamino-6-cyclopropylamino-s-triazine (IRGAROL 1051); cuprous thio cyanate; 2,4,5,6-tetrachloro iso phthalo nitrile; 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (SeaNine 211); dichlorophenyl dimethylurea (Diuron); 2-(thiocyanomethyl thio)benzthiazole; zinc pyrithione; 4-chloro-meta-cresol; arsenic trioxide; cis 1-(3-chloroallyl)-3,5,7-triaza-1-azonia adamantane chloride; zineb; dichlofluanid; folpet; thiram; oxy tetracycline hydrochloride; ziram and maneb. This list includes compounds which are known to be highly toxic (e.g. cyanides, arsenicals) or to act as endocrine disrupters (e.g. zineb, maneb, ziram)(Colborn *et al*., 1993) but negligible data concerning contamination, (potential) effects and risks of these compounds in the coastal and marine environment are available.

This project has the objective to provide information and tools which enable environmental managers at national and international levels to address the issue of antifouling agents in a systematic and effective manner. The following activities are underway:

- a survey of antifouling agents and products being used and marketed;
- an assessment of geographical patterns of usage;
- a database is being established with environmental and toxicological properties of these compounds using information from literature and data generated in the project;
- suitably sensitive analytical techniques to measure environmental levels are being developed;
- extent of contamination of European coastlines is being assessed;
- fates and effects in (semi-) field conditions are being investigated;
- models to predict future concentrations levels and effects in selected European coastal zones will be developed using the data obtained;
- products will be compared regarding environmental properties (fates, toxicity etc.) and effects using different scenario's for usage.

Partners involved include experts in analytical/environmental chemistry, ecotoxicology, modelling and risk assessment with considerable experience in marine science. They represent several EU States which cover a large proportion and diverse EU coastal areas. An industrial perspective is included through the participation of an antifouling biocide manufacturer.

INTRODUCTION

Antifouling paints are a necessity for shipping operators and are considered to be indispensable by owners of small boats. Consequently, the market for antifouling paints is large and is important from a commercial point of view. Successful products are used in large quantities and, as a result, concentrations of antifouling agents may be high, in particular at hot spots such as marinas, harbours and near shipping lanes with high traffic densities. Without a well-founded management strategy, however, large environmental problems may lay await and environmental managers urgently need information and tools which allow them to assess environmental impacts of such new products.

Attention was initially drawn to one of these alternative antifouling products: 2-methylthio-4-tertiary-butylamino-6-cyclopropylamino-s-triazine (trade name IRGAROL 1051). This is a triazine herbicide (in the same family as atrazine and simazine) which has proven to effectively inhibit the primary colonisation of hulls by algae. Following development of suitably sensitive analytical techniques, concentrations of up to 1.7 µg/L were found in marinas with widespread contamination throughout the Côte d'Azur coastline (Readman *et al*., 1993). Subsequent surveys (Tolosa *et al*., 1996) indicate that levels have remained comparatively stable. Since this initial work, other scientists have also reported comparable levels of contamination from IRGAROL 1051 (Gough *et al.,* 1994; Toth *et al.,* 1996; Zhou *et al*., 1996; Ferrer *et al*., 1997; Scarlett *et al*., 1997 & 1999; Ferrer & Barcelo, 1999; Biselli *et al*, 2000; and Thomas *et al.*, 2000). Pearce (1995) appraised the situation with regard to the contamination from IRGAROL 1051 reporting further unpublished discoveries. He also described assessments by the pesticides division of the Swedish inspectorate who concluded that the compound tends to accumulate in fish, degrades "very slowly" in aquatic environments and is likely to accumulate in waters and sediments. Indeed, the question of potential environmental effects has generated considerable speculation. The manufacturers (Ciba Geigy) have published some toxicological data relating to "acute" toxicity (1988, IRGAROL 1051 in antifouling paints, Technical Bulletin 03/88-31). The minimal inhibition concentrations (MIC) for the alga *Enteromorpha intestinalis* and various diatoms (including species of *Navicula*, *Nitzschia*, *Amphora*, and *Achnanthes*) were reported to be 10 µg/L. No information was, however, available for sub-lethal effects. Dahl & Blanck (1996) described experiments which demonstrate that IRGAROL 1051 can significantly inhibit periphyton photosynthetic activity at levels as low as about 20 ng/L (Dahl & Blanck 1996). Also macroalgal reproduction-related processes are affected at low concentrations (120 ng/L for significant inhibition of growth of *Enteromorpha intestinalis* spores, Scarlett *et al*., 1997). Even vascular plants in the marine environment (*Zostera marina*) have been shown to be affected by 200 ng/L (Scarlett *et al.,* 1999). These toxic levels are within the concentration ranges reported for environmental samples. This raises the question as to whether or not coastal ecosystems are at risk (Pearce, 1995; Readman, 1996; Evans *et al*., 2000; and Thomas *et al*., 2000). Results indicate that perturbations in phytoplankton communities will occur with the current levels of contamination.

Thus, for just this one of the alternative/additive antifouling agents the potential for environmental damage has already been demonstrated. Negligible information is available concerning the others. The final product of this project will be to provide an assessment of the potential impact from the various antifouling agents and to recommend preventative measures and/or remedial/advisory actions where necessary.

RESULTS

Significant progress has been achieved during the first year of the ACE programme. All tasks are on-track.

USAGE OF BOOSTER BIOCIDES

All partners have undertaken their national surveys. Results are summarised in Table 1

Table 1. Ingredients permitted for use on yachts < 25 m. (as of 2000)

	UK	Fr	Gr	Sp	Sw	Dk	Nl
Copper (1) oxide	+	+	+	+	+	a	+
Copper thiocyanate	+	+			+		+
Cu powder			+		+	a	
Zinc oxide			+				+
Chromium trioxide							+
Diuron	+	+	+	+		?	+
Irgarol 1051	+	+	+	+	+	?	+
Zinc pyrithione	+	+	+			+	
Dichlofluanid	+	+	+	+			+
TCMBT	+						
Chlorothalonil	+	+	+				
TCMS pyridine	+						
SeaNine 211	+			+		+	
Ziram			+				+
Zineb	+						+
Folpet			+				
Number of organic boosters	9	5	7	4	1	2	5

Notes: DK: voluntary agreements; "a"– to be phased out in 6 years (leaching rate regulated)

There are notable differences in usage patterns of booster biocides on pleasure boats throughout the European region. The most commonly used biocides are: copper-oxide, Irgarol, diuron, dichlofluanid, and zinc pyrithione. In some countries, recent regulations and voluntary agreements have caused a shift in the usage patterns, especially from diuron and Irgarol to zinc pyrithione and SeaNine. For copper oxide, there are regulations on leaching rates and even a ban has been proposed. A survey on the antifouling biocides admitted in U.K showed that copper(1) oxide, diuron, Irgarol 1051 and zinc pyrithion are the most used compounds. The survey in the Netherlands showed that 5 organic compounds are currently registered for use as antifouling agents, i.e. diuron, Irgarol 1051, dichlofluanid, ziram and zineb. Copper-oxide will possibly be banned totally in the Netherlands. Residues of antifouling compounds have been detected in marine environments throughout Europe, sometimes where they are not permitted e.g. diuron was detected in Swedish sea water where the usage of this compound is not permitted. In Denmark, a new regulation was implemented on January 1, 2000, which includes a ban on Irgarol and diuron for boats < 25 m. In Denmark, from 2003 no booster biocides will be allowed unless they comply with a stringent safety and health risk assessment (R 53 - Risk of long term effects on the aquatic environment).

Areas most susceptible to contamination along the coasts of U.K., France, the Netherlands, Spain, Greece, Sweden and Denmark have been identified. Geographical differences in the use of antifouling paints were assessed indirectly from data for pleasure craft, fishing boats, ferry boats, tankers etc. (from different National services) concerning the following:

- number of registered boats and the number of new registrations for a given year;
- the number of port facilities and installations for pleasure craft;
- boating intensities on the National continental shelves;
- counting of ship and boat traffic through sea ports and sea-going sluices and
- locations of marina and yacht havens in the coastal areas (a distinction was made between shipping traffic which is pleasure-craft related and shipping traffic which is related to commercial activities).

This data is being used to direct the design of the coastal surveys to investigate the extent of contamination of European coastlines.

SURVEY AND CRITICAL ASSESSMENT OF ENVIRONMENTAL AND TOXICOLOGICAL PROPERTIES

A literature survey on potential compounds to be studied within ACE has been undertaken. Focus was on ecotoxicological effects in the marine environment and on biochemical modes of action. In the open literature, however, ecotoxicological information is scarce for most compounds. Data on environmental/ physico-chemical properties of the booster biocides has been completed up to the present time and is being inputted into the database. This combined information will serve as a basis for selection of compounds for ACE to focus experimental work on. Information will be updated throughout the duration of the project.

ANALYSES OF ENVIRONMENTAL SAMPLES

Literature on analytical techniques has been screened and is summarised in three publications (Ferrer & Barceló, 1999; Castillo & Barceló, 1999; Martinez, Ferrer & Barceló, in press).

Preliminary method development work has been undertaken by most partners. The studies have aimed at finding the most sensitive and suitable analytical techniques. Extractions include the use of SPE-disks and SPME-fibres, XAD-2 resin and liquid-liquid extraction. Quantification procedures tested include capillary gas chromatography (GC)-NPD/ECD/FPD and MS, GC-ion-trap tandem mass spectrometry and high performance liquid chromatography (HPLC) coupled to electrospray tandem mass spectrometry and HPLC-APCI-MS. An analytical method for the determination of mancozeb, maneb thiram, zineb was also developed using UV-Vis spectroscopy.

- **FOCUSSING THE RESEARCH**

Following extensive discussions at the first Annual Workshop (February 2000), booster biocides were selected for study in the countries involved. Topics considered included usage, transport, reactivity, toxicity, and the availability of analytical facilities.

The core group of compounds to be monitored within the ACE Programme was selected as: Irgarol 1051; Dichlofluanid; Chlorothalonil; SeaNine; Diuron.

Zinc pyrithione was also considered to be important even though the compound is difficult to analyse. It was considered most feasible that sample analyses for this compound should be undertaken by those partners best suited in terms of analytical facilities.

Toxicity tests will focus on Irgarol 1051 and SeaNine (it was considered that adequate data is already available for diuron). Further long term and field toxicity tests will then focus on zinc pyrithione (assuming appropriate analytical support is available).

Endocrine disruption experiments will focus on the core compounds and additionally on zinc pyrithione.

- **RESULTS TO DATE**
- **Environmental Analyses:**
- Field validations of the selected analytical techniques have been undertaken and coastal surveys have commenced. Areas identified as being potentially subject to most contamination are being targeted for assessment. 'Good geographical coverage' is also, however, being incorporated as a prerequisite in survey design. A critical feature relating to the potential for pollution by antifouling agents is the dissipation of the compounds from marinas and harbours. It is accepted that toxic concentrations are likely to exist in direct proximity to vessels, and the primary concern is that coastal environments adjacent to port facilities will be impacted (as was the case for TBT). As part of the surveys undertaken, intensive investigations will be performed at the most contaminated locations to investigate dissipation. Samples will be exchanged between partners in order to ensure that a full data set is generated for each area. The survey data produced by individual partners will be compiled to provide a Europe-wide assessment of coastal contamination with the antifouling agents in question and maps depicting the extent of contamination of European coastlines by the selected booster biocides will be generated.

Toxicity Studies:

Microcosm studies on the effects of SeaNine 211 on marine periphyton and natural phytoplankton communities were conducted during summer 1999. Preliminary analyses of the results suggest effects in the low nanomolar range. In another microcosm experiment, bacterial degradation of SeaNine was investigated. Results indicated slow degradation of SeaNine, with toxicity persisting for 28 days.

A field study on the effects of Irgarol 1051 on periphyton community tolerance was performed in the Fiskebäckskil area on the Swedish west-coast during summer 1999. The observed community tolerance was stronger than observed in a previous study (Blanck & Dahl, 1994, unpublished) and the reason for this is now being investigated.

Novel toxicological techniques have also been developed using flow cytometry and pigment analyses to assess the effect of Irgarol 1051 on natural phytoplankton populations.

DISSEMINATION OF RESULTS

An ACE web site has been set up at www.pml.ac.uk/ace.

A concise relational database, built in Microsoft Access 97, has been constructed and will be made available through the web.

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TITLE: SCOUR AROUND COASTAL STRUCTURES (**SCARCOST**)

CONTRACT NO: **MAST3-CT97-0097**

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SCOUR AROUND COASTAL STRUCTURES (SCARCOST)

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INTRODUCTION

When a structure is placed in the coastal environment, it will change the flow pattern in several ways, some examples of which are given below:

- Reflection of waves, leading to increased wave action in front of the structure.
- Diffraction of waves around the structure.
- Formation of horseshoe vortices at the heads and vortex shedding behind the structure.
- Contraction of currents (like a tidal current in front of a breakwater).
- Breaking of waves at the sloping walls of the structure.

These changes usually lead to the scouring of sediment from around the structures. The scouring of sediment poses a threat to the stability of the structure.

The objectives of the present project, SCARCOST, are

- To study the potential risk for scour in the vicinity of coastal structures; and
- To prepare and disseminate practical guidelines, to be developed from the research programme and also taking into account all "state-of-the-art" knowledge.

To achieve these objectives, the study has concentrated on obtaining a profound understanding of the physical processes involved. This will include 1) the flow processes in the overlying water, and 2) the behaviour of the sediment bed. Laboratory measurements of flow, sediment and scour processes have been carried out on a wide variety of coastal structures such as detached breakwaters, submerged breakwaters, individual piles, vertical large cylinders (such as platform legs and bridge piers) and pile groups. The objectives of these experiments have been to unveil the mechanisms responsible for scour. These experiments have been complemented by field experiments, and limited mathematical modelling efforts on issues related to scour and also wave-induced excess pore pressure in the soil in conjunction with the processes of scour and sinking of armour blocks.

The structures specifically covered in this project are: Detached breakwaters; Detached submerged breakwaters; Vertical piles; Large vertical cylinders; Pile groups; Breakwater elements; Scour protection; Filters and armour blocks, etc.

The project started on 1. September 1997, and runs for three years. The main results have been disclosed in ICCE 1998 Copenhagen Conference, and Coastal Structures'99 Santander

Conference among others, and will be discussed in the coming ICCE 2000 Sydney Conference, and in an end-users conference “Presentation of Research Results in Coastal Engineering, Scour Around Marine Structures, and Morphodynamics Around Coastal Structures” in Paris 3-4. October, 2000 (e-mail to hildur@isva.dtu.dk for information on this latter conference).

The project is organized in two main tasks: Task 1. Flow and scour processes, and Task 2. Sediment behaviour close to the structure and scour.

FLOW AND SCOUR PROCESSES (TASK 1)

The work in Task 1, led by HR, concentrates on the interaction between the water flow and the sediment at the toe of the structure. The work is sub-divided into four topics:

TOPIC 1.1. FLOW AND SCOUR PROCESSES AROUND VERTICAL CYLINDERS. The data on scour around vertical cylinders - slender piles, pile groups and large diameter cylinders - has been obtained in wave flumes and wave basins. Test conditions have covered the cases for waves alone, including non-linear shallow water waves and breaking waves, as well as waves and currents. The work on scour around pile groups has been published Sumer and Fredsøe (1998) and Mory et al (1999). Additional test results were obtained for the scour and settlement of a single pile into the sand bed. A 3D numerical model for bed scour around a slender pile has been devised (Roulund et al, 1998).

TOPIC 1.2. SCOUR AT RUBBLE MOUND BREAKWATER. Experimental results for the scour development at the toe of a rubble mound breakwater (RMB) have been published (Sumer et al, 2000). This work investigated the scour development at the trunk section of a breakwater and the efficiency of scour protection measures. The results have been extended to the 3D case through test data for scour development around a shore-parallel RMB. The data was collected in a large 3D wave basin. A total of 5 tests investigated the time development of scour and the equilibrium morphology around the breakwater for normal and oblique incidence waves and with a tidal current. Scour protection measures were tested and the influence of storm (breaking) waves was simulated. The first results have been published (Sutherland et al, 1999a) and a data report written (Sutherland et al, 1999b). Measurements of the pore pressure field in the bed at a number of locations during the 3D tests will enhance the link with Task 2 of the project.

TOPIC 1.3. SCOUR AROUND SUBMERGED BREAKWATERS. The large-scale 2D wave flume experiments on scour development at the toe of submerged breakwaters is underway. The tests show the extent of scour development under different wave conditions and varying levels of freeboard. Scour protection measures will be tested. In parallel, mathematical modelling of the wave hydrodynamics and morphodynamics around the submerged breakwater has been completed. These results are used in conjunction with some earlier test results to determine both the hydraulic performance of the structure and the seabed scour. Early results have already been published (Gironella and Sanchez-Arcilla, 1999).

TOPIC 1.4. THE EFFECT OF TURBULENCE ON SEDIMENT TRANSPORT. The turbulence levels in the vicinity of coastal structures can be high and the flow field non-steady and non-uniform. The influence of an external (grid) turbulence field on the bed shear stress and sediment transport has been measured in steady flow flume experiments. The sediment transport rate has been measured for normal and enhanced turbulence levels over flat and rippled sand beds. Two further practical aspects have been considered; (1) given the magnitude of the extra turbulence, can the sediment transport rate be calculated?, and (2) can the magnitude of the extra turbulence be predicted without recourse to in-depth investigations? To address these issues a baseline study of the detailed processes of suspended sediment transport in a turbulent tidal flow has been completed. To extend these data, the results from numerical simulations have been applied to quantify the effect of enhanced turbulence levels on suspended sediment transport (1DV model), and bedload (CFD code). The effects of breaking waves, turbulence and vortex shedding on bed stability and scour have also been assessed (Simons, 1999), and an analytical approach for predicting sediment transport proposes. The data from the above studies will be input to the project database, and the key results will provide input to the design guidelines. The new findings will be collated with existing available information when formulating the guidelines (e.g. Whitehouse, 1998).

SEDIMENT BEHAVIOUR CLOSE TO THE STRUCTURE AND SCOUR (TASK 2)

The work in this part of the project (Task 2, led by SINTEF) concentrates on the processes associated with the sediment, which is closely related to the wave-generated pore pressure in the sediment bed. This task is sub-divided into six topics:

TOPIC 2.1. WAVE-GENERATED PORE PRESSURE AND SCOUR AROUND BREAKWATER ELEMENTS. UOX has carried out field measurements on wave generated pore pressures in a sand seabed. A typical element of a breakwater (a rubble mound stone) is simulated with a truncated cylinder placed on the seabed with the axis vertical. Wave-induced pressures are measured on the cylinder as well as in the seabed. There is also an altimeter and an inclinometer to monitor the scour at the cylinder as well as the tilt of the cylinder. UOX has actually achieved four field deployments of an instrumented cylinder. Due to experimental problems, the two first were unsuccessful, but the two following ones successfully produced data. Considerable erosion and consequent tilting of the model breakwater element have been observed in all the deployments. The data is being analysed.

TOPIC 2.2. NON-LINEAR MODELLING OF WAVE INDUCED PORE PRESSURES. SINTEF has modelled pore pressure and effective stresses using non-linear material models. The non-linear material is a swelling soil model.
Based on numerical results, the following conclusions have drawn: (1) Elasto-plastic soil behaviour reduces gradients out of the seabed when critical gradients are reached. (2) Critical gradients out of bed can be reached with a small content of gas in the pore fluid. (3) Shallow water non-linear breaking waves gives lower gradients out of bed than "linear non-breaking" waves of similar height and period in the same water depth. See also Ilstad et al. (2000).

TOPIC 2.3. WAVE BOTTOM PRESSURES AND WAVE KINEMATICS IN THE SURF ZONE. NTNU and SINTEF have obtained spatial and temporal variations of the dynamic bottom pressures and the wave kinematics in the vicinity of the wave breaking point in shallow water. Different numerical schemes have been tested to calculate the surface elevation, wave kinematics and bottom pressures FIRAM (Finite Element Reynolds Average Model), VOF (Volume Of Fluid) and COBRAS (Cornell Breaking - Wave And Structures). The latter model seems so far to give reasonable agreement with measurements. See also: Arntsen et al. (2000).

TOPIC 2.4. SEDIMENT TRANSPORT/SCOUR BY ACCOUNTING FOR THE EFFECT OF MOMENTARY LIQUEFACTION. This work includes the set up of two pore pressure models. They have been tested against each other, and against some laboratory data on wave induced pore pressures. Laboratory experiments have been conducted to examine the effect of seepage on the near bed hydrodynamics and bedload transport. Mean horizontal velocity profiles have been obtained near the bed. Comparison of direct Reynolds stress measurements with other shear stress estimates obtained close to the bed indicates that the turbulent kinetic energy and the inertial dissipation methods are inaccurate when significant seepage occurs. Preliminary results of some exploratory laboratory experiments indicate that seepage into the flow may result in enhanced bed load sediment transport, although further tests are required to substantiate this.

TOPIC 2.5. PENETRATION OF BLOCKS INTO THE BED IN THE ABSENCE OF FILTERS. ISVA has undertaken an extensive series of experiments on the penetration of blocks into the bed in the absence of filters. The bed is exposed to progressive waves. Two kinds of experiments have been made: The undisturbed-flow experiments, and the experiments with the structure model (a pipe, a sphere, and a cube). In the former experiments, the pore-water pressure has been measured across the soil depth. The pore-water pressure builds up, as the waves progress. The soil is liquefied for wave heights larger than a critical value. Regarding the experiments with the structure model, the displacement of the structure (sinking or floatation) has been measured simultaneously with the pore-water pressure. The influence of various parameters (such as the initial position of the object, the specific gravity, the soil layer thickness, and the wave height) has been investigated. It was found that while the pipe sank in the soil to a depth of 2-3 times the pipe diameter, the sphere sank to even larger depths. The pipe with a relatively small specific gravity, initially buried, floats to the surface of the soil. The results have been published in Sumer et al. (1999). In another study in this topic, a random walk model has been developed to predict the buildup of pore pressures in soil with and without the presence of a structure, Sumer and Cheng (1999).

TOPIC 2.6. CYCLIC STIFFNESS OF LOOSE SAND. NTNU has carried out an extensive experimental program to measure the geotechnical properties regarding the cyclic stiffness of loose sand from a sand quarry at Hokksund, Norway, and on the soil used by ISVA in their wave flume experiments. The results of the investigation have been published in two internal reports.

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INTERNET ADDRESS OF THE PROJECT

http://www.isva.dtu.dk/scarcost/scarcost.html

TITEL: VALIDATION OF LOW LEVEL ICE FORCES ON COASTAL STRUCTURES: **LOLEIF**

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VALIDATION OF LOW LEVEL ICE FORCES ON COASTAL STRUCTURES

Joachim Schwarz

INTRODUCTION

Coastal structures in northern and central European waters as well as offshore structures for exploration and production of hydrocarbons from the European Arctic have to be designed to withstand the forces applied by moving ice. Ice forces govern the design in most cases where ice is present. The largest ice forces are caused by pressure ridges and by level and rafted ice on vertical structures.

About these ice forces there exist an extraordinary uncertainty between the prediction by scientists around the world; the predictions scatter by a factor of 10 to 15.

This situation as well as indications that the forces are indeed smaller than predicted by most of the scientists have stipulated a group of seven research organizations from six countries in Europe to propose a R+D-project to the European Commission for funding within the MAST III Programme. The proposal was accepted and the project started in August 1997.

The project consists to two main research areas:

- Field test on ice forces against a lighthouse in the northern Gulf of Bothnia and the determination of ice thicknesses and the mechanical properties of the respective ice (level ice and ridges).
- Development of numerical methods to predict these ice forces.

PROJECT METHODOLOGY

FIELD MEASUREMENTS AND NUMERICAL MODELLING

The ice force measurements in full scale were carried out in two winters (98/99 and 99/00) at the lighthouse Norströmsgrund which is located in the Gulf of Bothnia close to Lulea/Sweden. This lighthouse was chosen because the vertical concrete shaft (7 m diameter) had earlier been equipped with a multigonal steel belt at which ice force measuring panels could easily be mounted. Nine ice force measuring panels (1.65 m x 1.25 m) were specially designed, manufactured and mounted to the lighthouse in 1998. One of those panels consisted of eight small triaxial load cell panels (0.4 m x 0.5 m each) in order to determine the effect of the surface area interacting with the drifting ice. The panels were mounted half way around the lighthouse directed to ENE. The ice thicknesses were measured by a sonar device which was located at the bottom of the lighthouse foundation in 7 m water depth several meters infront of the vertical shaft. As redundancy for the sonar ice thickness measuring system an EM-log plus laser distance meter was installed in 1999 hanging 2.0 m above the ice infront of the lighthouse.

Ice compressive strength tests were carried out in the field as well as in the ice mechanics laboratory of HSVA in Hamburg together with tensile strength and fracture toughness tests.

The ridge mechanical properties were determined by a specially designed shear apparatus, consisting of a steel frame and a hydraulic punch piston, by which the unconsolidated ridge material was pushed downward under water. These tests were carried out in ice ridges embedded in landfast ice offshore Oulu.

Four different numerical modelling approaches have been established to predict the forces of drifting ice against vertical structures:

- Dynamic ice-structure interaction model
- Fracture dynamics model
- Ridge load model
- Probability approach

RESULTS

1. Evaluation of existing ice force prediction methods

Published ice force data and the corresponding ice property data have been evaluated [Loeset, S. et al., 1999]. Especially the ice force measurements at the Molikpaq structure in the Beaufort Sea have been made available [Wright, B., 1999] and are part of the LOLEIF-reports. There are several reasons for the wide scatter of ice force predictions identified. In some cases model test data have been used to derive a prediction formula, in which case incorrect transfer functions have been used to predict the forces in full scale from small scale tests. In other cases, the forces have just been predicted by numerical modelling using assumptions on the failure processes and criteria, which have proven to be not realistic (plastic limit analysis).

2. Field Tests

- Mechanical Properties of the Ice

The punch tests in ridges, where the consolidated upper surface was manually cutted, provided information on internal shear angle and cohesion of fragmented ice [Heinonen, J., et al., 2000] to be used in the numerical force predictions. The compressive and tensile strengths of the ice gathered in the vacinity of the lighthouse Norströmsgrund are relatively high compared to data published in literature. The reason for this result may be that the ice specimen were loaded parallel to the long axis of the crystal columns. More data on ice mechanics, especially on the fracture toughness are being analyzed in order to be used in numerical calculations of ice forces.

- Ice Forces

	WINTER 98/99	WINTER 99/00
Lighthouse occupation	23 days	55 days
Recorded raw data	abt. 500 MB	abt. 3 GB
Recorded time laps video sequences	abt. 600 h	abt. 1300 h
Ice structure interaction events	60	Not yet defined

Ice forces have been measured at the lighthouse in two winters. In 1999 approx. 500 MB raw data were recorded during 60 ice force events (ice-structure interactions) (Table 1). Unfortunately in mid March '99 some of the electronic cables of the ice load panels were ruptured by ice (cable protection channel was destroyed). After in summer 1999 the measuring equipment was repaired, in winter 2000 approx. 3GB data were recorded with all eight large and eight small panels working well. Time records of several ice force panels are shown in Fig. 1. The ice-structure interaction was covered by time lap video cameras over 600 hours. Ice thicknesses were recorded by sonar and by EM-log (Fig. 2).

Even though the raw data are still being processed and analyzed the following results and conclusions can be drawn:

(1) The largest level ice forces did occur when the ice cover had a large extent creating the confined state of stress within the ice. In this case the ice failed in crushing starting with horizontal splitting (cleavage) in the middle of the thickness. This was observed earlier by Hirayama et al. [1974] in laboratory tests and will be considered by the relevant numerical model.

(2) A further criterion for maximum ice forces is the simultaneous failure of the ice over a large area. This happened after the ice cover had been stopped and a static load could create a close contact between structure and ice (nearly 100%) due to plastic deformation. When in this case the static load increased until the ice cover failed at the lighthouse, maximum total ice forces were measured due to simultaneous ice failure at several panels. A dependency of effective ice pressure on the area/width of the structure has been obtained.

(4) The effect of the strain rate (ice velocity) on the ice load has been identified (lower ice loads at higher velocity).

(5) Unconsolidated pressure ridges did cause only a slight increase in the ice load.

<u>Numerical Modelling</u>

- Ice Structure Contact Model

VTT in cooperation with the State University of St. Petersburg have developed a 2-D model to simulate the splitting process at the ice edge including horizontal cleavage cracks and subsequent inclined shear failure. The model shows that the resistance of the ice increases, when the contact between the ice edge and the structure changes from a line-like contact into an areal contact. [Shkhinek, K. et al., 1999].

- Fracture Model

Ice force measurements in northern Japan (the author visited the test site in 1999) showed by pressure sensor film covering the indentor face that the stresses at the ice edge are concentrated close to the mid-way through the ice thickness (line-like contact).

These observation were used by the Cambridge team to the development of a fracture mechanics model of ‘hot spots’ where most of the contact force concentrates [Dempsey, J.P. et al., 1999]. The model is based on simple idealisations with spherical and cylindrical symmetry, and predicts behaviour in semi-quantitative terms. These models are currently being developed further.

- Ridge Load Model

Helsinki University of Technology has completed a LOLEIF-Report [Heinonen, J. et al., 2000] which includes measurement data, analysis results and the description of the theoretical model.

The further development of the theoretical model for the mechanical behaviour of the rubble in the ridge keel is advancing. Mohr-Coulomb parameters have been determined to give the best fit for the test data. A method to pinpoint the most likely rubble data point for friction and cohesion has been demonstrated. Both analytical and Finite Element models have been used to analyze the test data. The USERMAT material model routine has been implemented in ABAQUS Finite Element code to observe the time dependent progress of failure surface in the rubble.

- Probability Approach

The Norwegian Institute of Technology has developed a program on the basis of MATLAB. This enables access to a standard user interface as well as mathematical functions. Seven different ice load algorithms are implemented as well as the findings from previous work (Report in preparation).

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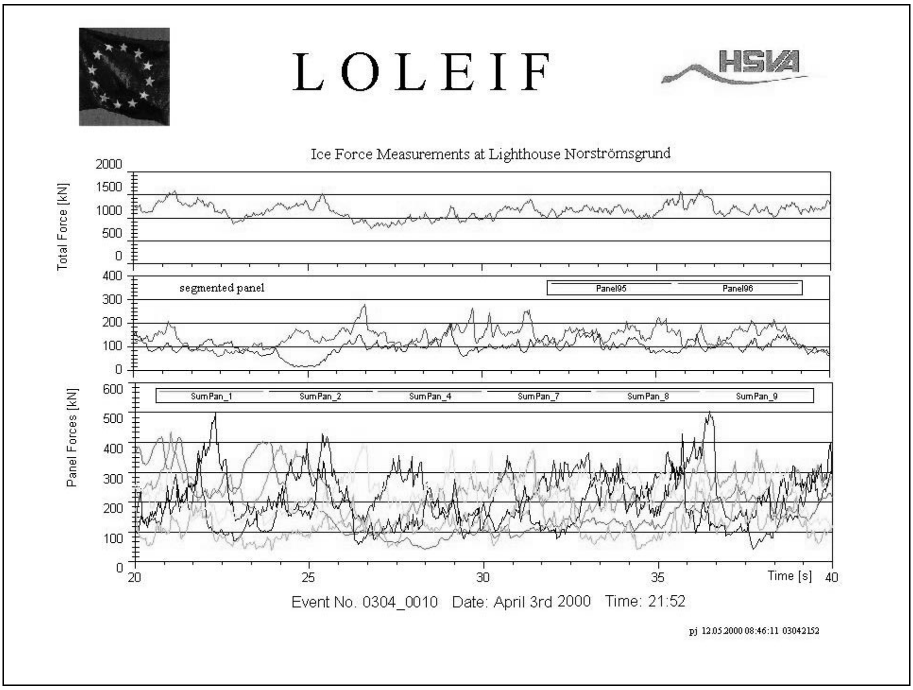
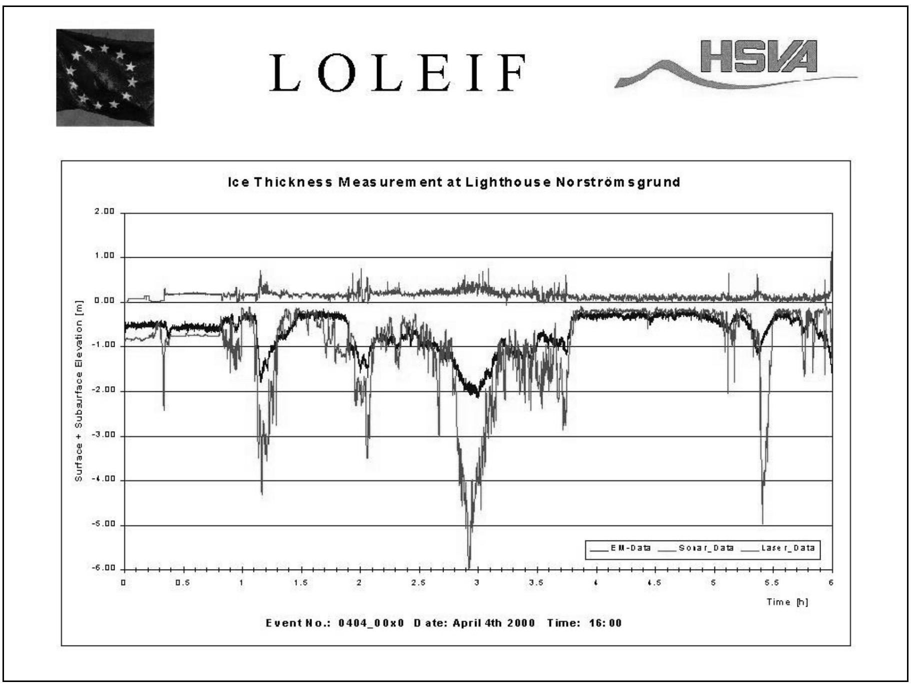


LOLEIF
HSVA
Ice Force Measurements at Lighthouse Norströmsgrund
Total Force [kN]
segmented panel
Panel95
Panel96
Panel Forces [kN]
SumPan_1
SumPan_2
SumPan_4
SumPan_7
SumPan_8
SumPan_9
Time [s]
Event No. 0304_0010 Date: April 3rd 2000 Time: 21:52
pj 12.05.2000 08:46:11 03042152

Fig. 1



LOLEIF
HSVA
Ice Thickness Measurement at Lighthouse Norströmsgrund
Surface + Subsurface Elevation [m]
EM-Data
Sonar_Data
Laser_Data
Time [h]
Event No.: 0404_00x0 Date: April 4th 2000 Time: 16:00

Fig. 2

TITLE : THE OPTIMISATION OF CREST LEVEL DESIGN OF SLOPING COASTAL STRUCTURES THROUGH PROTOTYPE MONITORING AND MODELLING : **OPTICREST**

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THE OPTIMISATION OF CREST LEVEL DESIGN OF SLOPING COASTAL STRUCTURES THROUGH PROTOTYPE MONITORING AND MODELLING

OPTICREST

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INTRODUCTION

Sloping coastal structures such as seawalls, breakwaters, sea dikes,… are essential in coastal protection and harbour sheltering. Although many research has already been carried out, some aspects of their design still remain unsolved. Actually, crest level design is based on laboratory scale models solely. In the MAST II-project 'Full scale dynamic load monitoring of rubble mound breakwaters' (MAS2-CT92-0023) it was stated that wave run-up is underestimated by small scale experiments. Prototype measurements carried out in this project confirm this conclusion. As overtopping and spray are closely related to run-up, it is expected that prototype data analysis results from overtopping and spray measurements may deviate from laboratory experiment results.
The main objectives of the OPTICREST-project are

- to provide end users with improved design rules for the crest level of sloping coastal structures, based on full scale data and supported by model tests
- to verify and to calibrate scale models and to obtain better scale modelling techniques
- to calibrate numerical models with full scale data in order to improve the numerical schemes for the simulation of wave interaction with sloping coastal structures
- to upgrade, improve and optimise existing run-up monitoring devices and software

Major emphasis is put on the collection of prototype data on run-up, overtopping and spray.

PROTOTYPE MEASUREMENTS

Prototype measurements are carried out at two different sites. At the northern part of the west outer harbour of Zeebrugge (Belgium) a rubble mound breakwater (armour layer consisting of 25 ton grooved cubes) is fully instrumented. In Petten (the Netherlands) run-up data is collected on an impermeable smooth sea dike.

In Zeebrugge a measurement jetty has been constructed. Fig. 1 shows a cross section of the Zeebrugge breakwater. The wave climate in front of the structure is recorded by two wave rider buoys which are located at a distance of 150 m and 215 m from the breakwater slope.

Wave run-up is detected simultaneously by a spiderweb system and by run-up gauges. The spiderweb system consists of a set of vertically placed stepgauges between the measurement

jetty and the armour layer. Out of the spiderweb measurements, the run-up level can be calculated as the intersection point of the theoretical line representing the slope of the breakwater and the line defined by the instantaneous water level detected by the two most landward spiderwebs which are (partly) submerged.
The run-up gauges are mounted along the slope of the breakwater on top of the armour units. With these gauges run-up levels are detected straight forward.
The run-up gauges measure the run-up in a direct way and the spiderweb system in an indirect way through an algorithm. Nonetheless, both different run-up measurement techniques give comparable results.
A video camera, placed under the jetty and directed towards the breakwater, provides visual information on the run-up on the breakwater.

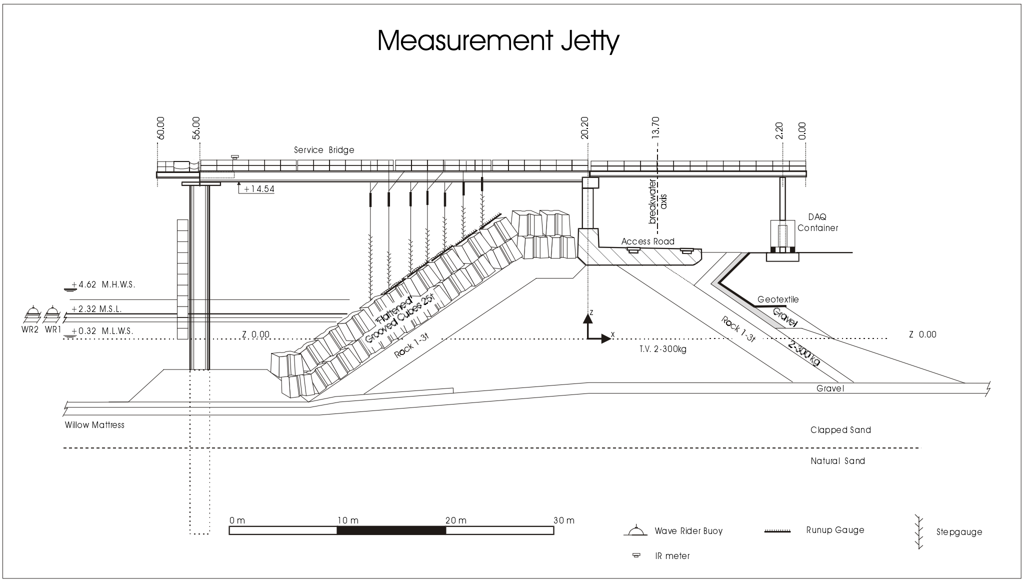

Fig. 1: Cross-section of the Zeebrugge breakwater and instrumented measurement jetty (situation April 2000)

The wave overtopping is measured by an overtopping tank constructed just behind the access road on the crest of the breakwater. This tank catches the overtopping water and a compound weir controls the outflow of the water. The overtopping discharges are calculated by making use of the calibration formula of the weir and by measuring the water height inside the tank, determined by two pressure sensors. Wave detectors placed on the crest allow to detect the number, the location and the extent of the overtopping waves.
When waves strike sea walls, the turbulent water produces large amounts of spray (i.e. little saltish water drops) which are transported inland by the strong coastal winds. Spray data is collected by means of six traditional rain gauges which are placed on a line parallel to the jetty in the extension of the overtopping tank. As wind is regarded to have an influence on the run-up, the effect of wind speed and wind direction is also studied through anemometer data.

The sea-dike in Petten is a smooth and impermeable slope, protected with basalt blocks and asphalt. Fig. 2 and fig. 3 show the cross section of the dike with the locations of the different measurement devices. Several wave rider buoys, pressure sensors and various types of gauges are installed to measure the wave climate in front and near the dike. Wind vanes and anemometers supply the wind data. Attention is paid to the morphology of the field site. The foreshore is characterised by a bar and a trough which have a big influence on the wave climate, partly due to the quick changes of the bottom profile. A run-up gauge mounted along the slope detects the run-up levels which can be checked by video recordings.

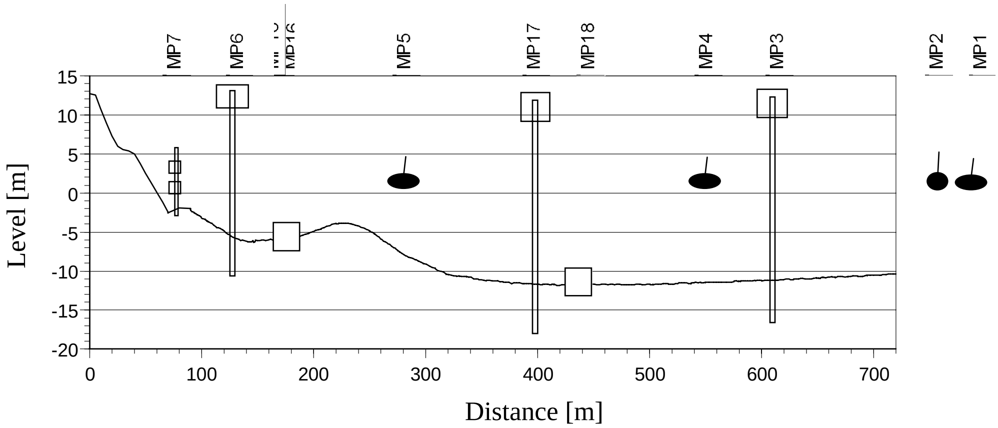

Fig. 2: Position of measuring locations in the surf zone. The wave buoys MP1 and MP2 are located at a distance of 8300 and 3500 m from the crest of the dike (x = 0)

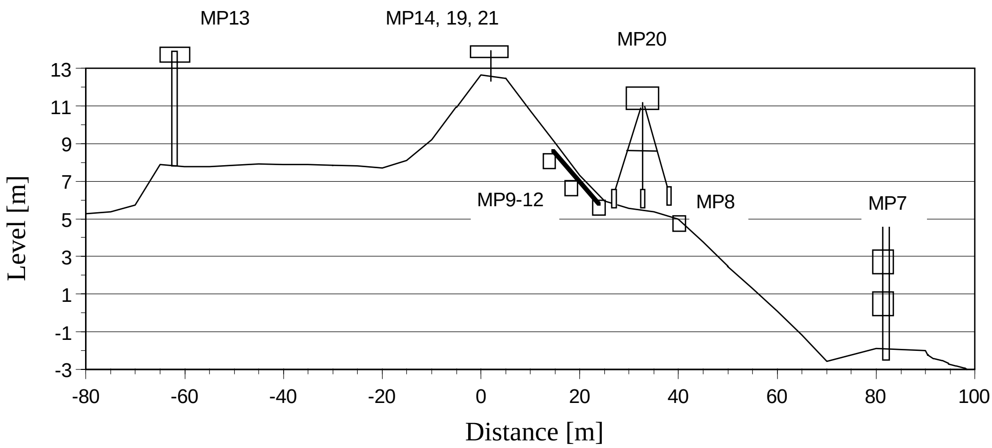

Fig. 3: Position of measuring locations in the run-up zone

LABORATORY MEASUREMENTS

In order to optimise the measurement equipment for run-up, several preliminary laboratory tests have been carried out on both rough and smooth slopes. Finally, a new digital step gauge has been developed (fig. 4). The end of each needle of the comb can be adjusted to the profile of the slope so the distance between the armour units and the gauge is less than 2 mm. In case of a traditional (analogue) run-up gauge the distance between the armour units and the gauge can mount to much higher values. First results show that higher run-up levels are detected with this digital step gauge than with a traditional run-up gauge.

Both the Zeebrugge and the Petten sites are accurately modelled and tested in 5 different laboratories. Model tests are carried out in 2D wave flumes (Flanders Hydraulics, Delft Hydraulics and Universidad Politecnica de Valencia) and in 3D wave tanks (Aalborg University and University College Cork) to cover a whole range of parametric tests and the reproduction of measured storms. The scale of the models varies between 1:30 and 1:40. In order to model the flow in the core of the breakwater properly a special scaling method has been chosen for scaling the core material (Burcharth et al. (1999)), resulting into coarser core material than the overall scale. The Zeebrugge model is also tested in a combined wave flume and wind tunnel to study the influence of wind on run-up, overtopping and spray.

Fig. 4: UG-step gauge

Failure of a seawall is often initiated by damage to the crest. When waves overtop the structure, the downrushing water may damage the landward slope of a dike. This can lead to the total failure of the structure.
Therefore the crest stability is studied in a wave flume. A series of model tests on wave overtopping and wave run-up is carried out to investigate wave overtopping rates, overtopping velocities and water layer thicknesses for different seaward (1:6, 1:4 and 1:3) and landward slopes. Tests are performed for regular and irregular waves, for different freeboards and water depths,… in order to test a wide range of parameters. The results of this investigation will help in a better assessment of the crest stability of overtopped structures.

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• DISCUSSION OF RESULTS

Analysis of the available Zeebrugge data reveals many points of interest. The dimensionless run-up value $\frac{Ru_{2\%}}{H_{mo}}$ seems to be dependent on the water level: $\frac{Ru_{2\%}}{H_{mo}}$ values increase when water depth decreases. Ru is defined as the difference between wave run-up level and mean water level. The run-up which is exceeded by 2 % of the run-up events is called $Ru_{2\%}$. H_{mo} is the significant wave height, based on spectral analysis. When time series of

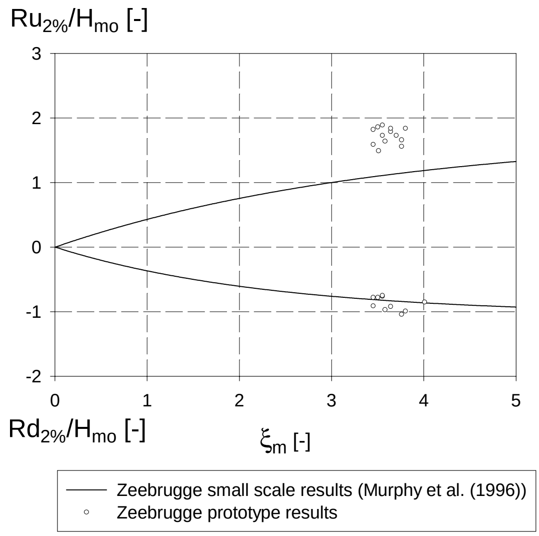

Fig. 5: Comparison between prototype and scale model wave run-up results

approximately 2 hours at high water are analysed, a mean dimensionless run-up value of 1.80 is obtained. This value is higher than the values obtained in the small scale model tests up till now. Actually (May 2000) further more detailed analysis of both prototype and scale model measurements is carried out. At mean tide $\frac{Ru_{2\%}}{H_{mo}}$ increases to 2.25. This phenomenon has to be checked in more detail as well. A run-down value $\frac{Rd_{2\%}}{H_{mo}} \cong 0.90$ is deduced from the prototype data. Fig. 5 shows the prototype results for 13 storms (during the period 1995 to 2000 with H_{mo} varying between 2.40 m and 3.10 m and $T_{0,1}$ varying between 5.8 s and 6.6 s) together with earlier small scale test results (Murphy et al. (1996) and Troch et al. (1996)). At present (May 2000), laboratory tests are still going on.

