NATO SACLANT
UNDERSEA RESEARCH CENTRE

ANNUAL PROGRESS REPORT 2001

CRV Leonardo
Technical Specifications

Length overall	28.6 m
Beam	9,0 m
Draft	2.5 m
Light ship displacement	337 t
Full load displacement	393 t
Propulsion	3 Cummins prime movers Diesel electric driven Twin Azimuthing Thrusters (Aft), 360 Pump Jet Bow Thruster (Forward) Power Management Dynamic Positioning (SDPII)
Acoustics	5 knot low noise condition
Total power	1170 kW
Max Sustained sea speed	11.0 knots
Range at 11 knots	1500 nm
Crew	5 (48 years of research vessel experience in total)
Scientific staff	7

Main Deck Machinery

Aft Crane	1.5 t
Forward Crane	1.0 t
A-Frame Aft	2.5 t
Large Oceanographic Winch	2000 kg Line Pull
Small oceanographic Winch	2000 kg Line Pull
CTD Winch/Gantry	250 m depth capability

Navigation/Research

Kongsberg suite:

Kinematic GPS	RTK200
Data Fusion	MDM400
Echo-Sounder	EA400 (Dual frequency)
Motion Sensor	MRU-5
Multi-Beam	EM3000 (Moon Pool)
Acoustic Positioning	HiPap 500

ISM code equivalent procedures applied on board

Annual Progress Report 2001

CONTENTS

Annexes

Foreword by SACLANTCEN Director

This report describes how the Centre has discharged its mission according to its Charter. Although not yet concluded, the process of establishing a stable funding régime reached an important phase in June, when the Senior Resource Board endorsed and the Defence Planning Committee approved resource requirements necessary to sustain a viable Undersea Research Centre for NATO. These requirements, put forward by SACLANT in the overarching SACLANTCEN Capability Package are commensurate with NATO Minimum Military Requirements and the SACLANT core mission. The Capability Package is designed to address existing and projected shortfalls, including the common-funded part of the Littoral ASW and MCM programmes (to which high priority is allocated in the Concept Development and Experimentation initiative) the research aspects of the NATO Concept of Operations on Rapid Environmental Assessment and those elements of MO2015 that are appropriate to common-funded undersea research.

The year 2001 witnessed several important "firsts". Construction of NATO's second[1] ship, CRV Leonardo, was officially begun in May by laying the keel at the Investrem Remontawa shipyard, Gdansk. In November, the completed hull was transported to Liverpool, where McTay Marine, as main contractor, is responsible for the fitting out. The commissioning is scheduled for September 2002. This new state-of-the-art research asset will provide a capability, which is clear evidence of NATO's continued support for undersea research as carried out during the 42 years since the Centre was founded. The Leonardo will allow the Centre to continue to make essential contributions towards scientific solutions of the complex problems confronting NATO forces, now and in the future when conducting operations in the littoral.

In April, after considerable preparation, we embarked on the implementation of ISO 9001:2000, a quality management system that provides a tried and tested framework for a systematic approach to the management of business processes. The implementation involves significant effort from personnel at all levels. In September a one-day workshop was held, attended by all staff, to garner their views regarding the efficiency, effectiveness, strengths and weaknesses of processes at the Centre. Several improvements and suggestions were proposed and incorporated into the ISO framework, which includes processes related to management, finance, procurement, personnel administration, engineering, sea trials, computing support and management. The ISO work is conducted in parallel with normal activities. Formal certification is scheduled for the second half of 2002.

In the second half of 2001, NATO's first autonomous undersea vehicle (AUV) was delivered to the Centre. It is worth remembering that the Centre initiated its AUV scientific programme more than two years ago before the AUV-MCM concept was singled out for priority in MO 2015. Hundreds of thousands of dollars of extra equipment and manpower were made available to NATO by a number of national research institutions and universities, testimony to the Centre's reputation for excellence, thus enabling the Alliance and its Nations to maintain the momentum of progress.

[1] The first being the SACLANTCEN research vessel *Alliance*, commissioned in 1988

For the first time in 10 years, the Alliance deployed to the east coast of North America from April until September for joint research programmes with US and Canadian partners.

The scientific activities that constitute this report are numerous and varied:
In the Rapid Environmental Assessment Thrust, littoral ocean prediction skills were demonstrated during major trials in the Adriatic and the Gulf of Maine. A new AUV-based expendable bottom penetrometer and a method, which deduces bottom reflection properties from noise directionality were successfully tested.
In the Mine Countermeasures thrust, further progress was made on synthetic aperture sonar (SAS). The first successful experimental results, combining motion estimates from an inertial navigation system and data-driven micronavigation techniques were obtained. This will allow an order of magnitude improvement in SAS performance in complex, littoral environmental conditions.
The work in the Littoral ASW thrust during CERBERUS '01(a joint experiment with Germany and the United Kingdom in the South Western Approaches) demonstrated the potential of the concept of interoperability of multistatically networked Low Frequency Active Sonar.
The Command and Operational Support thrust produced Version 1.0 of PLANET ASW Operational Planning Tool, which has been selected as the prototype tool for the capture of ASW Operational Planning Requirements for NATO's Maritime Command and Control Information System. Furthermore, exercise analysis support has resulted in statistically significant performance data for use in the NATO Defence Requirements Review.
The detailed Annual Progress Report, which follows is designed to allow the reader to judge the success of the Centre in fulfilling its mission during 2001, within the constraints of available funding.

Thrust 01 Rapid Environmental Assessment (REA)

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Project 01-A: Rapid assessment of operational ocean parameters (Alliance days - 56, Manning days - 15)

Operational Relevance

Provides tools for the measurement and real-time analysis of the oceanographic and acoustic parameters to enhance understanding of the complex physical processes of the ocean. An integrated and comprehensive REA capability will enable the generation of a timely environmental picture of an operational area, allowing the maritime commander to exploit the environment to his strategic and tactical advantage. Exercise support and MCM percentage clearance trials are programmed in order to quantify REA operational gains.

Ocean modelling

Environmental observations are fundamental to the initialization and updating of ocean forecasts, an essential component of effective and efficient REA operations.

As observations are the most expensive part of the forecasts and often difficult to achieve, reduction is desirable. Adaptive sampling is one method to reduce the number of observations, i.e. features and structures are only sampled in space and time where and when it is necessary to acquire information on the dynamics which evolve them. The primary goal of ASCOT (Assessment Skill for Coastal Ocean Transients) is to develop adaptive sampling strategies for ocean forecasting, using minimum input, to enhance the efficiency, improve the accuracy and to extend the scope of nowcasting and forecasting of oceanic fields.

The primary tool, the Harvard Ocean Prediction System (HOPS), which has been in use since 1996 at SACLANTCEN, has three major components: a data module, from which nowcast fields are derived by objective analysis; a numerical model module, from which dynamical interpolated fields are derived and a data assimilation module which allows integration of the most recent observations into the numerical simulations.

In order to improve weather predictions, forcing fields from forecast models were improved with information from local meteorological stations. The latter were used as ground truth for the forecast fields. Forecasts from the US COAMPS weather prediction model for the Mediterranean have been archived since the beginning of the year 2000.

Oceanographic experiments

Two major Coastal Predictive Skill Experiments (CPSE) concept demonstration oceanographic trials were executed in 2001, ADRIA01 (23 January - 16 February) in the Adriatic Sea, and ASCOT01 (2 - 26 June) in the Gulf of Maine.

ADRIA01

The primary objective of ADRIA01 was to develop a capability for the rapid assessment and prediction of littoral ocean conditions. A specific objective was, to use the oceanographic data of a repeat survey in the northern Adriatic for validation of model forecasts.

The ocean model employed was the Harvard Ocean Prediction System (HOPS) solving the full set of prognostic differential equations, thus enabling a forecast of the evolution of ocean

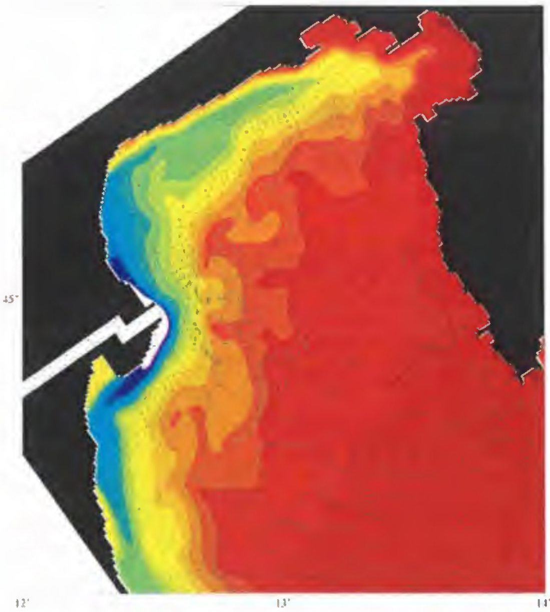

Fig. 01-A/B.1 *Surface salinity and velocity of the long-range HOPS forecast for February 11. Salinity is indicated by colour, the displayed range is 20 - 40 ppt. Salinity values < 20 ppt are not contoured.*

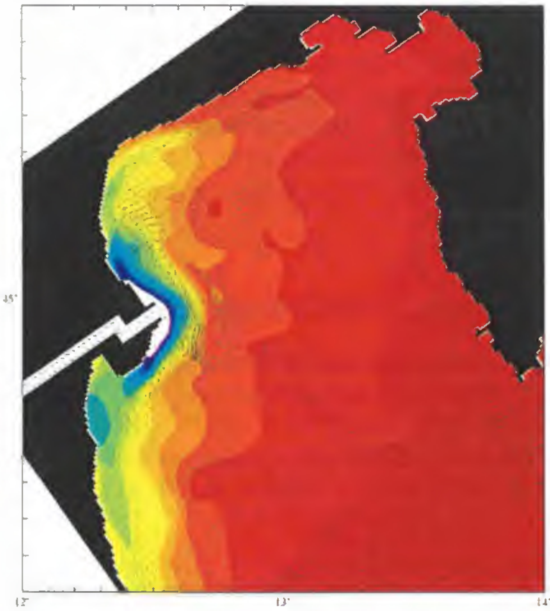

Fig. 01-A/B.2 *Surface salinity and velocity of the short-range validation forecast for February 11. Salinity is indicated by colour, the displayed range is 20 - 40 ppt. Salinity values < 20 ppt are not contoured.*

parameters. In ADRIA01, HOPS was initialized from measurements acquired in the period January 28 - February 4 and forecasts of the oceanic environment were continued until February 11. While before February 4, the model solution was constrained by assimilated data, the assimilation weight was steadily decreased. Hence, with time, OPS "forgets" the observations and becomes progressively more under the control of its internal dynamics and predicted atmospheric forcing.

In order to validate the HOPS forecast, a second model run was initialized using data from a repeat survey, which was conducted on February 7-10. The modelled surface salinity and velocity fields for 11 February displayed in Figs. 01-A/B.1 and 01-A/B.2 show that the forecast overestimates the extent of the low salinity lobe originating from the Po, whereas the velocity fields are in relatively good agreement.

Further validation of the long-range forecast was performed by comparison with measurements. Figure 01-A/B.3 shows currents measured by ship-mounted ADCP in the period of time February 7 - 14. The northern Adriatic was sampled between days 7 and 11, therefore the currents may be compared with the modelled ones of Fig. 01-A/B.1. The observed and modelled patterns exhibit a broad inflow into the northern Adriatic in the east and a narrow return flow close to the Italian coast.

Forecasts of sea surface temperature were validated with satellite AVHRR images. The predicted sea surface temperature of February 11 from the long-range forecast is displayed in Fig. 01-A/B.4. Typical features are the ribbon of cold water < 11° C along the Italian coast and warmer water up to 15° C further offshore. The modelled patterns are confirmed by the satellite image of the same day (Fig. 01-A/B.5). Note that the colour scales of the figures are slightly different.

ADRIA01 was the first real test of HOPS in very shallow water < 50m. It was demonstrated that HOPS provides reliable forecasts of temperature, salinity and currents within a forecast range of about 3 days. Longer-range forecasts are less reliable, mainly because atmospheric forecasts exceeding 3 days are not available or not reliable. Ocean forecasting in very shallow water depends critically on the quality of atmospheric forcing. A fundamental shortcoming of weather forecasts is that the

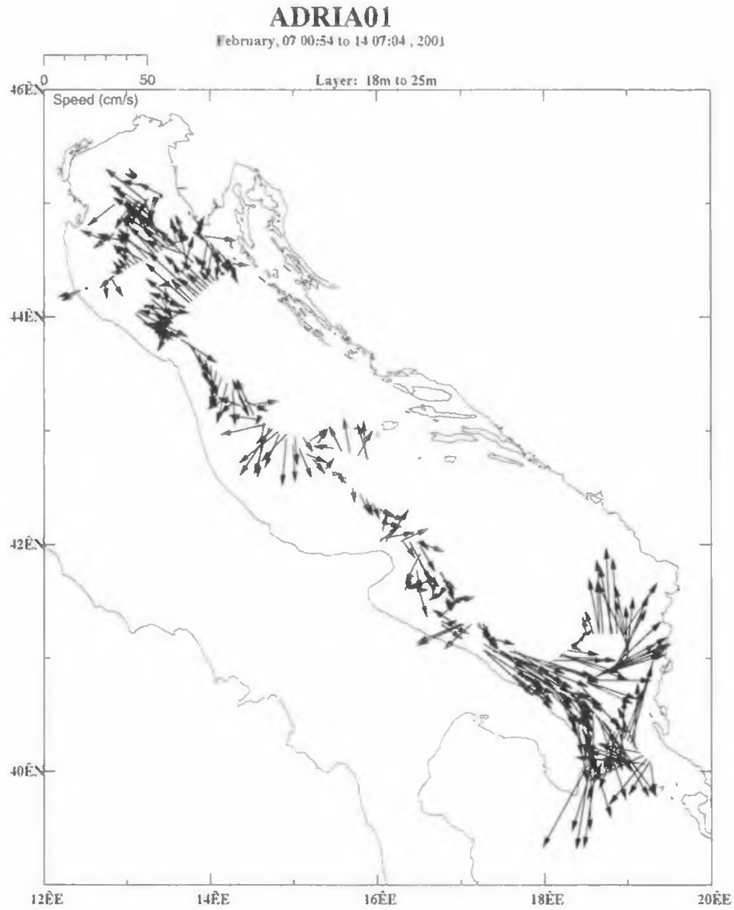

Fig. 01-A/B.3 *Near surface currents (18 - 25 m depth range) of the Adriatic, measured by ship-mounted ADCP between February 7 and 14.*

horizontal resolution is still 1 - 2 orders of magnitude worse than the resolution of ocean forecast models, which makes it almost impossible to predict the coastal ocean correctly.

ASCOT01[1]

During ASCOT01, the Gulf of Maine and Massachusetts Bay were sampled twice along the same tracks (Fig. 01-A/B.6); the first data set was used for HOPS initialization and the second for assessment of the forecast skill. Drifters were deployed in the model at the time and location corresponding to the deployment of real drifters and their tracks were evaluated by Lagrangian integration of the model velocity fields. The results were compared with the tracks of the real drifters, (Fig. 01-A/B.7).

Objective methods to assess the forecast skill are under development. They will be applied to the ASCOT01 data set and ASCOT02, which will take place in the Mediterranean near the island of Elba in May 2002.

[1]As by coincidence, the *Endeavour* and *Oceanus* (Woods Hole Oceanographic Institution) were operating in this area, it was agreed to share the data acquired.

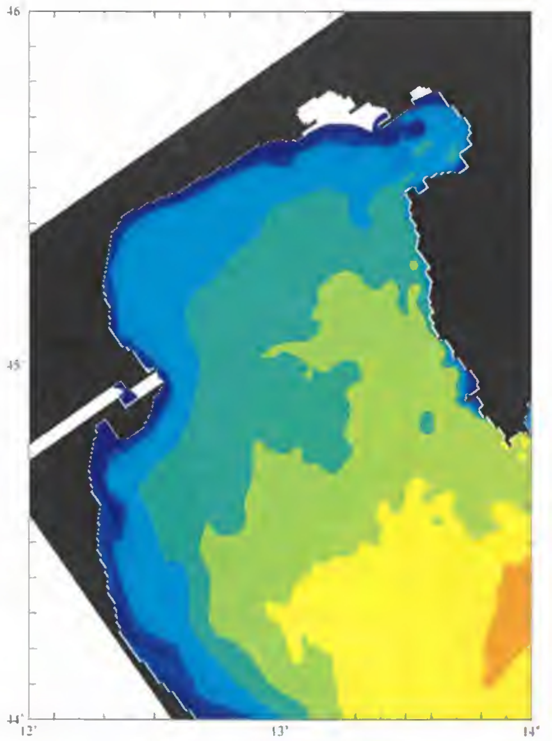

Fig. 01-A/B.4 *Long-range forecast of sea surface temperature for February 11. Temperature is indicated by colour, the displayed range is 6 - 16 ° C, the contour interval is 1 degree. Temperatures below 6 ° C (in the Po river and the northernmost Adriatic) are not contoured and left white.*

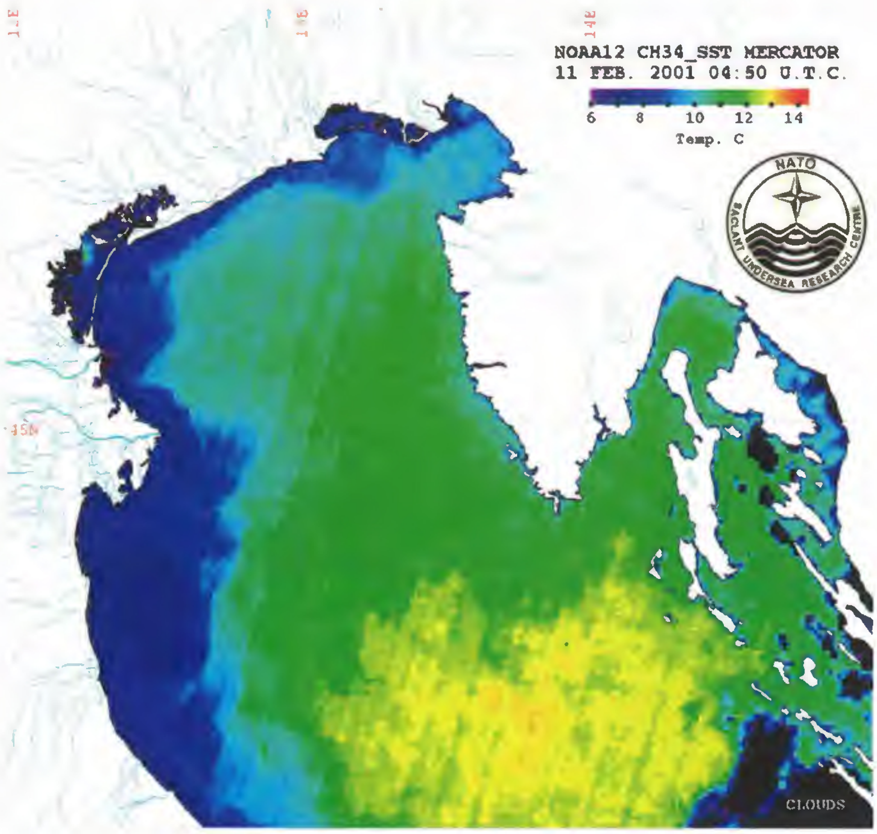

Fig. 01-A/B.5 *Satellite AVHRR image of sea surface temperature on February 11, measured by the NOAA 12 satellite.*

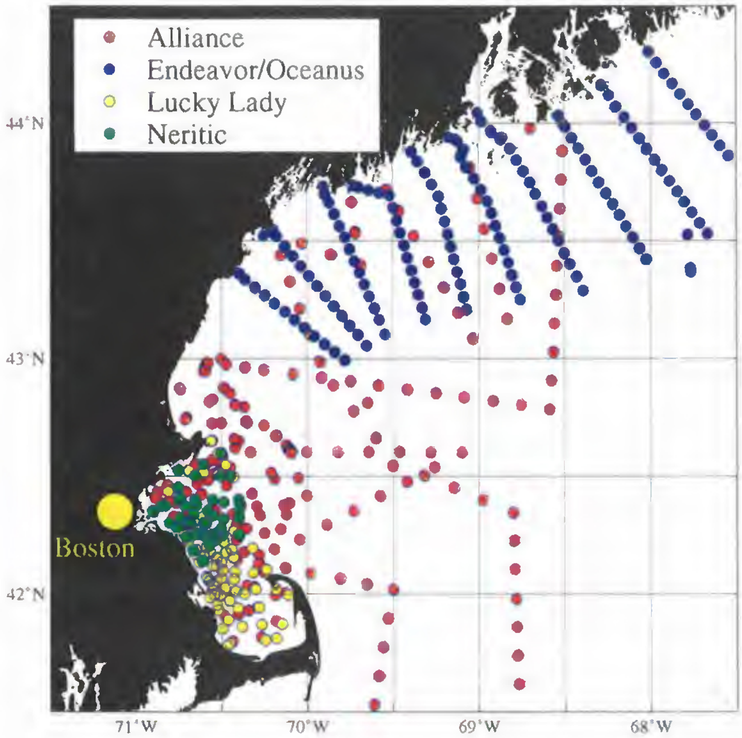

Fig. 01-A/B.6 *CTD positions in the Gulf of Maine and Massachusetts Bay during ASCOT01. The magenta-coloured dots indicate positions occupied by NRV Alliance twice during the initialization survey 6 - 17 June and again 19 - 24 June for the assessment of the forecast skill of the model.*