For the Pettemer sea dike a reasonably good agreement between the prototype data analysis results and the results from the laboratory experiments is found. A non-dimensional run-up of about 2 is obtained (fig. 6).

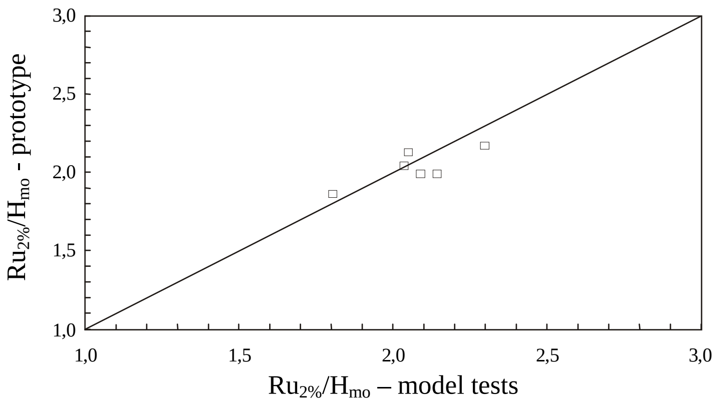

Fig. 6: Comparison between wave run-up measured in prototype and in model tests (van Gent (1999))

NUMERICAL MODELLING

Numerical models play a very important role in research and design of coastal structures. Therefore it is of paramount importance that these models are as accurate as possible. The one-dimensional (e.g. ODIFLOCS, FLOx) numerical models are used as practical tools, whereas the two-dimensional models (e.g. 2D-HYDROTUR, NASA-VOF2D, SKYLLA, VOFbreak²) are regarded as research tools that require improvements in order to enhance their practical value. In a first stage, an existing code is refined to treat arbitrary free surfaces and internal obstacles by improving the numerical methods. Secondly new modules with a more thoroughly calculation of particular physical phenomena are implemented.
Up till now, numerical models have only been calibrated against scale model test results. In this project, these are calibrated with the results of the prototype measurements. The numerical models are also considered as a complement to the laboratory and field measurements obtained in the OPTICREST-project, to provide clues for interpreting eventual discrepancies, as well as

alternative methods for the evaluation of critical quantities as wave run-up, overtopping velocities and volumes,…

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EUROPEAN SHORE PLATFORM DYNAMICS (ESPED):

MONITORING THE DOWNWEARING OF SHORE PLATFORMS

IN THE CONTEXT OF THE MANAGEMENT AND PROTECTION OF ROCKY COASTS

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SUMMARY

The ESPED project has three main objectives:

1) to monitor the evolution of shore platforms in the EU by
   - establishing rates of downwearing of the platforms in a wide range of coastal environments
   - studying changes in the surface morphology of the platforms
   - measuring the rate of sea cliff recession in order to relate it to the rate of platform lowering
2) to enhance understanding of the physical, chemical and biological processes that control platform evolution
3) to model the evolution of shore platforms over time in order to predict the effects of proposed engineering structures and possible changes in sea level.

INTRODUCTION

Inter-tidal shore platforms are a common feature of many European rocky shores. They are especially well developed in areas of cliffed coastline. The platforms help to protect the cliffs and also sea walls and other engineering structures by absorbing and reducing wave energy. Paradoxically, despite their importance in coastal defence and coastal management, shore platforms remain poorly studied and little is known about the erosive processes that both shape and destroy them. It is generally assumed that wide platforms are much more protective than narrow platforms, but platform gradient is probably also important. Models exist regarding the evolution of platforms over time but there has been little empirical research to test the validity of the models. Much research to date has been concerned not with the platforms but with determining the rates of cliff retreat and on the design of engineering structures to protect the base of rapidly eroding cliffs along the increasingly urbanised shorelines of Europe. However, cliff erosion and the life span of engineering structures are closely controlled by the evolution of the shore platforms. Coastal protection agencies and engineering contractors have historically often assumed that the platforms are relatively stable and unchanging, but this is frequently not the case.

The ESPED project, which started in 1998 and is due to end in 2001, brings together a multidisciplinary team from five EU nations to further understanding of the processes and rates of change on shore platforms around the coasts of Europe (see Foote *et al*., 2000). These platforms exist in very different climate, tide and wave environments, and have a varied history with respect to the rise and fall of land and sea levels both in the past and at the present day.

The erosion dynamics comprise three fairly distinct components broadly defined as the physical loss of rock mass through wave action and mechanical weathering, the chemical losses due to solution and other processes and biological losses associated with the action of the invertebrates that live and graze on the platforms. Together they lower the platform surface and a major objective of the ESPED project is to identify the relative importance of these different components and how their contributions to downwearing of the platform may vary under differing environmental conditions. The project is also concerned to measure and compare current rates of platform downwearing in different parts of Europe.

CHOICE OF MONITORING SITES

ESPED has established a series of monitoring sites representative of the contrasting coastal environments of Europe. These sites are located on (i) the high wave energy, meso-tidal Channel and Atlantic coasts of southern Britain, northern and western France and Portugal with their warm to cool seas of average salinity, (ii) the low energy, micro-tidal Baltic coast of Sweden with its cool to cold sea of low salinity and (iii) the low energy micro-tidal Mediterranean coast of mainland Spain and the Balearic Islands with their warm sea of above average salinity. At all sites two representative transects have been established along which sampling is concentrated.

In the Mediterranean, nine monitoring sites have been established on Mallorca on limestones and dolomites in the Serra de Tramuntana, Serres de Llevant and the Marina areas. A further site has been set up on the granite coast of Catalana. On the Portuguese coast three sites have been located: Ribeira d'Ilhas (40km northwest of Lisboa), Praia des Avencas (20km west of Lisboa), and Praia de Monte Clérigo (about 250km south of Lisboa). The hardest lithologies at these field sites correspond to wackes and marly limestones, whilst softer lithologies include soft marls, shales, and slates. Four field sites have been selected in France: Grandes Dalles and Eletot (Pays de Caux, Normandie) on chalk platforms, Plage de Sable Menu, (Presqu'ile du Croisic, Loire-Atlantique), and Port-Lin (Baie de la Nicouse, Presqu'ile du Croisic, Loire-Atlantique) on leucogranite platforms. The UK has four monitoring sites: three on the Sussex chalk coast at Peacehaven (an unprotected site and also a site protected by sea defences), Cuckmere Haven, and Birling Gap, and a fourth at St. Donat's (Glamorgan, South Wales) on Lias limestone (see Foote *et al*., 2000). In Sweden four monitoring sites have been established at Ramsvikslandet and Hovs Hallar on the west coast, and Fårö and Höga Kusten to the east. The Swedish field sites are comprised of a different rock types including granite, gneiss, limestone, and dolerite. Furthermore, the different sites experience a range of rates of isostatic uplift following the last glaciation.

GEOTECHNICAL INVESTIGATIONS

The project is concerned to measure rock geotechnical properties that are likely to exercise some control on platform development at the field sites. Schmidt hammer testing is being used in the field, together with surveys of joint spacing and direction. Laboratory tests include porosity and permeability determinations, point load and compressive tests. Due examination is also being given to the physical and chemical weathering processes active on the platforms, how they interact and combine, and are influenced by the geotechnical properties of the rocks at the different sites. In addition, a study is being made of the erosive processes active on the platforms, particularly abrasion, their relationship to the geotechnical properties of the rocks, and their effects on rates and types of sediment production and platform development. Abrasion mills are being used to simulate the action of the sea. In addition, small rock samples (tablets) are being attached to the platforms so that their weight loss can be monitored (Moses, 2000).

PLATFORM MORPHOLOGY

Another objective of ESPED is to investigate the varying morphology of the shore platforms at the study sites and relate it to the geotechnical properties of the rocks and sea conditions (fetch, tidal range etc.). Tacheometric surveys are being made of the platform surfaces and profiles. The intention is to construct a generalised morphometric map of each site showing the macro surface relief as well as to prepare detailed maps of selected individual micro-relief features, such as runnels and rock pools. The survey data will also be used to determine the width and gradient of the platforms, and to identify breaks of slope. The structure of the runnel systems will be analysed using network analysis. Calculations will be made of drainage densities, stream frequencies and other morphometric variables.

CLIFF RETREAT MEASUREMENTS

A further objective of ESPED is to investigate the rates and manner of retreat of the sea cliffs on the landward side of the shore platforms at the monitoring sites. By combining historic and contemporary data it will be possible to reach broad conclusions concerning the relationship between rates of cliff retreat and the rates of downwearing of the platforms. Existing maps and aerial photographs have been analysed, also historic photographs and other archival material. Different dates and scales of mapping in different EU countries has made cross-comparisons of historical rates of retreat somewhat difficult, nevertheless the ESPED team has already achieved a useful degree of transnational data harmonisation. At sites where the cliff faces are retreating at the most only very slowly, time sequence photography is being used to determine what changes, if any, are occurring. Standardised information is being collected on cliff profiles, cliff erosion processes, and the contribution of cliff retreat to sediment inputs to the marine environment.

BIOLOGICAL PROCESSES

ESPED recognises that bioerosion is an important element in platform evolution. The project aims to investigate the role of plants and animals in shore platform downwearing through a combination of field observations and laboratory experimentation. A preliminary study has been completed of the range and character of bioerosion mechanisms active on the shore platforms at each site. Seasonal changes in seaweed cover are being monitored to determine their role in shore platform development and sediment accumulation. Also being studied are seasonal changes in the populations of animals that contribute to rock destruction by boring and/or grazing. The ultimate objective is to assess the mass loss of platform material by biological organisms and to investigate how the rates of loss relate to the geotechnical properties of the rocks, and the rates of physical and chemical weathering. Special attention is being given to the analysis of faecal pellets of limpets and other organisms in order to estimate their contribution to platform downwearing.

MEASURING PLATFORM DOWNWEARING

ESPED is making innovative use of a new laser scanner which was originally developed at the University of Karlstad for field monitoring of the decay of rock art exposed to the weather (Swantesson, 1994; Williams, Swantesson and Robinson, 2000). This equipment has been specially adapted for use on the shore platforms, particular attention being paid to portability and speed of data acquisition. Computer software for the scanner has been further developed. Field trials of the new scanner have been successfully completed and it is now being used (together with two suitably modified and updated earlier versions of the scanner) to make detailed maps of small areas of the platform surface, enabling variations in microrelief (surface roughness and micromorphology) to be measured. By overlaying maps taken at regular intervals rates of change over time can be mapped. Information obtained by scanning is being combined with measurements taken with mechanical micro-erosion meters and detailed topographic surveying to determine current rates of platform downwearing. Tests will be carried out to compare the performance of the laser scanner with other available methods of measuring downwearing, including the micro-erosion meters and photogrammetry.

PROGRESS TO DATE

The ESPED project has run for only 18 months, and the data so far collected have been mostly of a baseline nature. However, much useful information has been gathered on geotechnical matters, platform morphology, cliff retreat and biological processes. Moreover, the successful deployment of the new scanner means that work can now progress rapidly on measuring platform downwearing. Micro-erosion meter measurements were made at all monitoring sites in 1999 and are due to be repeated this year (2000). Laser scans were completed at all sites in 1999, except those in France, which will be scanned for the first time this year.

Oil spilt from the Malta-registered tanker, *Erika*, which sank on 12 December 1999, washed ashore along the Brittany coast, destroying most of the littoral flora and fauna at the Le Croisic monitoring sites. Biological inventories were completed before the spillage, and will be repeated at intervals over the lifetime of the ESPED project (when it is safe to return to the site) to monitor rates of recolonisation by seaweeds and invertebrates.

The preliminary data suggest that there are wide variations in Europe in rates of platform downwearing. The French ESPED team has measured up to 2 mm of erosion in 6 months on the chalk shore platforms in Normandy, whilst on the other side of the Channel (La Manche) the UK team has measured up to 50 mm of erosion in 6 months within a boulder zone at the top of a chalk shore platform at Peacehaven. By contrast, at some measuring stations, no erosion has as yet been detected.

Construction of seawalls at the head of shore platforms can apparently greatly increase rates of erosion leading to the potential de-stabilisation of the seawalls. At Peacehaven a site on a chalk platform directly in front of a sea wall has recorded 33 mm of downwearing in 6 months.

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Volume 2

Marine Technology

III.1.1. Non-disturbing techniques

TITLE : AUTOMATED IDENTIFICATION AND CHARACTERISATION OF MARINE MICROBIAL POPULATIONS.

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AUTOMATIC IDENTIFICATION AND CHARACTERISATION OF MICROBIAL POPULATIONS (AIMS)

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INTRODUCTION

The population dynamics of microplanktonic communities is important to many aspects of marine science including the yield of fisheries, the impact of pollution on coastal waters and the role of the ocean in climate change. Marine microbial communities are taxonomically and functionally diverse, comprising phyto-, bacterio- and zooplankton. Moreover, the taxonomic composition and abundance of marine plankton is extremely variable over a wide range of space and time scales. Increasing our understanding of the interactions between different biological and physical processes in the marine plankton requires that we develop the ability to sample and analyse the physical, chemical and biological properties of marine waters on appropriate time and space scales.

The AIMS (Automatic Identification and characterisation of Microbial populationS) project is developing and integrating technology for identification of microbial cell populations and the determination of their cellular characteristics using analytical flow cytometry. This involves applying neural network approaches and molecular probes to the identification of cell populations, and deriving and verifying algorithms for assessing the chemical, optical and morphometric properties of these populations. The products of AIMS will be calibrated data, protocols, algorithms and software designed to turn flow cytometric observations into a data matrix of the abundance and cellular characteristics of identifiable populations. The main objectives of the AIMS project are to (i) provide software to automate identification and characterisation, including artificial neural nets, (ii) provide new data on the inherent physical and chemical properties of marine microbes and develop algorithms to compute inherent optical properties of individual cells and (iii) develop molecular markers for identification and characterisation of marine plankton. This paper describes the general approach and preliminary results of the AIMS project.

APPROACH

Analytical flow cytometry (AFC) permits the precise, rapid, repetitive description of the population structure of phytoplankton, bacterioplankton and microzooplankton. AFC obviates many of the problems associated with microscopy and other analytical methods, offering considerable potential for the rapid, accurate and precise analysis of phytoplankton and bacterial populations (Jonker et al., 1995). However, exploiting flow cytometry for examining marine microbial processes is still limited by data analysis techniques.

Most of the currently available AFC software provides single parameter histogram distributions and dual parameter scatter plots. However, the optical data can contain 5-11 measurements that could be used for discrimination. The vast quantities of multivariate data generated by flow cytometers provide a considerable challenge for data analysis. Utilising the multi-parameter data requires multi-variate data analysis techniques. Whereas multivariate statistical approaches can be very successful if the appropriate technique can be found (Carr et al. 1996), this is often not simple, and invalid assumptions about distributions can cause major problems. Artificial neural networks (ANNs) on the other hand, do not require a-priori knowledge of underlying distributions. Once trained they can make identifications in near real-time and have been shown to have considerable potential for identifying phytoplankton from AFC data (Boddy et al., 1994; Wilkins et al. 1996).

Species identification is not always possible based on light scatter and fluorescence characteristics, due either to similarities in the optical characteristics amongst species or to certain species having a wide range of optical characteristics, such as with clumped cells or chains. One possible solution to these problems is to develop species-specific oligonucleotide probes that hybridise only to their target species regardless of their morphology or life cycle stage. Flow cytometry or epifluorescence microscopy can detect a fluorescent label attached to these probes and the probe-conferred fluorescence identifies the target, thus verifying species identification. Fluorescent rRNA probes can discriminate amongst components of the plankton which do not contain autofluorescent pigments including bacteria (Amann et al., 1995) and protozoa (Rice et al. 1997). Developing probes for species or wider taxonomic groups is of fundamental importance in providing comprehensive descriptions of microbial communities and for assessing biodiversity at various taxonomic levels.

The measurements of light scatter and fluorescence taken by the flow cytometer characterise the cells and can therefore be used to calculate optical and chemical properties. The time of flight of a particle/cell through the measurement beam is related to a length scale of the particle, and the amounts of forward and side scattering of light by individual cells is related to shape of the cell in suspension. The red chlorophyll fluorescence is related to cell chlorophyll content (Jonker et al., 1995).

ARTIFICIAL NEURAL NETWORKS (ANNS)

Identification of microbial populations from flow cytometric observables is done using Radial Basis Function (RBF) ANNs. RBF ANNs can be trained relatively rapidly, and can discriminate unknown taxa from those taxa upon which a network has been trained. Detailed description of RBF ANNs is provided by Haykin (1994). The identification success of RFB ANNs is at least as good as other ANN paradigms and non-neural classifiers (Wilkins et al. 1996). Briefly, RBF networks have three layers of nodes. Flow cytometric data are input initially to the first layer, which serves merely to distribute these data to the hidden layer nodes (HLNs). The HLNs each represent a non-linear Gaussian basis function or kernel, the output value of which depends on the distance between the input data pattern and its centre. Several HLNs represent the data distributions for each species, and it is essential that there are sufficient HLNs to adequately fill the data input space. The outputs from the HLNs are passed to the output layer, which contains one node for each phytoplankton species. The output node with the highest value indicates the predicted identity of the input data.

ANNs learn from examples. To train an ANN, many patterns of flow cytometric characteristics are drawn at random from the data files for each of the target species and presented to the network together with the identity. The success of network training depends on the number of HLNs and a variety of other network parameters. These must be optimised by experimentally altering each of these factors in turn. The duration of training can be anything from a few minutes to half an hour or more, dependent on computer hardware, the number of species and complexity of the data. Once trained, the network must be tested using an independent data set drawn from the data files, and the identification performance evaluated by comparing the predicted identity of test patterns with their known identity. Misidentification results from overlap of character distributions, and can only be resolved by obtaining more and/or different characters. Within AIMS, data analysis approaches have been initially developed to recognise target organisms using data of known origin, mono-specific phytoplankton cultures.

Verifying the results of the networks is an area currently under development. One way to verify the identity of species predicted by an ANN is to transform the results into co-ordinates that can be used to produce sort decision boundaries on the flow cytometer. Cells can then be sorted from the sample by the flow cytometer and viewed by microscopy. This approach was tested as part of an experimental workshop of the AIMS project. Simple mixtures containing five species of cultured phytoplankton were analysed on the Becton Dickinson$_{TM}$ FACSort$_{TM}$ flow cytometer and identified by a trained RBF network. The clusters identified by the network as were highlighted in scatter plots within the *CytoWave* flow cytometry acquisition and analysis software package and gates were drawn round the highlighted regions. These co-ordinates were then transferred to the FACSort$_{TM}$ and were used as sort decision boundaries, one for each species. The sorted material was examined using microscopy and was identified as the target species, thus showing that sorting can be performed in conjunction with artificial neural nets.

There are several difficulties in extending the ANN methodology from laboratory mono-specific cultures to heterogeneous populations in the sea. Firstly, the number of classes in any natural seawater sample is unknown (i.e., the problem is unbounded). In addition, there may be taxa in the sample that have not been encountered by the network before. It is, therefore, essential to recognize these new taxa upon and to label them as unknowns. Encountering unknowns is common to biology but not to other areas of technology, and has not been extensively investigated. RBF ANNs can deal with unknowns by applying constraints to outputs of HLNs or to output layer nodes (Morris and Boddy, 1996). To validate and determine the such applications within the AIMS project, mixed cultures and natural samples will be used. Unknowns that have been found in a sample need to be identified. This can be done by microscopic or molecular analysis of sorted samples. Once identified, the new taxa need to be added to the network. To add new species to a network usually requires retraining of the network from scratch, which is time consuming and prone to error for those not specialised in the use of ANNs. A possible solution is to provide a library of networks, each of which discriminates a single taxon from all others (Morris and Boddy, 1998). Numerous individual networks will be implemented during the project and the facility to train a net for a new taxon will be made available. Appropriate single species networks can then be combined to provide identifications. Identification of taxa may, however, be less important than identification and quantification of functional groups of organisms, and this may be achieved by combining together appropriate groups of species.

Finally, obtaining truly representative training data is a major problem. Such data must cover the complete spectrum of biological variability within a species encountered in a natural environment. Data obtained from laboratory cultures do not accurately reflect characters of the same species in the field, because environmental conditions may dramatically affect cell characteristics measured by AFC. Ideally ANNs should be trained on data obtained from appropriate field samples. This will be achieved by identifying clusters of similar cells from AFC data (using unsupervised ANNs or statistical clustering methods), sorting these (as described above) and identifying the cells microscopically.

MOLECULAR PROBES OF TAXONOMIC AFFILIATION

Ribosomal RNA (rRNA) genes are ideal for the development of taxon-specific molecular probes. They contain regions of sequence diversity (variable regions) and regions of sequence similarity (evolutionarily conserved regions). The conserved regions can be used to design primers for amplification of rRNA sequences using the polymerase chain reaction (PCR). Other regions, with different degrees of conservation, can be used to construct family-, genus- and species-specific oligonucleotide probes. The high number of rRNA molecules per cell (up to 10^5) provides a large target that enables single cell analysis to be consistently achieved. Ribosomal RNA genes (18S rRNA in eukaryotes, 16S rRNA in prokaryotes) are used in the reconstruction of evolutionary relationships among species. As a consequence, a large number of sequences are available in public databases that can be used to develop taxon-specific probes.

Within the AIMS project, probes for the verification of phytoplankton taxa are being developed according to the following criteria: (a) relevance for European waters, (b) availability in culture collections for probe testing, (c) distribution of species over taxonomic groups and (d) different sizes and shapes of cells. These criteria make it possible not only to develop probes and general methodology required for the purpose of AIMS, but also to compare their usefulness over a broad taxonomic base, with an emphasis on phytoplankton species that are important for European waters. The probes range from higher group level down to the species level. The approach to probe design and evaluation is described in Jonker et al. (2000). Approximately one third of all probes used in the AIMS project have been successfully tested with *in situ* hybridisation and flow cytometry (e.g., Simon *et al*., 2000). These are mainly the ones that are specific for classes and higher groups of phytoplankton.

The development and application of specific rRNA probes offers great potential for the analysis of phytoplankton. As with all new methods, a number of questions remain, such as how these probes will perform in field tests. These questions will be addressed within the AIMS project, using experiments in mesocosms and research cruises. Also, new species must be tested with existing probes to confirm that probe specificity is maintained. The use of rRNA probes is a valuable tool for the identification and characterisation of phytoplankton populations either in combination with flow cytometry or with fluorescence microscopy. With this tool it is, for example, possible to monitor harmful algal blooms and to characterise species that cannot be cultured.

CHEMICAL, OPTICAL AND MORPHOMETRIC PROPERTIES

The light scattering and absorption properties of a microbe are directly related to the size, shape and refractive index of the cell (Morel, 1991). The refractive index of the cell is determined by its chemical composition (Barer and Joseph, 1954). There are two components of the refractive index of a cell; the real part and the imaginary parts. The real part of the refractive index, which is important to cellular light scattering, is related to the intracellular organic carbon concentration. In phytoplankton, the imaginary part of the refractive index, which is important to light absorption, is related to the intracellular pigment concentration. Simultaneous measurements of biomass, pigment content, light absorption, light scattering and cell size have been compiled from measurements on laboratory cultures in conjunction with determination of flow cytometric properties. This database is being used to estimate the real and imaginary parts of the refractive index of phytoplankton cells (following Stramski 1988) and to develop algorithms for estimating pigment and carbon contents of microbial cells from flow cytometric measurements.

INTEGRATING IDENTIFICATION AND CHARACTERISATION OF CELLS: THE AIMS SOFTWARE AND DATABASE

The main end product of the AIMS project will be an integrated package combining flow cytometry acquisition and visualisation software (*CytoWave*), artificial neural network software (*AIMSNet*), and algorithms to convert raw flow cytometric data into inherent properties of cells, such as, cell size, volume, pigment content and refractive index (*CellStat*). Supporting these products will be a database (*AIMSBase*) of biomass, pigment content, light absorption, light scattering and cell size compiled from laboratory cultures, a mesocosm experiment and a sea-going research cruise. Infomation on these products can be contained from the project website (www.flowcytometry.org).

A number of different analytical flow cytometers are being used within this project because differences in optical geometry can lead to wide variations in scattering signals and because the final software will be designed for use with multiple flow cytometer configurations. Measurements have been made using general purpose (Becton Dickinson™ FACScan™ and FACSort™, Coulter XL™) and specialised (CytoBuoy™, Dubelaar *et al*, 1999) flow cytometers.

The data acquisition and visualisation software includes integrated artificial neural networks for data analysis. This integration should permit near real-time ANN analysis of flow cytometric data. The results of an ANN analysis can be displayed graphically by means of standard representations of the data such as dot plots and histograms, as well as in tabular form, listing taxa present with an estimate of their abundance. The software allows trained ANNs to be generated for different combinations of species or subpopulations. The use of combinations of networks is also foreseen, allowing the rapid construction of networks to accommodate novel combinations of species by combining ANNs drawn from a library of existing pre-trained networks, each specialised to a particular group of species or set of environmental conditions.

In conclusion, progress in the application of ANNs, combined with the discrimination power of rRNA probes and the estimation of inherent properties of cells will greatly improve the application of flow cytometry for the automated analysis of phytoplankton in field samples and the use of flow cytometry for monitoring purposes.

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TITLE: SEDIMENT IDENTIFICATION FOR GEOTECHNICS BY MARINE ACOUSTICS

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SEDIMENT IDENTIFICATION FOR GEOTECHNICS BY MARINE ACOUSTICS

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INTRODUCTION

The main goal of the SIGMA project is to investigate the relations between the acoustical parameters of marine sediments (reflection factor, sound velocity, attenuation, dispersion etc.) and their geophysical and geotechnical properties (sediment type, grain size distribution, cohesion, gas content, etc.).

The acoustic parameters of the sediments will be estimated from wide frequency band measurements, which yield from the use of a steerable parametric array combined to a towed array of receivers. Such a source will allow to generate narrow spot measurements on the sediments and to estimate with high accuracy their acoustical properties.

The aim will be achieved by means of a multidisciplinary approach:

- acoustic modelling
- development of inverse procedures
- calibration
- generation of optimal test signals
- system identification
- validation by tank experiments
- development of specific instruments
- sea trials
- sea data processing and archiving.

DESCRIPTION OF THE OBJECTIVES

The overall objective of the SIGMA project is to enable the determination of the characteristics (i.e. fine scale structure and sediment properties) of the sea bed using remote sensing technologies based on the reflection of acoustic pulses. The objectives to achieve this goal are:

1. To treat the marine environment as a complex system to be identified. A MIMO (Multiple Input Multiple Output) SI (System Identification) scheme will be proposed to determine the sea bed characteristics.
2. To stimulate the marine system active acoustic sources will be used. High power acoustic signals (Multiple Inputs) will be generated using a steerable parametric array and a vertical parametric array, mounted in a tow fish. This will enable to transmit relatively high power acoustic signals into a spot on the sea bed, under a defined angle.
3. To observe the response of the marine system the scattered and reflected acoustic signals from the sea bed and from sub-bottom layers will be detected by means of a towed

hydrophone array (Multiple Outputs). To compensate for the motion of the tow fish (acoustic transmitter) a real time electronically stabilised system will be developed, while for the compensation of the movement of the towed array a special purpose acoustic device will be developed as well.

4. Theoretical and numerical accurate acoustic wave propagation models as well as inverse procedures will be investigated. The models and procedures will be generalised to include realistic cases like oblique interfaces, hybrid velocity profiles (continuously layered and stepped variations), inhomogeneities and inclusions. Direct inversion computational methods and parameter estimators, such as an MLE (Maximum Likelihood Estimator), will be developed and analysed taking into account instrumental factors, such as noise and the transmitter and receiver characteristics, which will be obtained by extensive calibration measurement procedures.
5. The theoretical models and inverse procedures will be validated based on the design of measurement procedures adapted to the wave propagation models. The validation will first be performed based on tank experiments (laboratory scale), before being applied to data from sea experiments (real-life). Ground truth will be obtained using conventional equipment and improved geophysical and geotechnical instruments like high resolution seismics and a geotechnical module.
6. Data analysis will be performed in order to investigate, in detail, the functional relations between the estimated acoustical parameters and sedimentological parameters obtained by ground truth in the sea experiments or from tank experiments, where the simulated sea bed can be made composed of calibrated sediments.

The data obtained, during the sea experiments, will be compiled in a GIS (Geographical Information System). The surveys, conducted in selected representative test areas, will, therefore, lead to the constitution of a well controlled data base on bottom characteristics. This data base will be available on a CD-ROM and the small test areas may be used as benchmark for future instrument calibration.

PROJECT METHODOLOGY

In this project, the estimation problem is formulated in the framework of system identification. The noise on input as well as output data will be taken into account, since, beside direct inversion schemes, a Maximum Likelihood approach will be used. This approach allows also the incorporation of the calibration procedure, which is a necessary step, but which has been omitted in various previous studies, as well as the model validation, since model errors can be detected and corrected easily as well.

A key issue of this project requires the use of a parametric array. Although the principles of operation of this type of sonar have been known for many years, the implementation of a system for sea surveys during rough surface conditions, for example sea-state 5-6. In particular, automatic beam stabilisation remains an important problem that will be addressed in detail in this project, so that the array can be programmed to transmit vertically downwards, through a repeated range of angles or at some preferential angle irrespective of the towed fish pitch.

In this project, it is aimed to demonstrate that the identification of sediment parameters can be performed using underwater acoustics, because the identification of sediment parameters fits into a global system identification approach. First acoustic parameters are estimated using robust estimators and then, using tank experiments and extensive ground truthing, functional relations between sedimentological and acoustic are inferred.

The way to sense the marine environment acoustically in the project, has advantages over the classical echo sounding procedures, where the angle of incidence during sea trials remains difficult to control. Therefore, two arrays are foreseen. A vertical down looking one (monostatic) and a second one (bistatic), which allows enhanced control of the zone to be insonified during the trials. It is envisaged that the second one will act like a looking glass, which can be moved over the sea bed, whereas the first one is used to deliver raw data representing the sea bed condition, such as the bathymetry and estimates of the sedimentation layers (rough measurements of the number of layers, thickness, etc.). This is used as a priori information in the system identification tasks to ensure fast convergence and minimisation of the modelling errors.

RESULTS OBTAINED

At this stage of project, some obvious results are already obtained from the partners involved in the SIGMA project, e.g.:

1. *Equipment development:*

   - *Development of a steerable parametric array* (Loughborough University group): A system has been designed and manufactured to include a facility allowing longer pulses of any reasonable type to be projected into the water. New software has been developed to allow dynamic stability of the beam and to allow received backscatter data to be captured and to be fully integrated into the GIS system. The system, together with the new software, was available for the first sea trials and improved for the second and third sea trials. Further development has continued on a new commercially viable replacement for the present transmission array to allow full two-axis steering of the beam. The system has been tested with dynamic stability and the preliminary analyses of the effects of this system have shown positive results.
   - *Development of a vertical parametric array* (Technical university of Denmark): The vertically-looking parametric acoustic array has been designed and developed, and an estimation of its operational capabilities has been worked out. It comprises four elements (Channel Industries PZT type 5800), each having a transmitting surface area of 15 x 15 cm2 and operating at a fundamental primary frequency of nearly 60 kHz, thus permitting a difference frequency in the region of 3-6 kHz.
   - *Development of a hydrophone streamer and positioning* (CPE - Lyon: Laboratoire d'Acoustique Systèmes, Signaux et Sonar): A hydrophone streamer and the positining system have been designed and manufactured at the beginning of the project in order to collect sea bottom echoes from the steerable parametric array (SPA).
   - *Improvement of a high resolution seismic system* (GEODIA): A high resolution seismic spread has been operated during the second sea trial. P-wave acquisition with a penetration of 5 meters below seabed along lines where sampling has been performed during the second sea trial. Results will be the definition of the P-wave velocity profile over the top 5 meters of the seabed, which matches the estimated penetration of the acoustic methods operated in the frame of SIGMA by LU and TUD.

2. *Modelling and tank experiments:*

- *Oblique and rough interfaces* (FORTH: Foundation for Research and Technology): An algorithm for the calculation of the reflection coefficient in cases of oblique interfaces between fluid, fluid-elastic, and elastic material has been developed in collaboration between TUD and FORTH. Also, formulae for the effective reflection coefficient for rough interfaces have been developed by TUD and FORTH for both fluid/fluid and fluid/elastic interfaces. Finally, models for saturated sediments, which take into account losses due to absorption and dispersion along the sediment, were applied and validated by VUB on reflection measurements in a container filled with sediment in normal and oblique incidence.

- *Continuous and hybrid gradient* (CPE-Lyon): The algorithms developed for treating the problem of studying the reflection from bottoms characterised by continuous and hybrid gradients have been successfully tested by tank experiments.
- *Inhomogeneous Layers* (CNRS/LMA): Several scaled models were designed to simulate homogeneous as well as inhomogeneous sea bottoms.
- *Inversion schemes development* (FORTH): An inversion technique based on system identification was also developed in the VUB. The Single Input, Single Output scheme MLE is extended to a Multiple Input, Multiple Output identification scheme. Furthermore, The development of the inversion codes for all possible cases to be encountered in the actual sea trials has been terminated. The codes correspond to the following cases :

  1. Single layer homogeneous fluid bottom
  2. Single layer homogeneous elastic bottom
  3. Bottoms consisting of two elastic or purely fluid layers with constant compressional and shear velocities.
  4. Bottoms consisting of two elastic or purely fluid layers. The layer in contact with the water column is characterised by linearly varying compressional and shear velocities.
  5. Bottoms consisting of two elastic or purely fluid layers. Compressional and shear velocities are considered constant in each layer. The interface between the first sediment layer is plane but not parallel to the water-bottom interface.

  The ones to be applied with the data of the sea experiment will be chosen on the basis of the actual geometrical characteristics of the environment, incorporating existing information on the bottom structure.

- *Tank experiments and algorithms validation* (FORTH): Experimental data obtained at CPE-LASSO, LMA and VUB have been used for the validation of the inversion algorithms. Problems encountered and dealing with the quality of the data have been solved.

3. *First Sea trial* (VUB, GEODIA): During the month of November 98, three main tests were performed in the site of Samdi, near Cherbourg (France). These experiments included: seismic, passive with streamers and active tests. Information from these sea trial tests was processed and made available on the SIGMA GIS data base.
4. *Second Sea trial* (VUB, GEODIA): A second extensive sea-trial has taken place in June 99, in which beside acoustics and seismics, also samples were taken from the seafloor for sedimentological studies. Information from these sea trial tests was processed and made available on the SIGMA GIS data base.
5. *Third Sea trial* (VUB, GEODIA): A third sea trial has taken place in April 2000. Information from these sea trial tests is under processing and will be made available on the SIGMA GIS data base.

6. *Data processing and inversion* (LU, GEODIA)*:*

    - A new PC-based transmission card is being manufactured to allow longer pulse lengths and pulse compression to be implemented and more pre-set signals for the dynamic stability system.
    - A first set of algorithms aimed at estimating the arrival time of the signals has been gathered in a routine called FIBAK. Five modes for computation are available, each of them having several parameters to be adjusted to the data. It has been tested until may 98 on different sets of data available by RACAL GEODIA.

7. *Functional relationships between the acoustic and sediment* (VUB): The results of analyse of the Kullenberg gravitational corer and the Reineck box corer are now available. We will be able to investigate the functional relations between the acoustical and physical parameters, when the acoustical parameters will be retrieved. This will allow us to validate the theoretical assumptions. Reflection and transmission tank experiments on prepared sediment samples with different characteristics were done by the VUB. Different wave propagation models (e.g. CQ visco-elastic, rational form model, Biot-model, Gassman model) were validated. Measurement of permeability, porosity and tortuosity were done by CNRS-LMA Marseille. Theoretical assumptions are validated.

8. *Designing and development of a G.I.S.*(VUB): A structured SIGMA GIS has been designed and developed to store pertinent information related to sediment identification for geotechnics by marine acoustics. Presently, it contains navigational data, backscatter and sedimentological data from the three SIGMA cruises, also bathymetric maps and some historical data of the selected sites for the project.

The following figures show some examples of SIGMA GIS map layers:

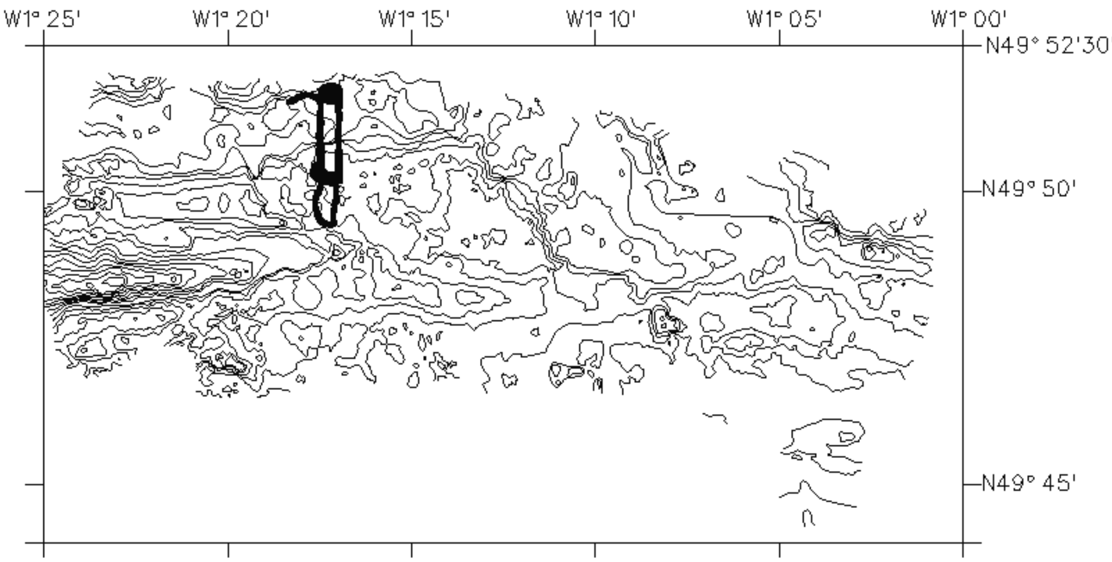

Fig.1: SIGMA project (EC-MAS3-CT97-0100): First measurement day: Vessel Track ('Belgica st9826a) (bold point), November 98: the data was loaded automatically in the SIGMA GIS database using the Intergraph MGE ASCII Loader tools.

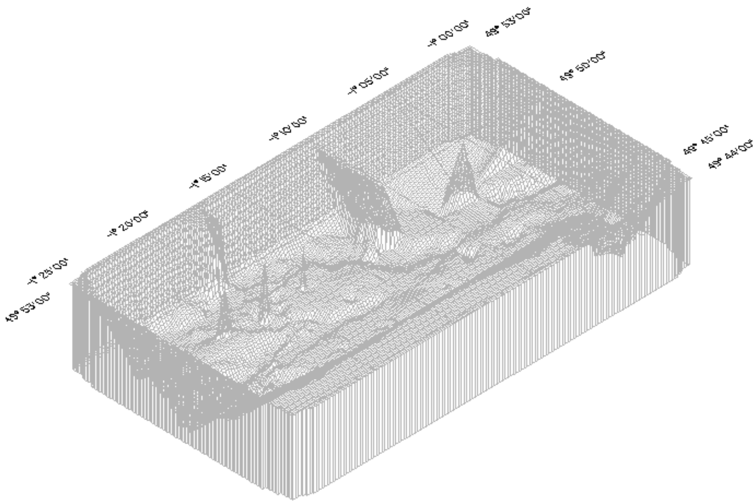

Fig.2: SIGMA project (EC-MAS3-CT97-0100): a 3D map showing isometric view of the seafloor (Samdi zone) (Sigma 1st sea trial st9826a) generated using TIN model.

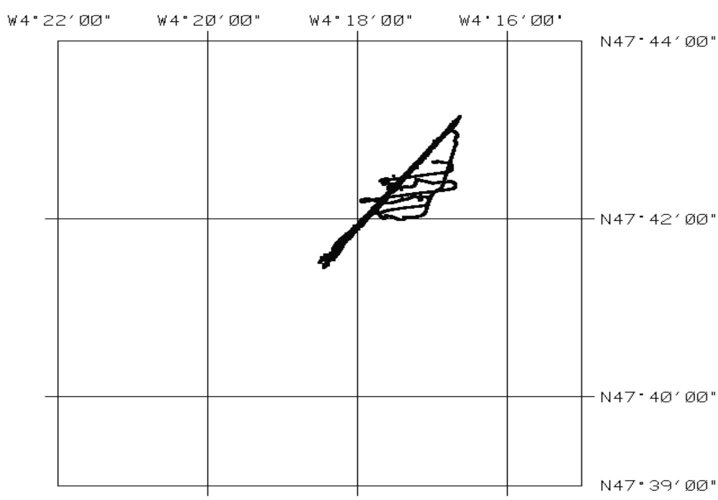

Fig.3: SIGMA project (EC-MAS3-CT97-0100): 4th measurement day: Vessel Track ('Belgica st9914a) (bold point), June 99: the data was loaded automatically in the SIGMA GIS database using the Intergraph MGE ASCII Loader tools.

TITLE: TRANSMISSION OF ELECTROMAGNETIC WAVES THROUGH SEA WATER FOR IMAGING, PARAMETER MEASURING AND COMMUNICATIONS: **DEBYE**

CONTRACT N^{o}: **MAS 3 – CT97 – 0105**

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OBJECTIVES

Overview

The nature of the ocean environment and its vast size has necessitated the development of sophisticated equipment and techniques. To facilitate scientific exploration a wide variety of systems and vehicles have been developed to operate either within the shallow continental shelf region or in deep oceans. For successful operation knowledge is required of the electromagnetic transmission properties of water over all distances both short and long. This information is required for such activities as:-

- Sensor Systems
- Imaging
- Position Fixing
- Measurement of Speed
- Obstacle Detection
- Guidance
- Communication of Data/Voice
- Remote Control

Where optical systems fail because of suspended matter, and acoustic systems because of high ambient noise levels, methods using electric and magnetic fields may offer an effective alternative for use over short distances.

Maxwell's equations predict the propagation of electromagnetic waves travelling in sea water. A linearly polarised plane electromagnetic wave travelling in the z direction may be described in terms of the electric field strength E_x and the magnetic field strength H_y with,

$E_x = E_o \exp(jwt - \gamma z)$, $H_y = H_o \exp(jwt - \gamma z)$

The propagation constant (γ) is expressed in terms of the permittivity (ε), permeability (μ) and conductivity (σ) by

$$\gamma = jw\sqrt{\varepsilon\mu - j\frac{\sigma\mu}{w}} = \alpha + j\beta$$

where α is the attenuation factor, β is the phase factor and $w = 2\pi f$ is the angular frequency.

The term $\varepsilon\mu$ arises from the displacement current and the term $\sigma\mu/w$ from conduction current. It is convenient to consider the solutions for the conduction band ($\sigma/w > \varepsilon$). and the dielectric band ($\varepsilon > \sigma/w$). For sea water the condition $\varepsilon = \sigma/w$ occurs for f = 1 GHz.

If we include the dielectric loss term then $\varepsilon = \varepsilon^1 - j\varepsilon^{11}$, where ε^1 is now the dielectric constant and ε^{11} is the dielectric loss factor, so that

$$\gamma = jw\sqrt{\varepsilon^1\mu - j\mu\left(\varepsilon^{11} + \frac{\sigma}{w}\right)}$$

Investigations of the parameters σ and $\varepsilon(=\varepsilon^1-j\varepsilon^{11})$ over the full EM frequency spectrum have been obtained in electrolytic solutions by using a wide variety of experimental techniques. The more popular techniques involve the use of coaxial transmission lines and waveguide cavities. If the sea water is in direct contact with the walls of the line or cavity then the conduction band losses apply. For example, a coaxial transmission line filled with sea water gave an attenuation coefficient α = 300dB/m for f = 67MHz, which is in good agreement with the conduction band solution as shown in figure 1. This result, shown by the symbol O, has been obtained by Scott and Smith, 1973.

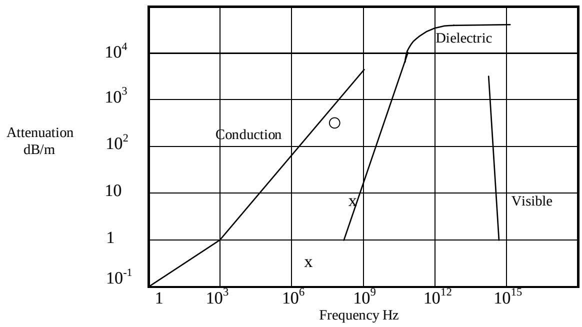

Figure 1 The EM Wave Propagation in Sea Water

A literature survey of EM wave propagation has shown that such measurements are scarce, but limited investigations have shown that short range propagation between a transmitter and a receiver is possible. (These have been shown by the symbol x in figure 1). Propagation in sea water at 7MHz (Bogie, 1972) has produced a transmission distance of 460m at a depth of 76m with the attenuation coefficient (α) of 0.23dB/m. Previous measurements by Liverpool have shown propagation down a waveguide (WG9A) immersed in sea water for a frequency of 500MHz. The propagation of this frequency, which is much higher than the waveguide cut-off frequency, is possible with an attenuation of 8dB/m with the propagation having a Gaussian type mode. Experiments by Vickers (Bogie, 1972) in the pure water of Loch Lommond have obtained a propagation distance of 30m for a frequency of 150MHz by using a simple whip antennae. These results have shown that when EM waves are propagated through sea water, the attenuation is reasonable and as expected from the dielectric theory. However, the launching of the wave into the water using conventional metal aerials occurs within the conduction band theory and may result in a loss as high as -50dB for a 14MHz frequency (Siegel and King, 1973).

By using a combination of experimental techniques it is possible to simultaneously evaluate a range of parameters for sea water such as σ, ε^1 and ε^{11} and the wave velocities v_σ and v_ε. Such an investigation will allow a detailed documentation of the properties of coastal sea water (clear, murky and polluted) to be investigated for a wide range of temperatures, depths and frequencies. Because of the longer wavelength of the EM waves, to be used in this study, it is anticipated that the effect of murky water or pollutants will be less severe than for the optical systems.

One important aspect of this detailed study would be an assessment of the possibility of short range propagation of EM waves through sea water for imaging, positioning and communications activities. The ability to communicate over a distance of 50m by using EM waves would have major scientific and commercial benefits for subsea activities. It is likely that wave transmission can be obtained over a distance of 50m at a frequency of about 1MHz provided sufficient transmitter power is available to compensate for both water attenuation and aerial losses. Modern communication systems can operate with a total system loss of -200dB. Thus allowing for total loss of -40dB by both the transmitter and the receiver and a -3dB/m loss in the sea water, a range up to 50m may be realised.

METHODOLOGY

The main activity of the research was to measure the propagation of EM waves through sea water over the frequency range 1MHz to 30GHz with special preference being given to the frequency range 1MHz to 3GHz because of the scarcity of experimental information. The parameters to be measured was the EM wave velocity (ν m/s) and the EM wave attenuation coefficient (α dB/m). A laboratory EM cavity, has been initially used for undertaking this investigation. Measurements were firstly undertaken using a rectangular cavity and filled with simulated sea water. This investigation was followed by further measurements using antennae within a laboratory test tank. These experimental results have been rigorously compared with EM wave theory for both the conduction zone and for the dielectric zone in order to understand the transition between the zones and to provide satisfactory models for EM wave propagation. A second series of experiments have been undertaken using transmitting and receiving aerials within both a swimming pool and a dock complex.
Based upon the results, two application activities will be undertaken in the immediate future namely:-

- A selection of the best operational frequency for short range transmission between 30m and 50m of the EM wave for use with imaging, communication, positioning and object tracking systems. A demonstrator system will be produced.
- The best operational frequency range for using the EM cavity to measure such parameters as σ, ε^{I}, ε^{II}, v_{σ} and v_{ε} and thereby investigate the effect of pollutants and turbidity around an outfall from sewerage and industrial waste water. A demonstrator system will be produced.

RESULTS

The test cavity was made from rectangular copper waveguide WG9A having a perspex lining 6mm thick. The internal dimensions of the cavity were 74mm x 31mm x 288mm. The perspex had a dielectric constant of 3.18 with a ratio $\varepsilon^{11}/\varepsilon^{1}$ of 0.0004 to 0.00080. The cavity used loop antennae, one at each end wall to act as the transmitter and receiver.

The results over the frequency range 1 to 1000MHz are given in figures 2 and have shown that propagation is possible in the presence of sea water at all frequencies over the entire range. The signal strength in distilled water is of the order of 226mV whilst in sea water it drops to 23mV when σ varies between 1 S/m and 4 S/m but increases to 40mV when σ = 10 S/m.

Laboratory Tank Result

The laboratory tank has dimensions 2m(w) x 1.5m(h) x 2.5m(l) and was constructed from PVC sheet within a welded metal frame. The tank was filled with either tap water or artificial sea water having conductivity whose magnitude varies from 0 to 4S/m. Both loop and dipole antennae were investigated with each transmitter and receiver being built upon a stand-alone box. Each PVC box was electrically screened and the transmitter (Tx) box contained battery operated electronics. Each antennae was fully immersed in the sea water in order to ensure that the transmission path was entirely through the water.

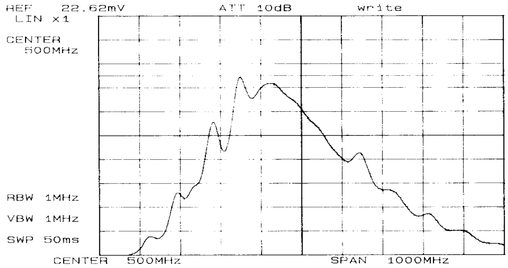

Figure 2 Spectral response for waveguide filled with 4 S/m conductivity

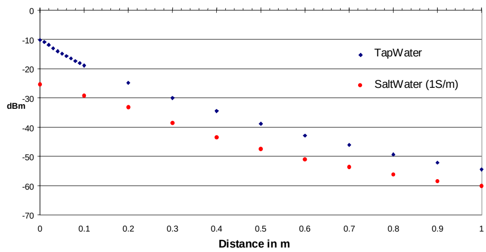

Figure 3 Dipole antenna (0.85m length), with Tx frequency at 5MHz

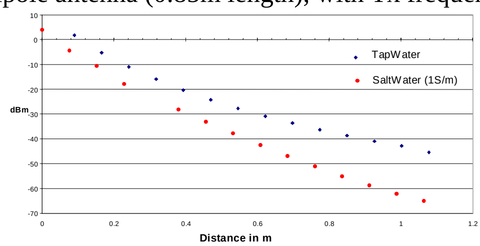

Figure 4 Loop antenna (0.35m diam), with Tx frequency at 5MHz

The result for 0.85m dipole antennae is given in figure 3 for a frequency of 5MHz and having a sea water conductivity of 1S/m at 20°C. The results have been compared with measurements taken in tap water. The results in both cases clearly show a near and far field having similar rates of attenuation. The strength of the EM wave electric field is about –15dB lower than in tap water and this effect was also observed in the results of the cavity experiments.

The results for the loop antennae are given in figure 4 are also for a frequency of 5MHz. The loop diameter is 0.35m. For this configuration in which the loop antennae are parallel there is less evidence of the existence of a long range field and hence these conditions can only be used for shorter propagation distances, unless the frequency is reduced.

CONCLUSION

The results obtained so far clearly indicate that it is possible to transmit EM waves through sea water. It is unlikely that transmission at high frequencies (~10'sMHz) can be obtained over long distances but short range transmission should be possible at a frequency of about 1MHz. The band width at this frequency should be sufficient for the transmission of digital pictures using image compression and slow update rate.

As regards the monitoring of pollution the high dielectric constant of sea water (~72) enable pollutants to be observed when contained in a cavity structure because they generally have a much lower dielectric constant such as oil (ε = 2.3).

Range finding can be attained by operation of either the dipole or loop antennae since both are capable of operating in the near field over a distance of 50m and longer if the frequency is reduced to below 1MHz. Propagation over shorter distances can be obtained by using higher frequencies. These operating conditions are suitable for object recognition. The detection of solid matter such as fish will also be observable either by interrupting the beam or by operating in a radar manner with back-scatter from objects being detected.

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TITLE: IMPROVED MICROSTRUCTURE MEASUREMENT TECHNOLOGIES FOR MARINE NEAR SURFACE FLUX STUDIES **(MITEC)**

CONTRACT NO: **MAS3-CT97-0114**

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IMPROVED MICROSTRUCTURE MEASUREMENT TECHNOLOGIES FOR MARINE NEAR SURFACE FLUX STUDIES (MITEC)

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SUMMARY

The project MITEC was focussed on the development of an advanced system for measuring, processing, and evaluating oceanographic parameters - stratification, mixing, fluorescence, near surface microstructure and others -, that are essential to determine near surface fluxes which are required for a correct description of physical and biological processes in the surface boundary layer of natural waters. Following objectives we could meet:

- Development of a free rising microstructure profiler measuring the near surface microstructure of temperature and current shear (turbulence) with the highest possible resolution. Other sensors providing information on bio-optical and standard oceanographic parameters can be integrated.
- Development, adaptation and qualification of algorithms prescribing, how to carry out the measurements and evaluate the measured data.
- Development, testing and qualification of software for data acquisition, calculation of basic turbulence parameters and data visualisation, designed specially for near surface uprising measurements. This software shall work routinely under field conditions.
- Laboratory and field measurements with the prototype to evaluate performance and to define the final product. Application studies that demonstrate the potential of the developed measuring system and data evaluation, for investigating near-surface flux processes in the water and the influence of small-scale physical processes on the dynamics of marine ecosystems.

The final deliverable should be a complete end-to-end system for the assessment of important physical and biological parameters, for gathering the data to evaluate the surface boundary layer processes. This final deliverable could only partially achieved, because the project was terminated after 17 months total duration. But the goal of the shared cost action programme MITEC, to develop and construct a highly advanced, integrated system for the measurement, processing, evaluation, and dissemination of oceanographic and limnic near-surface data was reached. The developed system is now on the market and it has the characteristics to become the world best commercial available profiler. Most of the work concerning the dissemination of results is ongoing and will be completed only within a time frame of about two years.

1. INTRODUCTION

The upper layer of the ocean, the so-called Surface Boundary Layer (SBL), is characterised by a highly dynamic behaviour with cycling between stable and unstable density stratification, depending on the relation between the turbulent momentum fluxes at the sea-atmosphere interface on the one hand and the corresponding buoyancy fluxes on the other. Vertical transport of momentum, heat and matter, and as a consequence all physical, chemical and biological processes in the SBL, are determined by this dynamic behaviour, which as a result affects climate and environment. Considering for instance the pelagic ecosystem, vertical transport causes nutrient pulses into the euphotic layer and sustains 'new' production of pelagic primary producers. In addition, small-scale turbulence has a pronounced effect on nutrient uptake, growth, strophic couplings and allelopathy of the smallest plankton organisms (see reviews e.g. by Thomas and Gibson 1990, Kiørboe 1993).

There are many unresolved problems in the experimental coverage as well as in the theoretical description and parameterisation of turbulent microstructures (Stips et. al. 1998). The same is therefore true for the related transport processes. There is no generally accepted parameterisation of the turbulent energy dissipation in terms of wind stress or heat flux in the near surface layer (Anis and Moum, 1995, Caldwell and Moum, 1995). Progress in this matter is necessary for investigations of any marine problem requiring knowledge of near surface fluxes at global, regional or local scale.

2. OBJECTIVES FOR MITEC

Exchange processes at the marine surface boundary are of a complex nature, comprising turbulent structures at different spatial and temporal scales. To improve our understanding of these processes to the point where they can be modelled or parameterised, it is essential to devise the means to acquire *reliable* data on the structures and interactions within the near surface layer. Small-scale turbulence in the surface boundary layer is relevant to many important physical and bio-geochemical processes in the aquatic environment, governed by mass, momentum and energy fluxes through the water-atmosphere interface. Consequently, these small scale processes are of important ecological relevance for aquatic systems in general and the marine surface boundary layer in particular. In addition, near surface transport processes represent a transfer function between the processes in the bulk of the water and their fingerprint at the sea surface - and this knowledge is essential for the correct interpretation of a satellite sensor's record of surface conditions.
Consequently the following two overall objectives were chosen for MITEC:

1. **to design, develop and construct an advanced integrated system for measuring, processing and evaluating oceanographic parameters - stratification, mixing, fluorescence, near surface microstructure and others -, that are essential to determine near surface fluxes which are required for a correct description of physical and biological processes in the surface boundary layer.**
2. **to perform application studies in order to demonstrate the potential of the developed system. This includes specifically the development of a methodology to investigate the influence of small-scale physical processes on the dynamics of marine ecosystems.**

After the beginning of MITEC, the project partner responsible for the hardware development, the company *ME Meerestechnik-Elektronik GmbH*, became bankruptcy. The MITEC steering committee proposed the new established company *Sea & Sun Technology GmbH,* (SST) which was founded by earlier leading engineers of ME-GmbH, as the new partner responsible for the MITEC hardware development. *ISW Wassermesstechnik Dr. Hartmut Prandke*, (ISW) which has most know how and experience in microstructure measuring technology, should act as a subcontractor to support SST in the microstructure technology development (the same construction with ME-GmbH and ISW had already been accepted by the European Commission).

Expecting the respective contracts with the European Commission, SST and ISW began with the hard- and software development for the MITEC project. Much of the development work foreseen in MITEC was carried out by SST and ISW on own resources until July 1999. However, the European Commission did not recognise the successful hard- and software development carried out by SST and ISW. The MITEC project was terminated by the Commission. Without expecting any additional funding, SST and ISW could not continue the development of new microstructure technology.

The output of the hard- and software development carried out by SST and ISW until July 1999, is the MSS microstructure measuring system. Not all system components could be realised as foreseen in the MITEC project proposal. However, the MSS microstructure measuring system is a high quality measuring system for marine and limnic microstructure/turbulence studies. With its outstanding properties, it is actually without competition at the word market.

3. Summary of achieved hardware developments

Until the termination of the MITEC project on August 30 1999, the following hardware development was realised by SST and ISW in collaboration with JRC:

1. The concept for all hardware and software development had been worked out. Necessary calculations for pressure resistance (housings), stability, buoyancy, and sinking/rising properties (profiler design, deployment technology) have been carried out. Materials and system components delivered by other companies (e.g., thruster, motors, electronic components, computers, syntactic foam) have been selected, detailed specifications (for cables) have been worked out.

2. The MSS profiler, qualified for sinking and rising measurements, has been developed and tested during several cruises in the North Sea and Baltic Sea.

3. The following sensor have been developed and tested:
   - Improved shear sensor PNS98
   - Improved temperature microstructure sensor
   - Acceleration sensor ACC98
   - Surface detection sensor

   The T/C microstructure sensor, fluorescence sensor, and the light scattering sensor for the MSS profiler could not be finished until the termination of MITEC

4. The shear sensor test device TSS1 has been developed and tested during several cruises

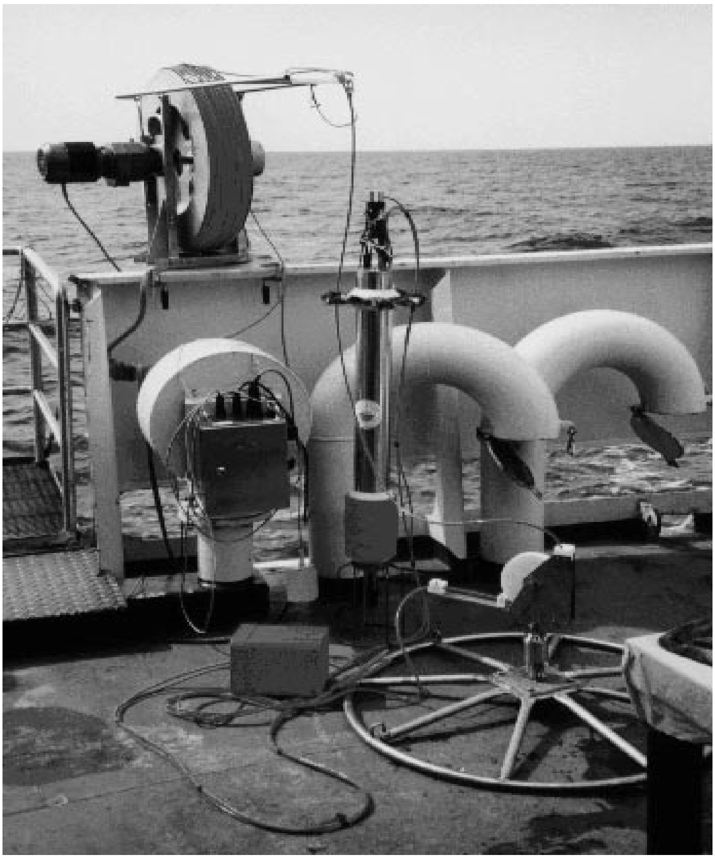
5. The deployment technology for the sinking profiler and the rising profiler in shallow water has been developed (ship winch for microstructure profiler SWM98, buoyancy body with

pressure sensor, guide pulley, swimming cable). While the ship winch could be tested during several cruises, the complete arrangement for the rising MSS profiler could be tested during 2 cruises in July 1999 and November 1999 in the Baltic Sea.

The deployment system for deep water could not be realised until the termination of MITEC.

4. PRESENTATION OF SELECTED HARDWARE COMPONENTS.

The complete microstructure system, prepared for rising measured is shown in Fig.1. The foto shows the ship winch for microstructure profiler SWM98 in the upper left part. The MSS profiler in the middle of the foto is balanced for rising measurements with red buoyancy rings. The ring of brushes ensures a rather constant profiling speed. In the lower right the guide pulley and the buoyancy body (red rectangular body) can be seen.



The realised system allows undisturbed measurements of microscale stratifi-cation and velocity shear between about 0.5 m and 3 mm. The small size and weight of the profiler enables easy handling during deployment and recovery operations.

Figure 1:
MSS profiler balanced for rising measurements (with red buoyancy rings and ring of brushes) together with the guide pulley (down right) and the buoyancy body (red rectangular body).

The sensor arrangement of the MSS profiler can be seen in Fig. 2. We would point out especially the position of the acceleration sensor, which is near to the shear sensors. The detection limit of the dissipation rate is the lowest level of dissipation which can be measured by a microstructure profiler. The detection limit is determined by internal vibrations of the profiler, caused by bending modes of the profiler housing, oscillations of profiler components (e.g., probe guard), and turbulence generated by the profiler itself. To estimate the dissipation rate detection level, the horizontal acceleration of the profiler at the position of the shear sensors has to be measured.
The acceleration sensor ACC98 is specially designed for this measurement. The ACC98 sensor has the shape of a slim cylinder. It is mounted together with the other sensors at the front end

of the profiler. Thus, the ACC98 sensor measures the vibration of the profiler in the position of the shear sensors (see figure 2)

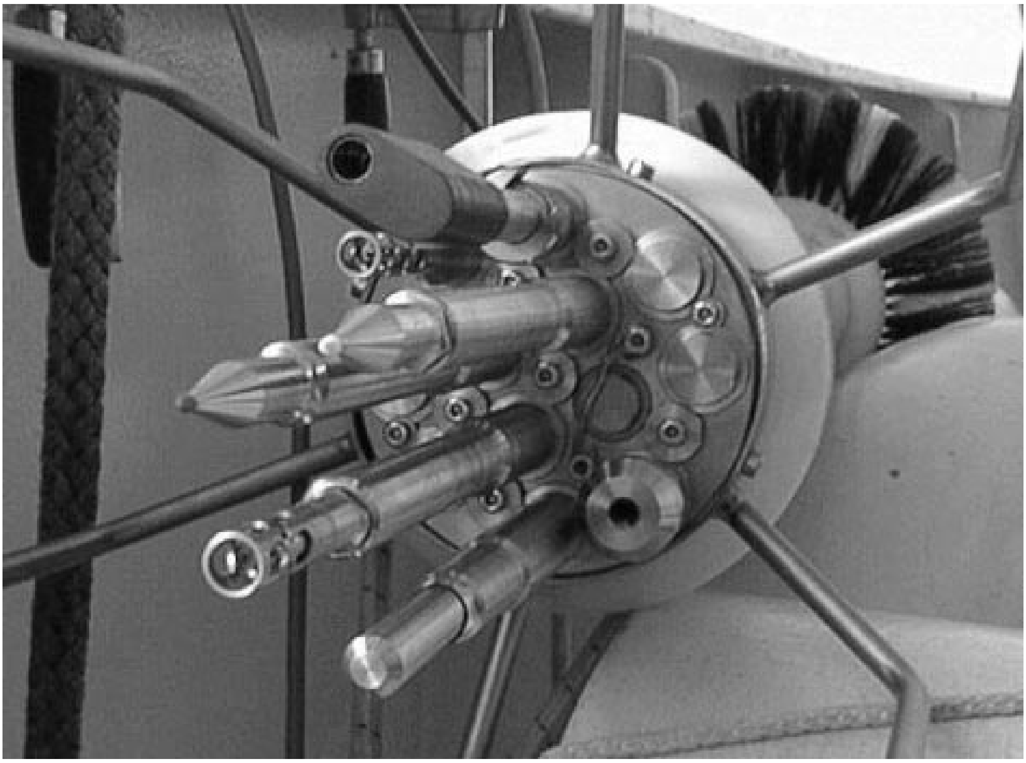


Figure 2:
Front end of the MSS profiler with 2 shear sensors PNS98 (centre left, with red and white tip, respectively) and an ACC98 acceleration sensor (centre down, cylindrical sensor). Between ACC and PNS (red tip) sensor is microstructure temperature sensor. Behind the microstructure sensors at the long shafts, the CTD sensors are placed at shorter shafts.

5. EXAMPLE OF RISING MEASUREMENTS

Rising measurements with the MSS profiler and the accessories as described in the previous chapter have been carried out the first time during the MITEC-Cyano 99 cruise in the Baltic Sea in July 1999. The guide pulley has been deployed approx. 150 m away from the ship (rv Aranda) in a water depth of 50 m. The ship was kept at position by dynamical positioning. A

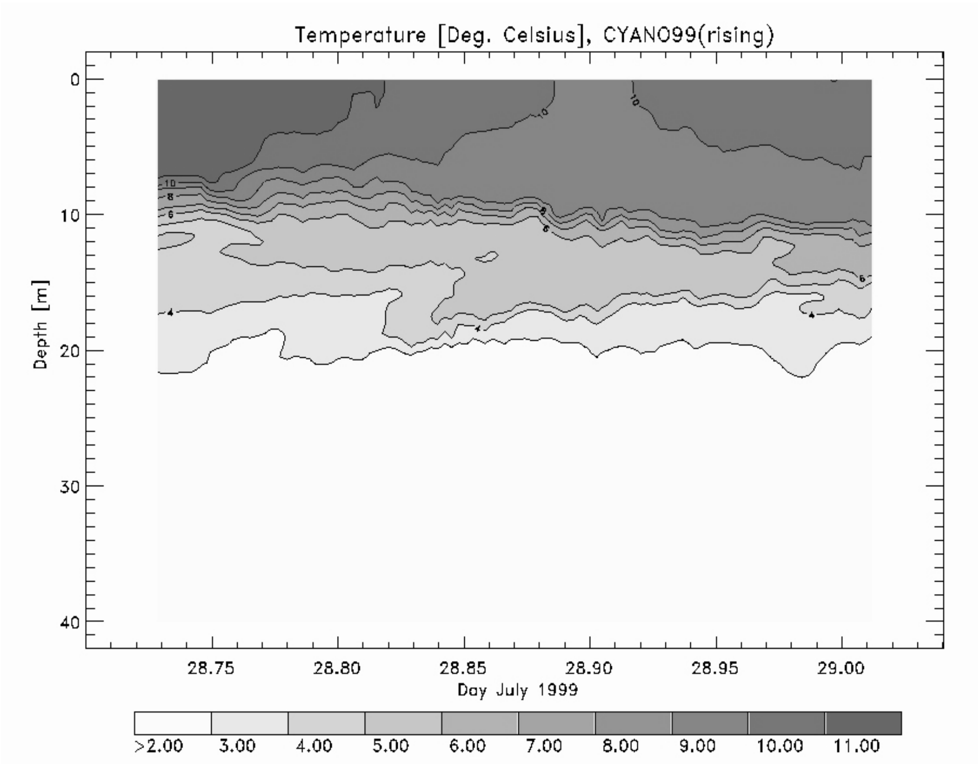


Figure 3a: Measurements of temperature with the rising MSS profiler of the Space Applications Institute , JRC, during the MITEC-Cyano 99 cruise in the Baltic Sea in July 1999.

series of 102 rising profiles from 35 m depth up to the surface were taken in 5 min intervals. The rising speed of the MSS profiler war adjusted to approx. 0.65 m/s. Principally, the complete system worked properly. Figure 3 shows the near surface temperature and dissipation rate time series as measured during this campaign.

Summarising the experiences with the rising microstructure measuring system for shallow water, it can be stated, that the combination of guide pulley, buoyancy body, and swimming cable is a proper arrangement for rising measurements in shallow water. This is especially valid for measurements from a stable platform or from the shore of a lake. At water velocities up to 0.30 m/s, rising measurements in 30 m depth intervals are possible.
If the measurements are done from a ship, a critical factor is to avoid movements of the ship. The positioning of the ship should be stable within distances of less than 20 m.

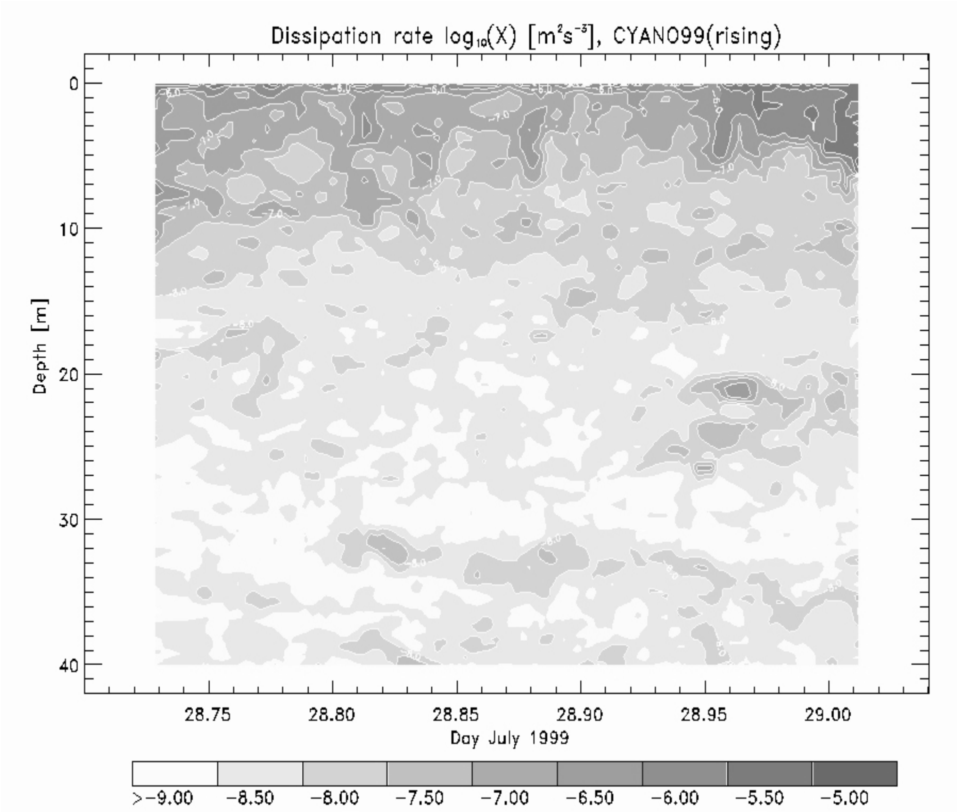


Figure 3b: Measurements of and dissipation rate of turbulent kinetic energy with the rising MSS profiler of the Space Applications Institute , JRC, during the MITEC-Cyano 99 cruise in the Baltic Sea in July 1999.

6. EXPLOITATION PLANS AND OUTLOOK

MITEC provides a unique and fundamental contribution to environment and climate change research, in the form of an improved understanding of near-surface physical and biological processes. This is relevant to such problems as gas exchange at the air-sea interface and the downmixing of greenhouse gases by turbulent mixing.

The development of the MITEC system creates new capabilities for observing and monitoring the marine environment and makes the European industry more competitive in the world wide market.

Furthermore MITEC allows the testing and verification of vertical turbulence models with respect to the conditions near to the sea surface. It will also allow comprehensive studies of physical-biological interactions concerning the appearance of noxious plankton blooms, and phytoplankton light adaptation to be made in the near future. In recent years a world-wide increase in the number of noxious plankton blooms has been observed, which had a particular impact on recreation, shell fisheries and fish farming. MITEC will contribute to the future investigation of physical-biological processes that affect such bloom formations. The scientific

publications to be produced will introduce a new strategy to study physical-biological couplings and thus create markets for the MITEC profiler.
The links between industry (SME's) and academic research are strengthened in order to improve technology transfer and ensure effective and continuing industrial exploitation of the results of MAST funded research. The development of such technologies will promote ecosystem research. It will also contribute to the understanding of bio-geochemical fluxes, the influence of small-scale physical processes on the dynamics of marine ecosystems, the impact of climatic change on atmosphere-sea exchange processes and the study of the dynamic properties of coastal systems.
After the partial successful completion of the project there is a precompetitive prototype available, which will form the base for a forthcoming project, to qualify the system for industrial production (possibly within EUREKA/EUROMAR).
MITEC provides a new and advanced tool for observations and flux studies in the near surface layer. This tool will help to improve the understanding of the processes in the near surface layer. This will benefit both marine science itself as well as the application of Remote Sensing in the marine environment, by improving the quality of the Remote Sensing derived data products of the marine environment. The European value-added industry will make use of the results to enhance its products and services to governments, marine research institutions and the marine-related industry.
MITEC is expected to support and stimulate research activities in aquatic systems including international marine programmes such as WOCE, JGOFS, GOOS, ELOISE and international lacustrine programmes such as EROS (Black Sea), ALPE (European Program on Alpine lakes), IDEAL (East African Lakes) and BICER (Baikal International Center for Ecological Research).

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TITLE: APPLICATIONS OF 3-DIMENSIONAL ELECTROMAGNETIC INDUCTION BY SOURCES IN THE OCEAN : **ISO-3D**

CONTRACT NO: **MAS3-CT97-0120**

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Applications of 3-Dimensional Electromagnetic Induction by Sources in the Ocean

7. ISO-3D

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1. INTRODUCTION

In the field of marine geoelectromagnetism, two important emerging technologies are leading to new opportunities for studying the properties of, and processes occurring within, both the ocean itself and the solid earth beneath it. Both of these technologies involve the measurement, for either geophysical or oceanographic purposes, of electric or magnetic fields induced in the ocean and the underlying earth by electromagnetic sources within the water column. The sources may be either natural or artificial. The two relevant technologies are controlled source electromagnetic sounding, and techniques for measuring naturally induced electromagnetic fields on the seafloor using ocean bottom instruments and telecommunications cables. ISO-3D is aimed at improving the exploitation of both of these techniques, and developing theoretical and experimental methods for making more effective use of observations of electric and magnetic fields in the oceans induced by both artificial and natural sources. The project is focused in particular on the extension of existing methodologies to take account of fully 3-dimensional induction geometries.

At the core of the ISO-3D project is the development of a computer modelling code able to predict the induced electric and magnetic fields from an arbitrary electromagnetic source, embedded in a structure in which the electrical properties of the ocean and the solid earth are allowed to vary in three dimensions. The project has developed this code, and is now exploiting it firstly in a series of numerical modelling studies; and secondly in a demonstration 3-D controlled source electromagnetic (CSEM) sounding experiment on the ocean floor. The target of the CSEM survey is the Lucky Strike segment of the Mid-Atlantic Ridge (SW of the Azores), where the upper oceanic crust is penetrated by a vigourous, high-temperature hydrothermal circulation system, and where constraints from the CSEM experiment on the porosity and temperature structure of the crust are leading to improved understanding of the physical processes associated with high temperature hydrothermal fluxes between the lithosphere and hydrosphere.

2. OBJECTIVES

The first objective of ISO-3D has been the development of the computer modelling code. Such a code did not previously exist, so it will have very wide applications in both physical oceanography and geophysics. Modelling studies for natural sources are investigating (i) the effects of induction on electromagnetic observations of basin-scale movements of water masses, at time scales up to and including long-term observations of climate-related oceanographic processes; and (ii) tidally generated electromagnetic signals observed both within the oceans and on land, and their applications in both physical oceanography and geophysics. The CSEM demonstration survey at the Mid-Atlantic Ridge is for the first time providing 3-Dimensional constraints on crustal electrical resistivity structure to a depth of at least 2 km beneath the seafloor.

The specific objectives of ISO-3D are:

1. To develop a numerical computer code for modelling the propagation of electromagnetic fields through a 3-Dimensional earth and ocean structure, with excitation by an arbitrary 3-Dimensional source in the ocean.
2. To apply the code to model studies of the use of basin-scale submarine cables for monitoring climate-related transport of water masses.
3. To apply the code to model studies of controlled source electromagnetic sounding (CSEM) experiments for investigating environmentally and/or economically significant structures and processes at and beneath the ocean floor.
4. To apply the code to model studies of the use of tidally generated electromagnetic (EM) field measurements for :

(i) assessment of the possibility of using seafloor EM measurements for the improvement of tidal corrections in satellite altimetry,

(ii) deep induction studies of the earth, using seafloor electric field or submarine cable voltage measurements,

(iii) structural studies of the continental margin, using fields measured on land,

(iv) possible monitoring of oceanic velocity fields by electromagnetic observing stations on land.

5. To carry out a demonstration CSEM experiment at sea to establish the viability of the technique for imaging 3-Dimensional sub-sea-bottom targets associated with structures at the Mid-Atlantic Ridge south of the Azores, within European waters.

6. To analyse and interpret the results of the demonstration experiment and hence to provide

(i) confirmation that the CSEM method can provide constraints on structure in complex 3-D environments,

(ii) an improved understanding of the physical environment of the upper oceanic crust within which hydrothermal circulation takes place at zero age on the Mid-Atlantic Ridge.

3. NUMERICAL CODE DEVELOPMENT AND TESTING.

The numerical model we have developed was motivated by the lack of a general-purpose numerical model code capable of predicting the electromagnetic field generated by arbitrary induction sources within the ocean in models of the Earth where the electrical resistivity varies in all directions. In particular, our aim has been to provide a controlled-source code capable of handling a three-dimensional Earth, and a motional-induction code capable of simulating the electromagnetic fields generated by large scale, relatively high frequency seawater motions such as the open-ocean tide, where self- and mutual induction must be considered in realistic models of the oceans and solid Earth on ocean basin or global scales.

Our approach to this problem has been to adapt a widely used and well tested numerical code for the related magnetotelluric (MT) problem to compute the electric and magnetic fields induced in the ocean and the underlying earth by general electromagnetic sources within the water column. Our new modelling code has therefore been based on the Mackie and Madden 3-D magnetotelluric code. The code uses conjugate gradients with incomplete Cholesky decomposition to solve for the electromagnetic field on staggered finite-difference grids. It first solves for the magnetic field, then computes electric field values as required. Including Mackie's incorporation of the correction first introduced by Smith for the divergence of the magnetic field, a number of the recent modifications by Booker and Mackie, and the addition of more general geometries based on earlier work of Flosadottir et al. with the Smith code, the new code can still be used to model the original MT field, but the parts of the code that set up the equation to be solved and afterwards calculate the electric field from the circulation of the magnetic field and the electric source currents have been extensively rewritten. The modifications have been designed so that the model equations are based strictly on the integral forms of the Maxwell equations. The code can now be used to model oceanic or man-made sources in Cartesian, spherical-Earth, or terrain-following coordinates for spatial scales ranging from crustal-scale controlled source sounding to basin-scale models of induction by the ocean general circulation and tides.

The most important added capability of the new code is the possibility of turning off the MT forcing and boundary conditions, instead specifying a prescribed electric current at one or more of the points where electric fields are defined on the model grids. Point sources, such as a controlled-source horizontal electric dipole, may be specified by input of a non-zero source current at one or a few grid points, while oceanic sources are modelled by source currents specified at all points within the model ocean.

Another new capability is made possible by the inclusion of metric factors that can be invoked to scale distances between points on the model grid so as to simulate geometric effects such as convergence of the meridians (and the shrinking of horizontal distances with depth) on a spherical Earth. In addition to large-scale models in which the Earth's curvature needs to be taken into account, this will also be used for terrain-following co-ordinates based on idealized topography or bathymetric data.

4. DEMONSTRATION 3-D CSEM SURVEY: THE '*MADRIGALS*' CRUISE, CD120

RRS *Charles Darwin* Cruise 120 – designated '*Madrigals*' (Mid-Atlantic Deep-towed Resistivity and Induction Geophysics), investigated the 'Lucky Strike' segment of the Mid-Atlantic Ridge - an area which lies to the SW of the Azores archipelago, and within the EEZ of Portugal. During the cruise we carried out a 3-D controlled-source electromagnetic (CSEM) sounding study of the upper and middle crust beneath the central volcano of the segment, in order to determine crustal electrical resistivity structure and hence to constrain the physical properties of the crust beneath a region of very active recent volcanism and current high- and low-temperature hydrothermal venting. The technological and methodological objective was to demonstrate a capability for collecting and analysing CSEM survey data from a highly 3-dimensional area of the ocean floor. The cruise was a collaboration between the University of Cambridge, UK; the Universities of Lisbon and Algarve, Portugal; and HALO Ltd, Reykjavik, Iceland.

The vessel sailed from Southampton on Tuesday 21/09/99. Additional scientists were embarked by boat transfer at Ponta Delgada on 27/09/99, and - after a brief test deployment of the DASI deep tow system on the Princesa Alice Bank - the vessel arrived at the primary work area during the evening of 28/09/99. Following completion of some wire tests and a sound velocity profile, 10 LEMUR instruments were deployed on the sea floor together with 6 acoustic navigation beacons and 4 near-bottom current meter moorings. Over the following 9 days, the DASI deeptow system was used to carry out 95 hours of CSEM transmissions at 0.25, 1 and 4 Hz along 212 km of tow track - a greater quantity of CSEM transmission time and line-km than had been achieved by any previous study. Only relatively minor delays were experienced during this period of the cruise. On completion of the DASI tows, six of the LEMURs and all acoustic navigation beacons and current meters were safely recovered. The vessel left the work area at the end of 12/10/99; disembarked part of the scientific party in Ponta Delgada by boat transfer on 14/10/99; and returned to Southampton, arriving on 19/10/99. Despite the serious loss of equipment, a large quantity of data was collected by the other LEMURs. All of these data are of excellent quality. The success of the DASI system in providing many hours and line km of transmissions also partly offsets the loss of receivers, and so despite the instrument losses we shall be able to produce a good determination of crustal resistivity structure and physical properties.

5. OTHER EXPERIMENTAL DATA

As part of the ISO-3D project, the Lisbon group have successfully established measurement and data logging equipment on the island of Madeira for monitoring the induced voltages in an abandoned trans-ocean telephone cable. The cable runs from Madeira to Sesimbre on the Portuguese mainland, and cable voltages have now been logged continuously since early 1999. The intention is that this will become a long time series measurement programme, allowing observations of motionally induced voltages – and hence determinations of integrated water mass movement – across the length of the cable on an interannual to decadal time scale.

In association with this work, the Frankfurt and Lisbon groups jointly established long period magneto-telluric sounding sites in Madeira during 1999. These data will allow transfer functions between the cable voltage and geomagnetic variations to be established, ultimately enabling the geophysical and oceanographic contributions to the observed volatges to be separated.

6. THE ISO3D WEB SITE.

Further details of the ISO-3D project, including fulltexts and diagrams from Annual and Cruise Reports and information on publications, can be found at the ISO-3D Web Site:
http://www.soc.soton.ac.uk/SOES/RES/groups/EM/iso3d/

TITLE : AUTOMATIC DIATOM IDENTIFICATION AND CLASSIFICATION (**ADIAC**)

CONTRACT N° : **MAST-CT97-0122**

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ADIAC: DIATOMS GO DIGITAL

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ABSTRACT. *ADIAC is the first MAST project to study the automatic identification of diatom images by computer. Now, two years after the project's start, it is taking shape in all planned tasks and as a whole. Very large image databases with taxonomic and ecological information have been created. These are already online accessible to diatomists as a new and electronic version of the classical atlasses. First software packages have been created for feature extraction and classification (identification) of diatom contours, and work concerning the extraction of features of the ornamentation is about to start. Also, first results on the automatic scanning of strewn slides are available, and strategic research with end-users on specific applications in order to develop exploitable products has started.*

INTRODUCTION

ADIAC started two years ago, on May 1st 1998. It is a first pilot project to investigate the possibility of identifying diatoms on the basis of image information, taking into account both the contour and the ornamentation of valves. Most information is online available at **http://www.ualg.pt/adiac/** and mirrored at **http://www.rbge.org.uk/ADIAC/** and this information will be regularly updated until, or even after, the end of the project which is foreseen in October 2001. Because a first pilot project cannot deliver a high-quality end product that is applicable in all phycological areas, an integral part of the project is concerned with the establishment of contacts with end users in order to define a follow-up project in which real applications must be challenged. Such applications are routine tasks in e.g. monitoring water quality, all relevant areas in geology or drowning cases in forensic research. Possible end users can contact the Coordinator or other partners in order to see how their input can optimise ADIAC's impact on their specific applications and requirements.

All ADIAC tasks have a direct link with automating the identification process: (1) scanning strewn slides at low magnification on a microscope fitted with a motorised stage to detect diatom positions prior to image capture at a high magnification, (2) to extract contours and morphological features from these, (3) the same for the ornamentation, and (4) to identify diatoms using information stored in image and taxonomic databases. The following Sections, contributed by the different partners, provide a snapshot of all current activities.

DATABASES

The contribution of the Royal Botanic Garden Edinburgh consists primarily of providing diatom images and taxonomic data, as well as taxonomic advice to the non-biology partners in the project. They are assisted by UNEW and ULP. RBGE has been building large image databases of several thousands of diatoms acquired directly from specimens on light microscopes. These images form the backbone of the automatic identification software to be developed, in that they serve as reference standards against which unknown specimens can be compared. They also serve as a ground for testing the identification rates of prototype applications, and several dedicated test sets are being compiled which allow problem areas to be addressed (e.g. how will the sys-tem cope with fossil material which generally tends to be contaminated with inorganic debris).

The development of these image databases also involves a rigorous examination of the taxonomic status of specimens included, and the provision of a full taxonomic information system which includes taxon names, taxonomic authorities, reference publications and lists of possible synonyms. These data are being stored in the Pandora taxonomic database system which has been developed in part at RBGE and is supported from there.

Data can be made available to web browsers by means of a data export module (HTMLExport), which allows data dumps that retain the relational structure of the database. The taxonomic data, along with the diatom images and ecological information about habitat etc, have now been made available to the public on the WWW (**http://www.rbge.org.uk/ADIAC/ db/adiacdb.htm**). All diatom images are also available in batches for public downloading, and their use by other pattern recognition workers and diatomists is actively encouraged.

The University of Newcastle (UNEW) provides specimens and working images to RBGE for final, high quality scans. To date, UNEW has selected, identified, and verified the taxonomy of approximately half of the images in the ADIAC database. Much of this work has focused on diatoms from lowland river and lake environments in an attempt to expand on the marine taxa collected in the first year, with the aim to broaden the taxonomic and morphological coverage of the databases.

Diatoms are sensitive ecological indicators of aquatic water quality, and environmental change. Within Europe they are routinely used to monitor the eutrophication and acidification of freshwaters, and current research is developing practical methods for biomonitoring of the coastal zone for a range of pollutants. The image database and automated identification procedures developed within ADIAC will thus be directly applicable to monitoring the quality of a wide range of European waters. Correct identification and a consistently applied taxonomy is a primary requirement for any practical biomonitoring tool. However, the use of diatoms or any other organism as a bioindicator of environmental conditions also requires that we have a knowledge of the ecological response to the pollutant, or chemical parameter or parameters being monitored. Thus an important part of any biomonitoring system is the linking of taxonomic information derived from species identifications with ecological information describing the environmental conditions represented by a particular diatom assemblage. To this end we have continued to develop a database of ecological information for each taxon imaged in the ADIAC databases. We have also developed a web interface to the database that allows dynamic retrievals of ecological information, and for this data to be embedded in the web pages of the main image database hosted by the RBGE. This provides a seamless integration of the taxonomic, ecological and image databases via a common web interface.

In situations where the automated identification procedures developed in ADIAC fail, or return ambiguous results in the form of multiple candidate taxa, the system will then require human intervention to make a decision as to the correct identification. In this case the diatomist will use a combination of his/her own expert knowledge and published morphological descriptions to differentiate between the candidate taxa. UNEW has therefore developed a pilot system to show how traditional published morphological information can be coded in a relational database, and how these data may be linked into the Integrated Database and used to guide human intervention for resolving the types of identification problems described above.

SLIDE SCANNING FOR DIATOM LOCALIZATION

Partner CSIC is working on this challenging problem by combining analyses at different magnifications. One problem is that slides may contain debris and broken or overlapping diatoms. Cairns et al. (1972) have proposed identification methods based on coherent optics and holography, but they did not consider the problem of the automation at low resolutions. Culverhouse et al. (1996) developed methods for phytoplankton identification using neural networks, but again they did not consider a fully automatic method. To the best of our knowledge, ADIAC includes the first approach to automate the image acquisition process. The algorithm consists of three steps:

1) Image analysis at a low magnification (e.g. 5x). At this resolution it is impossible to discriminate between diatoms and other objects, but this step only serves to extract possible candidate positions to be analysed at a higher magnification. The background is suppressed by a top-hat filter that also enhances amplitudes at edges, dots or lines. Then the image is binarised by histogram thresholding.
2) Stage micro-positioning. The positions of centroids provide the information to move the stage. Each particle is found using an automatic outlining technique. The (x,y) coordinates are given by the centroid of the best-fitting parallellogram, measured from the upper-left corner of the image. The particles are sorted according to their size. Once sorted, the coordinates are sent to the serial port of the stage controller after increasing the magnification.
3) Autofocusing. Here the requirements are speed, sharpness and robustness to noise. The Tenengrad method is considered to be one of the best. Recently other focus measures based on a modified Laplacian method have been published. CSIC has developed two improved methods by modifying the Tenengrad and Laplacian ones. Measurements show that they outperform the existing methods (Pech-Pacheco et al., 2000).

RECOGNITION AND CLASSIFICATION

The University of Algarve (UALG) is developing two strategies for a contour-based identification. In the first one, an ellipse is dynamically fitted to the contour until it covers the elliptical (central) part. Then a characteristic signal is extracted on the basis of the contour points and their distances to the ellipse foci. This signal is zero where the ellipse covers the contour, and unequal zero elsewhere, for example at the two valve endings in the case of pennate diatoms. These deviations from zero allow to characterise the shape in terms of symmetry type and end type, and provide a syntactical description that is interpretable by diatomists. First results showed that a correct hit rate beyond 90% can already be achieved, although the method has room for refinements. The method for the dynamic ellipse fitting will be published soon (Ciobanu et al., 2000a) and a full paper with identification tests is in preparation (Ciobanu et al., 2000b).

A second and new UALG method is based on a multiscale line/edge representation of the characteristic contour signal in the complex Gabor scale space in which (1) the signal is filtered with 360 complex Gabor kernels, (2) lines and edges are detected at all scales, (3) a stability analysis over neighbouring scales is applied and (4) features in terms of initial and final scales and amplitudes of the lines and edges are extracted. This method also allows for a syntactical analysis by diatomists in terms of shape features and species-membership confidence. First results on a group of *Navicula* diatoms based on an unsupervised fuzzy clustering showed that this might be one of the best approaches, although the method still needs finetuning.

The University of Groningen is studying the application of morphological curvature scale spaces. In both human and computer vision systems curvature extrema of the contour of an object are thought to contain important information about the shape (Leyton, 1987; Pavlidis, 1980). Since the curvature of the contour defines a shape completely, it should be possible to classify diatom outline shapes using the curvature. Methods based on mathematical morphology (Leymarie and Levine, 1988) have the advantage that the resulting features are localised on the contour, rather than delocalized such as Fourier descriptors. Therefore it was decided to extract the curvature information by multi-scale mathematical morphology. The ultimate aim is to obtain a small set of rotation, translation and scale invariant shape parameters, which contain as much information about the shapes of interest as possible. The method is based on an algorithm of Leymarie and Levine (1988). Their method uses sequences of morphological top-hat or bottom-hat filters with increasing size of the structuring element. After building this morphological contour curvature scale space, the most prominent features are extracted by an unsupervised cluster analysis. The number of extracted features matches well with those found visually in 92% of the 350 diatom images examined (Wilkinson et al., 2000). In most cases the mismatches were caused by spurious noise peaks. Hence, it is expected that some adaptive smoothing along the contour may improve the resolving power of the method.

The University of Berne is developing a feature-based retrieval scheme using symmetry measures, geometric properties, moment invariants, Fourier descriptors and simple texture features. Based on these features the image database is divided into classes using a decision tree based classification approach, which is inspired by the hierarchical classification procedure found in diatom keys (Barber and Haworth, 1981). Moreover, because of the huge number of classes involved, a one-level decision procedure as performed by a neural network or a statistical classifier does not seem feasible. An additional problem is the lack of enough training data. A decision tree based classification is a supervised learning technique that builds a decision tree from a set of training samples. The result of the learning procedure is a tree in which each leaf carries a class name, and each interior node represents a particular feature. Such a kind of a tree provides a set of rules which are very important for taxonomic identification tasks because it allows a human expert to change or extend the tree obtained from the decision tree induction procedure.

The decision tree was tested using a database of 468 gray level diatom images (Fischer et al., 2000). Using the features mentioned above it was studied how well the induced tree is able to classify unknown samples from a test set that were not used in the construction of the decision tree by the leave-one-out method. This leads to a recognition rate of about 69% if only classes with at least 10 samples are considered (presently there are not more than 10 examples per class available). In the near future the databases will be significantly enlarged. Hence, a further increase in the recognition performance can be expected as more samples per class become available.

FINAL SOFTWARE PRODUCTS

It was described above that ADIAC is a first pilot project and, as every pilot project, serves to detect the real problems and therefore to prepare a follow-up in which real-world applications must be tackled and final products must be developed together with end users. To give an idea of how such products might look, we will describe three scenarios that could all be developed. An integral part of all is a user-friendly interface for displaying image and other information, entering queries, and having access to very large databases. In view of the increasing performance of normal PCs and the availability of huge disks (now 50 Gbytes), the use of normal PCs is really a serious option, although users less familiar with computers might want to use some remote server with a proper soft- and hardware maintenance. The three scenarios are:

1) The use of image databases with taxonomic and ecological information that can be consulted if necessary, without an automatic identification of diatoms. This is the simplest option that can be realised on normal PCs in which the databases are used as an electronic atlas that can grow and eventually replace the normal (paper) atlasses.
2) An integrated system that combines the functionality of (1) with an automatic identification such that the system is given an image of an unknown diatom and it outputs a sorted list with the best matches from the database. This system can also be developed on normal PCs and guarantees a 100% availability for the users.
3) Users who don't need a 100% availability but only occasionally need to confirm their identification or need ecological factors can have access to a server connected to the Internet as well as a powerful computer or even a supercomputer. The server only is a front-end to the (super)computer which is required because many users, world-wide, can submit images and queries. Here there are two options: (a) sending an email with keywords (Identify Diatom) with an image in a certain format attached, upon which the server will respond by email, or (b) an interactive web-page with predefined queries and fields for entering file names and a link GO. Both options can be completely automatic, i.e. with no operator intervention.