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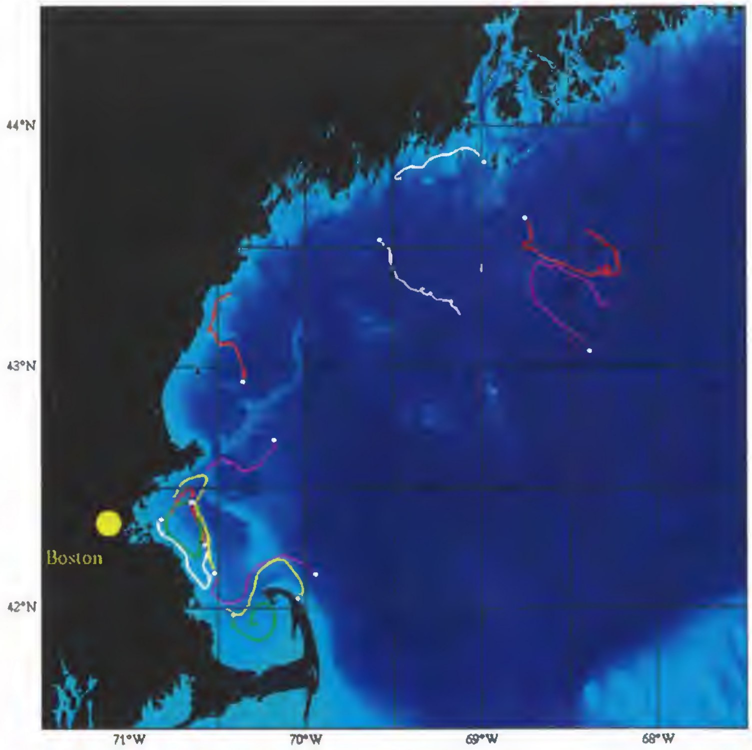

Fig. 01-A/B.7 *Simulated trajectories of Lagrangian drifters deployed at 10-m depth in the HOPS forecast model. The coloured lines show the trajectory of 15 - 24 June, the most recent drifter position is indicated by white circles.*

Coastal zone oceanography

Littoral turbidity and surface drift modelling

Several products made available by the nations, in particular by the NRL (US) were evaluated. A major experiment was designed for evaluation of the performance of several tools, using high-resolution oceanographic and meteorological data in 2002 in the Adriatic Sea[1].

Nearshore measurements

The Centre possesses significant capability for measuring environmental conditions such as incident wave fields and coastal currents in the relatively deeper waters of the continental shelf. Measurements of this type would serve as the far field boundary conditions for the type of surf zone modelling capability being developed. That which is lacking, is the ability to make measurements in the high energy, shallow water environment of the surf zone. For model validation as well as environmental modelling, measurements are needed which, at a minimum, provide information about the local wave field, water surface elevations, the horizontal current field and the state of wave breaking. After evaluating several options, a single underwater instrument package was identified, which can provide most of the required capability with some additional information. The centre is in the process of acquiring an array of acoustic Doppler velocimeters with incorporated compass, tilt, and pressure sensors, each of which will measure or permit the calculation of, the full velocity vector, the directional wave spectra, the sea surface elevation and fluid stresses. An array of these instruments will allow the characterization of the entire surf-zone. A video monitoring system has also been acquired to provide estimates of wave breaking as well as to place the point measurements in context in terms of the entire surf zone. Due to their compact nature, ease of operation and relative robustness, the velocimeters provide an ideal base for development of a sensor for real-time monitoring of the surf-zone. Experience with the integration of point measurements and video monitoring will provide a framework for the fusion of remote sensing and *in situ* measurements.

Nearshore modelling

Work has begun on developing a surf-zone modelling capability, which given appropriate far field input parameters, will predict breaking wave height, breaker type, surf zone width and longshore current. These parameters are of fundamental importance for the support of mine reconnaissance and clearance, shoreline assaults and transport of personnel and equipment across the land-sea boundary.

It was decided that the quickest method to develop a relatively robust near-term modelling capability would be by merging an existing 2-D shallow water wave generation and shoaling model with a relatively simple 1-D wave breaking and surf-zone circulation model. SWAN (Simulating WAves Nearshore)[2] has been chosen as the wave generation and shoaling model because of its relative sophistication, its wide application, and the high level of calibration and validation already achieved. The U.S. Navy Standard Surf Model (present version SURF3.1) has been chosen for the modelling of surf-zone parameters because of the physics included in the model as well as its focus on predicting quantities of military operational importance.

SWAN was installed and tested in time for valuation runs of the model using Linked Seas 2000 data from the field site at Pinheiro da Cruz. These runs are being analyzed to develop insight in how model runs should be performed on an operational basis. Figure 01-A/B.8 shows

[1]Participants in this project: Dalhousie University, Halifax, N.S.; University of Zagreb; CNR, Istituto di Biologia del Mare, Venice; CNR, Istituto Studio Dinamica Grandi Masse, Venice; OGS Trieste; University of Bologna; NRL, Stennis Space Centre, MS; NRL, Monterey, CA; University of Oregon; University of Washington, Seattle; Woods Hole Oceanographic Institution, Woods Hole.

[3]DELFT University of Technology

the output of an evaluation run over real bathymetry derived from the LIDAR surveys of the nearshore. The simulation is forced by an incident wave field which is uniform in the longshore. The model results at the shoreline show extreme longshore variation in wave height and direction on this relatively straight beach. It is likely that any circulation model forced by these results would give very different results depending on which of these shoreline wave conditions are used as forcing.

Surf3.1[1] was installed and tested using SWAN outputs from the Linked Seas 2000 simulations. Surf3.1 has been seen to run reliably and the individual runs appear to be consistent. However, uncertainty is observed when the outputs from individual runs are compared. Surf 3.1 was run for each of the profiles indicated by a heavy red line in Fig. 01-A/B.8. Longshore current magnitudes, even on neighbouring profiles, differ by as much as a factor of 5. Research indicates that this phenomenon is not real but related to wave shoaling models.

Work is continuing to:

- Determine the cause of the variations in the shoaled wave fields and how to adjust the modelling procedure without losing realistic features of the shoaling process
- Develop procedures to automatically fuse the wave shoaling and surf-zone circulation modelling.

  Investigate how well this hybrid modelling approach can be applied to littoral environments other than the straight beach.

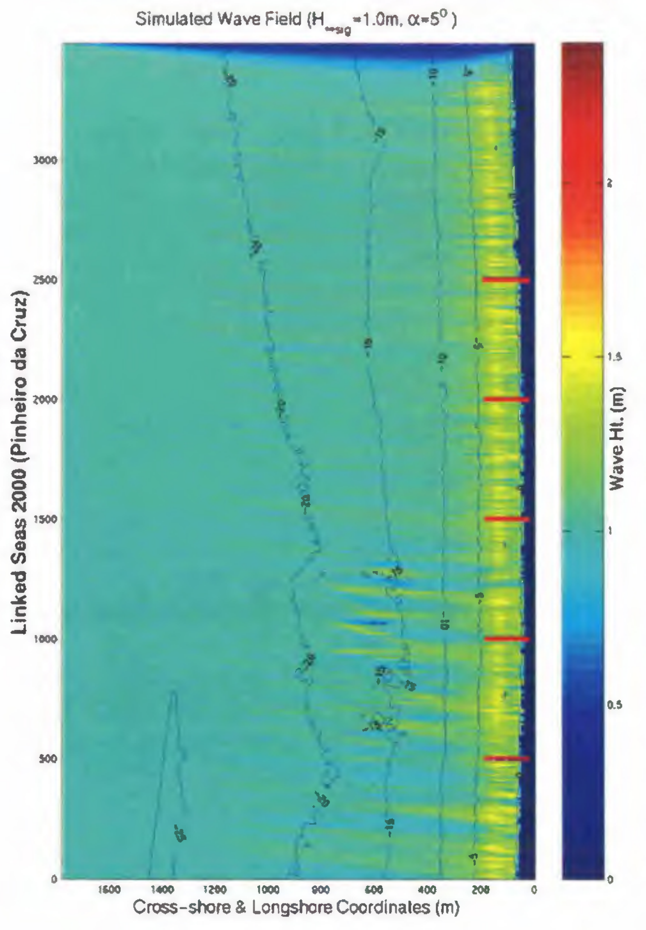

Figure 01-A/B.8 *Shallow water wave shoaling results from a SWAN simulation at Pinheiro da Cruz. Simulation was run using homogenous forcing on the seaward boundary (1 m. significant wave height and 5° incidence angle) with realistic bathymetry derived from high resolution LIDAR surveys. Surf3.1 simulations were run subsequently using the output from the profiles highlighted in red.*

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[1]Naval Meteorology and Oceanography Command

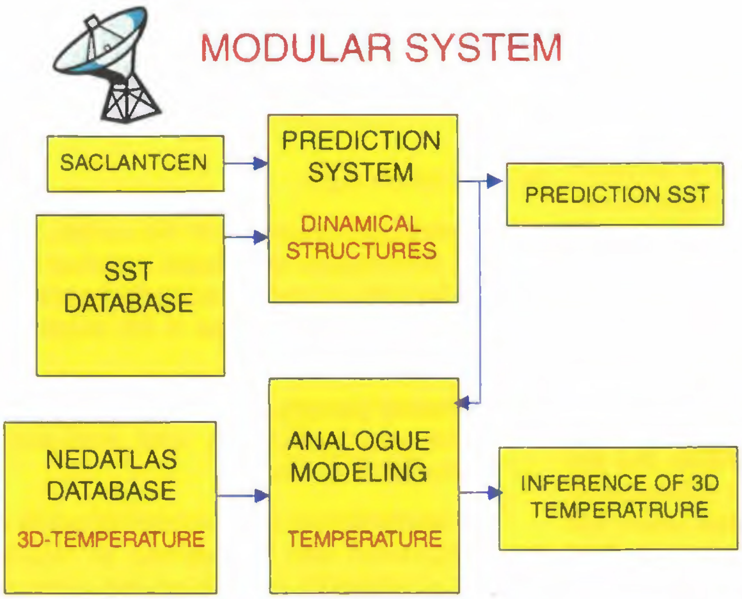


Figure 01-A/B.9 *Prototype of satellite based ocean forecasting system*

Remote sensing[1]

Rapid Environmental Assessment (REA) of ocean parameters of military relevance is needed to improve operational and tactical decisions. During crises, discrete and secure assessment of the environment is required.