The development of such products and services involves a lot of work, but their success critically depends on two factors: (a) an identification with a correct hit-rate beyond 95% and (b) the inclusion of all representative species from the real-world applications in the databases. In other words: ADIAC has still a long way to go!

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TITLE : SUBSEA TOOLS APPLICATION RESEARCH: **STAR**

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SUBSEA TOOLS: A CRAFT PROJECT TO RESEARCH AND DEVELOP A GENERIC TOOL FOR DIVERLESS APPLICATIONS

Mr Rodney Smith

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INTRODUCTION

The project consists of a consortium of companies and research organisations from the UK and from Norway working together to reduce the hazards of operations subsea, through ensuring that the subsea industry has the special tools that are needed for diverless operation. The tools are for attachment on ROV's and AUV's.

As offshore activity moves to operation at greater depths diving becomes progressively more dangerous and costly, or too hazardous to be accepted. This danger can be reduced and the costs minimised through ensuring that research technology is applied to the future use of remote controlled subsea tools.

This project will advance marine technology in subsea diverless operation and will provide EU SME's with a wider range of world class products for a world market. It will also benefit the wider EU marine industry through improving safety, reducing potential for environmental disasters and in increasing efficiency and effectiveness in managing the marine environment.

The research fits into Technology Stimulation Measures for SME's under the area: MAST-III. C.2.1.

PROJECT METHODOLOGY :
RELEVANCE TO INDUSTRY AND SME REQUIREMENT, OBJECTIVES AND DEVELOPMENT PROCESS

The offshore industry is moving rapidly towards diverless operation for sub-sea activities. This is driven by an increasing demand for safety and a move to deep sea operation where the risk to divers is significantly increased. This includes exploitation of resources beyond 200m and for research activity at 2000m and below. This activity is in extreme marine environments and in regional seas and where the use of remote operated vehicles (ROV's) and Autonomous Underwater Vehicles (AUV's) to replace diver operation is constrained by the flexibility of the general purpose robot arms used for underwater handling. Typically, the deep sea floor of the North Atlantic and Mediterranean, Baltic, Arctic and Sub-Arctic regions.

Improved understanding of seabed, and subsea environment (bethnic and meso-pelagic zone) is required by the offshore oil and gas industry, as it seeks improved efficiencies and operates in deeper waters and environmentally sensitive areas. Greater knowledge is also sought for oceanographic purposes, environmental monitoring, mineral extraction and marine cable installation. This understanding of the seabed is constrained by current methods/technologies.

The SME proposers manufacture component parts of products that address the issues and would benefit from improved product design. New approaches and technologies are required which will reduce the costs of collecting data, increase functionality and enhance mission robustness, enabling more data to be collected and more remote operation performed. The goal of the SME's therefore is to have available a tool or set of tools targeted at the tasks envisaged for deep sea operation.

The prime industrial/economic objectives are to reduce costs to industry of subsea activity and to increase the resources available for exploitation through enabling operation at greater depth and with advanced tools and tool systems.

Through reducing hazardous diver intervention in deepsea activity safety will be improved. Ensuring first time right fitting which will avoid waste and adverse environmental impact as accidents are reduced.

RESULTS

The deliverable is a multi-functional tool with a core framework or 'engine' which contains the principal power, control and data recording systems and which provides a common interface to specific mission oriented attachments.

The attachments have two specific market applications bolted connections and seabed sampling, but the two market applications share a common generic tool system design:-

- A tooling system whereby the tools and application specific items such as bolts and nuts are deployed by commonly used robotic manipulators used by light and heavy work class ROVs. This tooling system will be capable of: making up a subsea bolted connection and unmaking a subsea bolted connection. Bolt sizes up to 50mm AF are required up to 1500 ft lbf in tension and up to 2,000 ft lbf in release and 15 degrees of rotational freedom required for accurate alignment.
- The tooling system will use designs and approaches for power supply and system control, individual tool selection and tool transportation and storage which enable the use of other tools and devices to achieve other applications, with limited reconfiguration.
- The tooling system will use the standard elements identified above and be capable of obtaining seabed samples, including a range of seabed materials and of placing these samples in secure containers for transport to the surface by the ROV.
- Additional tools will augment the bolt connection system to allow other related tasks to be performed, such as flange alignment and flowline pull-in. These tools would be deployed by means other than robotic manipulators, by a Tool Deployment Unit (TDU) or skid attached to the ROV. This TDU would utilise similar control systems and power systems as the more simple, solely manipulator based system.
- A deployment unit or skid will be utilised for additional sensors and instruments to obtain oceanograhic data, to complement the manipulator based seabed sampling system. As above, this system should make maximum use of common elements, including additional common elements such as data loggers.

CONCLUSION

The current status of the project is prototype development and test. At this point the primary R&D is complete and the initial prototype is undergoing integration testing. It is scheduled to conduct wet test in September 2000, followed by subsea trials with a submersible. The results thus far provide confidence that the ambitious research objective will be achieved by the scheduled project completion date of 30 November 2000.

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TITLE: DINOFLAGELLATE CATEGORISATION BY ARTIFICIAL NEURAL NETWORK : **DICANN**

CONTRACT N°: **MAST MAS3-CT98-0188**

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DINOFLAGELLATE CATEGORISATION BY ARTIFICIAL NEURAL NETWORK (DICANN)

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ABSTRACT

DiCANN is an advanced pattern recognition laboratory system that is being developed to automatically categorise marine HAB Dinoflagellate specimens. A prototype of the system demonstrated accurate categorisation of 23 species of Dinoflagellate from microscope images. The project partners are also developing calibration techniques and standards for this new class of marine observation method. DiCANN uses artificial neural networks, an Internet distributed database and advanced image analysis techniques to perform natural object categorisation.

INTRODUCTION

Taxonomic categorisation of marine dinoflagellates is a normally a time consuming task for expert ecologists. Yet both marine ecology and monitoring of fisheries health and safety depend on the manual taxonomic identification of specimens from marine water samples. Routine analysis of large volumes of seawater is therefore not possible, ensuring that sampling regimes are always sparse and have a high cost associated with them. This coupled with a reduction in marine taxonomists emphasises the need for automatic analysis machines to assist ecologists. These instruments should provide automatic categorisation of species to genera, family or species level and they need to operate without supervision. They are not replacing the taxonomist, merely taking the more repetitive taxonomic tasks away from the human and so do not need to have a comprehensive range of categories within which they operate.

Automation of categorisation is not a new goal. Historically feature-based methods have prevailed, using digital image processing methods to measure various morphological parameters of specimens (cf. Ch. 8 Gonzales & Woods, 1993). For example Lassus *et al.* (1998) successfully used discriminant analysis of morphometric criteria extracted with a digital pattern-recognition system to differentiate species of Dinoflagellate (*Dinophysis fortii* and *D. acuta*). However, the selection of salient features is species specific and is also a time consuming process to develop. Digital image analysis performance is also reduced by the presence of noise, detritus and clutter, which is typical of pictures taken direct off-microscope.

For an automatic categoriser to become a laboratory instrument it needs to be robust and easy to configure as well as being accurate in its specimen labelling. Recent development of trainable artificial neural network pattern categorisers (Culverhouse *et al.* 1996, Tang *et al.*

1998) has simplified the development of such a tool for operation with field collected specimens, showing both intra- and inter-specific morphological variability.

This paper outlines the development of a new laboratory based machine designed for this purpose, called DiCANN.

DICANN OVERVIEW

DiCANN applies the coarse coded channel method for image analysis (Ellis *et al.*, 1997; Toth & Culverhouse, 1999) see Fig. 1. Specimen images are processed at low resolution through several complimentary channels. The resulting 142 bit descriptor is fed into an automatic categoriser for training and testing.

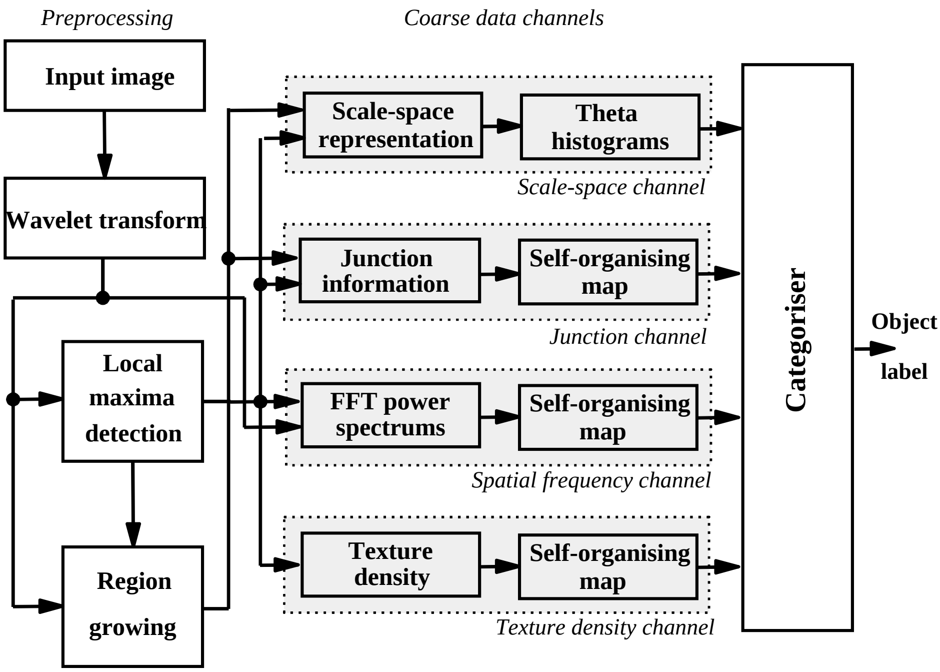

Fig. 1: Diagram of DiCANN system

An early prototype has been trained on 100 specimens drawn from an image database of over 5,000 field-collected dinoflagellates. Fig. 2 shows the prototype's best mean performance on test data drawn from the same database.

From Fig.2, human performance on a subset of the test data drops steadily as the task difficulty increases only attaining 86% accuracy on 23 species. This result was obtained from a panel of competent taxonomists. The increase in automatic categorisation performance when changing from 9 species to 14 species task reflects the introduction of additional coarse data channels into the analysis regime.

PROJECT METHODOLOGY

The project is split into three major sections, software development, specimen treatment and image database. Each is described in overview below.

SOFTWARE DEVELOPMENT

The DiCANN system is essentially software running on a personal computer. The development of DiCANN will follow standard soft-systems practices, which include rapid prototyping. DiCANN is being written in C++. It is expected that a series of software releases will take place during the life of the project. Each will be installed at marine laboratories within the consortium and users trained in DiCANN operations. Marine Ecologists will therefore be controlling the training and testing phases of DiCANN. How DiCANN is used and how it performs will be continuously monitored by the software development team. Releases of DiCANN will incorporate bug fixes and performance enhancements.

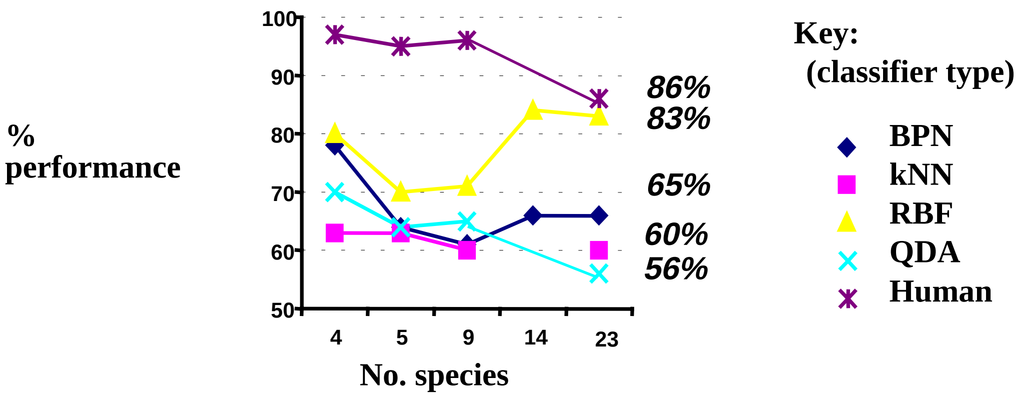

Fig. 2 Best mean performance of classifiers

Legend:

BPN = back-propagation of error feed forward Perceptron,
kNN = k-nearest neighbour statistic,
RBF = radial basis function network,
QDA = quadratic discriminant analysis statistic

SPECIMEN TREATMENT

Specimen images are taken using calibrated microscopes and 1:1 aspect ratio video cameras. The preferred fixative methods and specimen handling regimes are being evaluated by this consortium, to maximise the quality of computer photomicrographs taken of the specimens for the DiCANN system. Images are stored in an Internet database for access by all project partners. DiCANN will be trained on many hundreds of examples drawn from this database. Its performance as an intelligent cell counter of dinoflagellate specimens will be monitored during extended laboratory trials. Two main types of trial will be run, i) on specimens of Dinophysis cell cycle and ii) on routine HAB sampling from the Gulf of Trieste.

Fig. 3: Example specimen images

(a)*D. acuminata*, (b) *D. caudata*, (c) *D. fortii*, (d) *D. caudata*, (e) *D. sacculus*

Sources of the example specimen images shown in Fig. 3.
A) *D. acuminata*: 630x, Ría de Vigo (Galicia, NW Spain),
B) *D. caudata*: 400x, Ría de Vigo (Galicia, NW Spain),
C) *D. fortii*: 320x, Gulf of Trieste (Italy),
D) *D. caudata*: 320x, Gulf of Trieste (Italy),
E) *D. sacculus*: 320x, Gulf of Trieste (Italy)

DISTRIBUTED IMAGE DATABASE

A Distributed Image Database (DIB) on the Internet is a key part of DiCANN system (http://www.dist.unige.it/DICANN). The DIB provides the DiCANN members facilities and a query language on the Internet network to insert, modify and retrieve information about the specimens' images. These facilities can be accessed through a web interface available at the server site. The Internet User can query the DIB and directly retrieve the images and the related information from the web pages generated by the DIB.

CONCLUSIONS

Although DiCANN is still being developed it is clear from the extensive trials carried out prior to this project that DiCANN will be able to categorise marine dinoflagellates from microscope images to better than 80% accuracy. One question that was unanswered prior to the project start was "Can DiCANN operate fast enough?" At the time the concept model took 10 minutes to process each image. Thanks to increases in computer speed the first release of DiCANN will take just 6 seconds to process an image. This is well within the design requirement of one specimen per minute.

The task of developing DiCANN to laboratory prototype, although straightforward, is complex and time consuming. The project team hope that the development path adopted will ensure that DiCANN laboratory trials will be completed before the end of 2001 and that commercial exploitation can begin.

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III.1.2 Underwater communication and orientation

TITLE: LONG RANGE TELEMETRY IN ULTRA-SHALLOW CHANNEL : **LOTUS**

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Long Range Telemetry in Ultra-Shallow Channel

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INTRODUCTION

The main objective of the LOTUS project is to develop a method of communicating with a number of transmitter/receivers deployed in a wide area of sea or ocean without the need for cables. It is envisaged that, in a final commercial system, the units could be either stationary on the seabed, or drifting, or mounted on autonomous underwater vehicles (AUV's). In the experiments to be carried out during the LOTUS project, three receive/transmit nodes are employed with varying degrees of autonomy. Some will operate independently, while others may be controlled from adjacent vessels. In a commercial network the required distances over which communications take place are likely to be far larger than the water depth, and the region of sea could be either in a coastal zone, or in the open sea and this is reflected in the experimental scenario.

Two sets of sea trials occur in LOTUS [1]. One of these trials was carried out in the summer of 1999 and the activities relating to that exercise are included in this report. The second sea trials are planned for the summer of 2000. The first sea trials themselves were very successful and were carried out in the North Sea, a few kilometers (5-10) off the UK coastline. Data was recorded from fifteen locations over the 5 day recording period, in the latitude range

55^{o}07’ to 55^{o}11’ and the longitude range 01^{o}19’ to 01^{o}28’. Very calm weather throughout the test period considerably eased any handling problems, and enabled over 55 GBytes of useful data to be recorded.

SEA TRIALS OVERVIEW

Throughout the sea trials measurements were made of the environmental conditions. These were conducted from one of the support vessels, the University’s RV “Bernicia”, and are most directly related to the transmit end of the channel. Ambient noise conditions were monitored using a beamformer structure to enable the vertical directionality of noise sources to be determined.

A particular problem with noise measurement resulted from the very calm conditions on most experimental days. This led to very low levels of wave noise, this, together with the relatively large levels of ship generated noise - as a consequence of the necessity to keep the ship’s engines running at all times for safety reasons, resulted in difficulty in detecting ambient noise other than ship noise. It is also proposed, in future, to include an audio output from the noise measurement system in order to enable more rapid response to the monitoring of particular noise sources (at least those in the audio range) that appear during experiments.

A second monitoring system was also used to measure pressure, salinity and temperature. From these measurements it was possible to determine the sound speed profile in the region of the transmitter.

DESIGN OF EXPERIMENTAL EQUIPMENT

The first sea experiment required the deployment of two transmitter units and one, somewhat more structurally complex, receive unit. Once deployed both transmit units operated autonomously. The receiver structure was in continual contact, via cables, to a second support vessel. This vessel contained equipment for the recording and on-line analysis of received data. Both transmit units were powered by internal battery sources. These required daily replacement, thus it was necessary to recover each transmitter at the end of each day's experimentation and replace them on the seabed at the start of the next day's activities. The receiver system was left on the seabed for the whole of the experimental period (7 days), with cable recovery from a buoy at the start of each day. The carrier frequency of the transmitter was set to 9.5 kHz with a bandwidth of 2 or 4 kHz. The 4 kHz bandwidth was used for close range experiments while the 2 kHz bandwidth was used for the long range experiments.

As described, the first sea trials were used to acquire and store data from the array of hydrophones. Input data was sourced from two sea bed mounted nodes transmitting data simultaneously. In the second sea experiment, it is envisaged that two basic network protocol structures will be tested by upgrading the seabed node to have both transmit and receive capabilities. The first network will involve three nodes in a straight line, to form a basic repeater network. The second network will see the three nodes placed in a triangular network.

TRANSMIT SCENARIO

Off-line signal processing and analysis has been performed in order to determine both the quality of the data acquired during the first sea experiment and to assess the efficacy of the DS/CDMA multi-access algorithm [2]. Due to the constraints of space, we report the findings for only one transmit scenario. The transmit scenario was chosen from the the 1st day of the experiment. Figure 1 illustrates the scenario employed and the weather conditions on that day and it also summarises the system specifications. A 15-chip spreading code was employed for both users.

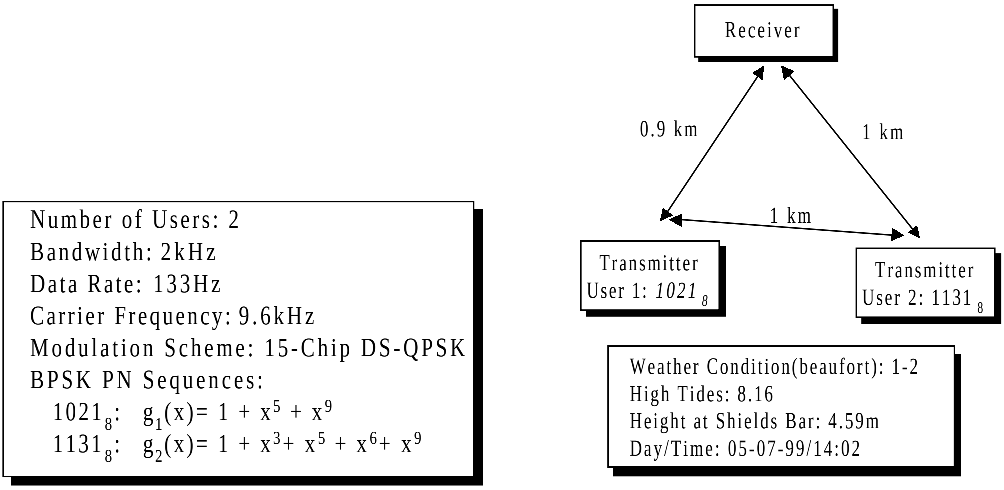
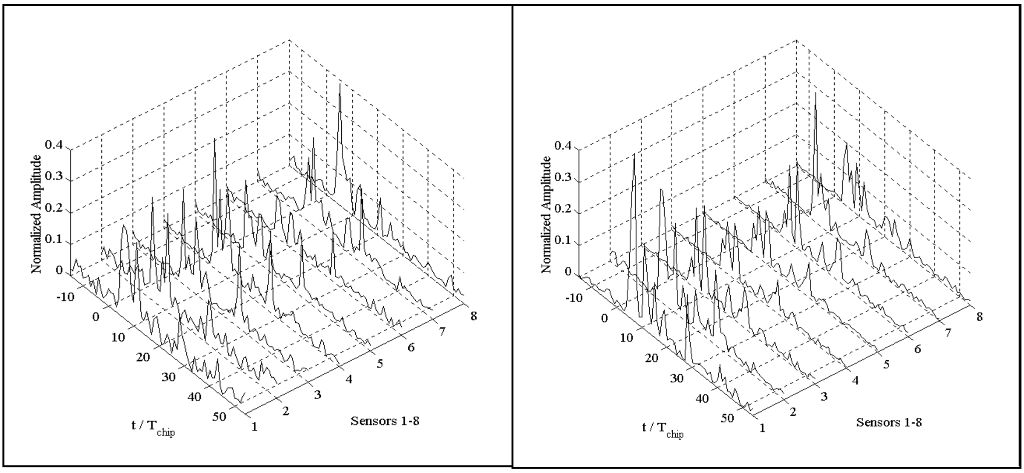


Figure 1 Transmit scenario

RESULTS

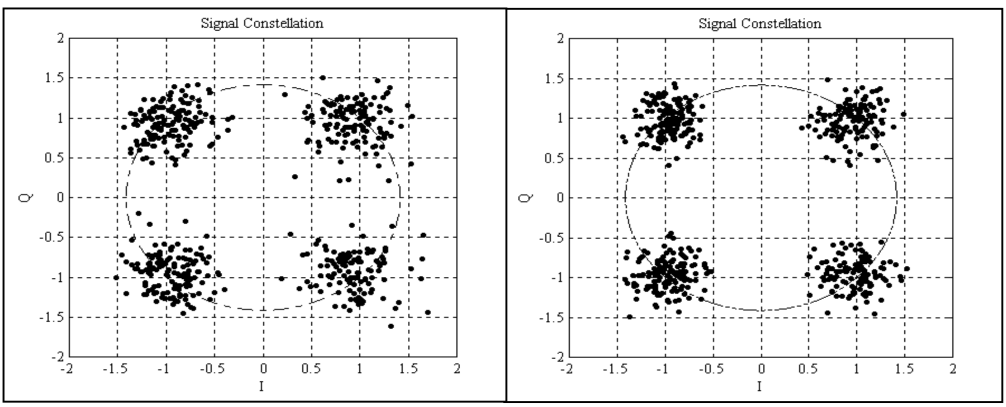
Figure 2 illustrates the complex-baseband channel impulse responses corresponding to the transmission of User 1 and User 2, respectively.. It can be seen that strong multipath signal components arrive even after 30 transmitted chips, which corresponds to a channel delay spread of approximately *1 ms*. The hydrophones themselves form a vertical array (1 lowest, 8 highest) with a horizontal sub-array (elements 3, 4, 5 6) in the centre of the water column.



User 1 User 2

Figure 2: Complex base-band impulse responses corresponding to the transmission of User 1 and User 2

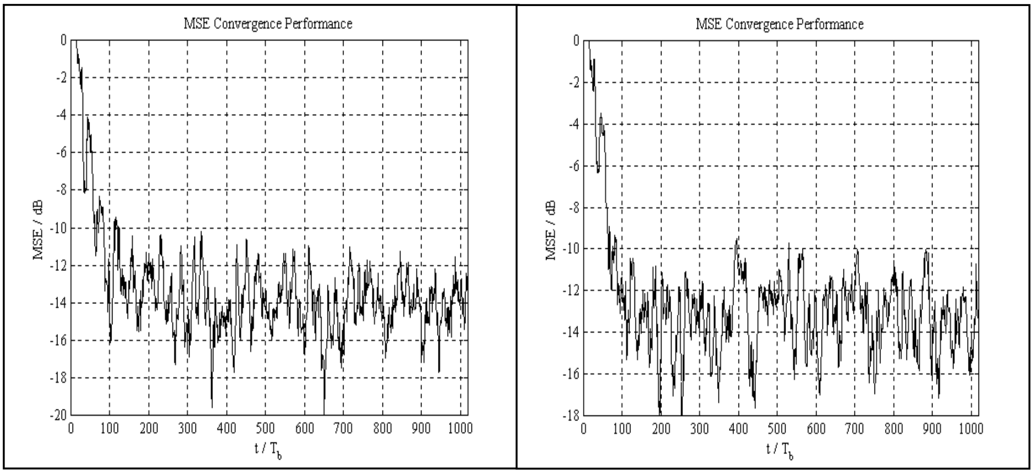
Figure 3 illustrate the I-Q signal constellation at the output of the DS/CDMA detector for User 1 and User 2, respectively. Figure 4 depicts the resulting MSE performance of the LMS algorithm. For User 1, it can be seen that after the initial training period the MSE fluctuates around a minimum of approximately –14dB with a variance of ±1dB. It should be emphasised that the results were obtained by processing the signals from all of the array sensors. Finally, no bit errors could be detected in the transmissions of user 1.



User 1 User 2

Figure 3: I-Q signal constellation diagrams for User1 and User 2 employing processing of array elements 1-8

The I-Q constellation diagram and the MSE learning curve for User 2 also show that after the initial training period the MSE fluctuates around a minimum of approximately –14dB with a variance of ±1dB. No bit errors could be detected in the transmissions of user 2.



User 1 User 2

Figure 4: MSE error convergence for User1 and User 2 employing processing of array elements 1-8

CONCLUSIONS

The results of this work demonstrate the feasibility of DS/CDMA for multi-access underwater acoustic data transmission. Additionally, the successful demodulation of recorded signal sets provides excellent inspection of the acquired-data quality.

ACKNOWLEDGEMENTS

This work is funded by the EC through the MAST-III initiative and their support is gratefully acknowledged. The work described here results from the combined efforts of all the LOTUS partners and sub-contractor and their contributions are gratefully acknowledged.

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TITLE : MAKING SEISMIC REFLECTION PROFILES AVAILABLE TO THE WIDER SCIENTIFIC COMMUNITY **: SEISCAN**

CONTRACT N° : **MAS3-CT97-0101**

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THE SEISCAN INITIATIVE: SEISMIC RECORD CAPTURE, IMAGE ARCHIVE, WEB ACCESS AND DIGITAL RECONSTRUCTION TO SEG-Y.

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INTRODUCTION

Several hundred thousand kilometres of marine seismic reflection records collected up to 30 years ago remain only as paper records; and this applies to European Exclusive Economic Zone (EEZ) surveys alone. These data records were collected during scientific programmes by academic institutions since the 1960s. Owing to deteriorating recording media (magnetic tape) and the absence of appropriate instrumentation these data cannot be re-played. Often the records remain boxed and un-referenced while gradually deteriorating; those of greater interest having suffered more by handling. SEISCAN is a project to rescue these early seismic records which, with few exceptions, have not been archived in any photographic or

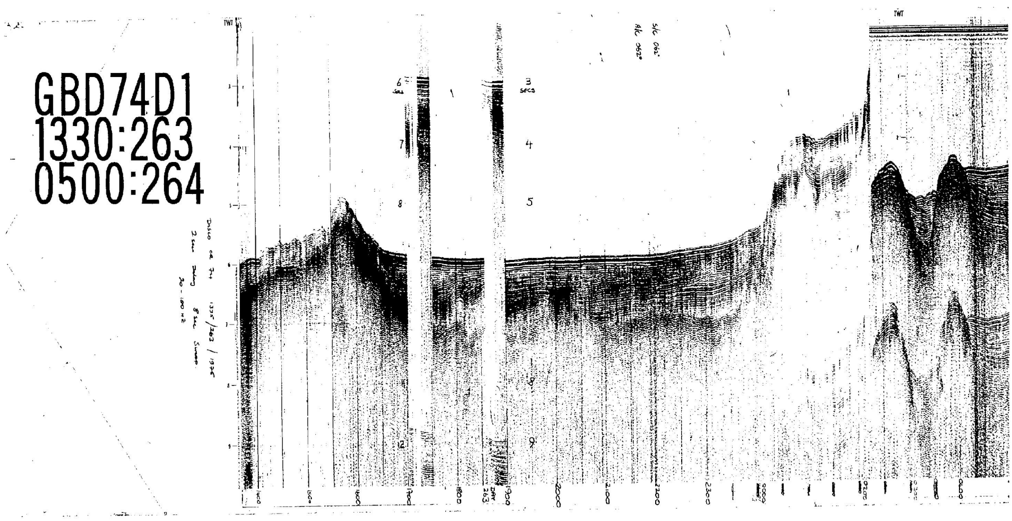

FIGURE 1. 300 dpi image of EPC seismic reflection record with 30 minute navigation time annotation. Image ID shows country code, survey roll & frame number with day/time of start and end.

other reproducible form. This 3-year MAST-III Supporting Initiative project involves 5 European partner institutions working with 2 commercial associated contractors. The 5 partners have overseen the initial phase compiling seismic record metadata prior to digital scanning and image processing. The image database created has not involved any cost to the contributing organisations (Miles et al., 1997,1998).

The data in question are the electro sensitive monochrome linescan (EPC) analogue line-scan records (Figure 1) that, if they were recorded on magnetic tape at all are no longer re-playable. As the data held in these records will have mostly been worked-up, possibly published, there are few Intellectual Property Rights issues that prevent their digital archival for future use. Much of these data lay un-referenced and inaccessible to many marine science workers for new regional analyses. These records are generally stored as rolls 50 cm wide and up to 20 metres long, readily handled by modern large continuous feed scanners. The SEISCAN data capture area is nominally limited to the European EEZ and beyond the 200 m shelf edge. These are areas critical to the monitoring of the marine environment and relevant to the environmental impact of mass wasting and slope stability. The data can also be used in preparation of submissions to the UN Law of the Sea according to the provisions of Article 76. Access to the information in these seismic records as digital images could also avoid unnecessary duplication of seismic acquisition. Data re-playable from magnetic tape is excluded in this initiative but digital reconstruction to wiggly trace and SEG-Y file format is part of the Technology Implementation Plan.

Image ARCHIVE

A fundamental factor in the set-up of this project has been a co-ordinated hardware and software strategy. Common Unix platforms operate CALDERA Cameleo imaging software that drives identical A0 format scanners at stations in Barcelona and Strasbourg. Processing centres in Southampton and Strasbourg also operate identical configurations. The partners in Athens and Trieste manage contact databases and advise on scanning issues. Therefore there is a degree of hardware redundancy in the event of maintenance. The Scanning centres have suitably enhanced storage facilities for data backup.

Each of the partners is responsible for liaising with marine research centres in their own countries and for agreed European regions. Information in the form of metadata, conforming to the FGDC (1994) standard, identifies qualifying seismic records and associated navigational information to enable the scanning phases to be organised. These metadata have

been fed through to the scanning centres in Barcelona and Strasbourg to co-ordinate database management of the seismic records, their navigation and scanned images.
Southampton and Strasbourg share the database management and data processing responsibilities of the seismic images. This includes the compilation of necessary navigational data to accompany the images. Processing as been carried out to specific quality control criteria laid down in a project QA handbook. The processing first inserts the unique image reference code based on country, survey, seismic roll and frame number. This enables cross-referencing of original, image and navigation from metadata to CD. Image enhancement clarifies and checks the images, compensating for background variations from fading, and electronic deskew and despeckle. Images created by the project are first backed-up to disk for processing and written to CD as a working archive. Processed images are returned to the data contributor for retention together with the original paper records. The processed images are then entered onto the project databases - A (Southampton) and B (Strasbourg).

RESULTS

DATABASES

The two databases are identical in hardware, software and structure; they complement each other to share the work-load. Rather than create a hybrid database, an image managent system '*Collection*' - a module in the Caldera Graphics *Cameleo* suite - was selected by the project. The advantages of this were to use an established image database supported within the unix OS and to continue our development with the SEISCAN sub-contractors Caldera.

'*Collection*' enables a user defined structure linked to each image consisting of *fields*. Each *field* defines either an image thumbnail (or mid-resolution image) or metadata to be assigned to that image. This way each thumbnail of a SEISCAN image is associated with a *Form* showing details of 'survey name', 'Latitude-longitude' and 'contributing organization' etc. This *Form* information can be interrogated via a *Search* box that enables selective metadata criteria to be used in locating specific images.

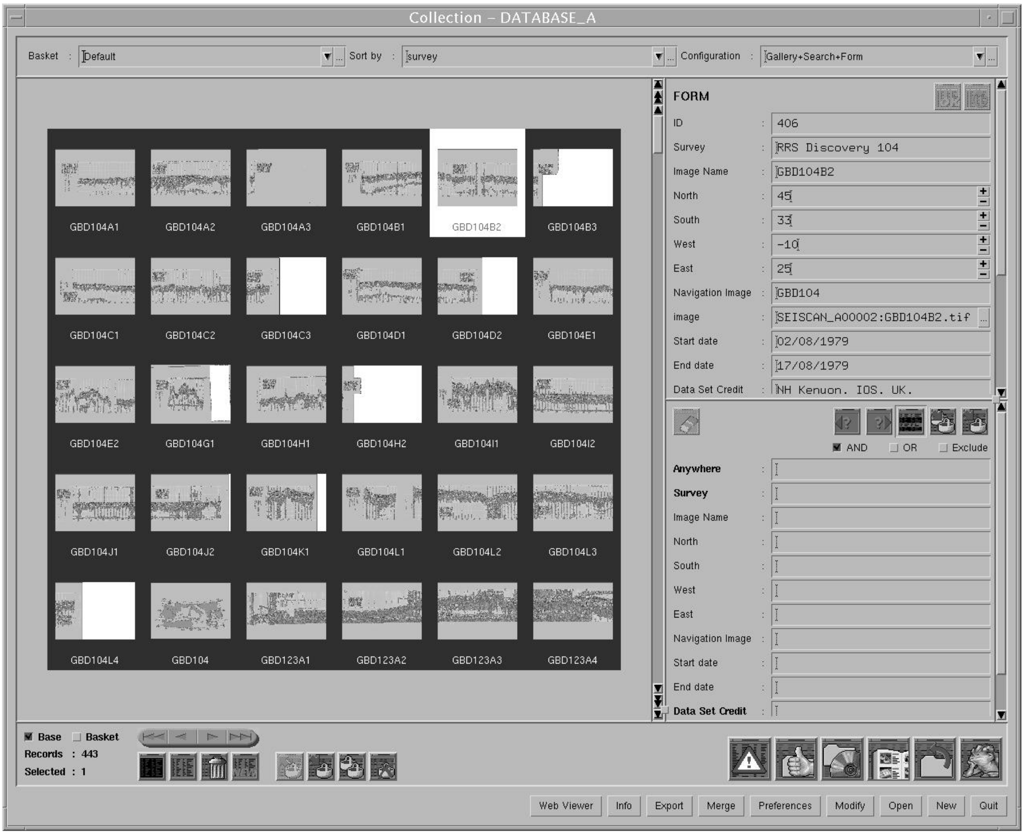

FIGURE 2. *Collection* database window showing thumbnail images with metadata assigned to selected image.

The real value of 'Collection' to SEISCAN is that it organizes the images onto offline CD storage suitable for long term archival while retaining the thumbnail and metadata for reference. In addition the thumbnail and mid-resolution images plus the form metadata of the database are copied to a Web Viewer for internet access by the wider scientific community while protecting the IPR of the full images. It is the intention of the project that the Web Viewer access will publicise the existence of data hitherto unknown that may have some new value. Responsibility for data access is deferred to data owners.

ON-LINE INFORMATION

Both data centres provide information on project progress and access to the Web Viewer at :

http://www.soc.soton.ac.uk/CHD/Research/SEISCAN (in English)

http://cats.u-strasbg.fr/seiscan.html (in French)

Data scanned

At the time of writing – 2.5 years into the project – the two data bases have archived 6153 scanned images. This represents 886,000 line kilometers of seismic survey that at current survey rates would cost some 15,000,000 Euros to re-acquire. Naturally not all these data would necessarily be desireable for acquisition had they not been surveyed previously but much is relevant to contemporary comercial and environmental research topics.

On completion of the project the images, their navigational information and metadata will be stored on CD and lodged in a European marine repository for long term security. Access to these data in the archive will be deferred to the contributing institution and not distributed by the SEISCAN project or the repository. In the event of accidental loss the repository would be able to replace images

DIGITAL TRANSLATION

Re-use of these archived data images beyond visual reference requires conversion to a recognised digital format – SEG-Y. A UK company - SeiScan GeoData - contacted SEISCAN following an early publication and collaborated in a trial image registration and sampling to create wiggly trace record sections from analogue lines-scan images. The preliminary results are being prepared for publication. The data have been deconvolved with an assumed commercial source signature; reprocessing with a more appropriate 'academic' source signature (i.e. a single channel airgun) is required to improve resolution.

The significant point of this result is that these data were never recorded in digital form or even plotted as wiggly trace. It is old analogue information taken from a electro sensitive print that can now be loaded into contemporary seismic packages for re-processing, re-interpretation and merging into regional analysis. This can avoid some new seismic acquisition costs in new prospect areas where there is a paucity of spec surveys.

As this commercial translation process is expensive SEISCAN has initiated a collaboration with CALDERA Graphics to develop a Cameleo module that will enable academic institutions to translate images to SEG-Y at a manageable cost and in modest amounts not viable commercially. This will enable the seismic images to be transcribed to SEG-Y format, loaded into seismic packages such as ProMAX, and used in research projects and in undergraduate and postgraduate training.

FIGURE 3. Seismic rolls arrive in cartons at one of the scanning centres.

CONCLUSION

This project has addressed a major task of locating and securing the seismic data that has been acquired during the past 4 decades; data that European funding institutions have already invested in. In the initial days of the SEISCAN proposal the project was quizzed as to how much data was in need of rescue and archive, and partly criticised for not knowing the answer. Well, we still don't know exactly. But one thing we are sure of is that there is actually more than we anticipated.

The work required for the scanning, management and archiving of the images has been substantial and project resources have been stretched. Our success has also been assisted by additional support from our home institutes in recognition of the importance of the initiative. There has also been considerable effort by all project members in creating dialogue with institutions who have kindly taken the project on its integrity and loaned data for scanning. We are sure they are satisfied with the results, particularly as they can now show that long term archiving has been achieved.

The digital transcription forms an important part of our Technology Implementation Plan. We believe it will have wide applications in both the commercial sector and the academic community.

SEISCAN is still aware at the scale of the outstanding task and as a result strives to obtain further funding to meet the archival needs of data sets in other deep-sea areas.

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TITLE : SHALLOW WATER ACOUSTIC NETWORK : **SWAN**

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SUMMARY OF SWAN PROJECT OBJECTIVES AND ACHIEVEMENTS

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INTRODUCTION

The SWAN project concerns the investigation of innovative solutions for a basic building block of an acoustic underwater communication network, that is a receiver equipped with an array antenna. The objective is to advance shallow-water coherent communication techniques, and in particular to achieve high reliability, fast self-start capability and self-recovery either in the presence or in the absence of training sequences.

Acoustical communication networking in shallow water gains an increasing interest, due mainly to the needs of environmental monitoring. today's communication techniques concerning the physical layer do not have the reliability needed for long-term unattended operations.

The project broad objective is to advance the shallow-water coherent communication techniques at the physical layer level of the communication hierarchy; this will constitute an important step for the synthesis of reliable networks.

The project specific objective is the investigation of innovative solutions, at the physical layer level, for a basic building block of the communication network, that is the Multi-Element Multi-User (MEMU) array receiver operating either in the presence or in the absence of training sequences.

The project partial objectives are:

- characterising the acoustic propagation in shallow water;
- synthesising innovative array processing algorithms in a multi-element multi-user receiver node;
- implementing a channel and node simulator, for performance evaluation on synthetic data;
- acquiring data in sea trials in the North Sea for off-line testing and performance evaluation of the processing and the modelling;
- implementing a data management structure according to the code on Data Management in MAST-III projects;
- disseminating the collected data for beneficial of the Community RTD;
- exploiting the project results.

The **methodologies** to achieve the objectives are the following.

- Analysis and modelling of the shallow water acoustic propagation channel.
- Analysis and upgrade of the decision-directed array processing algorithms in a receiving network node, combining jointly synchronisation and fractionally-spaced decision feedback equalisation.
- Analysis of blind techniques for channel estimation and symbol detection.

Performance evaluation obtained first on synthetic data generated by a channel and node simulator, then on data gathered at sea

PROJECT ACHIEVEMENTS

SHALLOW WATER ACOUSTIC CHANNEL MODELING

As acoustic vectors for communication systems, shallow seas are particularly complex channels, because of unavoidable multiple interactions with rough boundaries: the corrugated sea-bed, and the moving rough water-to-air surface; the resulting signals are corrupted by the phenomenon classically called ″*fading*″, in a way that seems unfortunately more complex than in classical fading channels (like Hertzian waves in the lower atmosphere) : the random fading part of the response is quite generally combined, particularly for short propagation ranges (less than a few km's), with more stable contributions, that travel directly from source to receiver, with no surface interaction, and that may fluctuate, at their own different rate (generally slower), due to other phenomena (movements of the source and receiver, tidal oscillations and internal waves in the water column, *etc*.). Such channels can not be understood and analysed within the classical frame of ″*Rayleigh channels*″; a minimal modelling has to be the far less common ″*Rician*″ channel. Our "ambitious" objective is to derive an operational model for such complex fading channels.

A version of the channel stochastic simulator was developed, finalised and distributed to the partners for evaluation. This latest version include the modelling of spatial correlation between different receivers at different locations, and gives the user the opportunity to generate the signals that may be simultaneously collected on several transducers, i.e. to simulate arrays with correct inter-correlation. The user is also given the opportunity to evaluate synthetic scales, more grossly, but with a direct interest for quantifying the capabilities of channel, or for comparing different configurations (correlation lengths or times, channel spreading, energetic balance between random and deterministic parts of signals, etc.). The model was played in the SWAN experimental configuration planned in May 2000 in order to produce some recommendations for the sea trial concerning the receiving array geometry and the environmental measurements to be carried out in order to bring adequate elements for model validation.

Investigations of the ROBLINKS data collected during the common SWAN-ROBLINKS experimental campaign of May 1999 displayed interesting fluctuations, which could be interpreted as arising from an unexpected "direct" effects of the swell: in very shallow waters (about 20.m), the variations of water height associated with swell or wind-waves produce fluctuations in static pressure and horizontal water velocity, that generate fast horizontal fluctuations of the sound-speed profile. A model was developed for evaluating the orders of magnitude and observability of this unexpected phenomenon, negligible in most configurations, but important in very shallow waters like those involved in the experiment and in most coastal areas; a salient property of this effect is its very high sensibility on the angle between the source-to-receiver axis and the propagation direction of swell.

BLIND AND TRAINED SIGNAL PROCESSING

1. Decision directed equalization

Multiple access communication has been an area of active research for Underwater Acoustics (UWA) channels over the recent years. However, an UWA channel is characterised as a multipath channel due to signal reflections from the surface and the bottom of the sea and also volume scattering. Because of sea-wave motion, the signal multipath components undergo time-varying propagation delays that result in signal fading. In addition, there is frequency dependent attenuation, which is approximately proportional to the square of the signal frequency. These result in the effect of inter symbol interference (ISI) in the received stream.

Apart from suffering from ISI, a multi-user network also suffers interference from other acoustic modems, or commonly known as Multiple Access Interference (MAI). Several types of MAI cancellation schemes have been devised over the years, this report reviews a number of the MAI cancellation schemes.

The multi-element single-user (MESU) decision-feedback (DFE) receiver has been shown to effectively combat multipath fading and ISI problems. In a network scenario, apart from ISI, the receiver suffers also from Multiple-Access Interference (MAI) from other users. Conventional communication network (as in the case for CDMA) employs a bank of matched filters to act as an optimum multi-user detector, that decodes each user's signal. More recently, several types of MAI cancellation schemes were introduced. The Multi-Element Multi-User (MEMU) DFE uses the "crossover" feedback filters to cancel out user's interference. Another type of MAI cancellation proposed for radio communication, employs a multistage decoding.

The decision directed equalization algorithms generally gave a bit detection error of ($P_e<10^{-4}$) for the far distances, 2000m and 5000m, and bit detection error ranges in ($P_e< 10^{-3}$) up to ($P_e< 10^{-2}$) for the shorter distances, 500m and 100m. These differences in results appear to lies mainly in the strong multipath in short distances that gave rise to high ISI.

2. Blind equalization

The main topic addressed so far is the analysis of the blind equalisation algorithms based on cyclostationarity which could be used within an underwater acoustic communication system.

The analysis of the data collected during the first experimental campaign has shown a wide variability of the estimated BER, ranging from optimal results (zero errors in 9000 symbols) to completely random decoding of the transmitted message (BER close to 50%). This variability appears not only between different data sets, but also within a single data set, between different receivers in the receiver array.

The comparison of estimated bit error rate and acoustic transmission channel behavior as function of time shows that the former is heavily dependent on the latter: when the channel is slowly time varying the equalization algorithm appears to be capable of achieving very good performance, however, in many cases the channel shows fast time changes, with timescale close to one or a few seconds, which cannot be tracked with the algorithm used.

3. Decoding of OFDM modulated signals

Among the data modulation types transmitted during the first SWAN sea trials, there are some Orthogonal Frequency Division Multiplexing (OFDM) data. In OFDM several carriers within the available bandwidth are transmitted at the same time, each one carrying a fraction of the whole data rate. The reduction of data rate on each carrier allows a reduced sensitivity to inter symbol interference, which can be coped with the introduction of a small guard time between symbols.

The received signal is distorted by the acoustic channel, in order to recover the phase of the transmitted signal, the phase of the channel frequency response function (FRF) must be estimated somehow. The most straightforward (and commonly adopted) approach is based on the use of some "probing" tones among the carriers transmitted, i.e., some of the symbols transmitted during each block are assumed known at the receiver. The comparison of known transmitted signal with the received one allows the calculation of the channel FRF at the frequency corresponding to the probing tones. The channel FRF corresponding to the informative tones is then estimated by a suitable interpolation or prediction scheme.

A fundamental limit of this kind of modulation is the selective frequency fading. If the channel frequency response has a very low amplitude at a given frequency, the corresponding carriers are highly affected by noise and the data carried is unrecoverable. For this reason, OFDM modulation requires also error correction coding of data.
Working with this kind of modulation the BER achieved ranges from 0.2% to 3%, with a data rate of 2048 bit per second (not accounting the overhead due to error correction coding).

SEA TRIALS

The location of both sea trails has been chosen to be the permanent Measuring Platform 'Noordwijk' (MPN) in the (Dutch) North-Sea.
In the first sea trial (May 1999) two installations were used:

- ❖ A *fixed* installation for the *receiver* (RX), to be moored on the Meetpost Noordwijk platform: six receiving transducers are immersed, moored, powered and electrically connected to the data acquisition hardware; the signals acquired from the transducers are pre-processed and stored on the platform.
- ❖ A *mobile* installation, onboard a support ship, where a *transmitter* (TX1) and its driving equipment is installed, deployed underwater at each ship stop for each single measurement, and recovered after measurement completion.