Until now, satellite data have been a valuable tool for the assessment of *actual* environmental conditions. The goal of the project is to develop an *operational* ocean *prediction* system based on satellite data.

A prototype modular satellite based ocean forecasting system was developed, (Fig. 01-A/B.9). The first module consists of a sea surface temperature (SST) prediction system. The prediction system was developed by training evolutionary and fuzzy logic algorithms with historical weekly averaged SST data. Predictions on weekly time scales (one or two weeks ahead) are obtained, providing as an input to the prediction module, weekly averaged SST images processed from the SACLANTCEN satellite receiver. A second module processes the forecast SST field, extracting from an oceanographic database of *in situ* observations, past situations with similar SST patterns to the one predicted. Analogue modelling is applied to infer, from the forecast SST field and historical data, the three-dimensional temperature field.

A test of the operational system was carried out during *Sirena* 2001 experiment in the Ligurian Sea. Figure 01-A/B.10A shows the forecast SST field for the week of September 24-30, predicted two weeks in advance. Figure 01-A/B.10B displays the weekly mean SST observed during that week. Although the small scale variability is not predicted, predictions and observations agree in the sub-basin scale distribution of the SST. Figure 01-A/B.11 shows the temperature section in the first 100 m, inferred by the system along the section shown in Fig. 01-A/B.11. The SST section was estimated two weeks in advance.

[1]Due to REA Capability Package funding delays, comparisons between remotely observed and measured currents in littoral areas have been postponed until 2002/2003.

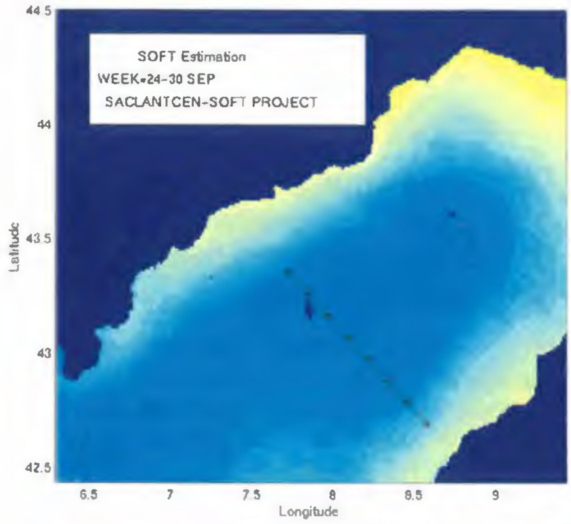
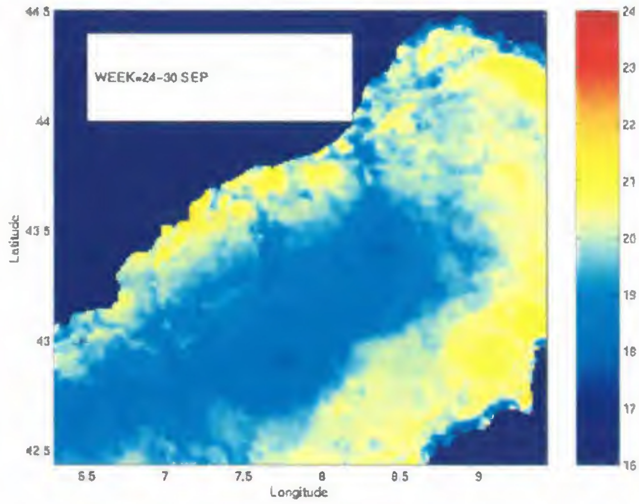


Figure 01-A/B.10 *Prediction of the weekly mean SST for the week September 24-30 in the Ligurian Sea. B) Observed SST field during the same period*



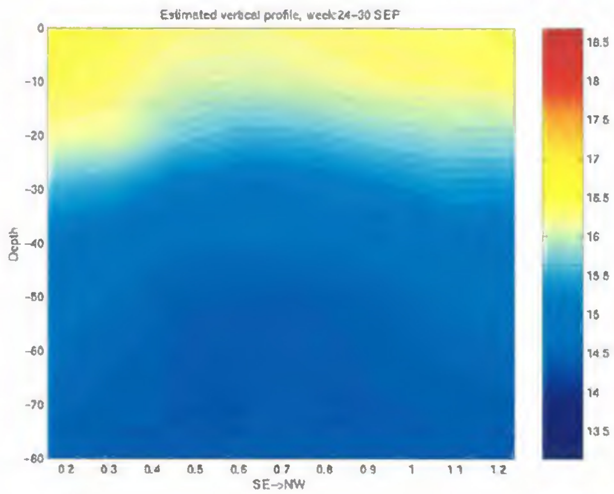


Figure 01-A/B.11 *Inferred temperature profile for the first 100 m along the section shown in Fig. 01-A/B.10A.*

Figure 01-A/B.12 *SEPTR.*

REA acoustic and oceanographic sensor buoys

The SEPTR instrument (Shallow-water Environmental Profiler in Trawl-safe Real-time configuration) is designed to be deployed close to the bottom, with an automated water column profiler capacity, from the bottom up to the surface (Figure 01-A/B.12). The profiler provides two-way communications ashore *via* cellular phone or satellite, when surfaced at regular intervals. The bottom platform is computerized with an array of sensors, as is the profiler system, which transfers data and commands between the bottom platform and the shore laboratory in near real time.

Several tasks were completed, contributing to the development of an operational system and several trials were made for the evaluation of sensors, mechanical and electronics components and software.

An engineering test on the SEPTR first full-featured prototype was conducted (Golfo della Biodola e Golfo Stella, Island of Elba) in the period 22 - 28 November 2001. The main purpose of the test was to evaluate performance of mechanical and electronic components.

The SEPTR was deployed in 11 m water depth in order to facilitate underwater observations by diver and ROV. Profile measurements on temperature, conductivity, water velocity and pressure were executed at regular intervals (Figure 01-A/B.13).

Subject to satisfactory testing of additional components, SEPTR systems will be deployed on an operational basis early in 2002.

REA communications, data fusion and Geographic Information System support for REA data handling

Data Fusion, GIS and distribution methodologies developed for REA exercises and trials (i.e. Rapid Response 96-98 and Linked Seas 2000) were used in support of several campaigns, in particular ASCOT 01, off the West Coast of the United States. A major improvement this year was the migration from Inmarsat B to VSAT on the R/V *Alliance*, significantly increasing bandwidth availability. Data acquired during the ASCOT 01 trial east of Boston was readily made available to the global community *via* a SACLANTCEN home page at significantly increased speed and reduced transmission cost. Scientists onboard were able to access databases around the world, previously unavailable to them. Equally, scientists and engineers ashore could also provide assistance remotely.

Figure 01-A/B.13 *SEPTR.*

For ASCOT01 and ADRIA01 cruises, GIS systems were configured and fed with data for background layers for coastline and bathymetry, in conjunction with oceanographic profiles, sea surface temperature, and Sea floor samples. A third GIS system was set up to publish the SOLMAR data. All systems were made accessible on the SACLANTCEN Unclassified Network or on the Internet with access limited to external authorized users.

Project 01-B: Rapid environmental assessment of operational acoustic parameters

(Alliance days - 12, Manning days - 21)

AUV support for seabed mapping and characterization

NATO planning anticipates significant use of autonomous underwater vehicles (AUVs) for MCM, ASW and AW. Applications include efficient and clandestine route or reconnaissance surveys of seafloor and water column properties with near-real-time data return. Recent progress in underwater robotics has been aimed at developing autonomous networks of fixed moorings and AUVs with inter-vehicle synchronization, communication and precise navigation to achieve a large spatial sampling for acoustic and non-acoustic measurements. This concept is well suited to clandestine military oceanography in denied areas and has potential for the development of co-operative multi-vehicle systems.

A four-year Joint Research Project[1] designated GOATS (Generic Oceanographic Array Technology Systems) was initiated in 1998 for the development of environmentally adaptive AUV technology applicable to REA and MCM in coastal environments. The work combined acoustic and oceanographic modelling with three experiments (1998, 1999, 2000) involving networks of AUVs and autonomous sensors. The rich data set acquired has been analyzed and described in the open literature and at a final conference at SACLANTCEN on 21-22 August 2001, attended by 60 scientists from 8 NATO Nations.

Autonomous ocean sampling network (AOSN) technology

A new paradigm in ocean science and technology, AOSN consists of fixed moorings and AUVs linked by state-of-the-art acoustic communication technology. The GOATS prototype observation network (Fig. 01-A/B.14) was based on the *Odyssey* class vehicle (MIT), the *Ocean Explorer* (FAU), the *Taipan* (LIRMM), SEPTR profilers and the TOPAS tower facility (SACLANTCEN). The vehicles and instruments were deployed from R/V *Alliance* and workboat *Manning*.

AUV navigation

A new method for terrain aided navigation called Terrain Referenced Integrated Navigation (TRIN) was developed at the Norwegian Defence Research Establishment (FFI) in the 1990s. In addition to a minimal set of dead-reckoning sensors, the method requires data from any instrument that can measure the distance to the seafloor in one or more known directions, such as a multi-beam echo sounder (MBE) or a Doppler Velocity Log (DVL). During the GOATS 2000 experiment, FFI conducted several runs across Procchio Bay (Island of Elba) using an EM-3000 MBE onboard the R/V *Manning*, for the purpose of bathymetric navigation experiments in zones with moderate depth variations. The TRIN algorithm was implemented using a full-state Kalman filter with a hydrodynamic model for the AUV. The algorithm has been extended to accept a generic dynamic model, allowing the use of data acquired from *Manning* and other surface or underwater platforms. The navigation method performs well on the data recorded during GOATS 2000, even when using as few as three beams from the MBE. Consequently, it is reasonable to assume that even a DVL will be sufficient for accurate bathymetric navigation with this method. The difference between the GPS trajectory and the TRIN navigation solution is shown in Fig. 01-A/B.15. The upper diagrams show the performance when bathymetry measurements were not used; the lower diagrams show the error of the complete TRIN

[1] Participants: FFI Norwegian Defence Research Establishment, Florida Atlantic University, Harvard University, Heriot-Watt University, LIRMM, MIT, University of Colorado

system. The green curves are the standard deviations from the Kalman filter when navigation updates occur.

Geographical Information Systems

With the advent of AUVs as a common tool in mine countermeasures, large sets of high quality sonar and video data can be rapidly acquired. Manual mission analysis is time consuming and limits the operational effectiveness of AUVs. Geographical Information Systems (GIS) developed at the Heriot Watt University (HWU) and SACLANTCEN address these issues. They enable the visualization and the automatic processing of geo-referenced multi-sensor data. The relevant information extracted can be exported to tactical decision systems (such as MEDAL). The HWU SeeTrack system supports side-scan sonar, digitized video and bathymetric data as shown in Fig. 01-A/B.16. Automatic target detection in sonar and video data can be performed. The modular, architecture permits simple integration of additional data processing. In GOATS 2000 the data analysis time was

(a)

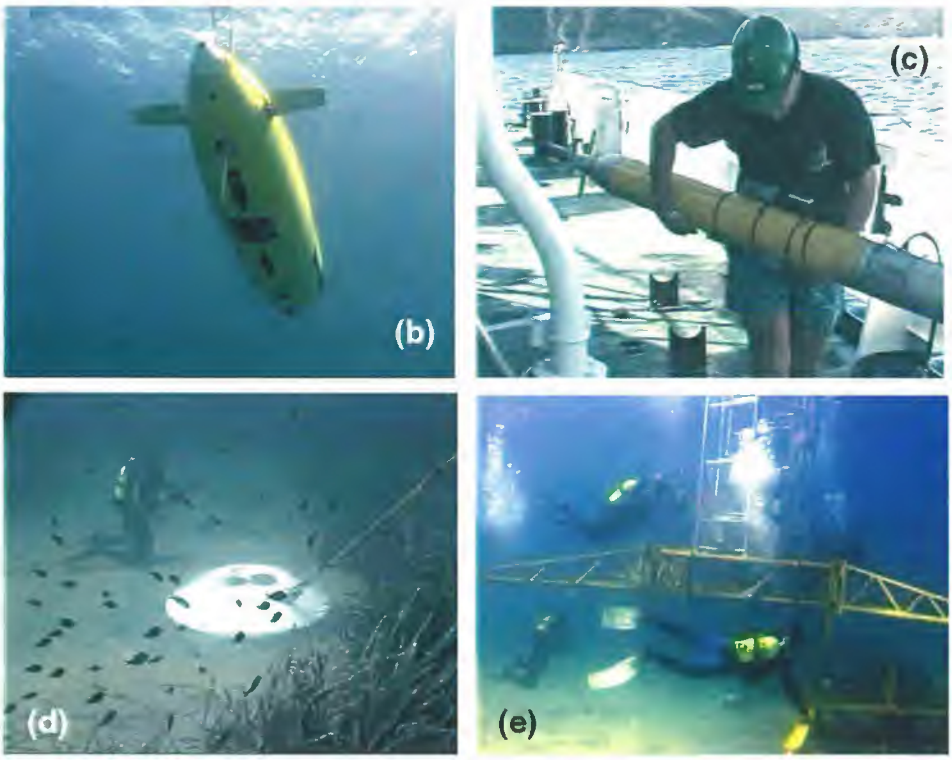


Figure 01-A/B.14 *The GOATS observational network was based on Odisseys (a), Ocean Explorer (b), Taipan (c), SEPTR profiler (d), TOPAS tower and rail (e).*

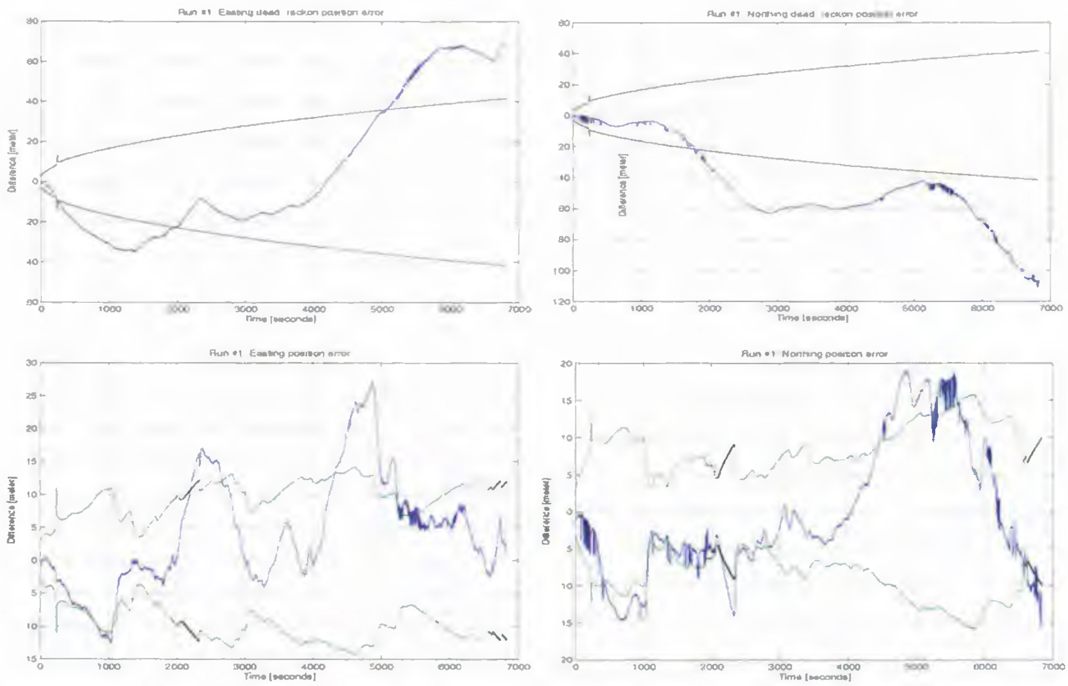


Figure 01-A/B.15 . *Latitude and longitude error for navigation run in Procchio Bay using only three beams of the EM-3000 sonar. Dead-reckoned solution (top) and terrain referenced (bottom).*

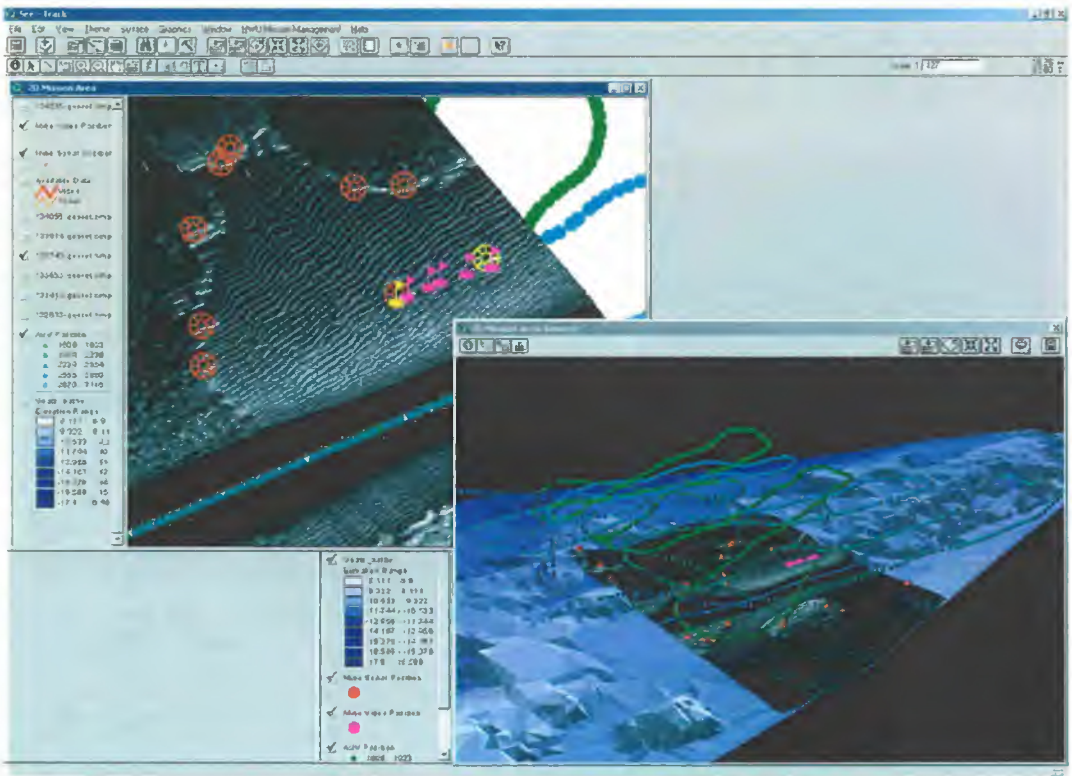


Figure 01-A/B.16 *A SeeTrack view of an MCM mission performed by the Ocean Explorer in Biodola Bay. The visualization environment is populated with automatically and manually detected mines, side scan sonar images, vehicle trajectory and bathymetry.*

significant reduced thanks to its built-in set of algorithms and the fusion of sensor data in a single common environment.

Multiscale environmental assessment studies (MEANS)

The oceanographic objective of the GOATS 2000 experiment was to predict the conditions in the AUV operating area, using a concatenation of nested models of increasing resolution. The models, which were initiated by an oceanographic survey at the beginning of the experiment, produced real time forecasts. Model data were compared with *in situ* measurements. A novel aspect of the forecasts was the forcing of the Corsica channel region by the external general circulation and the concomitant forcing of the Procchio Bay operational domain by the channel circulation.

The modelling team issued 11 sets of model forecast products for three modelling domains in real time over the Internet. Comparison with sea surface temperature and current data showed that model results accurately forecast local conditions. The circulation in Procchio Bay was forecast by assimilating into a dynamical model only data external to the Bay. There was general qualitative agreement between the CU-POM and HOPS models which were nested for the first time. Figure 01-A/B.17 shows the HOPS and CU-POM fields for 4 October 2000. The warm patch at the northeast corner of the domain, the most readily identifiable difference between the model fields, appears to be a model artifact.