The receiving array consists of 6 hydrophones, that will be mounted to the MPN. The hydrophones are used in 3 rows with 2 hydrophones per row. Horizontal spacing is 15 cm, and vertical spacing equals 4 m. The lowest element is 3 m from the sea bottom. Data have been gathered at 8 TX locations corresponding to the ranges from 50 to 5000 m.
One Sea Campaign consists of:

- ❖ *One session for 'ship noise characterisation'*: i.e. one data gathering session when ship is moving from closest ship stop (50 m from MPN) to next ship stop (500 m from MPN).
- ❖ Data gathering sessions performed at each ship stop, including different kind of signals for: Instrumentation check, system calibration, ambient noise characterisation, and transmissions of useful signals.

Several environmental parameters have also been measured.
The signals transmitted at each ship stop include PSK modulated signals with several different bit rates and OFDM signals. The frequency bandwidth used ranges from nearly 8 kHz to nearly 12 kHz.
For the second sea trial (planned for May 2000) in addition to the two installations described above a third installation will be used:

- ❖ A *second mobile installation*, onboard of a second support ship, where a second *transmitter* (TX2) is installed. The transmitter will be equipped with a projector in the same band as the TX1 one. This transducer will transmit messages different from those transmitted at the same time from TX1, but with same modulation and signal characteristics.

This will allow the direct test of multiple user access to the network (the multiple access has been simulated with first sea trial data by summing together data gathered in different sessions).
Moreover the experience of the first sea trial have suggested a change in the receiver array configuration, which will be made by three receivers on a row, with half wavelength spacing, plus an additional receiver on the same row at nearly one m distance and two more receiver above and below these at three m of distance.

TITLE : LONG-RANGE SHALLOW-WATER ROBUST ACOUSTIC COMMUNICATION LINKS **: ROBLINKS**

CONTRACT N° : **MAS3-CT 97-0110**

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ADVANCES IN THE ROBLINKS PROJECT ON LONG-RANGE SHALLOW-WATER ROBUST ACOUSTIC COMMUNICATION LINKS

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4. Abstract

*Within the ROBLINKS project waveforms and algorithms have been developed to establish rob*ust *underwater acoustic communication links with high data rates in shallow water. To evaluate the signalling schemes, a wide range of experiments has been performed during a sea trial that has been held in May 1999, in the North Sea, off the Dutch coast. The analysis of the resulting data set shows that the original aims of ROBLINKS with regard to data rate and transmission range are achieved and in some respects even surpassed.*

INTRODUCTION

The importance of underwater acoustic communication is steadily increasing. This communication is of importance for underwater activities ranging from data transfer between underwater and surface platforms, remote control applications such as underwater vehicles and robots, communication with divers, etc. With regard to underwater acoustic communication, the main difficulty associated with a large range/depth ratio is time spreading due to pronounced multipath propagation. This occurs in addition to high temporal (phase) and spatial variability.

The scientific innovation of the ROBLINKS project is that it focusses on continuous parallel identification of the channel response, to provide self-adaptive algorithms insensitive to channel fluctuations. Two competing strategies are investigated: identification with parallel monitoring and blind identification. Identification with parallel monitoring is established by transmitting a superposition of a known reference signal and a communication signal that is taken from an alphabet of signals orthogonal to the reference signal. By monitoring the reference signal one can estimate the response of the channel and correct for its detrimental effects. This approach has the disadvantage that only part of the energy is devoted to the communication signal. The blind approach does not utilize a reference signal. To correct for adverse channel conditions a self-trained, decision-directed equalization algorithm is used. The two approaches are evaluated on basis of data collected during a sea trial in a coastal part of the North Sea, which took place from April 30 to May 7, 1999. Further information on the project can be found in [1] and on the project homepage http://www.tno.nl/instit/fel/roblinks/.

OBJECTIVES

Present communication systems have good performances but they either have poor bandwidth efficiency (noncoherent methods), are limited by a time spread that is less than the symbol duration (differentially coherent), or require operator assistance to adjust the receiver parameters to the channel. The specific objectives of ROBLINKS are:

1. To develop new signal concepts and algorithms for optimal coherent signal processing in the time domain to achieve reliable long-range underwater acoustic communication in shallow waters at a large range/depth ratio (≥ 100). The aim is to achieve this at reasonable data rates (≥ 1 kbit/sec), and within the frequency band 1-15 kHz. The proposed algorithms should be self-adaptive with regard to environmental variations. The word "robust" in the project title is used in this particular sense.
2. To evaluate experimentally the performance of these waveforms and processing algorithms with data acquired during a shallow-water sea trial. Selected waveforms and processing algorithms are implemented in a real-time system and the real-time performance is evaluated with data recorded during the sea trial.

THE SEA TRIAL

Experimental set-up

A trial has been executed in the North Sea, approximately 10 km off the Dutch coast near the coastal resort Noordwijk. A data set was collected to evaluate the communication waveforms and processing algorithms and to assess the propagation conditions. The water depth at the location of the trial is approximately 18 m. The bottom is relatively flat with sand rims reaching heights of up to one meter. Two platforms were involved in the trial, HNLMS Tydeman and Meetpost Noordwijk.

HNLMS Tydeman, an oceanographic research vessel of the Royal Netherlands Navy, acted as the transmitter platform. The acoustic source used to emit the signals had a source level between 185 dB (re 1 μPa @ 1m) and 195 dB over the frequency band from 1-15 kHz. The source was deployed at a depth of 9 m.

Meetpost Noordwijk, a fixed research and monitoring platform owned by the Dutch Directorate-General for Public Works and Water Management, was the receiver station. A vertical array of 20 hydrophones, 60 cm apart and thus covering the greater part of the water column, was vertically fixed between a beam connected to the platform and a weight on the bottom of the sea.

Fig. 1 displays the set-up of the acoustic experiments. It also indicates the main problem encountered in shallow-water acoustic communications, namely multipath propagation. Sound scattering off the sea bottom and water surface is also indicated. This gives rise to reverberation. Further, reflections off moving surfaces, such as waves, contribute to the Doppler spread of the signals.

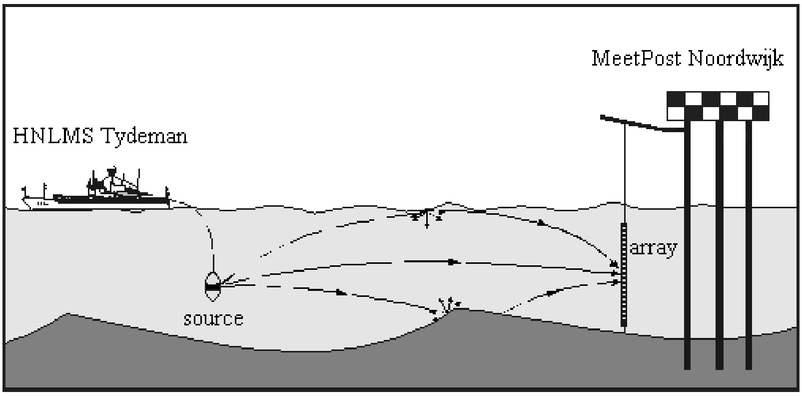

Fig. 1. Set-up of the experiment

Measurements

Communication signals were transmitted along two different tracks: a primary track from west to east, and a secondary track along the coast (more or less south → north). The first part of the experiments took place in a fixed point to fixed point configuration with moorings of HNLMS Tydeman at 1 km, 2 km, 5km and 10 km distance from Meetpost Noordwijk on the primary track and at 2 km distance on the secondary track. A moving point to fixed point configuration was used in the second part of the experiments in which the HNLMS Tydeman was sailing along the primary and the secondary track.

To assess the propagation conditions, each communication signal (with a typical length of about 13 minutes) was preceded by

- 60 seconds of noise recording to determine ambient noise levels;
- A CW (10 s) at the passband centre frequency, to determine the Doppler spread;
- Two linear FM sweeps (10 s over the frequency band 1-14 kHz and 0.2 s over the signal passband) to determine multipath propagation.

All project partners defined a set of communication signals. TMS created sequences containing a reference signal, RUB concentrated on blind equalization algorithms and TNO confined itself to more conventional modulations like BPSK to enable a comparative evaluation with the newly developed waveforms.

The acoustic experiments were complemented by a range of environmental measurements, such as CTD probes to determine sound velocity profiles and XBT casts to record temperature profiles, and echo soundings to determine the bathymetry of the tracks.

The trial has resulted in a vast, high-quality data set. The most illustrative and interesting part of the data set will be made available to the EU research community via the IFREMER/SISMER data banking centre. Information about this selected data set can be found in [2] and at the ROBLINKS archive http://www.ifremer.fr/sismer/program/roblinks/.

RESULTS OF THE DATA ANALYSIS

Analysis of the channel response

The 10-s FM and the CW signals have been analysed to estimate the time spread and Doppler spread, respectively. This is reported in detail in [3]. Typical values for the time spread are between 14 ms at shorter ranges (1 and 2 km) and 8 ms at the longer ranges (5 and 10 km). The structure of the different arrivals is rather stable at lower frequencies, whereas at higher frequencies (above 6 kHz) the temporal and spatial variability is significant. A typical value for the relative Doppler spread is $\Delta f / f = 2 \times 10^{-4}$.

Performance of high data-rate BPSK-signals

For the comparative evaluation of the newly developed waveforms with conventional modulations, a number of BPSK signals were broadcasted. These signals consist of standard Nyquist raised cosine pulses, supplemented with a pseudo random learning signal and two displaced carriers. The learning signal serves to estimate the channel response, and the displaced carriers are useful for timing recovery. Processing at the receiver includes linear least-squares equalization, adaptive beamforming and decision-directed equalization. After some fine-tuning quite good results can be obtained. For example, a signal of 4 kbit/s transmitted in a moving point to fixed point configuration is successfully demodulated to yield a zero bit error rate. The details are reported in [4].

Transmission using parallel monitoring

Results of the analysis of the communication signalling schemes with a reference signal at ranges of 2 and 5 km are presented in [5]. The transmitted signal is based upon Gold or Oppermann sets of sequences and consists of a superposition of one fixed reference sequence for the purpose of channel identification and up to 16 sequences with arbitrary indices and phases to carry the useful information. First analyses, using long signals (2 minutes) from a single hydrophone channel and robust and simple reception algorithms (without fine operator tuning and/or delay for channel identification), have already shown that transmission with very low bit error rate (BER ~ 10^{-4}) is possible for data rates up to 800 bit/s.

Transmission using blind identification

To investigate the feasibility of a completely self-recovering equalization and synchronization method, a system which uses offset-quadriphase-shift keying (OQPSK) signals was designed first. The number of message bits in each of these signals was approximately 10^5. By exploiting the special OQPSK modulation structure and by jointly processing the outputs of 3-7 hydrophones, a relatively simple symbol-spaced linear adaptive multichannel-equalizer could be applied with great success to the entire medium-range (2-5 km) experimental data. It could be demonstrated that bit error rates of approximately 10^{-4} were attainable without channel coding and with data rates ranging from 500-4000 bit/s. The results also show that virtually the entire number of bit errors per signal occur during the initial acquisition phase of the equalizer which lasts for a few thousand symbols at most. Additional details are presented in [6].

CONCLUDING REMARKS

ROBLINKS continues until the end of November 2000, and the receiver algorithms will continue to be improved until that day. Yet, the results more than half a year before the project end already eclipse the original objectives in several respects, viz.,

- The reported bitrate of 4 kbit/s surpasses the 1 kbit/s minimum objective;
- The transmission range of 5 km exceeds the 2-km distance that corresponds to a range/depth ratio of 100:1;
- Successful *mobile* underwater acoustic communication at high data rate has been demonstrated.

During the remaining project duration, further algorithm improvements will focus on the aspect of robustness. Furthermore, a real time implementation of the 'best' algorithms is being made.

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TITLE : UNDERWATER DIVING INTERPERSONAL COMMUNICATION AND ORIENTATION SYSTEM FOR MARINE SCIENCE AND DIVING APPLICATION : **UDICOS**

CONTRACT N° : **MAS3-CT98-0165**

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CONTRIBUTION TO UNDERWATER DIVING COMMUNICATION AND ORIENTATION

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ABSTRACT

The aim of this project is to perform European diver-borne communication and orientation systems reaching high intelligibility level for the first and real time detection for the second. Feasibility of both systems has been demonstrated. For the communication application, using electrical transmission, the electrodes geometry has been studied in terms of power ranging effects and electrical safety.

INTRODUCTION

European union has 90 000 km of sea coasts and 47% of its population lives at less than 50 km from the sea. Many of the regular diving practitioners express the need for both an interpersonal diver-borne communication system and a real time orientation system. The UDICOS (Underwater Diving Interpersonal Communication and Orientation System) project is born from this need. For the intercommunication part, the final aim is to develop a system using bone conduction audio transmission via the standard scuba mouthpiece, in order to reach high phonation and audition intelligibility. For the orientation part, the final objective is to perform a real time localisation of the diver's ship with user friendly display.

PROJECT METHODOLOGY :

Intercommunication

Most of the underwater communication studies deals with ultrasonic acoustic propagation. But this way of propagation encounters numeral difficulties in terms of propagation quality (ground and surface reflection, echo, deviations due to thermoclines,...). That's the reason why the electrical transmission has been chosen, to match the high intelligibility level given by the using of bone conduction. Experiments realised without modulation have shown the feasibility of the concept. The electrical solution had already been studied by [1-5]. The present study has followed three main objectives:

- To analyse electrical losses in sea-water
- To define optimum frequencies
- To optimise electrode design & materials

Orientation

The electrical field approach can't be used for orientation application, due to the large non uniformity of the generated field. This system uses an acoustic field generated from the ship. The feasibility of this application has been established, and the developments are now focused on the portability and real time aspects of the system.

RESULTS

The intercommunication main results are summarised in the following table. The simulations are realised with the finite element software FLUX-EXPERT®, distributed by the company SIMULOG [8]. The experiments have been realised on Mediterranean sea and Leman lake.

PARAMETER	STUDY TYPE	MAIN RESULT
Frequency	EXPERIMENTS	50% losses at 50 kHz
Electrical water conductivity	SIMULATION	- Water resistivity enables to generate strong electrical potential difference with low power consumption
Shallow water	SIMULATION	- Strong ranging attenuation
EMITTING ELECTRODES		
Surface	SIMULATION EXPERIMENTS	- Enhancement of ranging/power ratio - Establishment of minimum surface
Radius	SIMULATION	- Enhancement of ranging/power ratio
Spacing	SIMULATION EXPERIMENTS	- Enhancement of ranging/power ratio
Geometry (confidential)	EXPERIMENTS SIMULATION	- Enhancement of ranging/power ratio
Axis orientation	SIMULATION	≈ same order field in both radial & axial directions Choice of vertical position for practical reasons
RECEIVING ELECTRODES		
Axis orientation	SIMULATION	30 dB saving with reception // to emission

The electrochemical effects on the electrical consumption (for a given ranging) have been studied. These losses can be minimised by finding a compromise between the electrode surface and the current density. Ranging versus power charts have been established for different types of emission electrodes, in order to quantify the respective influence of the electrodes diameter and surface.

The electrical safety criteria [9-15] have been studied depending of the diver clothes (short, diving suit, gloves). The human body admissible current criteria for a contact longer than 10s is 10 mA (IEC 479 safe curve for a.c. current). For the case of 30m range communication between divers wearing only shorts (worst case, $1m^2$ of electrical contact with water), the electrical safety is achieved with reasonable size electrodes. The electromagnetic effects are under study but their environmental impact is more difficult to establish.

CONCLUSIONS

The development realised on the scuba mouthpiece insuring communication through bone audio conduction is now finalised on a first serial product using plug to plug conduction (SCAPHONE® , distributed by TFE company). To achieve the final step of diver born product, the water transmission will be more deeply studied (signal modulation, simulation of induced magnetic field and frequency skin effect on the power ranging).

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TITLE : ELECTROACOUSTIC PROTOTYPE FOR CONTROLLING THE BEHAVIOUR OF MARINE MAMMALS

CONTRACT N° : **MAS3-CT98-0184**

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ACOUSTIC BASED METHOD TO PREVENT THE MORTALITY OF SMALL ODONTOCETES IN FISHING GEARS

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INTRODUCTION

A wide variety of human activities threaten coastal cetacean populations world-wide in a number of different ways. Although artisanal fisheries tend to be of lower environmental impact when compared to industrial fishing there is still an effect.

Increasing attention has been paid in the last decades to the ways in which fisheries may affect marine mammal populations and to the ways in which marine mammals might compete with, or cause damage to, fisheries. In 1994 the International Whaling Commission stated that marine mammal by-catches due to fishing operations are the main cause of mortality for various marine mammal populations. On the other hand, fishermen argue that cetaceans compromise their catch and cause serious damages to their nets. In particular, in Sicilian seas the interaction between dolphins and the activities of small fisheries is intense because they are mainly competing for the same resources (Mazzola *et al*. 1996). In this interaction both sides lose something. Dolphins become entangled and wounded in fishing nets and often loose their life; while fishermen suffer both damage to their nets and losses in their catches.

In order to reduce by-catches of cetaceans, in the recent past several experiments were conducted to address this problem following two different approaches: 1) modifications to the fishing gears, by using passive acoustic devices (Lien *et al*. 1990, Goodson 1993, IWC 1994, Koschinski and Culik 1997); 2) installation on fishing gears of acoustic alarm devices (ADD) and/or acoustic harassment devices (AHD) (Lien *et al*. 1990, IWC 1994, Gearin *et al*. 1996, Dawson *et al*. 1997, Koschinski and Culik 1997, Kraus *et al.* 1997, Stone *et al*. 1997, Laake *et al*. 1998, Johnston and Woodley 1998). The control of behaviour using acoustic devices seems to be one of the best solutions to minimise the negative effects of such an interaction, also contributing to the dolphins conservation. Looking at the results of these studies, it is clear that the problem of repelling dolphins from fishing gear or preventing entanglement has not yet been completely solved.

PROJECT FRAMEWORK

In 1994, in order to investigate the reactions of bottlenose dolphins (*Tursiops truncatus*) to different acoustic stimula (Mazzola *et al*. 1996, MED/93/011) a set of experiments was conducted in the «Severtsov' Institute of Evolutionary Morphology and Animal Ecology» dolphinarium (Russian Academy of Sciences, Moscow). The experiments allowed us to select two repelling signals: one emitted by a killer whale (*Orcinus orca*), the other one by a specimen of bottlenose dolphin captured in the Black Sea. The prototype designed during those tests was subsequently used to the open sea trials (S. Vito Lo Capo, Sicily, Italy, Fig.1). That study outlined that psychological repelling signals lose their effectiveness with time, probably as a consequence of habituation to the emitted signals. That project also included a census of dolphin by-catches which occurred during small fishery operations in Sicily. Data were acquired through fishermen log-books and interviews.

In order to design a new acoustic prototype, according to our previous results, a new research project was submitted to the frame of Technology Stimulation Measures for SMEs of the Marine Science and Technology (MAST) programme, thanks to the financial aid of an Exploratory Award (contract n. MAS3-CT97-0133). The project, entitled "Electroacoustic prototype for controlling the behaviour of Marine Mammals (EMMA, contract n. MAS3-CT98-0184), was approved and then started in August 1999.

The scientific and technical objectives of EMMA concern the implementation of an acoustic device for controlling the behaviour of dolphins, in their natural environment to prevent the interactions with the coastal small fisheries. The new prototype will be based on physiological and not psychological dolphins response. Since the project started recently, in this paper we present the consortium, the project plan and the activities to date.

EMMA is structured in ten tasks and six sub-tasks (Fig. 2). Its framework follows these steps:

1. creation of bibliographic database;
2. theoretical studies of dolphin Sonar;
3. identification of the most important organs of dolphin Sonar;
4. creation of morphometric database (original morphological data of Odontocetes auditory system);
5. mathematical evaluation of the Natural Frequencies of Resonance (NFR) of main components of the Sonar;
6. tank experiments to measure the actual natural oscillations of the different components of dolphin Sonar;
7. definition of acoustic deterrent signals through a mathematical model and the results of tank experiments; in this task the effects of dolphins habituation to the repulsive signals will be considered;
8. design and realisation of the new prototype to be tested during the subsequent steps;
9. floating cage experiments to evaluate the efficiency of the selected signals;
10. possible re-designing of emitted signals structure;
11. assessment of the efficiency of selected signals in open sea experiments;
12. design and realisation of a set of prototypes and their testing during real fishing actions in a wide sea area close to S. Vito Lo Capo (Fig.1).

At the present we gathered over 400 papers on dolphin sonar, cetacean acoustic capabilities, auditory system, dolphin-fishery interaction. We also completed the study of the functioning of dolphin's hearing and sound transmitting system. The melon, the air sac system (tubular, vestibular and premaxillary sacs), the lower jaw and the timpano-periotic bulla were selected as main organs for evaluating the NFR. The collection of biological samples from stranded dolphins is in progress.

After the first EMMA plenary meeting, held in Trapani (22-23 February 2000), we began to design the Emma project Web Site. The user-friendly structure foresees public pages, and others only for the project partners. In order to monitor the ongoing of EMMA and to get the feedback from all partners involved, the achievement of each task and further steps of the project will be accessible on the site. The extensive bibliography gathered until now will be usable by the public.

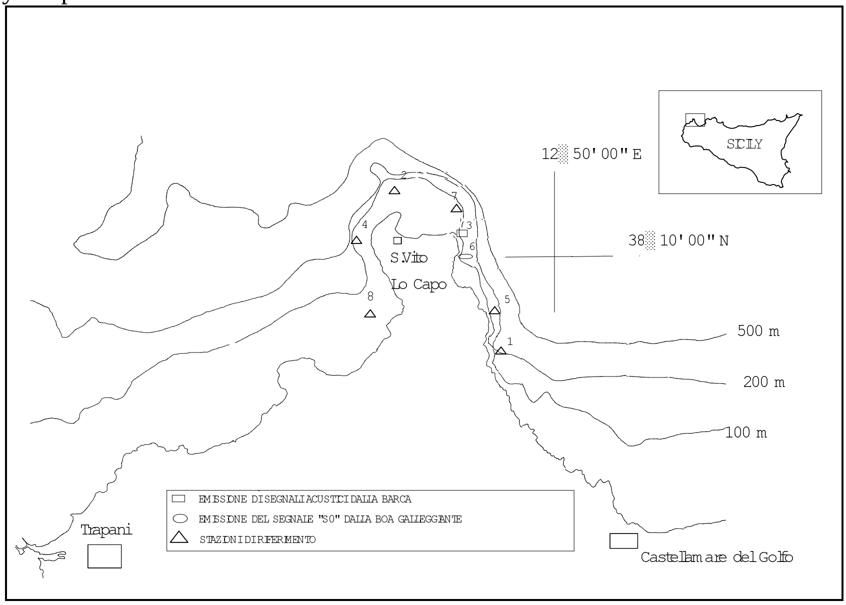

Fig. 1. Study area and position of stations of the at sea experiment

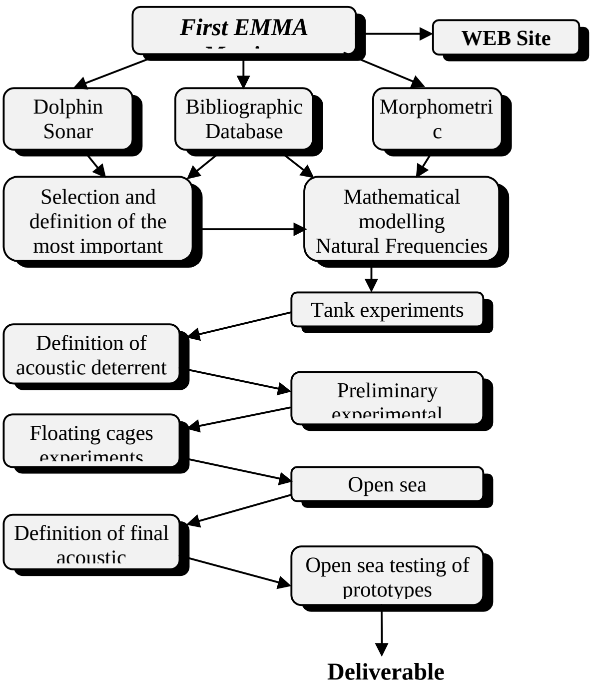

Fig. 2. EMMA framework

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III.1.3. Underwater viewing

TITLE: HIGH RESOLUTION IN SITU HOLOGRAPHIC RECORDING AND ANALYSIS OF MARINE ORGANISMS AND PARTICLES **: HOLOMAR**

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HIGH RESOLUTION *IN SITU* HOLOGRAPHIC RECORDING AND ANALYSIS OF MARINE ORGANISMS AND PARTICLES (HOLOMAR)

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HOLOMAR OBJECTIVES

The objective of HOLOMAR is to develop, construct and evaluate a fully-functioning, prototype, underwater holographic camera and associated replay system for large-volume holographic recording and analysis of marine organisms (marine plankton and seston) within the upper water column. The camera allows holograms of partially overlapping volumes to be simultaneously recorded with either an in-line (object in transmission) or an off-axis (object in reflection) holographic geometry. A dedicated, hologram replay facility containing fully-automated image analysis and data extraction facilities will allow species identification and measurement of local concentration of a variety of marine organisms. The holo-camera will be capable of either ship deployment or attachment to a fixed buoy and will be appropriately automated and controllable from the ship. The use of the entire system will be demonstrated and evaluated in a series of laboratory, tank, dockside and sea trials.

METHODOLOGY OF HOLOGRAPHIC RECORDING AND REPLAY

Holographic imaging offers marine scientists an alternative to conventional imaging for the visual recording and measurement of marine systems. It permits non-intrusive and non-destructive analysis of the organisms and particles in their natural environment, while still preserving their relative spatial distribution. High resolution, 3-d images of an underwater scene are recreated in the laboratory and located in the real-image space in front of the observer. Images are directly interrogated by measuring microscopy or video to extract information at any point in an individual plane of the image to give the dimensions, shape, identity and relative position of the particles. This ability to "optically section" the image is what sets holography apart from standard photography or stereo photogrammetry. Since a pulsed laser with a short pulse duration is used for the recording, the object scene is effectively frozen at the recording instant allowing even fast moving particles to be recorded. The spatial distribution and relative location of the particles can be analysed as well as the individual particles. Detail of around 10 μm can be resolved in volumes up to 10^5 cm^3. Since the holograms are recorded on photographic emulsion a permanent archive is obtained.

Holograms of aquatic systems will be recorded *in-situ* using a pulsed laser. The "HoloCamera" allows holograms to be recorded, simultaneously, with either an in-line (object in transmission) or an off-axis (object in reflection) holographic geometry. Although the recording of the holograms take place in water, replay of the image is carried out in air, in the laboratory, to provide identification and measurement of the organisms and particles.

- *In-line holographic recording*: A single laser beam is directed through the sample volume towards the holographic plate and records the optical interference between light diffracted by the object and the undiffracted portion of the illuminating beam. The replayed hologram simultaneously forms two images located on the optic axis; which for a collimated beam are at equal distances on either side of the holographic plate. The organisms are illuminated in transmission and the scene should have an overall transparency of about 95% so that speckle noise does not seriously degrade the image quality. This criterion sets an upper limit on the recordable particle concentration at around 40 particles cm^{-3} (for 20 μm diameter particles and a recorded depth of 1 m). There is also a need to balance the size of the particles with the object-to-hologram distance. The upper limit for good size measurement is about 1 mm for a recording distance of 1 m; however, particles down to around 5 μm dimensions can be identified and measured with ease.
- *Off-axis Holographic Recording*: A two-beam geometry is utilised. One beam illuminates the scene and the other directly illuminates the holographic film at a known incidence angle. Interference occurs between diffuse light reflected from the scene and the spatially separate reference beam. On replay, the real and virtual images are spatially separated which makes their interrogation easier. Off-axis holography is usually applied to, primarily, opaque subjects of large volume, making it better suited to recording of more dense aggregates of marine particles. The scene can be front, side or back illuminated (or some combination of all three). Although there is no real upper limit to the size of particles that can be recorded (this is determined by available energy and coherence of the laser) the practical lower limit to the resolution that can be acheived is about 100 μm.
- *Replay and Data Extraction*: After chemical processing to preserve the interference pattern, the holograms are replayed in air, in the laboratory, using the real image mode of reconstruction. The illuminating beam is the phase conjugate of the original reference beam used in recording. Holograms are replayed in either in-line or off-axis modes depending on how they were recorded. A video camera (with or without lens, as appropriate) is mounted on computer-controlled x-y-z stepper stages. The camera is translated through the image to extract information regarding shape, identity, dimensions and relative position. Image analysis and data extraction facilities allows species identification and measurement of local concentration of a variety of marine organisms.

SYSTEM CONFIGURATION AND SPECIFICATION

The complete HOLOMAR system consists of two parts: the holo-camera for recording of the holograms and the reconstruction facility for the replay, analysis and data extraction.

5. THE RECORDING SYSTEM (HOLOCAM)

Figure 1 shows the holo-camera layout and configuration (not all beam paths are in the same plane).

- *Laser*: The laser is a Q-switched, frequency-doubled Nd-YAG (Quantel) with pulse duration of less than 10 ns and output energy of 700 mJ. Output wavelength is 532 nm (green - chosen to coincide with the optimum transmission window of seawater), in a single longitudinal mode with a coherence length in excess of 2 m. The laser and optical baseplates are manufactured from the same aluminium alloy to eliminate any problems that may occur due to thermal expansion. The power supplies and cooling system are located beneath the main optical baseplate on a secondary base.

- *Optical Configuration*: The laser produces two output beams: one of 100 mJ and the other of 600 mJ energy. The output from the laser is linearly polarised, in a horizontal plane but transport through the beam steering mirrors effectively rotates this, so that holographic recording occurs with vertically polarised light. The 100 mJ beam is split into two roughly 50:50 beams at the beam splitter (BS). The straight through path forms the illuminating beam for the in-line mode and the reflected path forms the reference beam for the off-axis mode. Both beams are expanded and collimated using a Galilean-type beam expansion optics to a diameter of 100 mm (λ/8 wavefront flatness over the whole aperture). The in-line beam passes into the starboard arm before being directed through a window into the water, through another window and onto the hologram plate located in the opposite arm. All windows are high quality optical flats (λ/10). The off-axis beam passes through beam steering and path-length compensation assemblies, before collimation to form the reference beam. The off-axis beam is then folded at a mirror and is incident on the plate at 60° to the normal.

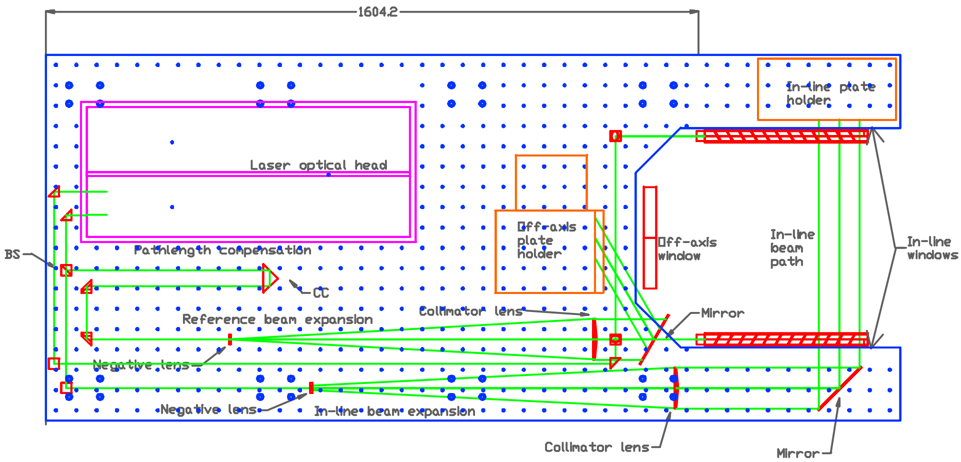


Fig 1: The Layout of the HoloCamera showing both in-line and off-axis paths

- *Subject Illumination*: The arrangement of in-line and off-axis holographic geometries allows simultaneous recording of partially overlapping volumes of water, to provide an element of cross-correlation between holograms. The in-line path records a water column of 500 mm by 100 mm diameter at 400 mm from the front face of the housing, whereas the off-axis hologram records almost the entire volume delineated by the front window to the end of the arms. For illumination of the off-axis volume, side illumination provides the best images when recording plankton. A novel "lightrod" has been devised to provide roughly even side illumination to the off-axis volume. This encompasses a hollow perspex pipe with 10 glass plates distributed equally along the length, positioned at 45° to the main axis. Each surface acts as a partial reflector, deflecting about 4% of the beam sideways into the object volume. The last plate is a totally reflector, which deflects the remainder of the light into the water. Three lightrods are mounted on the outside of the camera (two starboard, one port), with the 600 mJ laser output being split evenly between them.
- *Plate holders*: Two motor-driven plate holders and transport mechanisms were developed. For space reasons the off-axis holder will hold 25 plates and the in-line will hold 20. The glass plates are located in plastic frames and stacked in a detachable cassette. The plastic frames

protect the glass plates and provide a mechanical interface for the plate extraction and movement mechanisms. The cassettes ensure no exposure to stray light and allows the plates to be easily transported to and from the darkroom processing facility. The control sequencing is through software, running on the micro-controller system described below. One plate can be exposed every 10 seconds.

- *Electronic Control*: The Topside Control Console (PC) runs the main control program (a Windows based Visual C++ program) providing a user interface as well as displaying system information and storing data for each recording. A network of 3 micro-controller boards (Siemens C167CR) provides the backbone of the in-camera control system. Communication between topside and the camera modules is via a main umbilical using the CAN bus protocol. The first micro-controller board controls the laser (via a RS232 link) as well as thermally regulating the internal volume. The thermal control comprises a network of resistive heaters and temperature sensors to maintain the camera baseplate temperature at 20 °C (±1 °C). The second board relays data from the CTD sensors to the topside console and controls the motors for the in-line plate movement. The final controller operates the off-axis plate movement and monitors the humidity and tilt sensors.

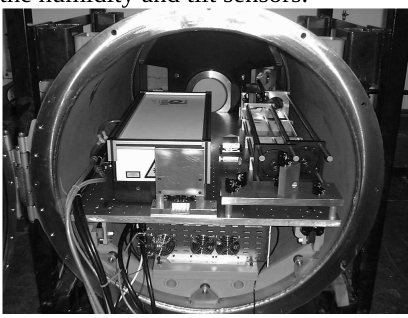


Figure 2 : Camera rear (inside)

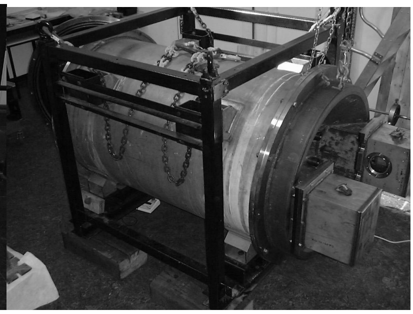


Figure 3: Camera housing

- Housing*: The entire camera is enclosed in a water-tight stainless steel housing and the overall dimensions are 1000 mm diameter by 2200 mm. The initial prototype system is capable of either ship deployment or attachment to a fixed buoy and will allow recording down to a depth of 100m. A CTD (salinity-temperature-depth) profiler is mounted on the frame together with a conventional video system to allow observation of the scene prior to hologram recording.*

6. The Replay and Data Extraction System (HoloScan)

Precision replay of the holograms is accomplished in a dedicated reconstruction facility comprising laser, reconstruction optics and image acquisition and analysis instrumentation.

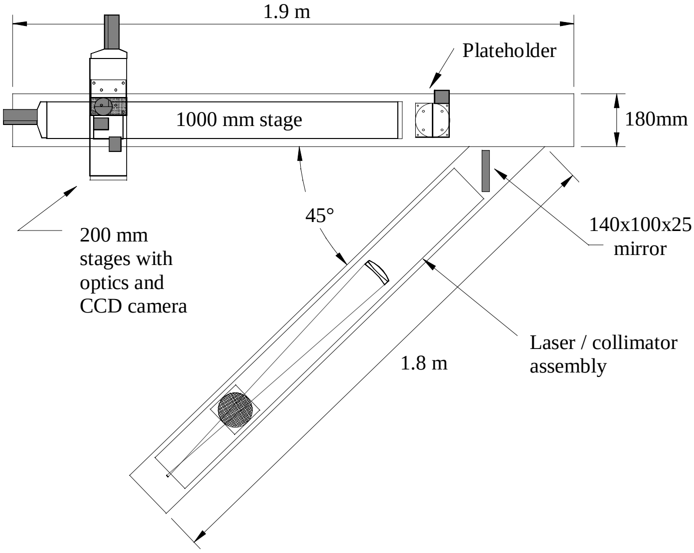


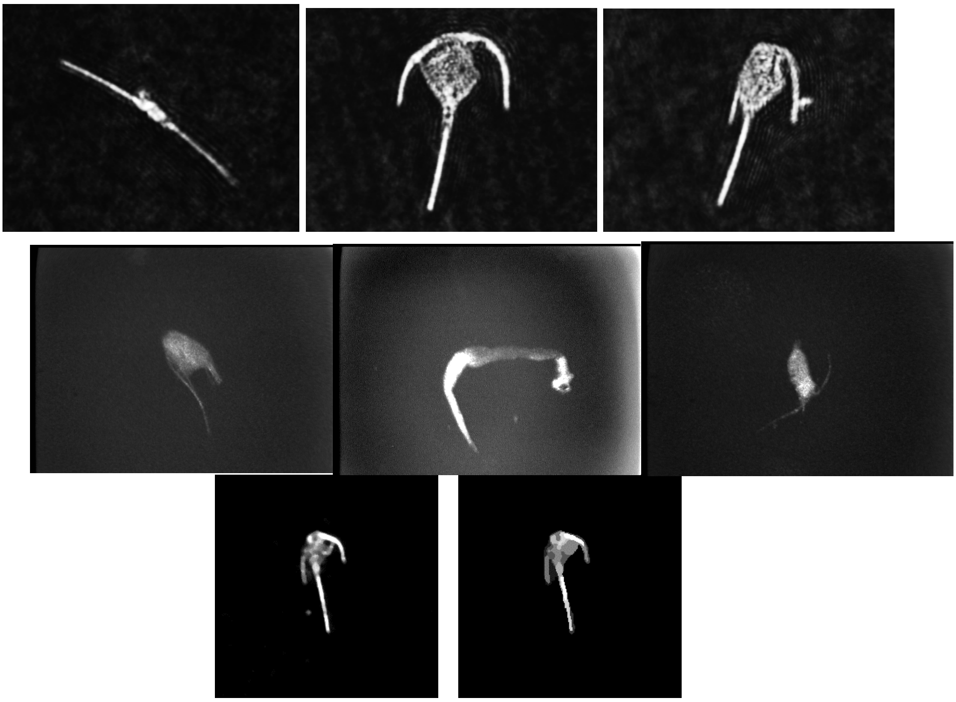
Figure 4: ‘HoloScan’ hologram replay machine (off-axis configuration)

- *Physical Layout*: Figure 4 shows a schematic of the replay system for in-line and off-axis modes. The replay laser (Kimmon 180mW 442nm HeCd) is mounted above the collimating optics (a reversed Galilean telescope producing a 100mm diameter beam flat to λ/5) along one arm. A set of computer controlled stepper-stages (Ealing DPS system, 1000 mm stage with 10 µm steps and two 200 mm stages with 5 µm steps) carrying a videocamera (JAI CV-M300 CCD) is mounted along the other arm. The plateholder is near the vertex end of the stage arm and it is possible to rapidly change the replay angle between the in-line (normal to plate) and off-axis angles. The video output is captured by a ITI PC-Vision frame-grabber and then processed to clean up the image and identify the true focal plane of each object within the 3-dimensional sample volume.
- *Scanning and Data Extraction Procedure*: The extraction of species distribution data is separated into three steps. Firstly, the videocamera is scanned through the depth of the sample volume (*z*) in a series of 0.1 mm steps. When the end is reached the camera is panned sideways before returning to eventually scan the entire volume. For each step, the embedded image processor receives the holographic images and processes them to clean up the noise, find plankton micro-organism and locate the true focal plane of each object within the volume. The system combines low (noise cleaning and image enhancement), middle (image segmentation, object localisation and tracking) and high level (3-d information extraction) processing modules that interact with a final high level module based on a neural net which allows species classification.

System Trials and Performance

The camera is in the final stages of construction. A large water tank is currently being fabricated which will encompass the front of the camera and allow completion of final laboratory testing before dockside trials take place in August/September 2000.

A series of photographs of reconstructed holographic images of preserved marine plankton may be seen in Figure 5. These were recorded in the laboratory in a Perspex tank using the camera’s laser and optical assembly. The top row of "raw" images are taken from in-line holograms (each image is 430 µm wide). The second row of "raw" images are taken from off-axis holograms (the organisms are of millimetre dimensions). The third row of images shows some processed images: the first is a noise filtered in-line image and the one on the right is post-segmentation in-line image.



III.1.4 Submarine geotechnics

TITLE : GROUTED OFFSHORE PILES FOR ALTERNATING LOADING: **GOPAL**

CONTRACT N° : **PL961178**

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IMPROVING CAPACITY OF OFFSHORE FOUNDATION PILES, THE GOPAL PROJECT

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ABSTRACT

The paper describes the GOPAL (Grouted Offshore Piles for Alternating Loading) conducted under the EC Mast Program. Innovative technology is being used to increase pile end bearing capacity substantially. Essentially, jet grout bulbs are installed beneath the tips of open tubular steel piles after driving. Field tests were performed at Dunkirk, France on 457 mm (18 inch) diameter piles in North Sea sands to prove the effectiveness of the technique. In parallel with this research, tension tests are being carried out on six plain driven piles to measure variations in shaft resistance with time, and also to examine cyclic loading effects.

INTRODUCTION

The GOPAL project is investigating a new technology to increase pile capacity in sands. Jet grout bulbs are created below the toe of conventional driven steel piles. The jet grouted "soil-cement" would classify as a sandstone of moderate strength and provides a substantial increase in pile end bearing. In parallel research, the project is also studying effects of pile ageing and cyclic loading in dense sands.

Motivation

Despite the industry thrust to ever deeper water and more extreme conditions, a large number of conventional platforms are still installed in shallow water. Many of these structures are standard steel jackets founded on driven pipe piles. In design, gravity and environmental forces act on the foundation pile giving both compression and tension loading. For typical designs compression loads are usually significantly greater than tension loads.

Piles resist applied loads by a combination of shaft friction and end bearing. Both components contribute to compression capacity while only shaft friction is developed in tension. As a result compression capacity is larger than tension capacity. To minimise pile length a balanced design would resist tension loads by shaft resistance and make up the difference between compression and tension loads through end bearing. Unfortunately, in most cases end bearing is not sufficient to meet this difference. Thus a significant portion of compression load must be taken by shaft resistance, requiring longer piles.

Solution

One solution to this problem would be to have stronger soils below the pile tip. Onshore, jet grouting is a proven soil improvement technique that is used to mitigate difficult foundation conditions. The main objective of this project is to investigate the potential of using this process to create a strong durable bulb of soil-cement below the pile tip, increasing end bearing and allowing a reduction in pile length.

The first step to develop this technology is to prove that it is possible to create a soil-cement bulb below the pile tip and importantly, to measure the increase in pile capacity. Grouting trials and load tests are being carried out on 457 mm (18 inch) diameter steel piles at a site in northern France. This paper discusses the jet grouting technique and field testing, and gives preliminary indications of five capacity increase.

Test Site

The field test site is located at Dunkirk on the northern coast of France on land made available thanks to the PORT AUTONOME DU DUNKERQUE authority. The area has been used for other pile load research in the past by the CLAROM group (Brucy et al., 1991) and previous tests by Imperial College (Chow, 1997).

JET GROUTING

Jet Grouting Method

Jet grouting is a ground improvement technique used to create an in-situ mass of grouted soil. The drillstring is advanced to the bottom of the grouting zone by rotary drilling. When the target depth is reached, a high pressure jet of cement grout is ejected horizontally from the drillstring. The jet cuts through the in-situ material, leaving behind a mixture of grout and soil. The drillstring is rotated and slowly lifted to form a soil-cement column. As the grout sets up, the material cures into a solid mass.

Double-fluid (grout and air) jet grouting was used. This system uses a concentric double tube drillstring carrying separate streams of high pressure grout and compressed air to the grouting head. At the ejection nozzle the horizontal grout jet is protected by a compressed air shroud to increase cutting energy, providing large column diameters.

Application of Jet Grouting Offshore

Jet grouting can be applied to piles offshore. In the particular case of platforms, a modified grouting rig can work from the jacket bracing or pile top. This rig will create the grout bulb by drilling through the open pile after driving but before the placement of topsides. A jet-grouted plug will be created inside the pile to ensure effective load transfer from the base to the pile steel. Initial estimates show that this work can be done without significant impact on construction times.

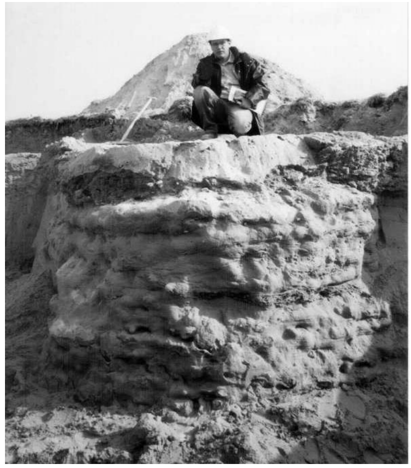


Figure 1: Jet grout bulb

Marine and near-shore construction also offer attractive applications for this technology. Harbour works, wharves, piers and bridges all could benefit from capacity increases with reduced pile lengths. In these cases the large number of piles required and longer time between driving and completion of the structure could provide even greater economic benefit.

Field Test

Field grouting trials were made at the Dunkirk site. The goals were a) to create shallow grout bulbs to determine feasible diameters and properties of soil-cement and b) to create a soil-cement bulb beneath a test pile. Six shallow bulbs were formed to evaluate the effects of grouting parameters on the size and strength of the bulbs. A soil-cement bulb was made below the test pile by drilling through the inside of the pile. After the base bulb was constructed, jet grouting was continued inside the pile, extending up to near the ground surface. This interior plug served to create an effectively closed-end pile bearing on the soil-cement base.

During execution all drilling and jetting parameters were continuously recorded. The jet spoil was collected for treatment, and was re-used for jetting on one of the bulbs. The cement content in the spoil was determined by means of a laser granulometer.

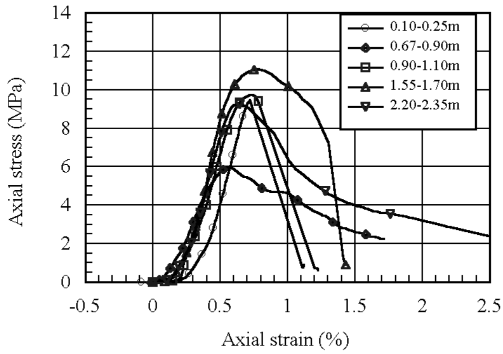
Fig.1 shows one of the shallow bulbs after excavation. Diameters of 2.8 m were obtained and the soil-cement was compact and high quality. As can be seen, the sides of the columns have distinct ridges left from the passage of the grouting jets. This irregularity would contribute to interlocking between the grout bulb and surrounding soil.

Laboratory Testing

After about 30 days of in-situ curing, samples were cored from the grout bulbs. The cores were subjected to an extensive testing programme at Imperial College, including high pressure (100 MPa) triaxial stress-path testing, chemical and fabric analysis, unconfined strength as well as typical index testing (moisture content, specific gravity, unit weight, etc.). Data from the cores were complemented by a parallel testing programme on laboratory prepared specimens examining effects of cement/water and cement/sand ratios on strength and soil-cement-steel interface friction and bond capacity.

As one example, Fig.2 shows the variation in unconfined strength with depth and radial distance from the centre of a grout bulb. While there is scatter of about ±30% about the mean in the strength data the soil-cement is very strong. In fact, the jet grouted sands would qualify as a sandstone of moderate strength.

Representative stress-strain curves from unconfined compression tests are given in Fig.3. This series shows samples from various depths in one shallow grout bulb. Note that the soil-cement fails in a brittle mode. The failure strain is of the order of 0.5% and there is a considerable strength loss between 0.5 and 1.0% strain. This feature must be accounted for in design.



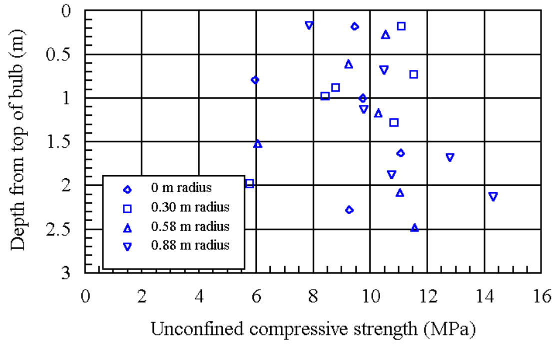


Figure 2: Radial variation of unconfined strength in jet grout bulb

Figure 3: Unconfined compression tests on soil-cement cores

Pile Load Tests

Load tests were carried out on 457 mm diameter (18 inch) driven steel pipe piles at the Dunkirk site. The tests were load controlled with 15 to 20 increments applied with pause periods of at least 30 minutes between increments. The increment sizes were reduced and pause phases extended towards the end of the tests. Following this procedure, each load test took up to 24 hours to perform. Three main test series were performed.

Capacity Increase from Jet Grouting

Compression tests were carried out on two 10 m long piles. One pile had a nominally 3 m diameter 5 m high soil-cement bulb formed at the tip and the other was an untreated control pile. The piles were loaded to failure in compression. The compressive pile capacity was doubled by the GOPAL treatment.

Evolution of Shaft Resistance with Time

There is considerable evidence that pile shaft capacity in sands increases with time (Chow et al., 1998). To continue this research, tension tests were performed on the GOPAL reaction piles. Tension tests were made on previously untested piles at 9 and 80 days and 7 months after installation. Combining this with previous data from the CLAROM study gives a total of 5 tension tests on previously unfailed piles and 5 tension tests on piles which had been previously tested to failure.

CONCLUSIONS

The following conclusions can be drawn from the GOPAL field programme:

- The feasibility of forming an artificial sandstone soil-cement bulb of up to 3 m diameter at the base of a driven steel pipe pile has been demonstrated.
- Pile load tests have been performed on a 457 mm (18 inch) pile with a jet grout formed base and an identical control pile.

- A major characterisation programme has been carried out on laboratory prepared and field cored jet grouting samples. Illustrative results have been presented in this paper.
- The field research into jet grouted pile behaviour has been integrated with a study of pile ageing in sand and cyclic loading effects.
- The study of ageing effects on driven piles gave results which are broadly compatible with previous research2,3. The cyclic loading experiments confirm the potential for substantial cyclic degradation of capacity identified in earlier studies by Imperial College at Dunkirk and other sites2,3.
- The GOPAL treatment approximately doubled compression capacity of the test pile. The method appears to have strong potential applications both offshore and onshore.

ACKNOWLEDGEMENTS

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TITLE : VERY HIGH RESOLUTION MARINE 3D SEISMIC METHOD FOR DETAILED SITE INVESTIGATION : **VHR3D**

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VERY HIGH RESOLUTION MARINE 3D SEISMIC METHOD FOR DETAILED SITE INVESTIGATION

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INTRODUCTION

The project is aimed at a cost-effective detailed 3D reconnaissance of seabed sediment properties for geotechnical and geological site investigation purposes. It involves two main objectives. The first objective is the development of a very high resolution 3D seismic method to be used for small-scale (100 m x 100 m) as well as intermediate-scale (1 km x 1 km) sites. The second objective is the extraction of geotechnical information from the 3D seismic data and the creation of a 3D physical model to the subsurface.

Given the variation in scale of the target sites, the acquisition task (**Task 1**) was involved in two different approaches. (1) Redimensioning and marinisation of an existing rigid 3D-field system for small-scale site surveys involving shallow water (up to 30 m). (2) Development of a flexible 3D-field system for intermediate-scale site surveys involving deeper water (up to 100 m).

Several attempts to achieve 3D Very High Resolution seismic surveys were carried out during the first two years of the project. Whereas seven selected european sites have still to be surveyed, three 3D VHR seismic data sets were successfully acquired in the framework of **Task 2** (Rhone Delta, Strait of Dover and St-Austell Bay).

Paying attention to the frequency content of the seismic data, specific 3D processing techniques have to be developed in order to correctly position the seismic events and to prepare the data for the extraction of geotechnical information (**Task 3**). In order to obtain optimal 3D imaging, pre-stack migration was applied on the data sets previously acquired. The final 3D image of the subsurface underlines the validity of the proposed acquisition and processing scheme.

A subset of the acquired seismic data will be treated for seismic attribute extraction (**Task 4**). Velocity analysis will be performed on additional « long offset (100 m) » 2D multichannel data. Determining the attenuation (Q-factor) will be carried out using the spectra ratio method. The recovery of acoustic impedance will require the use of seismic inversion techniques. Additional laboratory measurements will provide supplementary information to help assess the validity of the inversion (**Task 5**). Based on the information from the seismic attributes, and on the inter-relationships between geotechnical and acoustic properties, a 3D model of the physical and geotechnical properties of the study site will tentatively be proposed.

The project offers large technical potentiality and cost benefits to the offshore site investigation industry, including rig-site surveys, dam-site surveys, dredging operations, etc. Preliminary industrial market study performed within **Task 6** underlines its interest in the development of this new technology.

SEISMIC AND POSITIONING STRATEGY

Development of a 3D compact acquisition system
A new compact VHR 3D seismic acquisition system has been developed by RCMG for small-scale shallow studies. The system consists of a total of 8 dual-channel streamers (2 m channel spacing) attached to 6 modular floating "frames" joined by a central rubber boat. The seismic source, the Seistec, a wide band electrodynamic boomer is towed from the zodiac.

Development of a 3D compact acquisition system
The 3D flexible acquisition system (IFREMER) includes 4 streamers (6 traces each, 2 m spacing between traces). Concurrently to further theoretical studies addressing the design of divergent panels in the framework of seismic VHR surveys, Ifremer has developed "swinging booms" in order to handle its 3D seismic array. Whereas divergent panels are well adapted to handle large streamer spacing, their use becomes questionable for small-scale studies.

Positioning strategy
The success of any water-borne VHR 3D seismic method depends on highly accurate positioning of both source and receivers. One of the shortcomings of laser auto-tracking systems, is its restricted distance to the shore (between 100 and 500 m). Recent improvements of differential Global Positioning systems (GPS) allow much greater while offering the same accuracy (dm accuracy for the antenna). Addressing 3D VHR seismic measurements using a flexible system, real time positioning can be carried out using standard D-GPS technology. In the meantime, raw GPS data are collected both onboard the vessel and on land based station. Dedicated software allows the post-processing of the former data and therefore to obtain the desired accuracy.

Several sea-trials as well as site surveys have allowed to successfully qualify the proposed approach.

DATA ACQUISITION AT SEA

A wide scope of sites have been surveyed during the project, each site having a specific characteristic to illustrate the different possible applications of 3D VHR seismic technology: geotechnical, environmental and geological applications.
Paardenmarkt (Zeebrugge harbour, Belgium)
Toxic waste dumping site, marked by a strong lateral variation in facies and reflectors.
Schelde river (Antwerpen, Belgium)
A small clay diapir under the river Schelde in Antwerpen, water depth less than 10 m.
Rhone Delta (Gulf of Lions –Western Mediterranean Sea, France)
Highstand / lowstand sequences (late Quaternary, Holocene) marked by strong impedance contrasts.

Monaco harbour (France)
A very complex 3D structure marked by a strong sloping morphology, dipping bathymetry and highly variable geology.
Boulogne (Dover strait, France)
Failures zones in late Jurassic formations.
Liverpool bay (United Kingdom)
A complex Quaternary stratigraphy, marked by laterally and vertically highly variable glacial and post glacial deposits including buried channels and infill sequences.
Saint Austell bay (Cornwall, United Kingdom)
Buried channels and bedrock outcrops, 20 m waterdepth

3D DATA PROCESSING

Given the very high frequency content of the seismic data, the positioning of shot and receivers points has to be addressed accurately prior to any 3D seismic processing. The acquisition geometry is handled using floating "frames", divergent panels or swinging booms. Variations of vessel's speed and currents result in highly variable acquisition geometry with respect to the required accuracy (one meter in x, y position). Thus, this relative geometry is estimated at each shot using the direct source-receivers travel times. The vertical position of the acquisition system has also to be corrected from the tide (a tidal gauge is moored near the survey area) and from the swell.

The pre-processing of the seismic data consists in amplitude normalisation, mute of the water column, frequency filter and multiple attenuation. Then the major seismic processing step is the imaging performed by a 3D pre-stack depth migration using a Kirchhoff like algorithm. This method has proven its efficiency to take into account the real positions of sources and receivers, and to overcome the irregular spatial distribution of the recorded data. The final result is a 3D depth seismic cube regularly sampled with a typical bin size (x , y , z) of (2 , 2 , 0.25) metres.

EXTRACTION OF SEISMO-ACOUSTICAL PARAMETERS

Additional 2D VHR multichannel data (offset up to 100 meters) helps to constrain the velocity model. Tomographic inversion of the 3D seismic data allows to access the main characteristics (velocity and geometry) of the shallowest layers. However, the short offsets of the 3D system make the inversion unstable for deeper horizons.

The Q factor of the sediments will be deriving from the estimation of the amplitude attenuation using the spectra ratio method. For this purpose, an accurate travel times algorithm based on ray-tracing has been developed to perform true-amplitude migration.

This true amplitude recovery and wavelet processing are mandatory pre-processing to estimate acoustic impedance values from seismic data. This estimation will be performed by seismic inversion techniques which will be constrained by additional laboratory measurements on cores samples.

GEOTECHNICAL / PHYSICAL MODELING

Laboratory measurements provide additionnal information to help assess the validity of the inversion.
Laboratory analysis of the Monaco samples has concentrated on measurements of contained cores in order to provide supplementary data prior to extrusion from the barrels. Combining the compressional waves and apparent density data has allowed the generation of acoustic impedance profiles for all the collected cores.
The gravity cores taken in Liverpool bay were initially logged for acoustic velocity by transmission of an ultrasonic pulse across the contained cores. The cores were then tested for a number of geotechnical parameters including moisture content, pore water salinity, particle size distribution, bulk density, shear strength, Atterberg limits, content of organic matter and calcium carbonate, and grain specific gravity.
Based on the information from the seismic attributes, and on the inter-relationships between geotechnical and acoustic properties, a 3D model of the physical and geotechnical properties of the study site will tentatively be proposed.

EXPLOITATION OF RESULTS AND MARKET POTENTIAL

The objectives of market analysis was to develop a marketing plan that will ensure the maximum market exploitation for the VHR3D methods including the identification of which organisations to approach, a pricing policy and the particular types of services to offer.

The chosen method of market analysis was based on a three stage approach and the organisations were divided into two types: contractors and end-users. The “contractors” were defined as being those companies who would be likely to buy the system : methodology and to provide the service, and the “end-users” would be those organisations who would buy in the services of the contractors.

The first stage of the analysis involved identifying and producing potential client contact lists, for both contractors and end-users (this list also included academic and research institutions).
The second stage was to approach all the contact and to investigate their reactions and opinions on VHR3D.
The third stage of the market analysis which followed receipt and collation of the questionnaire results was to make follow up telephone calls to a cross section of the respondents which provided industry sector and world wide coverage.

The common feeling of the **contractors** was that the system sound interesting but has limited/targeted applications or niches. However the method could be applied in numerous sectors. This type of technology/methodology probably has a long way to go to be accepted and regularly used as current technology. It is a common feeling that technology needs to be constantly moving forwards. However, there are certain problems for which this type of system would be useful. Theses problem includes high lateral variability, with reference to pipe route survey, boulders and their accurate positioning, offshore bank systems, e.g. offshore Ireland, offshore wind generator pylons, glacial sediments and rough seabed, unstable sediments (slope).

End-users highlighted the current, relatively ineffective, pipe route survey practice where areas are swamped with geotechnical sampling. This could potentially reduced by more reliance on geophysical data and particularly where features can be accurately positioned and there is reliable sediment classification. However, the general consensus was that the VHR3D would have to be cost-effective and proven.

Most interest in the system came from the academic/research based institutes who have lots of ideas for potential applications.
Where the 3D project is of interest also is the geophyscal/geotechnical integration and extraction of geotechnical properties.

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TITLE : ADVANCED ROV PACKAGE FOR AUTOMATIC INSPECTION OF SEDIMENTS : **ARAMIS**

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ARAMIS,
A NEW SYSTEM FOR ROBOTIC INSPECTION OF SEDIMENTS, HAS SUCCESSFULLY COMPLETED THE FIRST TEST CAMPAIGN

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SUMMARY

There is an increasing demand by the scientific community for a mobile scientific platform capable of automatically obtaining samples of, for example, water and sediment, and of carrying out accurate quantitative photo and video transects. To address both the needs of state of the art scientific investigations and to improve the efficiency and economy of data collection, an innovative system, ARAMIS (Advanced ROV package for Automatic Mobile Investigation of Sediments), has been developed with the support of EC MAST III program. ARAMIS is a scientific and technological package, to be integrated with typical mid class existing ROV's. The ARAMIS+ROV system is aimed at providing a highly automated scientific tool for carrying carry out multidisciplinary missions. Such capabilities have been demonstrated by a first test campaign of the system, carried out in protected waters.

INTRODUCTION

There is an increasing demand by the scientific community for a mobile scientific platform capable of automatically obtaining samples of, for example, water and sediment, and of carrying out accurate quantitative photo and video transects. In particular, the possibility of actually inferring accurate and real-time dimensional information from TV pictures with the capability for absolute size measurements is deemed extremely valuable.

Up to the present day the majority of marine measurements (chemical, biological and physical) is taken by remote sampling techniques, i.e. by deploying the sampling devices directly from the surface. These techniques have inherent problems, such as: they are inefficient, sampling cannot be precision related to an underwater feature, is not repeatable, and can have a high degree of impact on the environment.

The employment of Remotely Operated Vehicles (ROV's) potentially alleviates such drawbacks. Indeed, the scientific community has been using ROV's for the past 20 years, but these have been mostly with 'off-the-shelf' models and very few have been adapted for specialized sampling.

To both address the needs of state of the art scientific investigations and to improve the efficiency and economy of data collection, an innovative system, ARAMIS (Advanced ROV

package for Automatic Mobile Investigation of Sediments), has been developed with the support of EC MAST III program.
This paper provides a synthetic description of the ARAMIS system and of its subsystems and of the first demonstration trials carried out.

THE ARAMIS SYSTEM

ARAMIS is intended to be easily integrated with typical mid class existing ROV's, providing a highly automated scientific tool for carrying carry out multidisciplinary missions. Capabilities include samples from the water column and sediments, multidirectional instrument profiling and quantifiable imaging.
The ARAMIS system consists of two parts:

- a suitable skid to be installed under the ROV
- a control console to be interfaced with the vehicle surface controller.

The skid itself includes:

- a core skid for missions with ROV's in the medium size class
- a large skid, including the core skid and additional equipment, for mission with ROV's in the large size class.

The ARAMIS skid has been designed to be modular allowing for different instrument configurations or even new suites of sensors in the future.
The core skid features, at the moment, two configurations:

- pelagic - for missions in the water column
- benthic - for missions near the bottom.

Fig. 1 provides a conceptual view of the underwater equipment in the large skid, which is equipped for both configurations. The large skid is partly derived from the experience gained in previous scientific research activities ([1]).
The resulting system (ARAMIS+ROV) allows the pilot/scientist to command easily in real time both the ROV and the scientific instruments/tools and thus to carry out the scientific mission in an efficient, reliable and repeatable way. In more detail, the system capabilities include:

- scientific capabilities in terms of data acquisition:
- automatic water physical and chemical profiles (CTD, Dissolved Oxygen, Transmissiometer, Fluorometer)
- automatic sea water sampling
- automatic sediment sampling
- physical and chemical sediment profiles (temperature, pH, H_2S, oxygen)
- micro-bathymetric mapping for geological and morphological analysis of bottom
- quantitative and dimensional video transects via processing of stereo TV images
- visual analysis of sea floor features through automatic image processing techniques.
- technological capabilities, in terms of navigation functions:
- automatic swim to a position
- automatic station keeping
- automatic navigation along a transect at a given bottom distance
- automatic landing on the sea bottom to take samples
- automatic obstacle detection and avoidance.

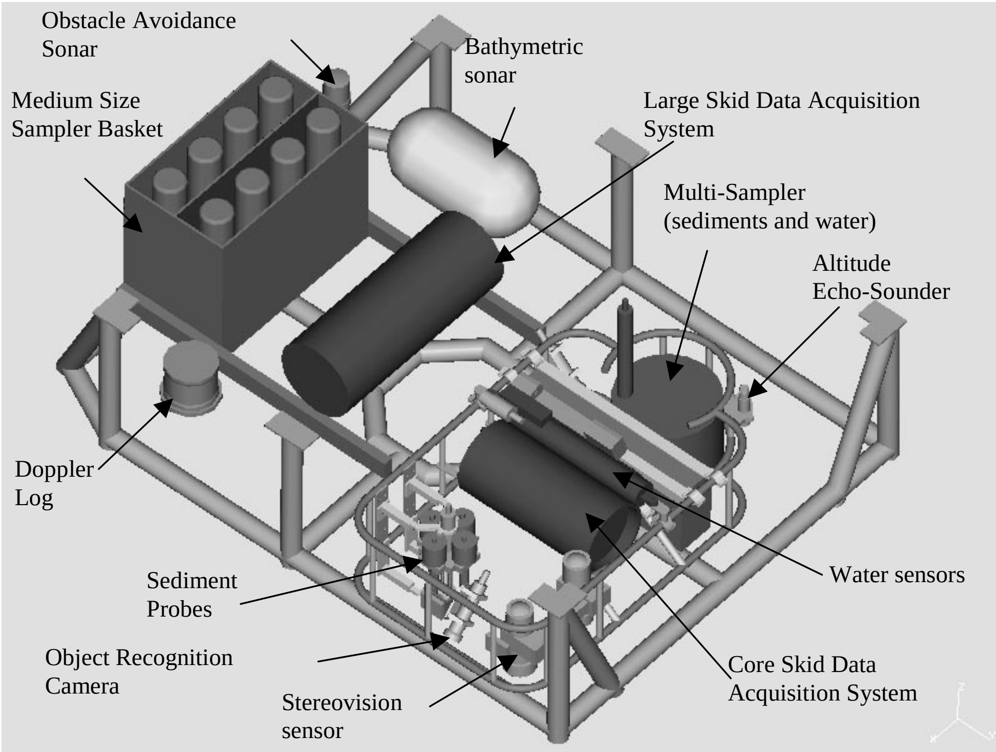

Fig. 1 Conceptual view of the ARAMIS large skid

The most outstanding features of the system can be identified as:

- availability of a quantitative imaging system, adapted from an existing a stereovision sensor [2], in place of more common, indirect, image scaling techniques based on laser spots: the on-line processing of stereo images allows for interactive measurement of bottom features (e.g. sizing of megafauna, density measurements of some species)
- capability to land on the sea bottom to take sediment cores and to perform physical and chemical sediment profiles
- capability to take physical and chemical profiles and replicate water samples at specified positions in the water column
- capability to automatically detect “interesting features” of the bottom by processing TV images
- capability to perform bathymetric survey of the bottom
- user friendly MMI (Man-Machine Interface) to program a mission as a sequence of operations of the ROV and of the instruments
- computer controlled ROV navigation (see e.g. [3]), based on various localization means (Long Baseline, relative position measurements, dead reckoning), with automatic avoidance of obstacles on the path (for a description see [4]); the relative position measurements are provided by the stereovision sensor mentioned above for the quantitative imaging, through its visual tracking capabilities.

The operation of ARAMIS

The typical Mission Profile of ARAMIS includes:

- deployment from vessel
- mission execution
- recovery to support vessel

All these operations can be automatic (by autopilot) or manually controlled by the ROV pilot.

A set of reference missions has been defined. Such a set is summarized by the table below, showing the scientific equipment involved in each mission.

The benthic missions have been further classified into:

- Survey 1: off bottom high survey mission (5-200 m above bottom)
- Survey 2: off bottom low survey mission (1 m above bottom)
- Survey 3: on bottom survey mission (0-1 m above bottom)
- Sample: sediment sampling mission.

	Pelagic Mission		Benthic Mission			
	Large Skid	Core Skid	Large Skid		Core Skid	
Subsystem			Survey 1	Survey 2	Survey 3	Sample
Water Sensors	X	X	0			
Water Sampler	X	X				
Bathymetric Sonar	0		X			
Quantitative T.V.	0		X	X	X	X
Obs. Rec. Cam.	0		X	X	X	
Sediment Probes	0		X	X	X	X
Small Sed. Sampler			X			X
Med. Sed. Sampler	0		X			

0 denotes "optional"

The system development and test campaigns

The ARAMIS system has completed the development phase. The demonstration test campaigns of the systems are to be completed in the course of the year 2000.

The first tests (large skid) were carried out in the Toulon Harbour (fig. 2), in May-June 2000. The ARAMIS large skid was integrated with VICTOR, the large size ROV provided by the partner IFREMER. This first phase of tests has allowed for in depth technical testing prior to scientific mission testing.

The second set of tests highlighting scientific practicality will take place in Crete in the Aegean Sea based on the IMBC research vessel Philia. In this case the ARAMIS core skid will be fitted under ROMEO, the medium size ROV provided by the partner CNR-IAN.

Several mission scenarios have been planned, although the programme is not fixed to allow for flexibility with respect to the weather. The primary objective is the mission scenarios is the active hydrothermal vent and seep areas near the island of Milos.

Fig. 2 The ARAMIS tests in Toulon, in May-June 2000. The ARAMIS large skid is fitted under the VICTOR ROV made available by IFREMER

RESULTS OF THE TEST CAMPAIGN

The test campaign in the Toulon harbour has just been completed. A huge database has been collected for accurate analysis in the next few months.

As a general remark, it can be anticipated that the conducted test campaign has demonstrated the technical feasibility of an integrated and multidisciplinary mission by a robotized ROV. Some of the operations successfully performed during a single ROV dive include:

- automatic execution by the ROV of a complex transect, preliminarily programmed through the system MMI
- detection of obstacles along the ROV path and automatic avoidance
- collection of water samples

- ROV landing on the sea bottom to collect small and medium size cores of sediments and to perform sediment profiling with sensor probes.
- quantitative imaging of objects lying on the sea bottom
- bathymetric survey of the bottom
- collection and recording of CTD sensor data during ROV navigation.

The gathered data have been stored in an organized database correlating the ROV navigational data to the scientific data.

CONCLUSION

The main features of ARAMIS, a highly automated scientific tool for carrying carry out multidisciplinary missions have been presented.
It is deemed that, thanks to its powerful combination of scientific and technological capabilities, ARAMIS is going to represent a breakthrough in the European oceanology research field.
The first test results confirm such expectations.

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TITLE : A UNIVERSAL DOCKING – DOWNLOADING - RECHARGING SYSTEM FOR AUVS **: EURODOCKER**

CONTRACT N° : **MAS3-CT97-0084**

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EURODOCKER – A UNIVERSAL DOCKING – DOWNLOADING - RECHARGING SYSTEM FOR AUVS

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SUMMARY

The EURODOCKER project has the objective of developing an unmanned support system for autonomous underwater vehicles (AUVs), to permit docking, data downloading and battery recharging activities to be carried out underwater. This system shall overcome two of the principal current restrictions to the use of AUVs, tied to their limited independence from expensive surface support, and the risks of loss or damage inherent to continuous surface launch and recovery operations.
The solution developed entails a submerged docking station for AUVs, that may be deployed either as part of an unmanned underwater platform on the seabed or lowered from a support ship from the surface. The system developed shall be suited to various AUVs that are now under successful development and aims at becoming a standard subsystem of any AUV support spread.
This project, supported by the EC MAST programme, is a joint RTD venture by five Partners: Maridan AS (DK); The Institute of Automation IAU at the Technical University of Denmark (DK); Studio Tre Ingegneria (IT); Orca Instrumentation (FR); and the Underwater Technology Centre of IW at Hannover University (DE) which is also the Co-ordinator. The project started in December 1997, and is due to end in November 2000.
Following an extensive market analysis to determine both the state of the art and specific AUV docking requirements, the solution selection and design activities have been completed. These covered the docking garage concept, launch and recovery, the homing procedure in term of both localisation and guidance, dynamics and control, and connector aligning and latching. Construction is now well advanced and the main components have already illustrated their efficiency in dry and wet tests at the IW laboratories.

INTRODUCTION

The EURODOCKER concept provides a universal autonomous Docking - Downloading - Recharging System for Autonomous Underwater Vehicles (AUVs).
This system overcomes the current restrictions of AUV’s, namely operative range due to limited energy storage capacity, and the repeated launch and recovery operations necessary to get the vehicle onboard the support ship. A submerged docking station for AUVs, either as part of an unmanned underwater platform on the seabed or lowered from a support ship from the surface, is a suitable means to solve these two problems.

OPERATIVE SCENARIOS

The following operative scenarios have been identified in which the EURODOCKER is envisaged to be used.

Operative Scenario 1 - Ship support at any water depth

The first Operative Scenario is based on the manner in which AUV's are currently operated, and therefore foresees the use of the EURODOCKER as a support to AUV's that are deployed and recovered from dedicated or chartered ships. It shall have the advantage of not requiring a launch and recovery operation for each mission, and thus the AUV may perform repeat missions without the requirement to be recovered on board the ship.

Operative Scenario 2 - Open water missions from Coastal waters

In the second scenario identified the EURODOCKER shall be placed on the ocean floor and not be deployed from a ship. The AUV shall treat the EURODOCKER as a subsea home base from whence it shall emerge to perform its mission, and to which it shall redock at the end of the mission for data downloading and recharging. This scenario shall permit the AUV's to perform repeat missions over a significant period of time without the necessity to recuperate to the surface or to have a costly vessel in support.

Operative Scenario 3 - Ice infested waters

The development of AUV's and their docking systems are considered essential 'technological packages' for the exploration and exploitation of Arctic and Antarctic waters. Within this scenario therefore the EURODOCKER would be placed on the seabed much as in scenario 2, however in this case in an area with periodic or permanent ice pack above it. The main advantages shall clearly be obtained from the cost saving tied to the use of expensive icebreaker vessels, and the vastly lengthened time that the AUV's can operate.

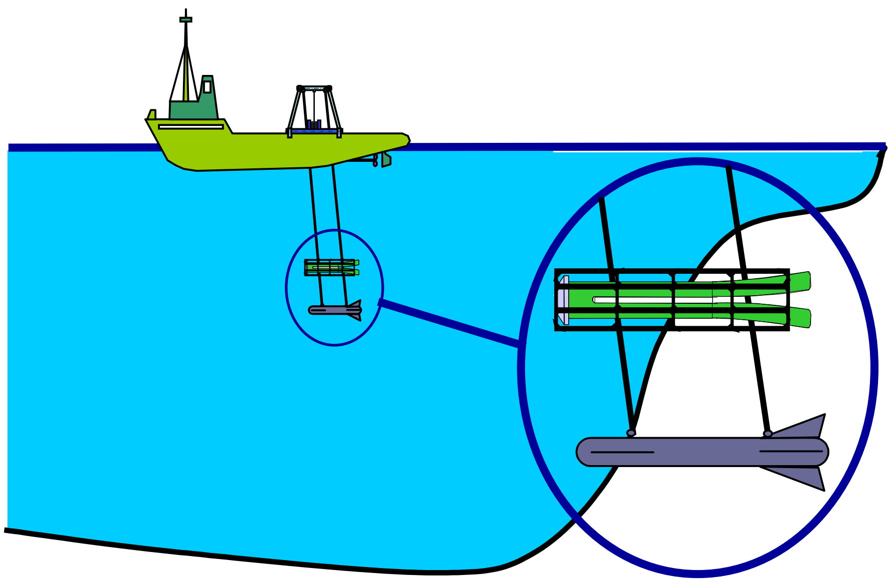

Fig. 1: Operative Scenario 1 – ship supported version

RESULTS: EURODOCKER SYSTEM DESCRIPTION

Homing System:
The long distance tracking of the AUV's, as assistance to or in back up to the on board navigation and positioning system, is performed utilising four GPS-LBL (Global Positioning System - Long Base Line) buoys for first circle re-entry. For scenarios in which the homing shall be performed under the ice, the buoys shall not be available and therefore a LBL (Long Base Line) system with a set of repeater stations shall be placed on the sea floor in the area of the EURODOCKER system.
Once the AUV is within 50 metres from the EURODOCKER an acoustics system for close range tracking is utilised to assist in guiding the AUV into the EURODOCKER. The acoustics solution consists of an USBL (Ultra Short Base Line) system, which is suitable for the close range approach. This narrows the position accuracy typically to * 20 cm, at a rate of 2-4 fixes per second. The USBL may be that of the AUV if it is already part of its equipment or may be on board the EURODOCKER. In this latter case the AUV shall carry only the transponder part of the system. The navigation of the AUV into the EURODOCKER is based on a passive role for the EURODOCKER system. This means that the AUV shall maintain navigation control but shall receive information on its position relative to the docking component from the EURODOCKER system.
AUV Mating and Release system:
The mating and release system is characterised by the following operative functions:

- fine guidance during docking;
- the manner in which the AUV is protected during docking and launch and recovery;
- the system for connecting the electrical connector to the AUV;
- and the manner in which the AUV is released for its next mission.

These aspects have led to the selection for a garage system as described below.
Garaging system:
The release and expulsion of the vehicle from the garage is performed by permitting the garage structure to open up or down (respectively when sea bottom or ship supported) so that the AUV can swim away under its own power.
The Launch and Recovery system
The Launch and recovery system is characterised by the use of guide wires and a dead weight, in order to reduce the horizontal motions of the EURODOCKER while crossing the splash zone. In this way the L & R system is compatible with sea state 4 without active systems.
The launch and recovery system satisfies the following operative requirements:

- Deployment of the garage to sea level on the lift wire, following which the garage is stopped via a variable buoyancy system and the lift wire made slack.
- The garage then continues its decent autonomously (in a negative configuration controlled by the variable buoyancy) down to the established depth.
- The lift wire shall be shackled to one of the guidelines every 10 meters to ensure it does not tangle.
- In order to return to the surface lift tanks are inflated from dedicated air bottles located on the garage.
- Once the garage is at its operative depth it can rest on suitable landing bumpers placed on the dead weight.
- When the AUV commences its homing procedure the garage can be brought up to a suitable distance above the dead weight, say 10 m, utilising the variable buoyancy system.

A more complete description of the EURODOCKER garage system is given below.

The **Support Structure** is characterised by the following:

- It is an open lattice structure.
- It is constructed in tubular members that are sealed to limit weight in water.
- Material for the structure is robust to ensure damage does not occur.
- A suitable corrosion protection system must be foreseen.

The **Bumper system** is characterised by the following:

- It is shaped so as to provide a conical entry point into the garage.
- It is lined with low friction material at the contact points.
- It is connected to the structure with elastomeric elements.
- It performs braking of the AUV within the garage.

The **Permanent buoyancy system**:

The actual weight/net buoyancy of the garage in water is the minimum necessary to guarantee that the garage shall descend down the guidelines under the force of gravity at a moderate velocity of * 0,2 m/s.

The EURODOCKER garage is composed of steel beam members that are sealed and therefore have a limited weight in water. The desired weight is achieved by use of suitably distributed permanent buoyancy elements and lead weights if necessary.

The **variable buoyancy system** (required only for the ship-supported version) shall:

- ensure that the garage shall float during the first phase of the launch operations down to the level of the water.
- permit the garage to descend under its own weight to the dead weight.
- raise the garage to a height of about 10 m above the dead weight.
- maintain a neutral position during the docking phase.
- return the garage to the surface for the recovery operations.

The **Mechanical block**, that:

- ensures that the AUV cannot accidentally be dislodged from the garage once it is docked.
- provides the positive reference position that shall permit the Power and Signal connector to be actuated.
- is an automatic system that is activated when the AUV enters the garage.
- permits the AUV to be released easily by the release system utilised.

The solution selected is a pin and groove system, due to its simplicity and ease of construction. The pin is provided by a dedicated fin that is placed on the AUV.

The **Power & Signal Connector** is suitable for relocation along dedicated rails within the EURODOCKER structure. The connector mating system is able to bring the plug of the connector into contact with the receptacle placed on the AUV within the tolerances that the connector system itself can cope with.

The **Umbilical system** has been specified as a typical, integrated, dynamic umbilical. It shall contain all the power and signal lines that are required between the garage and the surface. These is contained within two polyurethane sheaths, interspersed by a two contra-helically wound armour wires.

BOTTOM SUPPORTED SYSTEM

For the bottom supported system the solution that has been identified is for the use of the same garage described for the ship supported version, turned upside down and anchored to the sea bed via an anchor line. The anchor line is attached to a structure placed on the seabed.

THE PROTOTYPE

The Construction of the EURODOCKER prototype is well advanced and the main components have already illustrated their efficiency in dry and wet tests at the IW laboratories in Hanover, Germany. The system will finally be demonstrated under real environmental conditions in Denmark.

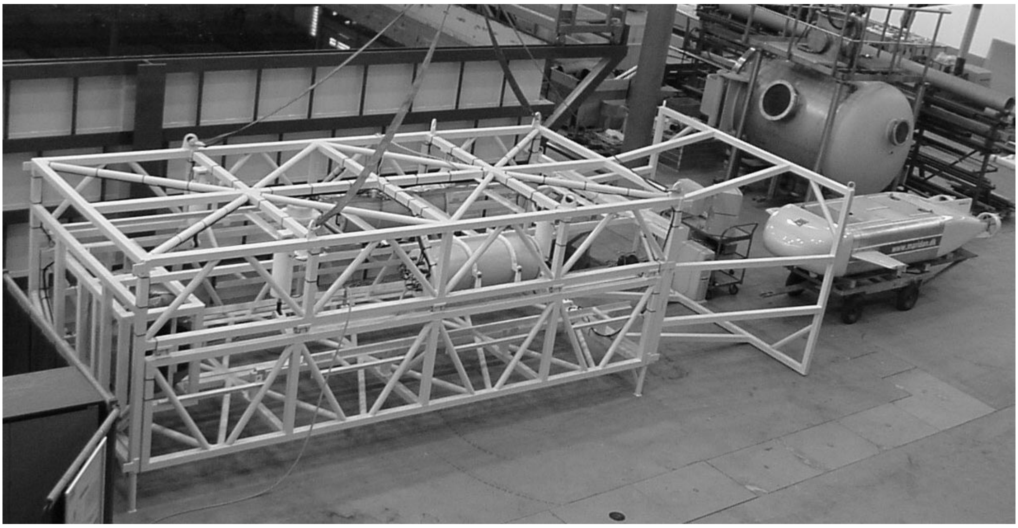

Fig. 2: EURODOCKER prototype with AUV “Martin”

CONCLUSIONS

The EURODOCKER project aims at the design, manufacture and testing of an underwater docking system for AUV’s. Its successful development will permit the exploitation of the enormous possibilities offered by AUV technology, ultimately resulting in cost effective underwater research, surveying and monitoring.

The EURODOCKER project is not tailored to a specific AUV, but shall be suited to the wide set of vehicles now under successful development, although Maridan’s Martin AUV has been taken as reference and shall be utilised for the tests. The end result of a viable Data Down Loading and Recharging system shall be obtained through the development of all the necessary technologies to permit the connection of the AUV underwater, including: homing, garaging, mating and launch and recovery.

ACKNOWLEDGEMENTS

The authors, on behalf of the whole EURODOCKER partnership, wish to express their gratitude to the Directorate General XII of the European Commission for the appreciation and final support of this project under the MAST III programme.

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TITLE : LIGHTWEIGHT COMPOSITE PRESSURE HOUSINGS FOR MID-WATER AND BENTHIC APPLICATIONS : **COMPOSITE PRESSURE HOUSINGS**

CONTRACT N° : **MAS3-CT97-0091**

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OBJECTIVES:

The aim of the project is to advance European capability in the design and manufacture of pressure resistant structures using fibre reinforced plastics (FRP), for applications in the oceans which include unmanned platforms, autonomous underwater vehicles, benthic landers, drifting floats and instrument housings.

The first objective is to advance capability is design procedures and tools for thick section FRP materials, to enable the manufacture of reproducible and reliable structures. The second objective is to demonstrate this capability by manufacturing an all FRP pressure resistant housing having a 2,000 metre operational depth capability. The chosen focus being a pressure housing for an autonomous underwater vehicle (AUV). The third objective is to establish the long-term integrity of FRP structures in the working environment, which is vitally important in a wide variety of applications. Within the project consideration will be given to extending the design tools and technology to depths up to 6,000 metres.

Success in meeting these objectives will strongly promote the use of weight- and cost- efficient FRP structures in future industrial and research applications in the deep oceans.

The project seeks to build on present knowledge and draws on the expertise gained by the participants in both national and EC funded programmes involving research on FRP materials in the following areas:

- structural design
- fabrication techniques and quality assurance
- testing and test procedures
- system failure modes
- theoretical modelling and analysis
- operational requirements

Methodology:

As stated the focus of the project is a FRP pressure housing for an AUV, comprising of a central cylindrical section with dome end closures. Obviously there are a number of promising fibre reinforced composite materials and some recent developments, such as hollow fibres – thermoplastic matrices, which may be suitable for high performance AUV hulls and deep ocean structures. However, the commercial availability, costs and fabrication risks rule out the use of these materials at the present time. It was therefore decided early on to utilise carbon fibre reinforced epoxy and a monocoque hull design. The central cylindrical section being fabricated by the filament winding process with the end-domes fabricated by resin trasnfer moulding or filament winding. While frame stiffened hulls or sandwich structures may be more efficient in the longer term, the lack of experimental data, limited design tools and risks associated with the fabrication processes along with the budgetary and timescale constrains rule out the use of these construction techniques in this project.

The project involves the design, fabrication and inspection, modelling, testing and analysis of a number of small-scale (175mm internal diameter) and large-scale (450mm internal diameter) cylinders and end-domes.

The design of the small-scale cylinders and their end-closures, as well as the design of the large-scale cylinders will be performed using both analytical and numerical modelling tools. The numerical tools will allow modelling of the actual material lay-up of both the cylinders and the domes, not only before buckling, but also in the post-buckling path. Buckling loads, buckling modes and ultimate failure pressures will be calculated. Strains calculated by these tools will be directly compared to the respective data measured in the experimental tests of the small and large cylinders/domes. In addition, a novel modelling technique will be used to optimise the filament winding angles and stacking sequences for each thickness of cylinder to be fabricated.

Fabrication of the cylinders will be carried out by two of the participating organisations to establish the best practice and to identify/solve practical manufacturing problems. Each cylinder will be dimensionally and non-destructively (ultrasonic) inspected to establish quality and detect any internal flaws (delamination). Experience gained in the fabrication of the small cylinders will be fed directly into the manufacture of the final large-scale demonstrator cylinder and the design and fabrication guidelines. The large-scale domes will be manufactured by the resin transfer moulding (RTM) process, while the small-scale domes will be fabricated by filament winding.

Axial compression tests will be carried out on a number of the small-scale cylinders. These will then be subjected to a hydrostatic pressure test up to failure with either metallic flat end plates or small composite end-domes. A number of the small composite end-domes will be tested individually prior to the fabrication of a matched dome/cylinder combination. A set of the large RTM domes will be tested, back-to-back, to establish their performance before a set is installed on the demonstrator cylinder.

In addition, a number of small-scale cylinders with flat end plates along with a large-scale cylinder and a set of large RTM domes will be deployed at sea at a depth of 2,000 metres for a period of twelve months. Each cylinder will be internally instrumented with battery powered data loggers which will collect and store strains for a period not less than 450 days. This will provide basic information on the creep properties of the composite material, the long-term stability of the construction (interface rings, seals etc), the interaction of different materials and water absorption.

The final test will be of an all composite demonstrator AUV designed to a working depth of 2,000 metres with a nominal factor of safety of 1.5. Failure pressure should therefore be in excess of 3,000 metres (300 bar).

In addition to the theoretical modelling and experimental tests the project will:

- draw up a statement on the functional requirements,
- identify potential applications/markets for the technology,
- promote the commercial exploitation of the technology.

The emergent design methodology arising from the work as a whole will provide vital information that may be used by engineers to help clarify and meet customers' requirements for pressure resistant structures in mid-water and benthic applications.

TITLE : ADVANCED SYSTEM INTEGRATION FOR MANAGING THE COORDINATED OPERATION OF ROBOTIC OCEAN VEHICLES - **ASIMOV**

CONTRACT N° : **MAS3-CT97-0092**

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ADVANCED SYSTEM INTEGRATION FOR MANAGING THE COORDINATED OPERATION OF ROBOTIC OCEAN VEHICLES (ASIMOV)

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SUMMARY

The main thrust of the ASIMOV project is the development and integration of advanced technological systems to achieve coordinated operation of an Autonomous Surface Craft (ASC) and an Autonomous Underwater Vehicle (AUV) while ensuring a fast communication link between the two vehicles. The ASC / AUV ensemble is being used to study the extent of shallow water hydrothermalism and to determine the patterns of community diversity at the vents in the D. João de Castro bank in the Azores.

1. PROJECT DESCRIPTION

This project puts forward the key concept of coordinated operation between an Autonomous Surface Craft (ASC) and Autonomous Underwater Vehicle (AUV) for marine data acquisition and transmission. By properly maneuvering the ASC to always remain in the vicinity of a vertical line directed along the AUV, a fast communication link can be established to transmit navigational data from the ASC to the AUV, as well as acoustic / vision data from the AUV to the ASC, and subsequently to an end-user located on board a support ship or on shore. Fast and reliable communications, as well as precise navigation, can thus be achieved by resorting to conventional systems. Figure 1 depicts the main systems required for vehicle navigation and control, as well as for acoustic communications between the two robotic vehicles. To give the work greater focus, the research and development efforts were aimed at performing realistic missions at sea, near the Azores islands, to determine the extent of shallow water hydrothermalism and the patterns of community diversity at the vents in the D. João de Castro Bank; see Figures 2.a and 2.b. In the missions of interest, the AUV is required to maneuver close to the seabed to detect the occurrence of bubble emissions from the vents, and to trigger the acquisition and transmission of time / position stamped sonar and video images to the support unit through the vertical acoustic channel, via the ASC.

Obstacle avoidance and bubble detection rely heavily on the development of a space-stabilized sonar head with vertical and horizontal transducer elements and the associated signal processing algorithms. Programming, executing, and modifying on-line mission plans for joint ASC/AUV operation were made possible through the development of dedicated systems for joint mission and vehicle control, as well as appropriate human-machine interfaces.

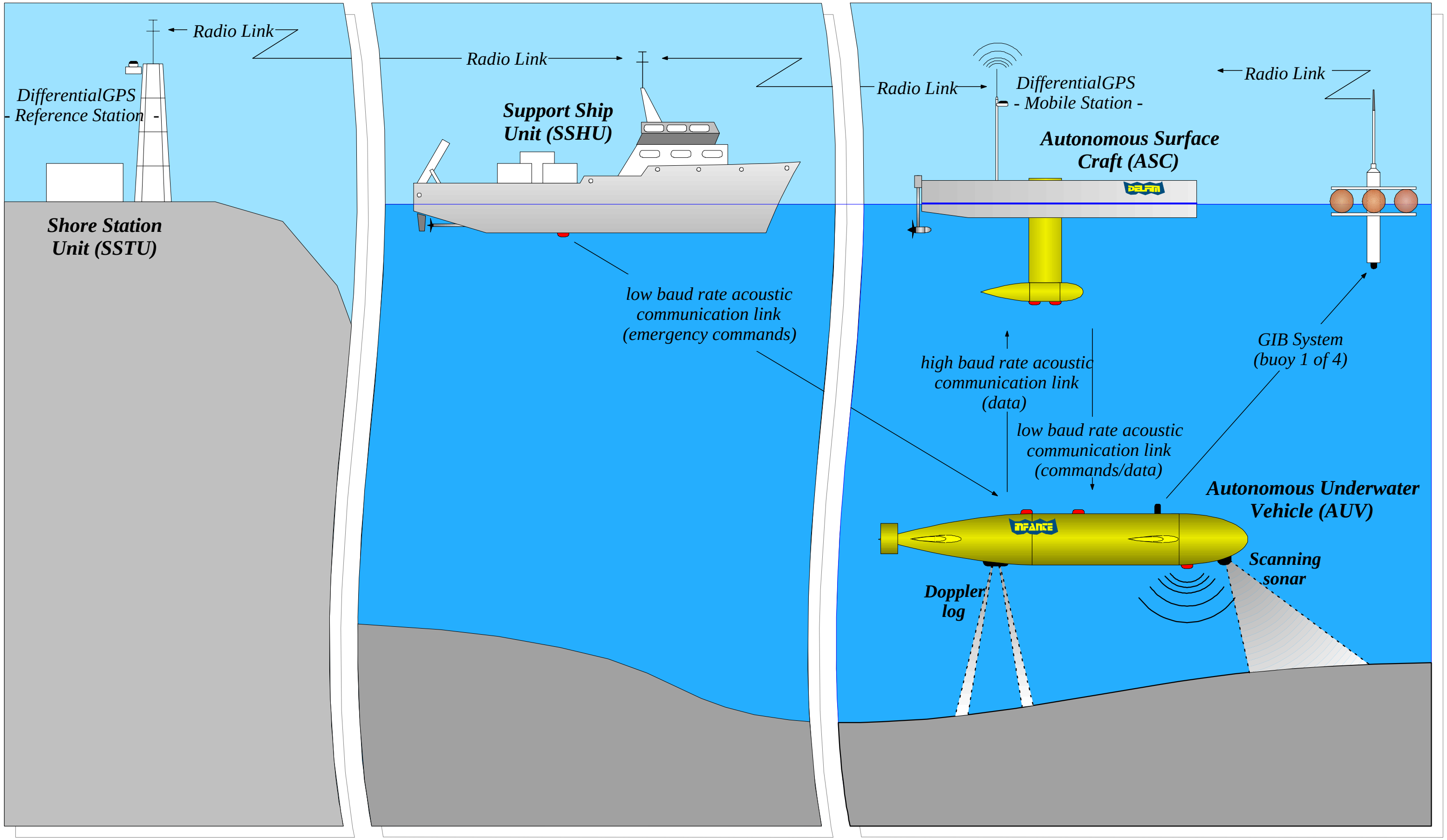
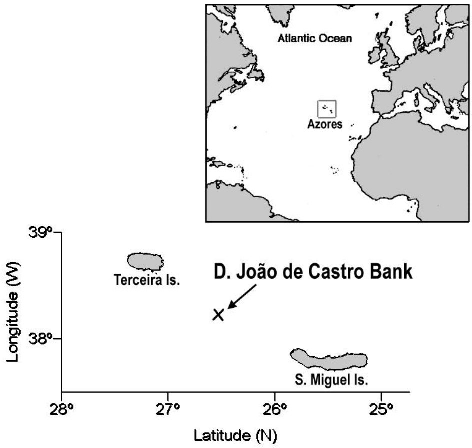


Fig.1. Coordinated Operation of the DELFIM ASC and the INFANTE AUV for scientific missions in the Azores.