Rapid Environmental Assessment (REA)

The GOATS 2000 experiment demonstrated the capabilities of AUVs as REA platforms for MCM in shallow and very shallow water. The *Ocean Explorer* equipped with a colour video camera and the Edgetech dual frequency DF-1000 side-scan sonar and the *Taipan* equipped with the Applied Microsystem CTD were launched from R/V *Alliance* to survey Procchio Bay acquiring side-scan sonar images and measuring water mass properties such as current, salinity, density and temperature, for use by the nested oceanographic models studied by MEANS. The side scan sonar data were used to generate geo-referenced acoustic images for comparison with ground truth data collected in the same area during previous experiments. The environmental information measured by the AUVs was fused in the SACLANTCEN GIS database. The tiled

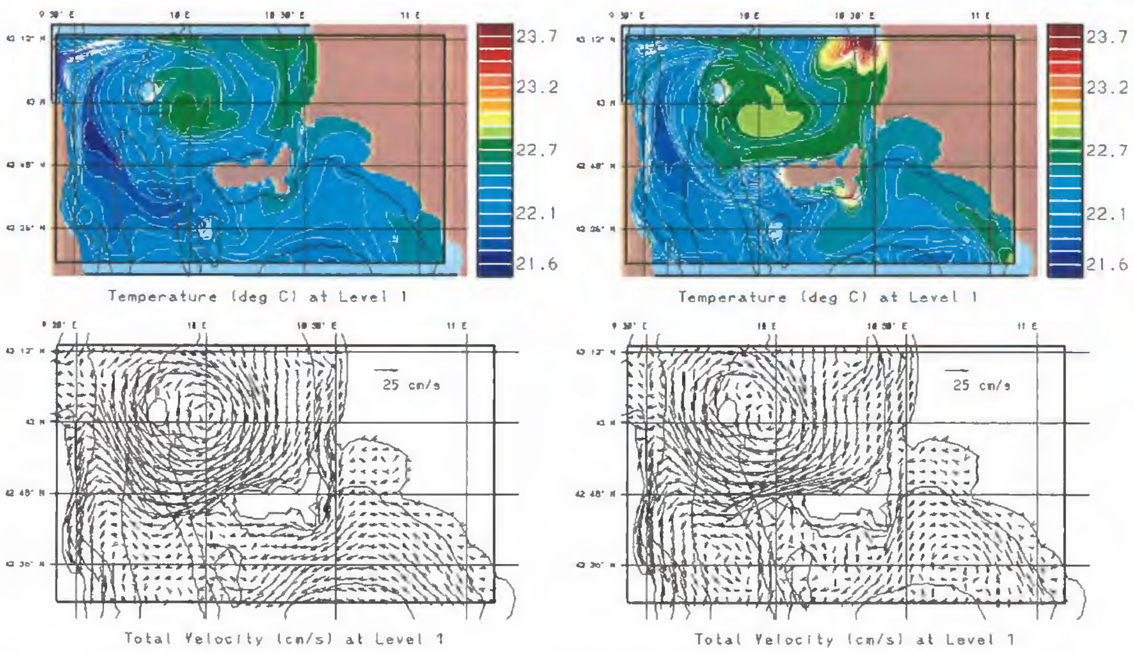


Figure 01-A/B.17 *A comparison of HOPS (left) and CU-POM (right) results for 4 October 2000.*

side scan sonar images were processed with unsupervised segmentation algorithms that demonstrated the capability to identify different types of sea bed (Fig. 01-A/B.18). The video images collected by the OEX were organized in a geographical database using the SeeTrack software developed by Heriot Watt University.

Mine Counter Measures (MCM)

A field of proud and buried targets at the main test site in Biodola Bay was insonified by the *TOPAS* parametric sound source mounted on the SACLANTCEN tower at a variety of incident and aspect angles. The MIT *Odyssey* sampled the target field acquiring data for validation of numerical models of mono- and bi-static seabed reverberation.

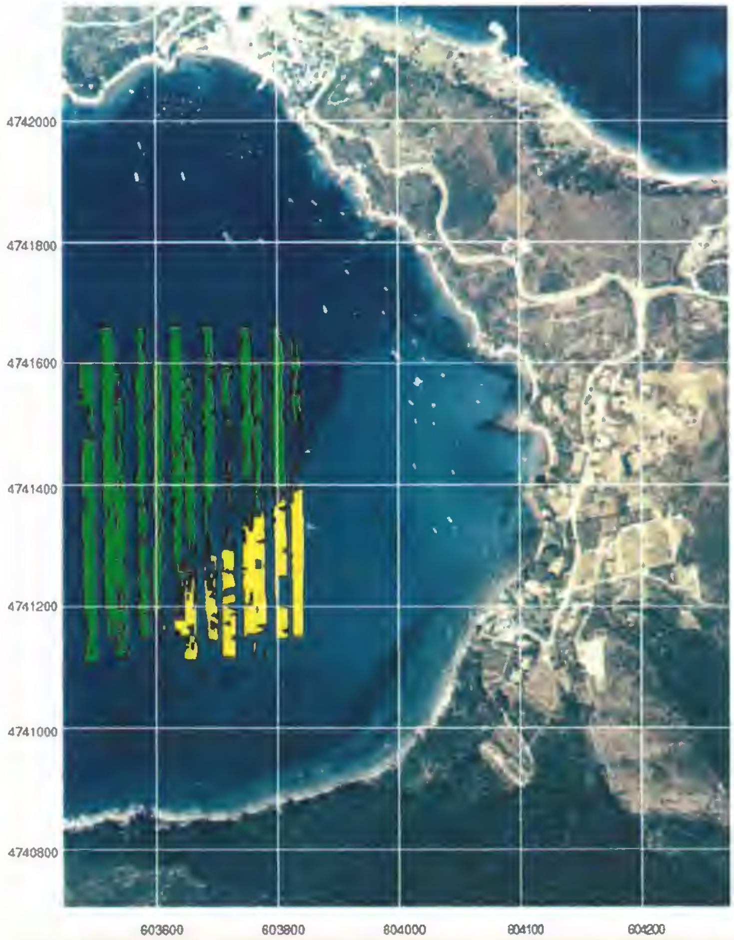


Figure 01-A/B.18 *The unsupervised segmentation algorithms applied to the side scan sonar data collected in Viticcio Bay correctly identified the boundary between sand (shown in yellow) and Posidonia (shown in green).*

A second field of proud targets including rocks and exercise mines such as the *MP80, Manta* and *Rockan*, was imaged at different aspects by the *OEX* equipped with the 390 kHz Edgetech side scan sonar, (Fig. 01-A/B.19). The angular interval between views is approximately 45°. For some aspects, the sand ripples significantly corrupt the object shadow. The data collected by the AUV have been analyzed by a supervised classifier trained to recognize a 2 m

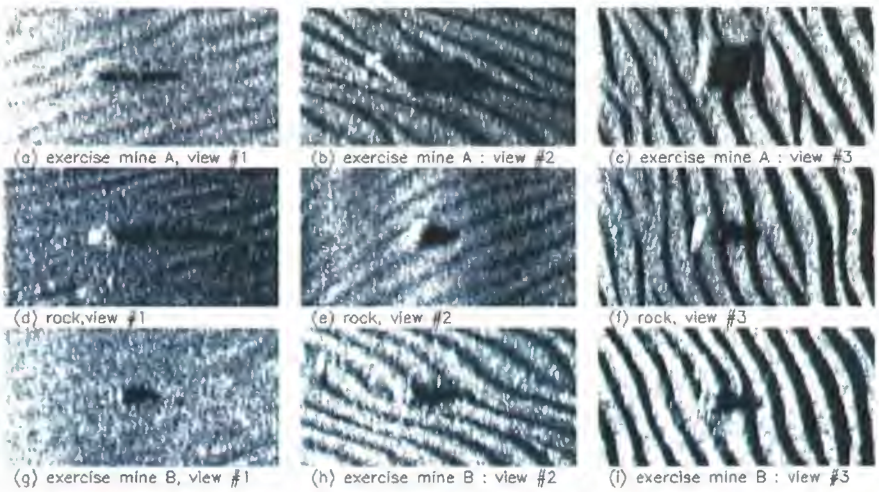


Figure 01-A/B.19 *Three aspects of three objects from the target field. The interval between views is approximately 45°.*

long, 0.5 m diameter cylinder at different aspects and a truncated cone 0.4 m high and with a base of 1 m diameter.

The results of the classification shown in the table are expressed as degrees of ignorance (IGNORE) and belief in three hypotheses: CYL (cylinder), TCONE (truncated cone) and NOT-MINE (object with a shape not known by the automatic classifier). The exercise mine A (*MP80*) is classified unambiguously as a cylinder. For the rock, the belief is shared between CYL, TCONE and NOT-MINE. The exercise mine B (*Manta*) is recognized as truncated cone (TCONE) but with a lesser degree of belief than for the MP80. This last result shows the limits of COTS sonar for target classification even if multiple aspects are fused, but demonstrates also the interest of multiple aspects for mine classification.

	IGNORE	TCONE	CYL	NOT-MINE
Exercise Mine A	0.01		0.99	
Rock	0.07	0.32	0.31	0.30
Exercise Mine B	0.11	0.68	0.21	

SACLANTCEN is particularly suited to host complex, multi-disciplinary, multi-national experiments. The engineering facilities, the availability of R/V *Alliance* and *Manning* and the wide scientific expertise at the Centre, allowed rapid integration of innovative ideas and technologies from different countries, to demonstrate the effectiveness of autonomous underwater vehicles as platforms for military and scientific applications. The scope of the work has been broad ranging from basic research such as the fundamental understanding of multistatic scattering from proud and buried targets, to prototype development such as the SeeTrack software.

The intermediate results and the video of the experiments have been shown in numerous NATO conferences and have contributed to raise the awareness of nations and military commands of the potential applications of the AOSN technology. The growing interest by the NATO community has stimulated numerous military and civilian visitors to witness the 2000 experiment from R/V *Alliance* and *Manning*.

The GOATS JRP also demonstrated the effectiveness of the Virtual Laboratory concept: scientists from many different nations and organizations worked for a period of four years exchanging ideas, acquiring and analyzing data and documenting their work, using mainly the Internet and the communication facilities available at the Centre and on R/V *Alliance*. During the 2000 trial, modellers located at SACLANTCEN, Harvard and Colorado Universities, interacted in real time with the scientific crew of R/V *Alliance*, to implement a truly adaptive oceanographic sampling experiment.

The three Elba experiments allowed the acquisition of a data set that will contribute significantly to progress in several fields: 3D modelling of target and bottom scattering, sound penetration in the sea floor, traditional and non-traditional AUV navigation, nesting of oceanographic models and their applicability to AUV mission planning, automatic bottom classification and automatic detection of proud objects.