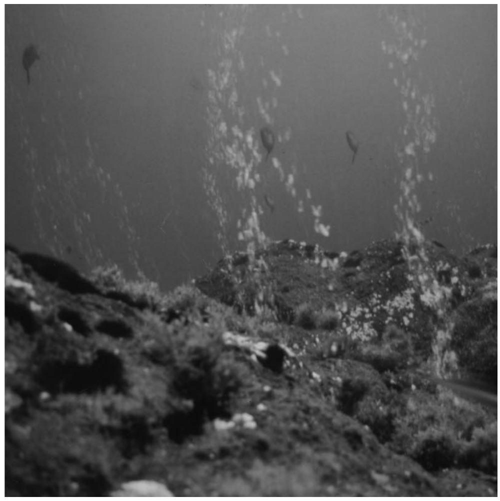


Figure 2.a The D. João de Castro Bank   Figure 2.b Hydrothermal activity.

Special emphasis is being placed on demonstrating all the steps that are necessary to acquire, process, manage, and disseminate data on hydrothermal activity to a wide audience of scientists, over the Internet. The reader is referred to [1]-[2] for a brief description of the technological challenges posed in the course of the project and for complete details on system design, development and testing at sea.

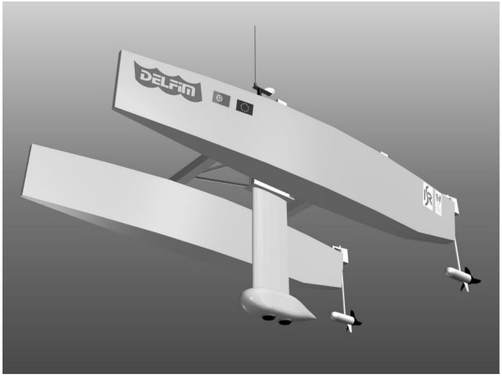
2. KEY TECHNOLOGICAL DEVELOPMENTS

2.1 Vehicle and Mission Control. Sonar Data Processing.

Two robotic ocean vehicles are being used in the ASIMOV project (see Figure 3): the DELFIM ASC and the INFANTE AUV, designed and built by the Institute for Systems and Robotics of the IST with the collaboration of the Portuguese companies RINAVE (Naval Engineering), Corinox (Mechanical Workshop), and Decatlo (Fiber Glass work).

The DELFIM craft was designed for automatic marine data acquisition and to serve as an acoustic relay between submerged craft and a support vessel. This will enable the transmission of sonar and video images through a specially developed acoustic communication channel that is optimized to transmit in the vertical. The DELFIM ASC can also be used as a stand-alone unit, capable of maneuvering autonomously and performing precise path following (see [4]) while carrying out automatic marine data (including bathymetric data) acquisition and transmission to an operating center installed on board a support vessel or on shore. This is in line with the current trend to develop systems to lower the costs and improve the efficiency of operation of oceanographic vessels at sea.

The DELFIM is a small Catamaran 3.5 m long and 2.0 m wide, with a mass of 320 Kg. The propulsion system consists of two propellers driven by electrical motors. The vehicle is equipped with on-board resident systems for navigation, guidance and control, as well as for mission control. Navigation is done by integrating motion sensor data obtained from an attitude reference unit, a Doppler log, and a DGPS (Differential Global Positioning System) [9]. Transmissions between the vehicle, its support vessel, the fixed GPS station and the control center installed on-shore are achieved with a radio link with a range of 80 Km. The vehicle has a wing shaped, central structure that is lowered during operations at sea. At the bottom of this structure a hydrodynamically shaped body is installed that carries all acoustic transducers, including those used to communicate with underwater craft. See [1] for details.



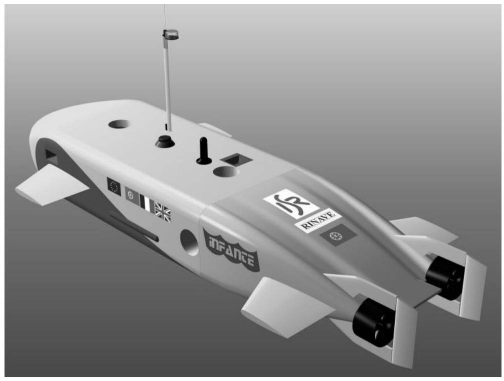


Figure 3.a The DELFIM ASC

Figure 3.b The INFANTE AUV

The INFANTE is an Autonomous Underwater Vehicle with a maximum operating depth of 500 meters. The vehicle is a major re-design of the MARIUS AUV, developed under the MAST-I and MAST-II Programmes of the EU in the scope of two projects coordinated by IST [8]. The INFANTE is equipped with advanced systems for navigation, guidance and control, as well as mission control. Navigation is done by integrating motion sensor data obtained from an attitude reference unit, a Doppler log, and a system for underwater positioning that relies on a set of four drifting buoys equipped with GPS receivers and hydrophones to capture the acoustic signals emitted by a pinger installed on the AUV (GIB system). Position updates from the GIB system are sent to the AUV via the acoustic downlink of Figure 1. Obstacle detection and avoidance, as well as terrain following, build on the acoustic sonar system designed by System Technologies and on sophisticated algorithms for sonar based maneuvering studied by ENSIETA [3]-[7].

Underlying the concerted operation of the two vehicles is a Mission Management Center (MMC), installed on-board a support ship (and possibly on shore), that is vital for managing all the phases of coordinated vehicle operation. The MMC hosts the computers in charge of implementing a Mission Management System (MMS) that plays a key role during the Mission Preparation phase. During this phase, an operator without detailed knowledge of the technical aspects of robotic ocean vehicles is capable of programming a desired mission in a high level language, have it checked for consistency, and translated into a mission program that can be compiled, downloaded to, and run in real time in the computers installed on-board the ASC and the AUV. During Mission Execution, the MMS enables the operator to play a very active role in assessing the state of progress of the mission and modify the mission objectives, if required, based on mission-related and field data received from the AUV through the uplink communications channel.

Each vehicle hosts a kernel of a Joint ASC / AUV Mission Control System that is in charge of accepting the joint mission program provided by the Mission Management System, and scheduling and coordinating the concerted action of the two vehicles, while enabling on-line intervention from the end-user. Furthermore, each vehicle hosts a local Mission Control System that is responsible for guaranteeing the integrity of the vehicle, controlling its dynamic motion and the acquisition and transmission of scientific data, as well as interfacing with the respective Joint ASC / AUV Mission Control System kernel.

Central to the implementation of the above systems is the concept of viewing all the modules inside each one of the vehicles as nodes in a *local area network*. The underlying distributed control architecture is supported on the industry standard real-time network CAN-bus and on Ethernet. Some of the nodes are devoted to relatively simple sensors and actuators, while others host powerful processors for more demanding computational tasks. At the same time the two vehicles, the support ship, and the store station are also viewed as local area networks nodes in a *wide area network* that is suported on efficient air and underwater communications. See [2] for complete details. The development of the local a nd wide area networks is now completed, and will afford engineers and scientists the means to interface their systems effortlessly and have easy access to vehicle / sensor data during operations at sea.

2.2 Sonar System.

The ASIMOV Sonar System (developed by System Technologies) has been designed to provide a variety of sonar services suitable for Autonomous vehicles. The Architecture of the Sonar system is based upon the use of single or multiple sonar heads that can be interfaced to the INFANTE AUV computer network. Access to any of the Sonar services is made by logging onto a Sonar Server. The server is responsible for managing and sharing sonar resources, and ensuring that vehicle safety critical functions, such as Obstacle Detection, will always take priority over any other less critical function, such as gathering environmental data.

For the INFANTE AUV installation, several sonar functions may be required during a mission, for example: i) Midwater Obstacle Detection, ii) Terrain Obstacle Detection, iii) Obstacle Location, iv) Obstacle Tracking, v) Obstacle Feature Identification, vi) Point Echo Sounding, vii) Swathe Echo Sounding, viii) Sidescan Survey, ix) Sub-bottom surveys, and x) Detection of Anomalies in the Water column. This list is by no means exhaustive, but illustrates the requirement for a general purpose Sonar system design that can accommodate more that one mission function. The alternative would be to have a specialized sonar for each job. By considering the minimum amounts of data required for each function, it was decided that general-purpose sonar head's resources may be 'time shared' between more than one user. So long as the highest priority mission critical users get sufficient data at the right time, the sonar head can then be used during 'idle time' to perform lower priority activities.

A major requirement for the ASIMOV sonar was that the data should be as 'user friendly' as possible. In practice, this means that beam shapes are as accurate and as 'clean' as possible to reduce echo ambiguities. It was also considered that the sonar should be stabilized in attitude to improve data quality and usefulness to the end user.

The ASIMOV Sonar Head incorporates a stabilized transducer drive mechanism that allows the transducer to be trained over a 270 degree super-hemisphere. The drive mechanism has fast servoing capability to give good stabilization response and allow rapid changes of scan direction. The stabilization of the sonar requires that vehicle attitude information is made available to the sonar over its data link, or via an auxiliary communications port. The transducer has several elements that are capable of generating a variety of beams, over a range of frequencies and beam widths. The choice of which transducer element, and what data the sonar will gather at any particular time are all selectable by the users.

Communications with the sonar head are conducted over a networked data link, which allows several sonar heads to be used simultaneously. This feature allows mission specific sonars to easily be integrated, and gives flexibility to an AUV supervisor to re-allocate sonar resources if redundant sensors are installed. The Sonar system has several 'potted' functions available to allow simple high level control, but is equally capable of being controlled directly by a user’s own special software. The development of the ASIMOV sonar system has progressed to the point where a system has been in-water tested, and integration with higher level AUV supervisor functions is underway.

2.3 Acoustic Communication System.

One of the main purposes of project ASIMOV is to demonstrate the potential applications of underwater autonomous vehicles (AUVs) for demanding scientific missions. Several factors that have hindered the widespread use of AUVs in practical applications can be traced back to the limited amount of data that can be exchanged in (almost) real-time between the vehicle and a mission control centre using acoustic modems. Most notably, such lack of interactivity prevents end-users from assessing the unfolding of missions, and re-directing the vehicle when appropriate.

Although acoustic modems use sophisticated processing techniques to compensate for severe distortions that affect the transmitted waveforms as they propagate through dispersive underwater channels, fundamental limits restrict the data rates that can be reliably achieved. Acoustic transmission always takes place vertically in the framework of project ASIMOV, thus providing a comparatively benign communication channel where high data rates are attainable. An Autonomous Surface Craft (ASC) moving in tandem with the AUV is the key technical component that enables vertical transmission without restricting the AUVs manoeuvrability. Besides relaying mission data to the base station through a high-speed radio link, the ASC also provides navigational data to the AUV.

Reference [5] discusses the specifications and implementation of the INFANTE AUV/ DELFIM ASC acoustic links, and illustrates their performance under real conditions. The operating scenario contemplated in the project is a shallow water volcanic plateau near the Azores islands, where hydrothermal sources are to be automatically identified and studied. Preliminary surveys have revealed high ambient noise levels across all the candidate modem operating frequencies.

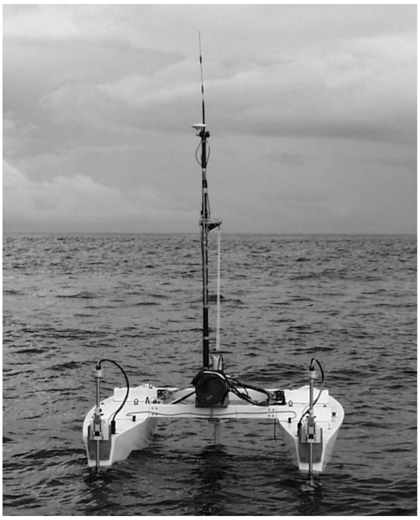
Two acoustic data links are used between the AUV and ASC. A bi-directional low-speed link (up to 300 bps) using robust non-coherent modulation transmits critical data between the two vehicles. A high-speed (30000 bps) unidirectional link using M-PSK modulation is used mainly for transmission of compressed still images from the AUV to the ASC. Important design considerations involve the acoustic compatibility between the two systems, as it should be possible to transmit emergency commands to the AUV through the low-speed link even when the high-speed link is active in the reverse direction. This requirement significantly restricts the placement of transducers to avoid pre-amplifier cross-saturation while retaining a compact mechanical assembly. Transducer directivity also needs to be carefully considered, as there is a delicate balance between the accuracy of the positioning systems that ensure an adequate AUV/ASC configuration and the optimal directivity that minimizes the intersymbol interference in the communication channel.

Apart from transducer customizations, the low-rate link is based on one of ORCA'S commercially available solutions. The high-rate link, however, was specifically designed for this project. The reader will find in [5] interesting discussions on the choice of a suitable DSP platform, as well as on several topics related to packet formatting and synchronization, Doppler compensation, timing/carrier recovery and channel equalization. Given the high operating noise levels, special attention was given to signal-space coding strategies (Trellis-Coded Modulation) that provide some gain while retaining robust performance under carrier phase instabilities. See [5] for a presentation of experimental results obtained during the ASIMOV'99 Summer mission.

3. TESTS AT SEA AND SCIENTIFIC RESULTS. FUTURE WORK.

During the period from July 1998 to December 1999, several tests were carried out at sea to evaluate the performance of the systems developed. The reports [2] detail results of tests with: i) the Acoustic Communication System (in Brest and the Azores), ii) the Sonar System (in the United Kingdom and the Azores), iii) the Sonar Data Processing System (in Brest), and iii) the Vehicle and Mission Control Systems (in the Azores and near Lisbon). During the Summer of 1999, extensive tests were performed at Praia da Vitória Harbour (island of Terceira, Azores) and in D. João de Castro Bank to test the navigation and control systems of the DELFIM ASC, as well as the communication and sonar systems in the actual, acoustically noisy environment of the bank. Furthermore, sidescan sonar and sonar data were obtained and further processed by ENSIETA to locate vents and to obtain a digital terrain map of the area for future use. Figure 4.a shows the DELFIM ASC starting the execution of an autonomous mission at the D. João de Castro bank, while acquiring bathymetric data. Figure 4.b is a bathymetric map of the area, that shows the remains of an old crater. See [2] for a description of the methodologies adopted by ENSIETA and the IST for map building based on a mechanically scanned pencil beam sonar and an echousounder, respectively.

During the missions in the Azores, the IMAR/DOP-UAzores provided extensive logistic support, including the Águas Vivas and Arquipélago vessels for vehicle and equipment transportation, as well as mission support. During the missions, scientists from the IMAR/DOP-UAzores and the University of. Wales, Bangore carried out scientific data collection aimed at building the embryo of an habitat map of the D. João de Castro bank. One hundred eighteen species were documented at the bank. It was noticed that the species do not differ significantly from those in other shallow water offshore banks. However, species diversity seems to be lower close to venting sites, probably due to an increase in toxicity. Benthic communities are dominated by the algae *Sargassum* sp. Fish communities are dominated by herbivorous *Kyphosus* spp. and *Balistes carolinensis*. Preliminary identification of bacteria present near the vents seems to indicate



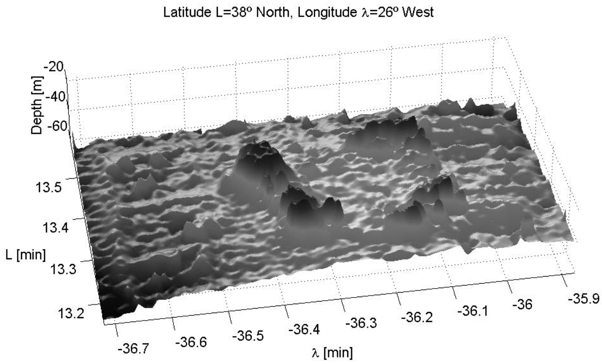


Figure 4.a The DELFIM ASC

Figure 4.b Bathymetric map of the DJC bank

that they belong to Baggiota group. This group is also present in the deep-sea hydrothermal vents off the Azores. With the objective of investigating differences in organism settling in venting and non-venting areas, several settlement traps were deployed at the end of the 1999 Summer mission. The traps will be recovered and examined in the Summer of 2000. Water samples were collected around the bank to detect methane plumes and other biochemical parameters. Their analysis seems to indicate the presence of venting activity at depths of 200 meters. Further work will aim at superimposing on a same map the bathymetry of the bank, together with scientific data related to the presence / intensity of venting, as well as other biological and geological data.

The project has reached the end of the first phase of basic system development and testing. The second phase will witness the complete integration of all systems developed by the different partners on the DELFIM ASC and the INFANTE AUV, and the execution of scientific missions in the Azores using the two vehicles working in cooperation.

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TITLE : GEOPHYSICAL AND OCEANOGRAPHIC STATION FOR ABYSSAL RESEARCH: **GEOSTAR 2** – ENHANCEMENTS OF THE SYSTEM FOR THE DEEP SEA SCIENTIFIC MISSION

CONTRACT N° : **MAST3-CT98-0183**

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GEOPHYSICAL AND OCEANOGRAPHIC STATION FOR ABYSSAL RESEARCH: GEOSTAR 2 – ENHANCEMENTS OF THE SYSTEM FOR THE DEEP SEA SCIENTIFIC MISSION

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INTRODUCTION

GEOSTAR 2 (GEophysical and Oceanographic STation for Abyssal Research) is a scientific and technological project funded by the European Commission in the framework of Marine Science and Technology Programme (MAST-III CT98-0183). The ongoing 2nd phase continues the first GEOSTAR phase (CT95-0007) ended in the 1998. The main objectives of both GEOSTAR projects are to realise and test an autonomous benthic observatory able to collect geophysical, geochemical and oceanographic data for long-term (up to1 year) in deep-sea (4000 m). GEOSTAR realised also a dedicated deployment/recovery system, based on a mobile docker concept, linked with the ship by an electromechanical cable (Beranzoli et al., 1998). The deployment/recovery procedure has been derived from the so called “two-module” concept successfully applied by NASA in many space missions (Apollo, Space Shuttles) where the Mobile Docker is both the carrier and a 2 way communication Surface-Bottom Station during all phases (e.g. for instruments check). The station is conceived to have a broad range of sensors. The simultaneous acquisition of a set of various measurements with a unique time reference can make GEOSTAR to be the first element of a future multiparametric ocean network. The presence of such a network is important considering, for example, that the present distribution of land-based geophysical observatories is inadequate for addressing important scientific issues related to many features of our planet both at global and regional scale.

The first phase (1995-1998), named GEOSTAR 1, was aimed at designing and realising the system and at verifying its performances and reliability (Favali et al., 1998, Jourdain, 1999). GEOSTAR 1 was deployed in Adriatic Sea from August 13th to September 2nd, 1998 at about 40 km East of Ravenna and at a depth of 42 m. During the 3 weeks mission the acquisition system recorded continuously for 440 hours (97.8% of the total time). A magnetic observatory and three broad band seismic stations were installed on land to integrate the geophysical measurements. The mission demonstrated reliability of the deployment/recovery vehicle, of the sensors and efficiency of the communication system Bottom Station-surface.

The second phase - started in 1999 - has the purpose to perform the first long-term scientific mission at abyssal depth for a period of at least 6-8 months. After geological and geotechnical surveys, done during the first phase, the deployment site was located in the Southern Tyrrhenian Sea at 25-30 km NNE of USTICA Island, at a depth of 3400 m. From the geological and environmental point of view this site represents an optimal observation point in order to obtain relevant information about geodynamics and oceanography of the whole Mediterranean basin. GEOSTAR 2 will carry new equipment for geophysical and chemical-physical analyses not available in the first phase.

THE GEOSTAR PROTOTYPE

GEOSTAR prototype is composed of two main systems: the deployment/recovery vehicle called **Mobile Docker** (MD), and the **Bottom Station** (BS) which host both all scientific instruments and communication systems.
The MD is mountable on and manoeuvrable from a research vessel of medium size, equipped with an electromechanical cable and a winch suitable for the depth mission (Gerber and Schulze, 1998). The MD is able to deploy and recover in deep-water loads up to 10 tons supplied with the interface for the MD-BS coupling (latch/release device). The horizontal mobility is realised by thrusters controlled via cable by the surface operator on the ship. Acoustic and visual systems are mounted on the MD helping to settle the BS in the selected area and to locate it. The MD once coupled with the BS constitutes the primary two-way communication link between surface operator and BS. When the BS, connected with the MD has reached the seafloor and the successful start of the different devices and of the is verified, the MD disconnects from the BS and returns to the surface. At the end of scientific mission, the MD is deployed again and drive to find and latch BS. Finally all system (MD+BS) is recovered on board. For the first long-term mission of GEOSTAR 2 the MD configuration has been improved; i.e. additional thrusters (2 for horizontal and 2 for vertical movements) have been installed in order to increase the mobility performances.
The BS is a stand-alone autonomous unit based on a four-pad aluminium alloy frame equipped with the sensor packages, the Data Acquisition and Control System, the power batteries and the communication systems (Gasparoni et al., 1998). On the BS there is also a set of sensors for the monitoring the status of devices (e.g., pressure, temperature, humidity, water intrusion in the titanium vessel, battery level). Table shows the packages sensors of first and second mission.

GEOSTAR 1	GEOSTAR 2	Objectives
Three axis broad-band seismometer	Three axis broad-band seismometer	Earthquake detection; Seismic noise studies
Scalar (proton) magnetometer	Scalar (proton) magnetometer	Geomagnetic total field intensity
Fluxgate (x-y) magnetometer	Fluxgate (x-y-z) magnetometer	Geomagnetic field X-Y components intensity
300 kHz ADCP	300 kHz ADCP	Current profiling
CTD	CTD	Conductivity, temperature, pressure
Transmissometer	Transmissometer	Gravity field studies earth tides
	Gravitymeter	Gravity field studies earth tides
	Space seismometer (three axis very broad-band)	Earthquake detection; Seismic noise studies
	Single point current meter (3D)	Current profiling
	Chemical Package (H_2S, pH)	Analysis of pH and H_2S with solid state electrodes (analysis of NH_3 and Fe with colorimetry under development).
	Water sampler	Collection and storage of discrete water samples

The Data Acquisition and Control System (DACS) switch on/off each device, manages the power regulation and distribution, check the status of the devices, requests data packages from the scientific equipment, performs a first level of quality check on the acquired data, and generates data files both for storage on the BS hard disks, retrieved after the recovery, and for transmission via the GEOSTAR Communication System.
The Communication Systems are based on different devices. The first one consists of a set of releasable capsules, called Messengers, located in the BS and able to transmit their data, collected according to sequences defined in the DACS, to a shore station over a satellite link. These floating capsules move toward the sea surface where they transmit their position and data recorded by all the instruments via satellite telemetry and can be recovered by a surface ship. The second device is an Acoustic Telemetry System originally developed for this application. This communication system can be used both as safety system to perform the same operations executable through the MD and as data back-up unit.
During the Ustica scientific mission, GEOSTAR will be equipped with a new near-real-time communication system: the basic element of this system will be a bi-directional link using both acoustic transmission (between the BS and a surface buoy) and a satellite telemetry (between the buoy and a shore station). In this way the operator will be able to retrieve data, check the system status and, if necessary, modify the mission configuration. GEOSTAR is in fact conceived as a tool open to many types of applications, including possibility of being reconfigured for different missions and different sites (both near the coast and in open seas).

THE SCIENTIFIC RESULTS OF THE FIRST MISSION IN ADRIATIC SEA

The recorded data during the first mission in Adriatic Sea gave the opportunity to verify the quality of the installation procedures selected in the design phase for specific sensors (Beranzoli et al., 2000).
The good quality of the magnetometers recordings is revealed by the comparison with the time series of Castello Tesino observatory (300 km far from GEOSTAR), and of the temporary station of Bosco Mesola (Ferrara, about 57 km far from GEOSTAR). It was also possible to roughly estimate the magnetic influence of the GEOSTAR frame and of the other equipment to the magnetometers. The results in terms of the geomagnetic deep sounding technique applied to the time variations of the horizontal and vertical components of the magnetic field provided interesting results in the framework of the regional tectonics (De Santis et al, 1999).
The performances of the seismological package with respect to the detection of regional and teleseismic events, demonstrated that the seismometer deployment procedure and the coupling of the sensor with the sea bottom were fulfilled. The spectral analysis of the seismic background noise showed that the effect of the thick sediment layer below the GEOSTAR mission site resulted to reduce considerably the detection capabilities of local earthquakes. This was confirmed by the comparison with the seismic background noise of Cesena, the on land temporary station closest to GEOSTAR, sited on a ground with almost similar geo-technical characteristics.
During GEOSTAR 1 the oceanographic sensors (ADCP and CTD) recorded correctly. The CTD sensor demonstrated that the acquisition of temperature and pressure data worked properly, but conductivity and transmissometer data suffered for fouling due to sedimentation. Therefore for GEOSTAR 2 mission it was decided to set the cell in a vertical position, less favourable to sedimentation, and to install a standard SBE5T pump able to flush the particles tending to sediment within the cell.

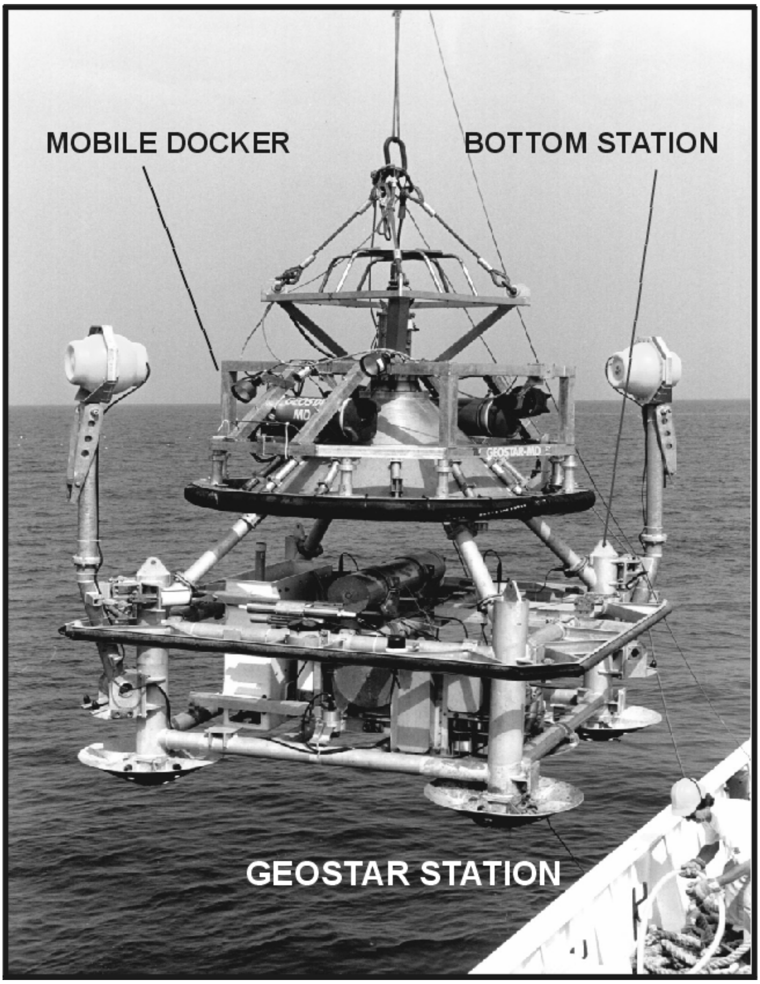
CONCLUSIONS

GEOSTAR 2 is a project aimed at demonstrating through a long term (6-8 months) scientific mission in deep sea conditions, the complete functionality of the benthic multidisciplinary observatory developed and tested during GEOSTAR Project. The deployment of GEOSTAR observatory for its long-term scientific mission in Southern Tyrrhenian Sea (3,400 m w.d.), in front of Ustica Island, is foreseen in September 2000 and it will ended in Spring-Summer 2001 with station recovery. For this purpose, the existing observatory has been appropriately enhanced to meet scientific mission requirements. The scientific target of mission in the Tyrrhenian Sea is to give a contribution to the better understanding of the geodynamics and the seismotectonics and oceanography of the Tyrrhenian Basin.

During the deep sea Ustica mission GEOSTAR will perform:

- continuous, long-term acquisition of three-component seismic data with associated observation of environmental parameters (current, temperature, pressure) and BS altitude (tilt, heading);
- observation of temporal variability of geophysical parameters (earth magnetic field, earth gravity field);
- observation of temporal variability of oceanographic parameters (currents in the water column, tide);
- observation of temporal variability of geochemical parameters (water temperature, conductivity, salinity, turbidity, pH, H_2S);
- water sampling at programmed times (samples will be then available for on-shore laboratory analyses ;
- acquisition of seismic data with an innovative sensor originally developed for missions on planet Mars.

Moreover, from December 2000 to September 2001, in the frame of the TYDE (TYrrhenian Deep-sea Experiment) project, a temporary network of the broad band Ocean Bottom Seismometers will be installed for the first time in the area of the Aeolian Islands. An on-land network of broadband seismic instruments covering southern part of Italy will be also present. The scientific objective is to perform analysis on data collected by GEOSTAR and OBS sensor joint to data recorded from the local, regional and national land-based seismic networks. The use of a more homogeneous stations coverage in this sector of the Southern Tyrrhenian Sea will be useful to obtain new tomographic models to better define the shape and the extends of the Ionian subducting lithosphere.



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III.2.2. Oceanographic measurement and sampling equipment

TITLE : GAS HYDRATE AUTOCLAVE CORING EQUIPMENT SYSTEMS : **HYACE**

CONTRACT N° : **MAS3-CT97-0102**

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HYACE, AUTOCLAVE CORING TOOLS FOR SYSTEMATIC OFFSHORE GAS HYDRATE SAMPLING, MEASUREMENTS AND GROUND TRUTHING

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1. Abstract : HYACE, an EU MAST III Project (EU MAS3 CT97 0102)

HYACE is the acronym for gas hydrate autoclave coring equipment system. The project started in December of 1997 and it shall last until December 2000. Eight partners from six European countries constitute the HYACE Consortium. It is coordinated by Technische Universität Berlin, Fachgebiet Maritime Technik.

Development and prototype testing of innovative, downhole actuated and downhole controlled autoclave coring systems constitute the central activities of the project. They were developed, designed and tested to sample a wide range of marine sediments at downhole conditions and bring the cores onboard while maintaining as many downhole parameters as possible. Particular targets are sediments on the deepwater covered continental slopes containing gas hydrates. Sampling tools include push, percussion and rotary corers. The corers are downhole driven by the drilling fluid and downhole motors instead of top drives onboard the scientific drillship.

The main scientific goal of the project is to contribute to systematic ground truthing of a necessarily ephemeral phenomenon of growing global significance: assessing quantitatively volatile gas hydrates in their natural deepsea environment. This must be achieved by obtaining validated parameters of the in-situ and downhole conditions to the largest possible extent. Complementary measurements while coring are furthermore important. Temperature and pressure monitoring had been selected upon request by the geoscientific community as the

initially most important parameters. A new method and tool to better use and analyse the autoclave core after retrieval onboard the research vessel by its pressurized transfer into a laboratory autoclave was developed. Technical outlines and a pilot instrument for pressurized core logging onboard and in the lab were established.

2. Technical scope and achievements of HYACE

On initiative of Fachgebiet Maritime Technik of Technische Universität Berlin, who took part in the gas hydrate ODP Leg 164, a consortium of European research institutes and public and private companies was formed in 1997. The goal of the group is to improve available but insufficient ground truthing technology in the general framework of international marine gas hydrate research with the financial aid of the EU Commission, which is acknowledged by all partners with gratitude.

The scope of work was based on the following main tasks:

- Define in more technical detail geological and performance requirements for the set of tools and methods to sample, measure in-situ and evaluate marine gas hydrates, the emphasis being on the sampling and sample evaluation processes,
- A rotary autoclave corer with downhole drive and control, fitting into standard bottom hole assemblies and wireline handling tools was developed for indurated sediments,
- Friable, hard and coarse grain size sediments associated with gas hydrates and/or free gas from the hydrates - the most difficult area of coring - need a percussion autoclave sampler, which was designed and offshore tested,
- Make available a push-in corer for soft sediments, including the essential autoclave function to fit into standard bottom hole assemblies and wireline handling tools to be more easily used worldwide and in Europe in particular,
- Transfer of autoclave cores under pressure, onboard ship, from the downhole to a laboratory pressure vessel,
- An autoclave core logging unit was conceived to analyze hydrate samples under pressure, in such a way that downhole conditions are preserved,
- Downhole measurements of those parameters which are needed for the systematic and technically controlled research of gas hydrates, such as temperature and pressure, readout onboard,
- Further studies are required to see whether existing techniques of downhole or in-situ measurements (below the borehole) are adequate to map those ambient conditions which cannot be inferred from the core,
- Establish the measurements to be made on the recovered samples and the method of such monitoring under pressure to arrive at input data for computer modelling to predict what happens with a change of pressure and/or temperature and what hydrate dissociation processes could be expected.

With those tasks and achievements, particularly on the hardware side, the partners of Project HYACE are accomplishing much more than what had been originally intended and contractually agreed with the EU Commission. The challenging European marine science topic "gas hydrates" is an incentive to do so. The partners hope that the EU Commission uses and supports this volunteering scientific and innovative thrust to promote European contributions to international geoscientific research and drilling in future years.

3. Status of the project in the second quarter of 2000-04-27

3.1 The second quarter of 2000, the last year of the project which was extended to Dec. 31, 2000, is characterized by

- full scale onshore tests of the HYACE tools, the autoclave downhole rotary corer (HRC), the autoclave percussion corer (HPC), to be also used in softer sediment as a downhole actuated push corer, and pressurised core transfer mechanism, including a laboratory test chamber, LTC,
- by preparation of the deepsea technical feasibility test with ODP´s RV "Joides Resolution" on Leg 191, July-September 2000 in the Northwest Pacific,
- by finalization of delayed ancillary tasks and subwork packages, preparation of the project termination, documentation, further uses and further project development.

3.2 The full scale onshore tests in ITE´s facilities at TU Clausthal, Germany, had started with tests of subsystems and with an additional vertical motion simulator developed and provided by IFREMER in late February. At he same time, the core transfer mechanism and the laboratory storage chamber were built and tested.

The downhole rotary corer was further assembled in March. Since April both systems, the downhole rotary corer and the downhole percussion corer are being tested. The test series include:

- functional tests of all systems and subsystems, including the core transfer mechanism,
- tests and parameter determination of both tools in simulating sediment, frozen fine sand, stiff clay; parameters being rpm, thrust, torque, pump pressure and flow variations; cuttings removal, core recovery (quantity and quality),
- performance optimization, documentation,
- establish assembly, operation, handling and maintenance details for the operation handbook,
- final safety checks and verification (TÜV),
- performance demonstration to partners, ODP, the EU and other interested parties.

3.3 Preparation for deepsea technical feasibility testing of the downhole systems and the core transfer mechanism aims at ODP´s Leg 191, and technical feasibility testing on the Shatsky Rise in the NW Pacific in particular. This Leg is scheduled for Yokohama /Japan, July 14, to Guam, September 15. Test drilling will take place in (indurated) carbonate sediments in 2000-3000m of waterdeepth. Altogether 72 h of testing are being planned. Goals will be:

- technical/ functional performance in the ODP standard scientific drilling system,
- pumping down of tools, landing, coring, drilling, core retrieval, autoclaving, tool retrieval on board, core transfer to laboratory pressure vessels,
- performance parameters, depending on geochemical properties,
- operational, handling and performance optimisation,
- completion of the draft operational manual,
- preparation of gas hydrate applications (ODP Leg 199, fourth quarter of 2001, Gas hydrate Ridge/ Oregon and further gas hydrate applications).

Alternatively , technical feasibility tests on ODP Leg 194, Marion Plateau, east of Australia, are considered for the beginning of 2001.

3.4 Finalization of delayed tasks include compilation and documentation of a design and test basis, application studies and interface definition of the HYACE systems for European (geotechnical) drilling systems and ships, detailed engineering of autoclave core logging.

3.5 Outlook

The most important immediate outlook for HYACE is the European contribution to International Scientific Drilling in ODP, particularly for gas hydrate projects in 2001 – 2003/04 and beyond, in IODP. ODP and JOI, the Joint Oceanographic Institutions in the United States, are interested to take up the HYACE developments and integrate them into ODP and, eventually, into IODP, the International Ocean Drilling Programm. A sequel project for HYACE, HYACE Demo, was submitted in February 2000 with the EU Commission to hopefully be able to take up those chances offered to European science and technology.

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TITLE : AUTOMOUS SYSTEM FOR MEASURING AIR-SEA FLUXES FROM VOLUNTARY OBSERVATION SHIPS AND BUYOS : **AUTOFLUX**.

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DEVELOPPING AUTONOMEOUS FLUXPACKETS FOR MEASURING THE AIR-SEA FLUX OF MOMENTUM SENSIBLE HEAT, WATER VAPOUR AND CO_2 FROM VOLUNTARY OBSERVATION SHIPS OR BUOYES

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INTRODUCTION

The objective of the AutoFlux project is to develop an instrumentation system "AutoFlux" for routine unattended use on Voluntary Observing Ships (VOS) and unmanned buoys, but also on other measuring sites in the near surface atmosphere, where flow distortion and platform motion may be a problem. AutoFlux will automatically produce air-sea flux estimates for the wind stress, buoyancy, heat, water-vapour and CO_2, using high frequency turbulence measurements. Improved fast response sensors are being developed and utilised, including a sonic anemometer/thermometer and a dedicated sonic thermometer. State of the art fast response instrument for routine micrometeorological estimation of water vapour and CO_2 fluxes is constructed and implemented into the system.
Based on already existing software the data handling systems is optimised and perfected for reliable extraction of flux estimates from the instrument data, as well as for keeping track of the system position and orientation.
The system concept is that the fluxes are derived from the turbulence spectra (mainly the so-called Dissipation method). This method minimises the effects of flow distortion and platform motion. The system is centred around an improved sonic anemometer/thermometer and employs as well a specific sonic thermometer and a dedicated humidiometer and CO2 instrument, employing infra red absorption technique. The system software manages the data conversion and storage/transmission as well as the position and orientation of the sensors.

RESULTS FROM THE FIRST PROJECT PERIOD (1998-2000):

The planned new instrument developments have been performed succesfully. A sonic anemometer/thermometer with improved ruggedness and an improved temperature channel has been produced, as has also a special dedicated sonic temperature unit. Both units have been through their first field test. The infra- red humidity and CO_2 sensors have been constructed and have gone through laboratory tests. Primary logging soft-ware has been developed and has been field tested during field cruises in the Arctic. Basic algorithms, relating the measured dissipations to the relevant fluxes, have been formulated and are awaiting further tests. Extensive field tests will take place in the remaining project period. Supplementary instruments for the field tests have been evaluated and response characteristics have been derived and discussed.

All partners in the project generally co-operate and discuss the final products. In the initial phase, most of the instrument development and construction is performed by partner Gill Instruments Ltd, that was responsible for the development and construction of the sound based instruments, and partner KNMI, that is responsible for the Infra Red absorption instruments, providing water – vapour and CO_2 concentrations. Similarly the sound based instruments are used for measuring wind velocity and temperature.

The main responsible partners for development of the logging soft–ware and algorithm development are Southampton Oceanography Centre and Centre d'Etude Environments Terrestres et Planetaire. The algorithms within the project are integrated into a software packet that convert the directly measured turbulence parameters to the fluxes of momentum, heat, water vapour and CO_2 that are is the final output of the AutoFlux system, together with time and space coordinates and some estimates on reliability. As such the algorithms will include the current scientific consensus about the relations between different aspects of the turbulence fields in the marine atmospheric surface boundary layer.

Risoe and Uppsala University are responsible for the initial field tests, that primarily take place off the coast of the Swedish island, Gotland. Also field test from scientific ship cruises have taken place and will continue for the rest of the project period , mostly conducted by Southampton Oceanography Centre. The Risø group has simultaneously been working perfecting the measuring systems and methods in order to be able to measure the CO_2 fluxes simultaneously with an independent method involving both eddycorrelation and equilibrator measurements. A problem with testing CO_2 measurements is that at present there is no generally accepted method for obtaining the ‘ true’ flux.

CURRENT STATUS OF THE AUTOFLUX PROJECT.

At present the integrated AutoFlux packet is going through a number of field test off the coast of Gotland This phase will last into the fall of 2000, where the cruise tests will be resumed for the integrated packet. Simultaneously, the overall performance and field worthiness of the packet continues tol be evaluated, and results are published and otherwise described for the relevant scientific and technical communities.

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TITLE : TRACE METAL MONOTORING IN SURFACE MARINE WATERS AND ESTUARIES: **MEMOSEA**.

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TRACE METAL MONOTORING IN SURFACE MARINE WATERS AND ESTUARIES
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INTRODUCTION

The need for monitoring of heavy-metals in marine environments is well established. The requirements for this have been specified by the Oslo-Paris convention. Analytical techniques with the necessary sensitivity and accuracy are available, but often they are time consuming off-line methods.

The major drawback of present analytical tools is that they are often fragile and their application in stand-alone systems is difficult. This is due to their size and weight (ICP-MS/GFAAS), operational difficulties and their sensitivity to matrix components present in sea water. In addition, the manual sample handling procedures involved in metal determination using present tools do not always preserve sample integrity.

Optical techniques based on molecular spectroscopy offer distinct advantages for reason of simplicity and absence of physical contact between the detection system and the analytes. In particular, luminescence methods (fluorescence, phosphorescence, chemiluminescence) offer potential advantages in ion determination: high sensitivity, ease of automation and straightforward application of fibre optics based remote sensing.

The project is aiming at the development of a marine water optical sensor for metals detection and at the development of dedicated analytical procedures.

Three of the partners were selected for their complementary experience in analytical and luminescence techniques. Each of them establishes an analytical method pertinent to the metals to be determined. Cu, Fe, Mn and Co are to be addressed by chemiluminescence methods; Hg and Pb by steady and time dependent phosphorescence (ms time-range); Cd and Zn by steady and time-dependent fluorescence (ns time-range).

One of the partners has to design a steady and time-dependent luminometer based on commercially available excitation, detection and optical parts. This generic equipment is to be adapted to the requirements of all the partners in the project. It is thus a further step towards a multi-element, multi-technique monitor.

A heavy metals preconcentration system is to be designed and constructed by the fourth partner. This preconcentration equipment becomes an integral part of the shared luminescence detector at the end of the project.

RESULTS

This project synopsis reports the state of the work, two years after its beginning.

LUMINESCENCE EQUIPMENT

The equipment constructed by Edinburgh Instruments Ltd has been tested for steady and time dependent fluorescence, for steady and time dependent phosphorescence ; it remains to be tested for chemiluminesecence applications.

PRECONCENTRATION

The aim is to use immobilized quinolin-8ol for the preconcentration of seawater heavy metals. Various immobilization supports, usable in a fluidised bed reactor were considered. Among those, controlled pore glass (CPG) is found to be the most appropriate support material.
CPG supported oxine has been synthesized. The material displays quantitative removal from the solution of most of the metals and shows suitable fluidisation behaviour.
A fluidised bed reactor using the selected material has been designed and tested. For all examined metals the yield of preconcentration is around 50% and does not vary significantly with flow rate
A first improvement consists in the addition of a vibrator mixer. The effect of this modification is to increase the yield of trapping from *ca.* 50% to near 100%. The time required to obtain a given preconcentration ratio has been reduced. A one hundred folds preconcentration ratio in one hour is now possible. This results from the choice of a two-stage preconcentrator that includes, in a first step, the removal of the solid and dissolved matrix by means of a fluidised bed. In a second step, the heavy metals are concentrated by means of a classical packed column.

CADMIUM AND ZINC

The monitoring of the two metals is based on the enhanced fluorescence intensities and modifications of the emission spectrum of aromatic-azamacrocycles systems induced by cations (A.W.Czarnik, 1992). As an example, the structure of an anthrylazamacrocycle is given in figure 1.

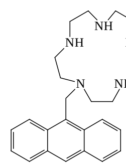

Fig. 1

Figure 1. Molecular structure of an anthrylazamacrocycle ; {1} is the molecule with five nitrogens

In alkaline conditions, the fluorescence yield of {1} is very weak; when chelated to Zn or Cd large but depending on the metal, dimension of the macrocycle and pH, chelation-enhanced fluorescence is observed.

THE FLUORESCENCE SIGNAL OBTAINED WHEN DIFFERENT SPECIES ARE PRESENT IN A SAMPLE CONTAINING AN EXCESS OF CHEMOSENSOR CAN BE EXPRESSED IN THE FOLLOWING WAY:

$$I_T(\lambda) = x \times I_{Zn}(\lambda) + y \times I_{Cd}(\lambda) + z \times I_{Ch}(\lambda) \qquad (1)$$

In these equations x, y, and z represent the relative molar fractions of the three species present in the sample. They are respectively: the chemosensor, the chemosensor chelated to zinc and the chemosensor chelated to cadmium.

$I_T(\lambda)$ represents the signal emitted by the sample; $I_{Zn}(\lambda)$, $I_{Cd}(\lambda)$ and $I_{Ch}(\lambda)$ represent the emission intensity of the chemosensor saturated by zinc, by cadmium, and the free chemosensor respectively. The molar fractions can be determined by resolving the equation system at two different wavelengths. Actually, since the fluorescence spectra are measured at a large number of wavelengths, this system is overdetermined. The overdetermined equation system can be resolved by using a so-called QR decomposition. The key step of the QR decomposition is the orthogonal factorisation of the matrix equation $A = Q \times R$ where Q is an orthogonal matrix and R an upper triangular matrix.

Table I reports some experimental data obtained on samples containing cadmium, zinc and an excess of {1}.(multiwavelength approach).

Table1

Analytical concentration (nM) in the mixture		Measured concentration (nM)	
Zinc	Cadmium	Zinc	Cadmium
125	125	120(4)	130(4)
95	30	100(5)	30(0)
45	15	50(11)	15(0)
30	95	30(0)	85(11)
15	45	15(0)	40(11)

1.1.1.1 Elimination of interferences

A large number of heavy metals present in variable amounts in seawater interferes with the fluorescence of the chelated chemosensor with Zn or Cd

Therefore, a separation technique was to be developed in order to prevent fluorescence quenching by interferents as copper, chromium, mercury, lead and cobalt (Kraus and Moore, 1953).

Using a 1X2 400 Dowex resin in the experimental conditions described by Kraus and Moore, cadmium and zinc can be successfully separated from a mixture of heavy metals. Furthermore, a preconcentration factor of 6-10 is observed.

The accuracy of the preconcentration-fluorescence detection technique was examined by the determination of cadmium concentration in water certified reference material obtained from the National Research Council of Canada, Marine Analytical Chemistry Standards Programme. Using our method, we found a cadmium concentration of 169 ± 13 pM in estuarine water SLEW-2. This result displays good agreement with certified values (170 ± 20 pM).

The procedures described with Cd can also been applied to Zn since all the reagents are the same, except for the buffer solution. It appears that the detection limit of Zn is 0.8 nM and that, at a concentration of 10nM, the relative standard deviation is 8%.

LEAD AND MERCURY

Three reagents forming Room Temperature Phosphorescent chelates with lead (namely: 8-hydroxy-5-quinoline sulphonic acid, 8-hydroxy-7-quinoline sulphonic acid and 8-hydroxy-7-iodo-5-quinoline sulphonic acid (ferron)) have been tested in a flow injection system. The flowing system of figure 2, where fixed volumes of reagents are merged on-line with fixed volumes of lead standards ("merging zones technique"), was developed and used throughout.