Delivery of SACLANTCEN vehicles

The delivery of the SACLANTCEN AUVs procured in 1999 from Florida Atlantic University (FAU) was expected in February 2001. However FAU failed to obtain the necessary export licence from the US Department of State until August 2001. The vehicles have been tested at the factory in October by a team of SACLANTCEN engineers and have been shipped to Italy for final acceptance tests at sea. The tests took place from 11 to 22 November on R/V Alliance and were only partially successful. The navigation performance of the vehicles and their launch and recovery system was not demonstrated due to technical difficulties. SACLANTCEN and FAU are negotiating the successful completion of the contract and a second sea acceptance test is scheduled for February 2002. Figure 01-A/B.20 shows the *Ocean Explorer* deployed from R/V *Stephan* during the tests in Florida.

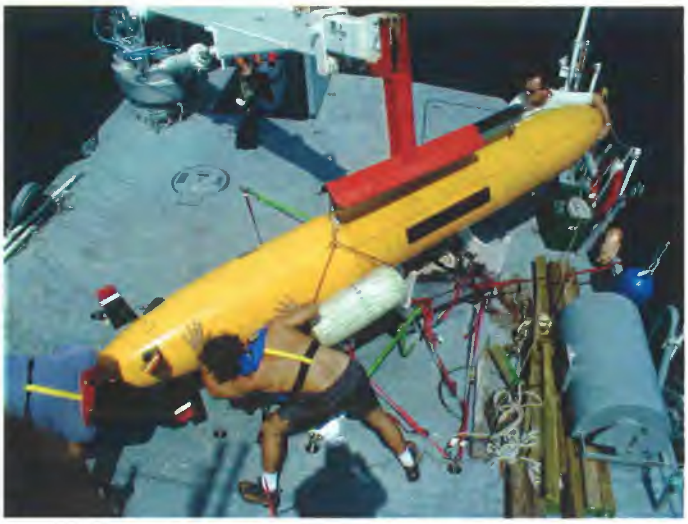


Figure 01-A/B.20 *The Ocean Explorer deployed from R/V Stephan during the tests in Florida.*

The eXpendable Bottom Penetrometer (XBP ®) as a payload for AUVs and ROVs

An eXpendable Bottom Penetrometer (XBP®[1]) was developed[2] for the *in situ* measurement of physical properties of sediments, undrained shear strength, dynamic shear modulus and an indication as to whether the sediment is granular or cohesive. Penetrometers dropping through the water column penetrate the sea bottom to different depths and at different rates depending on the geometry, mass and impact velocity of the probe and on the shearing strength of the sediment. Hence, if the physical dimensions and terminal velocity of the probe are fixed, it is possible to infer the shearing strength and certain other properties based on an analysis of the impact signature as well as a comparison with the signatures in a data base compiled from tests on many different kinds of sediment (Fig.01-A/B.21).

This technique was developed in order to address the problem of collecting amphibious warfare (AW), mine warfare (MW) and anti submarine warfare (ASW) environmental survey information in a relevant time frame and since 1996 has become an operational tool for MW and AW operations, for rapidly acquiring the seafloor factors affecting underwater operations.

Work is continuing with L-DEO and TUBITAK Marmara Research Center (MRC) to develop a remote sensing system based on the XBP, mounted on an autonomous underwater vehicle (AUV) to provide rapid assessment of certain seafloor geoacoustic and geotechnical parameters. This particular system has direct operational applications in mine countermeasures (MCM) and amphibious operations where *in situ* undrained shear strength of the sediment is an important parameter for mine burial modelling and in making tactical decisions for predicting mine burial, landing tactics and in shallow water ASW work where the properties of the bottom play an important role in problems involving submarine detection. The system is also an important tool for calibrating or "ground-truthing"

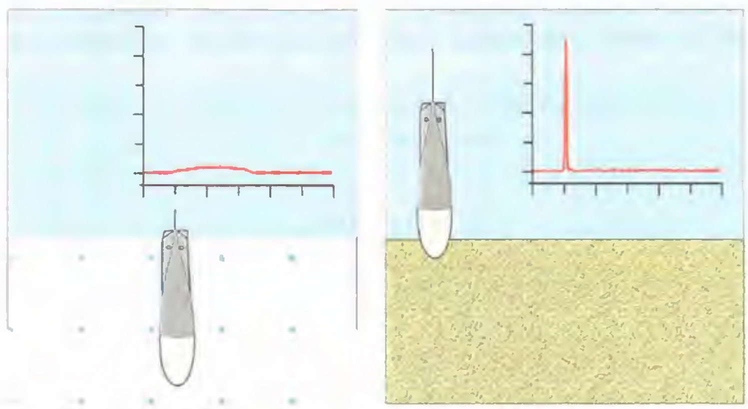


Figure 01-A/B.21 *Objects dropping through the water column penetrate the sea bottom to different depths and at different rates depending on the geometry, mass and impact velocity of the probe and on the shearing strength of the sediment.*

[1] US Patent No: 5,681,982 October 28, 1997

[2] Joint Research Project with the Lamont-Doherty Earth Observatory of Columbia University (LDEO)

some of the acoustic seafloor classification systems.

XBP launcher for ROV and AUV applications

The main objective of this work is to develop a compact launcher that is able to deploy a series of XBPs from an AUV or ROV such that the velocity of expulsion into the water column is

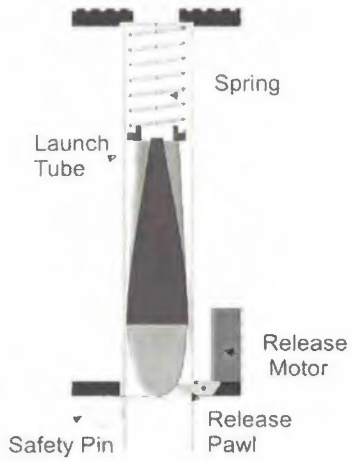


Figure 01-A/B.22 *The basic design of the launcher.*

approximately the same as the normal terminal velocity attained when an XBP is launched in the usual manner from a moving vessel. This velocity is about 7.2 m/s. By controlling the expulsion velocity from the launcher it will be possible to deploy probes from any depth in the water column with impact signatures the same as for the normal XBPs. Hence the extensive XBP database already available will be useable for interpreting results.

A single cell prototype launcher has been designed and built to be used in the multi-cell launcher (Fig. 01-A/B.22). This unit employs a coil spring that exerts an initial force of about 36 kg on the probe when it is loaded into a 5 cm diameter PVC tube. The launch tube is slotted to permit free movement of water behind the probe during launch and the motor-driven latch that holds the probe in place is designed to be safe against any possibility of accidental release due to shock or vibration, etc. A safety pin must be pulled prior to lowering the unit into the water. The modular design of this unit will allow it to be combined with additional cells to form a multi-cell launcher during subsequent phases of development.

The October 2001 experiment

During October 2001, a sea trial was conducted to test the newly developed system for AUV applications. Figure 01-A/B.23 shows the experimental configuration. R/V *Manning* anchored at a test site and deployed the frame containing the single-cell launcher, an echo sounder and a video observation camera (Fig. 01-A/B.24). Signals were transmitted *via* cable and analyzed onboard. XBP probes were launched with the prototype launcher at different depths and with the standard hand-held launcher. Received signals were used to compare response produced by the different launching procedures. Static cone penetrometer measurements were also conducted in each location for comparison and divers collected undisturbed bottom samples for further analysis of the physical characteristics of the sediments. Tests were run at several different locations with different bottom characteristics.

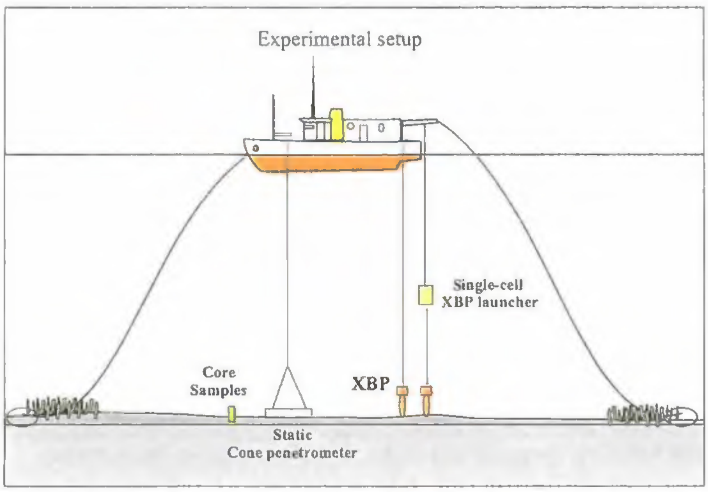


Figure 01-A/B.23 *Experiment configuration.*

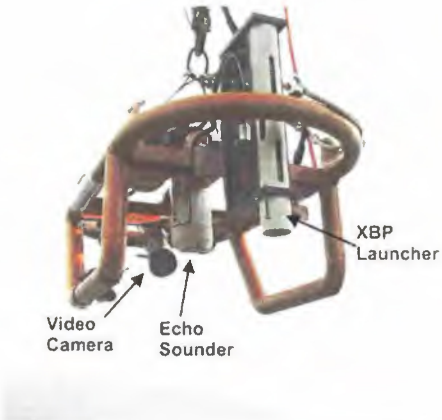


Figure 01-A/B.24 *The frame containing the single-cell launcher, an echo sounder and a video observation camera.*

Experimental results

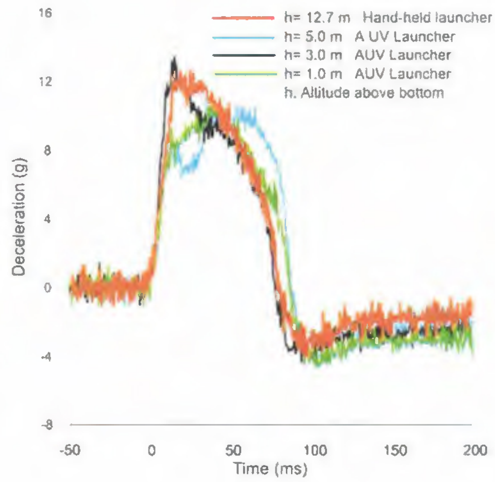
The experiments were designed to test the single-cell launch tube, which produces a probe velocity of approximately 7 m/s and to compare the impact signature with that obtained using a standard hand-held launcher. Figure 01-A/B.25 shows the comparison of XBP signatures obtained from launches at different depths and for launches with the standard hand-held launcher for a soft bottom. Figure 01-A/B.26 shows the comparison for a hard bottom. Launches made at different depths gave similar results to the hand-held launcher deployments and there is no depth dependence between launches made at different altitudes from the sea bottom.

Additional standard static cone test measurements were conducted and core samples were taken for ground truthing.