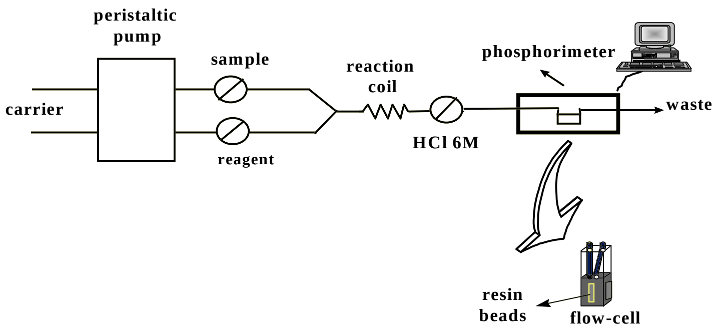

Figure 2.- Flow injection system for lead sensing.

As illustrated in figure 2, after on-line reaction, the formed anionic lead RTP chelate goes through the detection flow cell (placed inside the phosphorimeter), where it is retained on the ion exchange resin Dowex 1X2-200. Its RTP signal is then measured.
The effect of the following experimental variables upon the RTP analytical signal were evaluated : influence of the pH, concentration of the chelating reagents, methods to eliminate oxygen, salinity, carrier flow-rate, gating time of the photomultiplier. The interference effect of various species as Cd, Mg, Al, Hg, Zn, Cu, Co, Mn and Ca was studied, using 7-sulphonic hydroxyquinoline as chelating reagent in the presence of of 100 ng.mL^{-1} of lead. This last reagent was selected as it provided the best overall analytical performance for lead determination.

THE DETECTION LIMIT WAS 0.1 NG ML^{-1} OF PB(II). THE PRECISION (RSD) ESTIMATED ON A SAMPLE CONTAINING 100 NG ML^{-1} OF PB(II), WAS $\pm$ 3 % FOR THE THREE REAGENTS. THE RESPONSE TIME FOR FULL SIGNAL CHANGE WAS 5 MIN AND NO HYSTERESIS EFFECTS WERE OBSERVED.

So far mercury is concerned, the evaluation of six different reagents, which could form RTP chelates with mercury, namely: 8-hydroxy-7-sulphonic acid, 8-hydroxy-5-sulphonic acid, 8-hydroxy-7-iodo-5-sulphonic acid, thiamine and 6-mercaptopurine was carried out, as for lead. Using those reagents no RTP signal for mercury chelates was observed. However, good fluorescence signals were obtained for Hg^{2+} after reaction with thiamine and 6-mercaptopurine. Therefore, these reagents were selected for further mercury detection

The reaction of 6-mercaptopurine, leading to the fluorescent (6-mercaptopurine)$_2$ is still in the stage of a badge process and we will concentrate here on the reaction of mercury with thiamine.

A modified flow injection system was used for the determination of mercury with thiamine. In the system, the highly fluorescent thiochrome was formed as a result of the redox interaction of Hg with thiamine.

Thiochrome is retained on a solid support and its fluorescence is measured. Various resins have been tested and the highest fluorescence intensities were obtained when using Amberlite XAD-4. Moreover, different particle sizes of the packed resins were also investigated and particle diameters between 0.080-0.160 mm were selected for further experiments.
Presently, the detection limit for Pb is 3.6 ng mL^{-1}; the repeatability is +/- 3% and the response time is 5 minutes.

IRON, COBALT, MANGANESE AND COPPER

The construction of the FI-CL system is outlined on the basis of the manifold for the determination of dissolved Fe in seawater. For this purpose a FI-CL manifold based on the Fe(II) catalysed oxidation of luminol has been developed (Bowie et al.). In the manifold, three peristaltic pumps are used to deliver reagents, sample / buffer and wash solutions to the injection valve, preconcentration column and CL detector. A six-port injection valve is used to transport the sample to the detector. Three 3-way solenoid switching valves enable sample, sample plus standard addition(s) and wash solutions to pass sequentially through the manifold. In a first step, automation of the FI-CL system for the determination of Fe was provided via a D/A device control interface card housed in a desktop PC, previously used successfully in-house for FI-CL systems. The detection system currently consists of a quartz glass spiral flow cell mounted in front of an end-window photomultiplier tube, powered using a high voltage supply. CL signals are recorded using a flat-bed chart recorder or an integrator.
FI-CL technologies for other trace elements (Co, Mn, Cu) are based on the above manifold with minor modifications to suit the specific CL reaction system. Instrumentation is generic to all systems.

The automation of the FI-CL system for the determination of Fe is achieved through a Labview (National Instruments) environment run on a laptop PC. A digital i/o, 24 line TTL PCMCIA card (DIO-24) enables full control of FI components (switching valve, injection valve, pumps, autosampler), using a transformer box to modify 5 V signals generated by the card. A multifunctional 16 analog input card is used for acquisition of CL signals generated from the miniature photon counting head of the PMT detector. Signal output is modified through an in-house interface board into a frequency that could be acquired by the DAQ-700 card. The chemiluminescence chemistries for the determination of Fe, Co, Mn and Cu are summarized in table 2.

Table 2

Metal	Oxidation state	Principle CL reagent	Other reagents	Oxidant
Iron	Fe(II)	Luminol	NaOH	Dissolved O_2
Cobalt	Co(II)	Gallic acid	Methanol, NaOH	H_2O_2
Manganese	Mn(II)	Luminol	TETA	H_2O_2
Copper	Cu(II)	1,10-phenanthroline	CEDAB, TEPA	H_2O_2

Typical results obtained for Co (II) are given in table 3

Table 3

Sample	FI-CL	Certified value	CSV
NASS-4 (nM)	0.16 ± 0.01	0.15 ± 0.02	-
CASS-3 (nM)	0.60 ± 0.09	0.68 ± 0.11	-
SLEW-2 (nM)	0.93 ± 0.13	0.87 ± 0.21	-
Irish Seawater (nM)	0.35 ± 0.02	-	0.34 ± 0.01

In order to assess the practicality of shipboard operation of the FI-CL analyser and to validate the analytical method for samples containing relatively high trace metal concentrations, three trials were performed locally in the Tamar Estuary.
These surveys were designed to field test the instrumentation and investigate changes in dissolved trace metal concentrations in the estuary.
The FI-CL monitor was operated successfully during all three expeditions. No major instrumentation problems were experienced despite harsh weather conditions and the only difficulties encountered were de-frosting of the reagents and filtration of estuarine samples containing a high particulate load.

CONCLUSION

The Memosea project is progressing nicely along the schedule that was proposed initially in the Project Technical Annex.
Luminescence based techniques for the determination of Cd, Zn, Hg, Pb, Cu, Fe, Mn and Co have been developed for application to sea water after its preconcentration. With the exception of the chemiluminescence detection system which is to be completed, the instrumentation is ready for the collaborative laboratory and field trials that will take place during the period July-August 2000.

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TITLE : OCEAN TOMOGRAPHY OPERATIONAL PACKAGE AND UTILIZATION SUPPORT : **OCTOPUS**

CONTRACT N^o : **MAS3-CT97-0147**

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OCEAN ACOUSTIC TOMOGRAPHY OPERATIONAL PACKAGE AND UTILIZATION SUPPORT (OCTOPUS)

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INTRODUCTION

Ocean acoustic tomography, introduced by Munk and Wunsch (1979), has evolved over the past two decades to become a recognized tool in oceanographic research. This is largely a consequence of the implementation and successful completion of several experiments, which used tomography techniques to address scientific issues of interest (Munk et al. 1995).

Since acoustic tomography yields time series of horizontally integrated quantities, it is a useful complement to other physical observing techniques which usually obtain data at single locations in the ocean (hydrography, moorings) or which can only sense the sea surface (satellite remote sensing). In a sense, tomography is the only remote sensing method for the ocean interior, and therefore it is expected to play an increasingly important role both in future oceanographic research and monitoring/forecasting applications (e.g. GOOS).

The assessment of different observation techniques with respect to the future 'ocean observing system for climate' was the objective of the Oceanobs99 conference (held in St. Raphael, France, in November 1999), where the world observational oceanography community was represented. According to the conference statement, tomography can and should contribute to the future ocean observing system, at least in specific places; initial focus was suggested to be the Arctic Ocean (under the ice), the Strait of Gibraltar, and exploratory observations in the Atlantic Ocean (http://www.BoM.gov.au/OceanObs99/Papers/Statement.pdf).

To promote the operational use of acoustic tomography the OCTOPUS project is aimed at developing an integrated and easy-to-use tomography capability for the community of ocean scientists, service providers, and commercial enterprises, consisting of three main branches:

- A user-friendly software package (called TOMOLAB) for the design, processing and analysis of tomography experiments.
- A standard format to facilitate the exchange of tomography data (raw or processed) and a European tomography data bank.
- An SME-based capability for servicing tomography instruments and for tomographic processing (through TOMOLAB), as well as technical developments for operational usage.

The OCTOPUS project has been running since early 1998, funded by the EU/MAST-3 programme, and is planned to be completed in early 2001. In the following the various components of the project are presented in more detail.

THE TOMOLAB SOFTWARE PACKAGE

TOMOLAB is an integrated software environment, developed in MATLAB, providing easy-to use capability for the design, processing and analysis of ocean acoustic tomography experiments. It contains toolboxes for experiment and instrument description, ocean data analysis, forward and inversion-related acoustic calculations, tomography data pre-processing, travel-time estimation, peak identification and slice inversion (see Fig. 1). The scope of the various toolboxes is briefly described below.

- The experiment and instrument setup toolboxes are used to define/describe the geographical and geometrical parameters and data of tomography experiments as well as the parameters and data referring to the moored instruments and their components (controllers, clocks, transducers, receiving arrays, navigators).
- The ocean data toolbox handles historical and experiment-specific oceanographic information (data bases) and provides sound-speed and bathymetry sections, mean parameters for temperature and salinity, sound-speed EOF modes and their variances, as well as sound-speed to temperature conversion relations to be used for tomographic inversions.
- The acoustic toolbox is used to perform forward and inversion-related acoustic calculations for a particular experiment and using ocean data defined/provided by the previous toolboxes. The forward calculations refer to arrival patterns, arrival times and related quantities using ray-trace and normal-mode codes. The inversion-related calculations refer in addition to the derivatives of arrival times with respect to sound-speed modes (influence/observation matrices) for a set of background states.

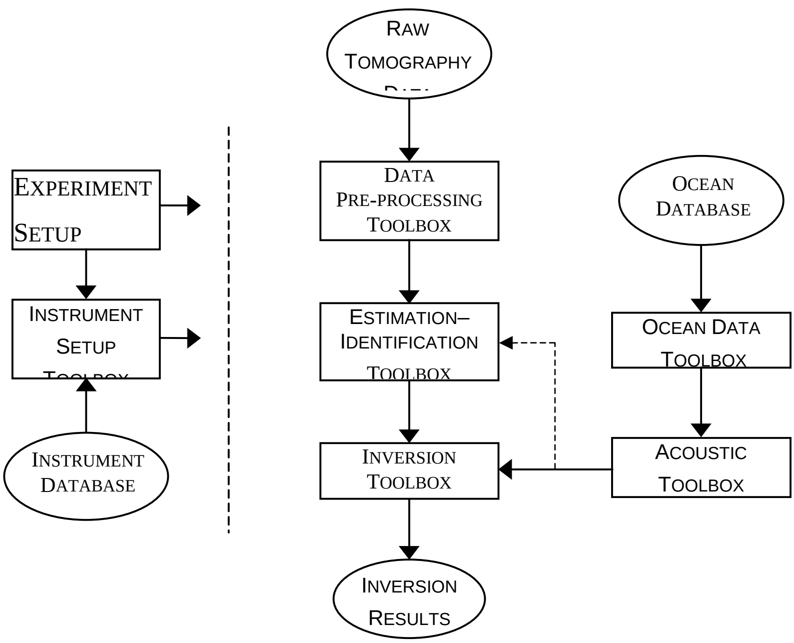

FIG. 1. A SCHEMATIC DIAGRAM OF THE TOMOLAB STRUCTURE

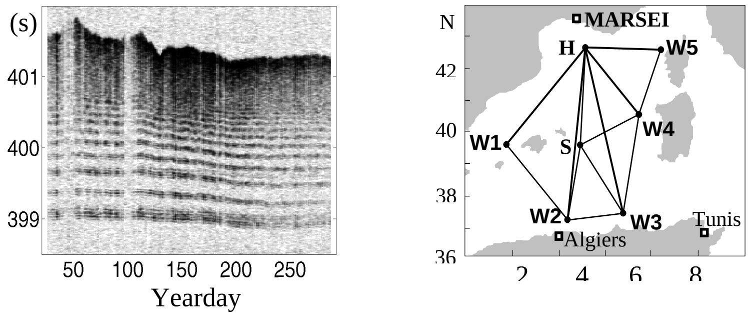

Fig. 2: Typical TOMOLAB input: Tomographic arrival patterns (left) along a 600-km section (W3-H) of the Thetis-2 experiment (right) over a period of 9 months.

- The pre-processing toolbox contains tools to perform correlation processing and Doppler analysis of the raw tomography data. It can be further used for normalization, windowing and oversampling, as well as for navigation (mooring-motion) and clock-drift correction of the acoustic data.
- The estimation - identification toolbox addresses the problems of arrival-time estimation, peak tracking and identification in the pre-processed acoustic data, using manual and statistical methods. This toolbox is used to convert the pre-processed acoustic data into travel-time data and identified peak tracks.
- Finally, the inversion toolbox is used to perform slice inversions and estimate averaged temperature distributions along particular sections. It covers a broad range of inversion methods, from traditional inversions of the identified peak tracks to simultaneous identification-inversion of the estimated arrival times (Skarsoulis and Send 2000) and matched-peak inversions (Skarsoulis 2000).

The above toolboxes have been developed in compliance with particular interface and integration specifications by 4 different groups (IfM, IACM, LIS and IFREMER), exploiting the available expertise of each group in the different fields. The interaction of the user with the toolboxes takes place through a graphical user interface under MATLAB. This interface contains among others an interactive geographical map, giving an overview of the experiment geometry on a geographical background and facilitating the definition, selection, and control of moorings and sections to be processed.

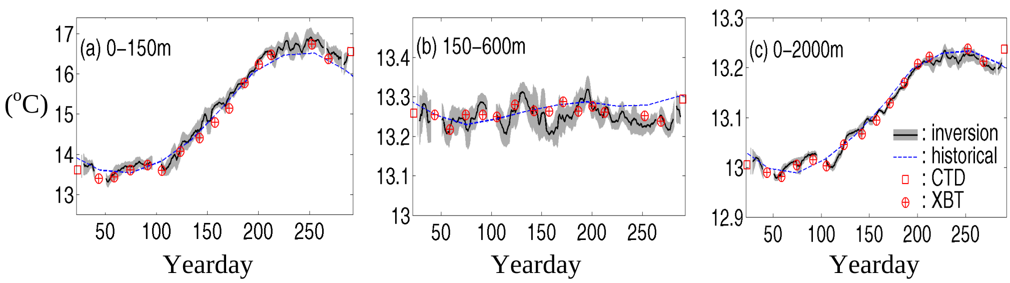

Fig. 3: Typical TOMOLAB output: The evolution of depth-averaged potential temperatures along the above Thetis-2 section, compared with historical, CTD and XBT data.

DATA FORMATS AND ARCHIVING

A standard data format has been established for experiment, instrument and tomography data as well as for intermediate processing results, upstream compatible with the software package and downstream compatible with the end user (exploitation) requirements. For the tomography data in particular, a set of standard levels of processing has been defined starting with raw data and ending with inversion results:

Level-0 data: Raw acoustic data as read from the instrument storage medium without any compression or processing.

Level-1 data: Complex correlated acoustic data (using a replica of the emitted signal) and, additionally, data with optional processing such as normalization, windowing and over-sampling, as well as navigation and clock-drift correction (output from pre-processing toolbox).

Level-2 data: Estimated arrival times from the acoustic data and, optionally, identified or un-identified tracks of arrival times through the experiment (output from estimation/identification toolbox).

Level-3 data: Slice-inversion results in the form of sound-speed mode amplitudes and sound-speed / temperature distributions obtained from the previous-level acoustic data (output from inversion toolbox).

The tomography data as well as all intermediate and final results are stored in NetCDF (Network Common Data Form) format (http://www.unidata.ucar.edu/packages/netcdf/), which is a self-descriptive, machine-independent format for representing and sharing array-oriented scientific data; NetCDF files can be accessed through the NetCDF library and interface. The flow of information between the various toolboxes of TOMOLAB takes place through NetCDF files referring to

- Experiment data
- Instrument data
- Ocean data
- Forward acoustic results
- Inversion-related acoustic results
    - Level-0 data
    - Level-1 data
    - Level-2 data
    - Level-3 data

The establishment of a data bank for tomography data is an important measure for dissemination and also to make tomography more accepted and widely used as "standard" data for research and for future monitoring/forecasting applications such as GOOS. Within OCTOPUS a data bank for European tomography data is established consisting of four modules.

- File server where acoustic tomography and environmental data sets are archived. These sets are handled using NetCDF and ASCII protocols.
- Oracle data base which records catalogues and metadata such as cruise summary, experiment and mooring descriptions.
- Web server which provides access to the catalogue and data sets. This server is dynamically linked to the Oracle data base and to the file server.
- FTP server which stores project results such as project documentation, file format description, software and data examples.

INSTRUMENT SERVICE AND DEVELOPMENTS

In the framework of OCTOPUS, an SME-based service capability for tomography instruments has been established by ORCA in Brest/France. Furthermore, technical developments, such as the establishment of testing, servicing, calibration procedures and protocols, have been carried out that will make the instruments more operationally useable. On the basis of these protocols a number of tomography instruments have been already serviced by ORCA.

A further development concerns the creation of a graphical man-machine interface under MATLAB for the tomography instruments used by the participants, to facilitate the procedures for preparation, deployment and recovery of the instruments. The interface is used to

- test the individual instrument modules as well as the integrated system,
- measure the instrument delays, gains and clock/emitter/navigation frequencies,
- calibrate the pressure/temperature sensors and the instrument clock,
- perform operational tests before deployment and after recovery of instruments, and finally,
- create a disk image of a recovered instrument, to be used for the generation of Level-0 files

In addition to the initial plan of OCTOPUS, developments have been undertaken to facilitate the operational and multi-purpose use of tomography instruments, in response to recommendations made at the Oceanobs99 conference. A first step is to use tomography sources to also provide sound signals for tracking RAFOS floats. Two transmitter modules of existing sources have been already modified to allow transmission of RAFOS signals and are currently tested in the framework of a nationally-funded tomography experiment in the Labrador Sea.

Secondly, steps have been taken in the direction of the future requirement of real-time data transmission. Tests have been initiated for surface-satellite data transmissions from a mooring, and for relaying data from simple subsurface instruments inductively along the mooring wire to the surface element. Once this approach is mastered, in theory any instrument with underwater connectors for accessing the data can be equipped with an inductive modem for extraction of data and transmission to the satellite float. Future projects should address this particular issue for tomography instruments.

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TITLE: SPECTROSCOPY USING OPTICAL FIBRES IN THE MARINE ENVIRONMENT : **SOFIE**

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SPECTROSCOPY USING OPTICAL FIBRES IN THE MARINE ENVIRONMENT (SOFIE)

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SUMMARY
The SOFIE project is a feasibility study whose aim is to design, construct and test a prototype instrument for the in-situ detection of selected pollutants and salinity in sea-water. A key issue is to combine four different spectroscopic methods in one overall instrument to have a versatile instrument which may be adapted later to other specific needs. To this end four sensors were developed for specific parameters and adapted to the requirements of the harsh marine environment. These sensors are being linked to two core instruments which were designed and built in this project. The final aim is to test the instrument under controlled conditions in flume tanks and finally in field trials with the instrument settled on an open frame ROV.

INTRODUCTION
Real-time and in-situ sensors offer new possibilities for monitoring and survey of the coastal zone which are complementary to existing measuring methods traditionally employing sampling. As some essential parameters to monitor water quality are based on optical methods, e.g. turbidity, colour, fluorescence of organic pollutants and pigments etc., the idea was to extend on one hand the possibilities of using optical methods by increasing spectral range and resolution accessible with one instrument and on the other hand by developing new sensors to be attached to this spectroscopic core instrument. The key to achieving of this aim is the use of optical fibres[i] and an especially designed imaging spectrograph[ii]. The basic lay-out of such an system is shown in Fig. 1.

The term "optode", often also referred to as "optrode" is derived from optical and electrode. The optode may be a sensor using the fibres only for transmission of the radiation or a section of the fibre itself may form the sensing area (i.e. a fibre optic chemical sensor, FOCS).

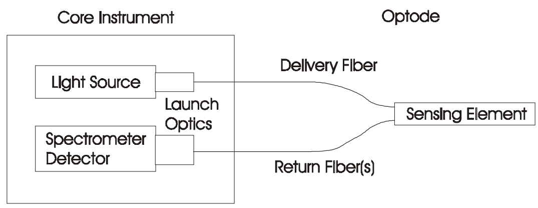

Fig.1 System of core instrument and optode

If the input fibres of several optodes are arranged at the entrance slit of an imaging spectrograph the spectra transported by each fibre can be registered simultaneously by a CCD array detector. This design inherently offers the ability for multiple-parameter detection. In this context, the issue was to find out what are the specific requirements for each method, how to combine them and where are the limitations. Another advantage of this optode system is the flexibility to exchange and add optodes.

The overall objective of the SOFIE project was to design, construct and test a prototype instrument for the in-situ detection of selected pollutants and salinity in sea-water. Key objectives were to find a compromise combining four different spectroscopic methods in one instrument, to develop the sensors and to adapt them to the requirements of the harsh marine environment. In parallel, the underwater core instruments had to be built including light sources, spectrograph and detectors and control unit compatible with the four sensors. Again, emphasis was put on rugged design and marinisation of instrumentation. After the laboratory test of the instrument, the instrument is being examined under controlled conditions in flume tanks and the final test will be a set of field trials.

RESULTS

General Design and Optodes

The four optodes chosen are listed in Table 1 with spectral range, target analytes and the spectrometer used. Details of the laboratory results from the sensors are published elsewhere.

Optode	Spectral Range	Analytes	Spectrometer
Raman/SERS	**800-910 nm**	Aromatic Hydrocarbons, PAH	**axial, dispersive**
Fluorescence	**420-600 nm**	Heavy Metals, Diss. Oxygen	**axial, dispersive**
Refractometry	**800-850 nm**	Salinity	**axial, dispersive**
IR Absorption	**2-20 µm**	Chlorinated Hydrocarbons	**FT-IR**

Table 1 Overview of spectroscopic methods used in the SOFIE project

Briefly, the surface-enhanced Raman scattering (SERS) sensor utilises the fingerprinting capabilities of Raman spectroscopy for substance identification. To this end SERS active substrates were developed suitable for operation in sea-water and to providing the sensitivity to measure analyte concentrations down to the ppb level. Analytes so far detectable are mono- or disubstituted benzenes and PAHs such as naphthalene, biphenyl etc.[iii,iv,v] The optode uses a backscatter configuration and exchangeable sensing layers. Practically the same collection geometry applies to the fluorescence sensor which targets dissolved oxygen for the demonstration phase utilising quenching of fluorescence.[vi] A suitable heavy metal sensing membrane may be introduced in this optode when it will be available.[vii]

The refractometric sensor measures salinity via the refractive index of the sea-water using a coated side-polished fibre.[viii] The salinity is needed because the SOFIE system is also intended for measuring in estuaries. The IR sensor uses evanescent wave absorption of the analyte which diffused into the polymer coating of a silver halide fibre. This method allows for substance identification and multicomponent analysis as does the Raman sensor, but the palette of analytes accessible is different: chlorinated hydrocarbons such as tri- and tetrachloroethylene are detectable as well as aromatic hydrocarbons BTX.[ix,x,xi]

The overall SOFIE system consists of an underwater instrument with two spectrometer modules to which the optodes are linked. One module for the VIS/NIR[xii] and the other for the MIR[xiii] because both spectral ranges are not compatible with one instrument The underwater equipment is linked to the surface control *via* cable which is also used for power supply. The system may be settled on a frame which will be lowered or an open frame ROV to move the sensors under water.

Core Instrumentation

Following is the description of the CI: Central part is a small-size axial spectrometer with a highly sensitive thermoelectrically cooled CCD camera. The spectrometer was designed and constructed to facilitate integration into the pressure housing ensuring a rugged design, and to cover a large spectral range with a good resolution. Therefore, an in-line configuration was chosen using a GRISM (grating and prism) as a dispersive element covering simultaneously two spectral ranges by exploiting the first and second order of diffraction. Thus, the 800 nm - 940 nm range is available for SERS and salinity optodes with an average resolution of 3.4 cm^{-1} per pixel and at the same time the 420 nm - 680 nm range for luminescence and absorption spectroscopy with a pixel resolution of 4.6 cm^{-1}. The 50 fibers of 50 µm core diameter at the entrance slit are currently split up into 4 different bundles suitable for four measuring channels. In addition to the spectrometer, the CI contains small and robust diode lasers with drivers and temperature controllers, electronics for the CCD control and data communication. All parts of the core instrument are integrated into a cylindrical housing of 1 m length and 250 mm outer diameter. The prototype CI having passed the pressure test is shown in Fig.2.

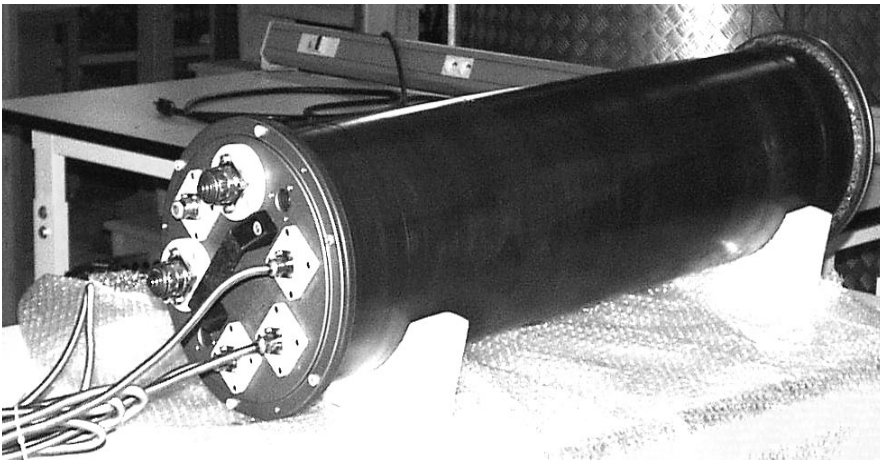

Fig.2 VIS/NIR core instrument after pressure testing

The FT-IR instrument contains a commercially available FT spectrometer whose optical and electrical components had to be completely rearranged to fit into the housing. The design is shown in Fig. 3. The fabrication of the instrument is currently being finished. The fibre-optic sensor is directly attached to the front plate to use a short fibre length.

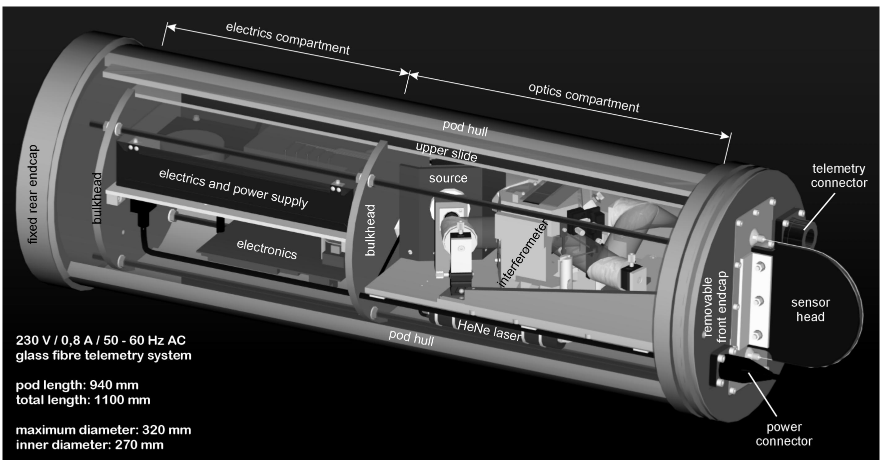

Fig.3 Underwater FT-IR instrument

Tests under Simulated Field Conditions

The construction of prototype equipment is accompanied by a series of tests which included as a first step the basic laboratory characterization of the sensors. A second test phase was devoted to investigate the behaviour of the sensor system under flow conditions to simulate the situation when the frame is moved or towed in the water. Here, hydrodynamic tests were performed and compared with model calculations using computational fluid dynamics. Further to these investigations, the marinised optodes are being subjected to chemical tests under flow condition. Fig. 4 shows the SERS optode in such an experiment.

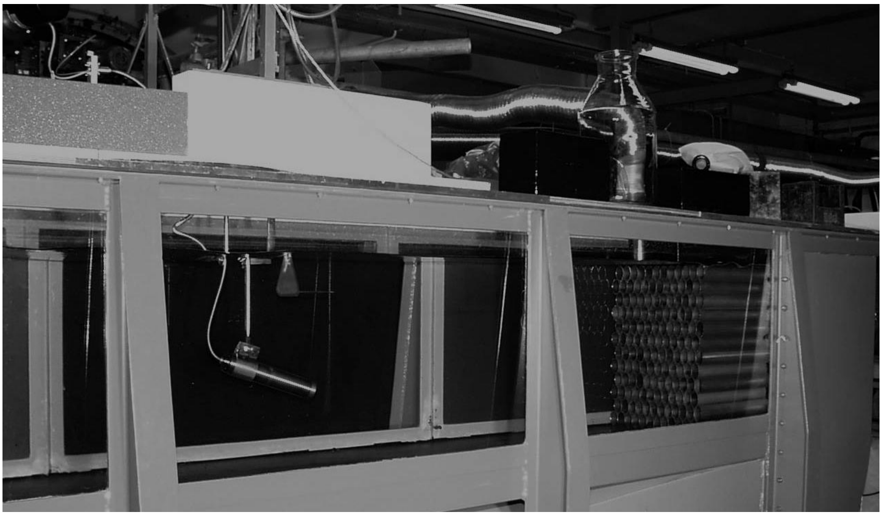

Fig.4 SERS optode in a flume tank experiment

The objective of this task is to characterize the sensor's response under controlled large scale conditions. This is the final test of function of the assembled instrument necessary before moving the SOFIE system to the stage of field trials. Initial results with the SERS optode showed encouraging response in the frequency and time domain detecting pollution with a naphthalene cloud in the flume tank.

CONCLUSION AND OUTLOOK

The construction of SOFIE prototype instrument is finished with CI and SERS optode. The other optodes and the FT-IR instrument are nearly finished. The equipment is currently engaged in the testing phase under controlled large scale conditions.

Fig. 5 shows as an outlook, the SOFIE system mounted to the open frame ROV which is under construction.

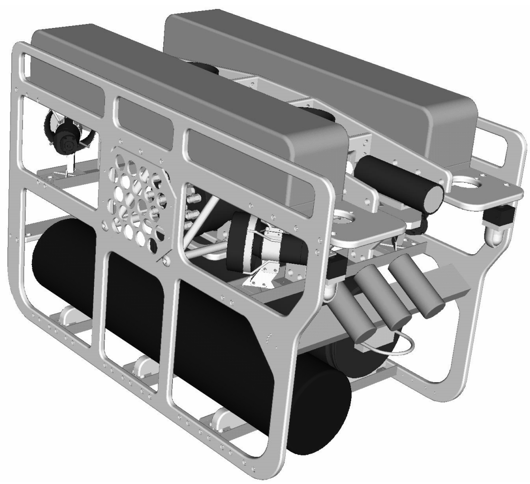

Fig.5 SOFIE system integrated into an open frame ROV

In conclusions we may state that the optode-based instrument has promising potential for qualitative and quantitative detection of pollutants and chemical parameters in sea-water. The sensitivity is high enough to reach the low ppb level with selected analytes and with response times in the range of few minutes. The palette of analytes and their limits of detection are certainly subject to further improvement.

The concept of optodes linked to a core spectrometer offers great flexibility to fit for different deployment scenarios and future applications. It is a new analytical tool opening interesting perspectives for *in-situ* measurements - not only to the ocean scientist.

ACKNOWLEDGEMENTS

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TITLE : DEVELOPMENT AND TEST OF AN INNOVATIVE ION SELECTIVE ELECTRODE MONITORING AND CONTROL SYSTEM FOR TOTAL NITROGEN IN MARINE WATERS.

CONTRACT N° : **MAS3-CT98-0177**

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DEVELOPMENT AND TEST OF AN INNOVATIVE ION SELECTIVE ELECTRODE MONITORING AND CONTROL SYSTEM FOR TOTAL NITROGEN IN MARINE WATERS

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1.1.1.1.1.1 INTRODUCTION

Coastal Zone pollution and Eutrophication of marine waters have been identified as key environmental issues and problems affecting the seas around Europe (1). The major contributing element to these problems is Inorganic Nitrogen, the levels of which are rising at an alarming rate.

Current farming practice in many countries, including excessive use of Nitrogen containing artificial fertilisers, seepage of animal waste into water ways, inadequate treatment of human sewage and several industrial processes are major contributing factors. This excess of inorganic Nitrogen usually occurs as Nitrate which is a nutrient leading to Eutrophication (1).

Eutrophication can lead to algae blooms, proliferation of seaweed and many other adverse effects on marine life depending on levels of pH, dissolved oxygen, salinity and temperature. Nitrate may convert to other toxic forms of Nitrogen including Ammonia, Ammonium, or Nitrite. These substances may also be produced by uneaten food in farmed fish, excreta, chemicals/therapeutics and dead fish. All of these Nitrogen species combine to exhibit varying degrees of toxicity on farmed fish including poor reproduction, stress, and chronic illness (Ammonia), acute toxicity (Nitrite) and greater competition for oxygen and Nutrition (Nitrate). The main economic niches to suffer adversely from excessive Nitrogen levels are persons engaged in mariculture, commercial fishing, hobbiest fisherman or persons engaged in scientific studies. These sectors are the main focus of this project but people engaged in tourism and provision of amenities may also be effected.

These problems are occurring at a time when classical agriculture is being put under increasing pressure. Growth of world population and hence food requirements, the non-sustainability of classical agriculture, pollution produced by agriculture, and the emphasis being put on fish consumption promotion by the FAO all indicate that aquaculture is an excellent alternative as a source of food.

At present there is no in-situ or on-line testing capability available to measure total Nitrogen in marine waters. An opportunity has been recognised by the consortium partners, all of whom are currently involved in environmental sensing, signal trasmission and pollution control to produce a low cost sensor array to measure all of the above mentioned analytes simultaneously

in-situ (Nitrate, Nitrite, Ammonia, Ammonium, pH, salinity, temperature and dissolved oxygen). The device will take the form of an array of individual sensors which will be configured into a sonde and placed at the site or various sites in areas of marine waters where fish farming is being engaged in.
Signals from the various sensors will be sent by telemetry to shore. The various levels of analyte will be recorded and computed into total Nitrogen. The signal transmitted to shore will be recorded and used to measure various levels of Nitrogen, forecast pollution trends, toxicity, etc., and a signal may then be sent back to the measuring site to initiate the denitification control or other remedial action where appropriate.

The first real time monitoring device of total nitrogen in-situ in marine waters with consequent dramatic ability to predict high levels of Pollution/Eutrophication, safety of water, suitability for bathing, risk to health of farmed fish and of fish in the wild state.

- 90% cost reduction compared to laboratory testing.
- Detailed provision of nitrogen levels for marine science studies.
- Infinitely improved capability to farm a wide range of mature fish species and new species
- Major business opportunity for more start up SME's in fish farming.
- Better utilisation of food/energy conversion
- Better knowledge of growth requirements of larva, new species and shell fish.

SOCIAL OBJECTIVES:

Due to the reduced requirement for sampling, substantial improvement of safety in the work place for persons involved in fish farming or other marine occupations. Access to and ease of handling of technology for a non scientific segment of the community.

- Substantial ease of mind for mariculturalist where they can check the levels of nitrogen on their PC at a glance rather than having to worry about detrimental toxicity defects to fish stocks.
- Ability to forecast pollution levels for amenity professionals, bathers and professional or hobbyiest fishermen.
- Substantial increase in employment for the SME's involved in the consortium (a forecast of at least 100 extra jobs) with consequent increase in turnover and profitability and market penetration.

PROJECT METHOLOGY:

Ion selective electrodes (ISE's) of optimal performance based upon published construction principles and composition for measurements of Nitrate, Nitrite Ammonia and ammonium have either been assembled or bought from commercially available sources where these are representative of the current state of the art and have been tested for a required function in marine matrices.

THE MEASURING PROGRAM FOR THE NITRATE ION SELECTIVE ELECTRODES (ISE) IS AS FOLLOWS:

Nitrate Ion selective electrodes from Metrohm, Orion and Mettler as well as those manufactured by Reagecon, were included in the overall testing. Measurements were carried out on the Nitrate Ion selective electrodes in Nitrate solutions where the concentration was varied from 0.0001 M/L up to 0.1M/L at two constant temperatures (10 & 20 ^{o}C) and constant pH (pH 8.4 for ocean water). The temperatures of 10 and 20 ^{o}C were chosen because they bracket the average temperature of sea water.

In order to keep the pH constant a small amount of Sodium Hydrogen carbonate ($NaHCO_3$) (~ 0.2 gr/L) was added to each solution. Initially tests were carried out in ultrapure water and in solution containing 0.2 g/l Sodium Hydrogen carbonate solutions to measure the combined influence of pH and carbonate. The resulting pH (of approximately 8.1 to 8.6) and carbonate concentration corresponds to the conditions expected in marine waters. Different Nitrate salts {such as Potassium Nitrate (KNO_3) and Sodium Nitrate ($NaNO_3$)} were added to determine the influence of the cation (the Potassium and Sodium ions). Furthermore the interference of chloride, bromide, sulphate and nitrite ions were tested in the Sodium Hydrogen carbonate ($NaHCO_3$) solution. Concentration ranges similar to those expected in seawater were chosen. The influence of chloride was examined at two different molalities (0.25 M and 0.5 M, the latter to be expected in seawater) in order to demonstrate the growing impact of interference. The interference of pH, bicarbonate, chloride, nitrite, bromide, fluoride and sulphate ions in nitrate/bicarbonate/ water mixtures at constant temperatures was assesed in order to determine the selectivity coefficients as a function of the concentrations for the various sensors. All measurements were carried out at constant Nitrate concentrations (up to 0.1 M). With the exception of the pH interference the pH of solution is fixed by the carbonate buffer system to approximately 8.4.

To measure the pH interference at a constant, i.e. zero bicarbonate concentration the pH was varied by adding Nitric Acid (HNO_3) or Sodium Hydroxide (NaOH) to bicarbonate/ free water/ Nitrate solutions. To prevent the absorption of Carbon Dioxide (CO_2) from the air the solutions were sparged with Nitrogen. When the bicarbonate concentration was varied by adding Sodium Hydrogen Carbonate ($NaHCO_3$) the pH was fixed by adding Nitric acid (HNO_3). At pH 8.2 to 8.4 the fraction of dissolved Carbon Dioxide (CO_2) is negligible and the fraction of carbonate (CO_3^-) only about 2 percent of the total carbon so that the bicarbonate concentration is equivalent to the amount of Sodium Hydrogen Carbonate ($NaHCO_3$).
Measurements of Nitrate were then carried out in an artificial seawater matrix, varying systematically the Nitrate level and the concentrations of all interfering ions found.

THE MEASURING PROGRAM FOR THE NITRITE ION SELECTIVE ELECTRODES (ISE) IS AS FOLLOWS:

Measurements have been performed on Nitrite electrodes from REAGECON and Orion. In all experiments the Nitrite ($NaNO_2$) concentration was varied from 0.0001 M up to 0.01 M at temperatures of 20°C and 10°C. The interference of chloride, bromide, sulphate and nitrate ions were tested. For these ions concentration ranges that may be expected in seawater have chosen. Since a pH range of 4.0 – 5.0 is recommended for the Orion electrode, most of the measurements have been carried out in dilute aqueous HCl solutions at pH 4.5. According to the technical information supplied by Orion long term exposure to pH greater than 8.0 may damage the nitrite electrode membrane. That being the case the Orion ISE is not suitable for Marine applications.

THE MEASURING PROGRAM FOR THE AMMONIUM ION SELECTIVE ELECTRODES (ISE) IS AS FOLLOWS:

Testing was carried out on Ammonium sensors obtained from Orion and Mettler as well as those manufactured by Reagecon. In all experiments the Ammonium (NH_4Cl) concentration was varied from 0.00005 M up to 0.1 M and measurements performed at temperatures of 20°C and 10°C. From an evaluation of the toxological data compiled by the consortium it has been established that an expected maximum concentration of approximately 0.0003 mol NH_4/l in seawater.

Apart from the measurements made in ultrapure water the interference of Sodium (Na^+), Calcium (Ca^{2+}) and Potassium (K^+) ions was also determined. Concentrations were chosen that may be expected in seawater. The influence of Sodium ions was examined at 0.5 M while the influence of Calcium and Potassium was measured at 0.01 M.
The solution pH was not adjusted by Sodium Hydrogen carbonate ($NaHCO_3$). We chose the pH arising under atmospherical conditions instead (pH 5,3-7,0) to avoid the reaction of NH_4^+ to NH_3 as to be expected in a basic solution.

RESULTS

Results for testing the Nitrate Ion Selective electrodes:
At 20°C the combined pH/carbonate influence is negligible in the case of the Reagecon and Mettler-electrode, but significant for low nitrate concentrations in case of the Metrohm and Orion electrodes. At 10°C the combined pH/carbonate influence is somewhat higher. The interference of chloride is substantial at Nitrate concentrations less than 0.001 M. At higher concentrations the slope became nearly independent from the chloride concentration and the lines showed only a shift which increased with rising Chloride concentration.
For concentrations to be expected in seawater the interference of Bromide (Br^-) and Nitrite (NO_2^-) is smaller than that of the chloride (Cl^-) ions. The influence of Sulphate (SO_4^{2-}) was negligible. ($Cl^- > Br^- > NO_2^- > SO_4^{2-}$).
To summarise the testing at 10°C it may be stated that the interference of all ions is slightly smaller than at 20°C.
At 20°C in ultrapure water and 0.2 g/l $NaHCO_3$-solution slope and linearity of the Reagecon- and the Mettler-electrode are very good, while the Metrohm- and Orion-electrode showed somewhat higher deviations from the Nernstian behavior. At 10°C the slope of the Mettler - electrode differs somewhat more from the Nernst value, while the slope of the Reagecon - electrode agreed very well.

RESULTS FOR TESTING THE AMMONIUM ION SELECTIVE ELECTRODES:

All electrodes showed a similar pattern of behaviour when being tested. The interference of potassium and sodium ions was substantial at ammonium concentrations less than 0.002 M, while the influence of calcium was negligible. At higher concentrations the slope become nearly independent from the concentration of the interfering ions. The interfering ions behaved similarily at 10 degrees Celsius and at 20 degrees Celsius.
At 10 and 20°C in ultrapure water the slope and linearity of the Reagecon- and the Orion-electrodes are very good, while the Mettler electrode shows somewhat higher deviations from the Nernstian behavior (See table below).
The differences between the both Reagecon electrodes are negligible.

Electrode	t (°C)	Slope* (mV/M)	Nernst (mV/M)
REAGECON 03	20	57	58.17
REAGECON 04		57	
Orion		57	
Mettler		52	
REAGECON 03	10	56	56.18
REAGECON 04		55	
Orion		54	
Mettler		51	

Table 2: Slope of different electrodes in ultrapure water

All electrodes had very short adjustment times in 0,0001 M NH_4^+ even after 5 days of dry storage. Contrary to former measurements with Nitrate selective electrodes very little adjustment problems were found for all Ammonium (NH_4^+) selective electrodes even in the presence of interfering ions like Sodium (Na^+) or Potassium (K^+) at concentrations similar to those to be expected in seawater.

RESULTS FOR TESTING THE NITRITE ION SELECTIVE ELECTRODES:

The drifting behaviour observed during the adjustment time measurements also influences the measurements of the concentration series.

Period of dry storage	pH	Electrode	Adjustment time/ minutes
1 day	**6.2**	**REAGECON 09**	12
		REAGECON 10	12
		ORION	55
4 days	6.0	**REAGECON 09**	14
		REAGECON 10	15
		ORION	50

The interference of the chloride ion is significant in the whole concentration range but much smaller than in the case of the nitrate and ammonium electrodes. The chloride interference of the Reagecon electrodes is smaller than the influence on the Orion electrode.

In the concentration range to be expected in seawater the interference of Bromide (Br^-) and Nitrate (NO_3^-) is negligible at both temperatures. At 20°C the interference of Sulphate (SO_4^{2-}) is moderate, at 10°C the influence of Sulphate (SO_4^{2-}) is small.

At 10°C interfering ions had less of an impact than at 20°C.

At pH 4.5 the slope of the Reagecon and the Orion electrode are satisfactory. The slopes of the REAGECON electrodes are somewhat closer to the theoretical value (Nernst value). At pH 8.5 the curves differ significantly from the values measured at pH 4.5. Slope and linearity of the Orion electrode were very poor in the whole concentration range. In the range $m_{NO_2^-} < 0.001$ mol/kg the slope of the REAGECON electrodes differs significantly from the theoretical value (Nernst value).

RESULTS FOR TESTING THE REFERENCE ELECTRODES CONSTRUCTION AND COMOPSITION:

Reference electrodes of a large variety of construction and composition reflecting the current state of the art and proprietary knowledge have been prepared and challenged for speedy response, reproducibility and particularly long term stability in marine matrices and capable of withstanding bio-fouling. Depending on the outcome of subsequent specialised biological and physical testing there are 2 prototype reference electrode designs which can be proceed with.

MANUFACTURE OF CALIBRATION SOLUTION:

The nature of marine and ocean water composition has been researched and an array of calibration solutions have been formulated and tested in terms of primary ion concentration. These solutions and analytical test methods are appropriate to them have been validated using certified reference so that an unbroken chain of traceability with regard to chemical measurement is conferred on the multi-sensoric array in terms the chemical calibrants to which they will be subject in use.

DESIGN AND MANUFACTURE OF A PROTOTYPE CIRCUIT BOARD:

A prototype circuit board capable of taking sensor signals, performing A/D conversion, including an EEPROM, analogue and digital inputs and outputs has now been designed. This will be the heart of the signal processing and control function within the sonde and in conjunction with a transponder unit will enable communication to shore and interface with a personal computer for monitoring and control purposes.

DEVELOPMENT OF SOFTWARE :

Software has been developed for the expression of raw signal data (in millivolts) as ion concentration (pX). There is an interface between raw data signal transmissions and control command and integrational date with graphical user interface has been achieved using commercially available front end software (Intellution TM Fix 32 which is automation software). The software allows for trends to be graphed, levels to be analysed, and computed decisions to activate control hardware and to enable report functions.

CONCLUSION

Of the 10 major project milestones given, at this mid term stage of the project, 5 of these milestones have been reached and this is as planned for the project. The most significant technical innovation and highest element of technical risk - the development of ion selective electrodes which go beyond the state of the art and are capable of direct measurement of nitrogen components in marine waters has been delivered. Reference electrodes suitable for use with these ion selective electrodes, designed specifically for long term stability in the presence of marine matrices have been delivered with the required technical characteristics. In order to ensure the quality of the analytical measurements derived from these sensors, appropriate chemical calibration materials of know ion content have been delivered which additionally feature the necessary validation and traceability to international units of measure for the appropriate analyte concentrations.

The electronic hardware and the associated control, reporting, measurement and display software have been delivered. The telemetry link between the remote sonde and the host PC has substantially been designed but in the light of current developments in GSM technology this is still being developed and is not fully delivered. The stage has therefore been set for the remaining parts of the project which should now flow as anticipated and these would include the development of the software to include predictive/expert element, mechanical engineering of the sonde housing an associated hydraulics, integration of electronics and of the multi sensoric array as well as the extensive plan of required function testing and field trials.

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