Future work: combining a number of single cells into a multi-cell launcher

The design of the single cell launcher used during the trial is such that a number of the units may be combined into a compact multi-cell launcher (8, 10, 12 etc) that can easily be installed in a remotely operated vehicle (ROV) or an autonomous vehicle (AUV) with the triggers wired in such a way that each XBP can be launched at random upon command. An important design feature of the multi-cell launcher will be the incorporation of weight-compensation chambers that will insure the stable depth operation of an AUV during successive releases of the XBP probes and resultant loss of weight.

The multi-cell system will allow the AUV/ROV to be utilized as a vehicle for surveying the sea bottom conditions over a prescribed area by dropping the probes in a regular pattern and then contouring the results as (Fig. 01-A/B.27) in NATO REA exercises over the past several years. The primary advantage of the multi-cell launcher would be that the probes could be launched covertly in any depth of water and from any height above the bottom with results that should be completely consistent with the SACLANT XBP database.



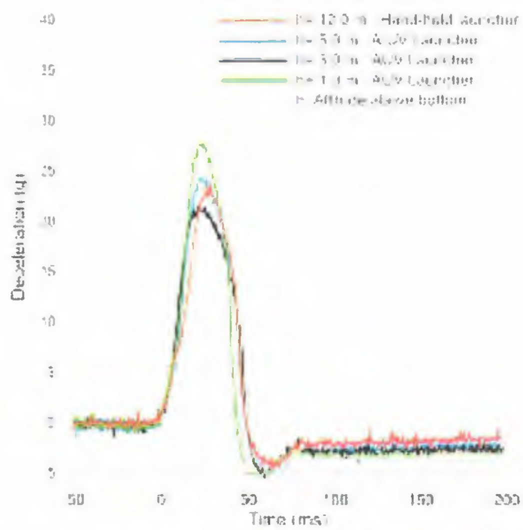


Figure 01-A/B.25 *XBP signatures obtained from launches at different depths and comparison with the standard hand-held launcher for two soft sediment bottoms.*

To explore the potential of the XBP as a payload for AUVs, L-DEO and TUBITAK Marmara Research Center (MRC) will build a new system consisting of a multi-probe payload to be mounted on an AUV/ROV. This, in conjunction with a data acquisition system designed and built by SACLANTCEN, will be the essential tool for experiments planned for 2002 and 2003.

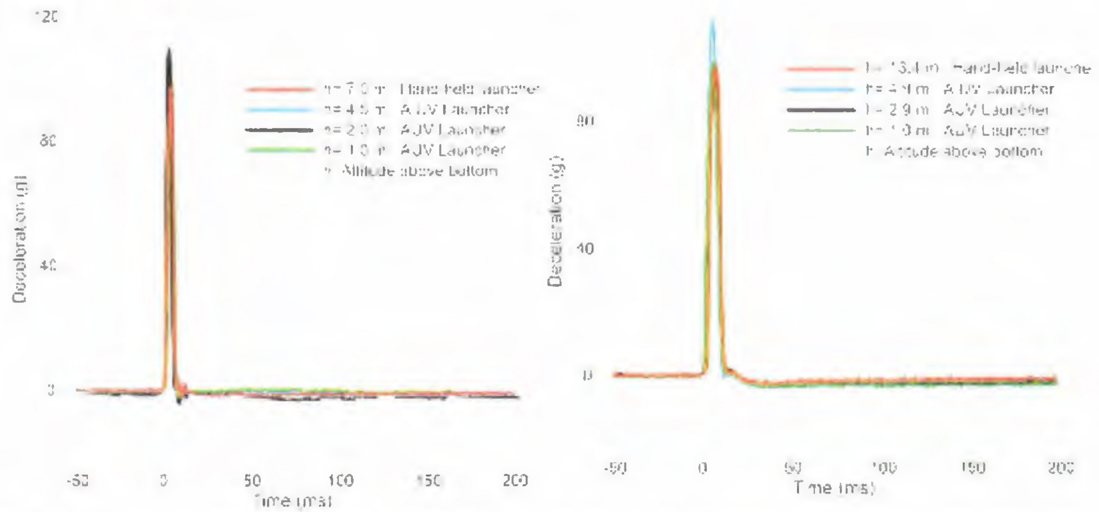


Figure 01-A/B.26 *XBP signatures obtained from launches at different depths and comparison with the standard hand-held launcher for two areas with hard bottom.*

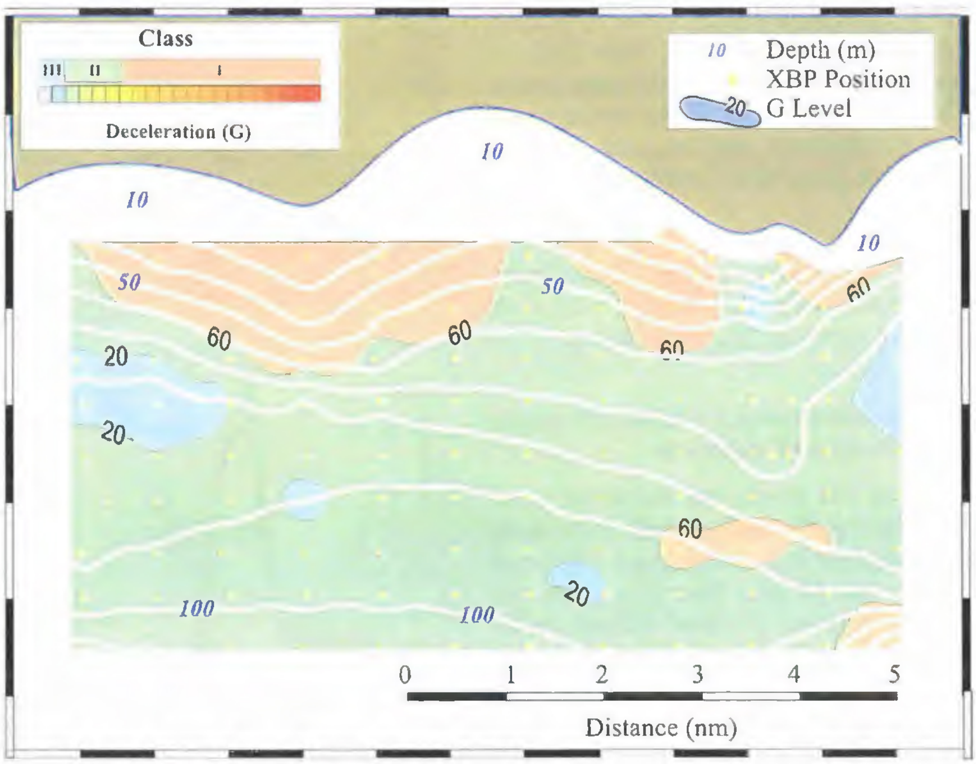


Figure 01-A/B.27 *An example of classifying bottom conditions for mine burial parameters over an area by dropping the probes in a pattern and then contouring the results as in NATO REA exercises over the past several years*

Rapid estimation of seabed parameters

The prediction of sound propagation in the ocean by numerical models is critical to the design of active and passive sonar systems, estimating and optimizing their performance and deriving figures-of-merit (e.g. detection range). Operationally a figure-of-merit indicates the maximum range at which a target can be detected with given ambient noise and reverberation levels. Successful prediction of sound propagation in shallow-water areas is highly dependent on the state of the underwater environment that can vary in time and space. One of the key parameters that affects the prediction of sound propagation in shallow waters is the nature of the seabed. The seabed often consists of a complex layering structure where each layer has specific acoustical properties in terms of layer thickness, sound speed, density and attenuation. These properties are considered constant in time for the acoustic frequencies used in sonar systems for ASW.

During MAPEX2000, on the Malta Plateau, a towed source and towed array were used to mimic an active sonar system to demonstrate the feasibility of applying the "through-the-sensor" concept to extract seabed properties. The concept is based on Matched-Field Processing that includes numerical propagation models.

In 2001 a ray-trace model was implemented in the SACLANTCEN standard geo-acoustic inversion package SAGA, which improved the computation speed by orders of magnitude. Computational efficiency continues to improve to the point of virtually real-time seabed characterization. The new version of SAGA will be applied to the MAPEX2000 data for multi-ping geo-acoustic inversion along a range-varying acoustic track.

The uncertainty of the inferred seabed properties depends on the water column conditions at the time the acoustic transmission is performed as shown in the ADVENT'99 experiment. The sound speed in the water column is time- and range varying, which affects propagation and therefore, prediction capability.

The time dependence of the sound speed profile determines the requisite interval between environmental and acoustic measurements to avoid decorrelation of data. The range dependence determines the distance at which sound prediction can be performed before new information of the environment is necessary.

Determination of the environmental time and range dependence on acoustic propagation and geo-acoustic inversion was one of the main objectives of ASCOT'01, conducted in June 2001 off the east coast of Massachusetts Bay. Signals transmitted along a fixed propagation path from a bottom-moored sound source were

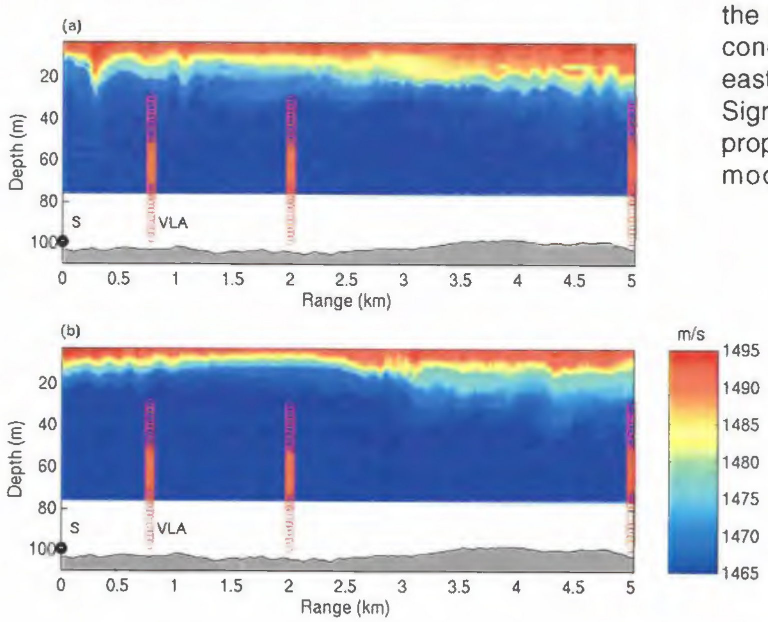


Figure 01-A/B.28 *Sound-speed structures acquired along the 5-km acoustic track during the ASCOT'01 experiment. The source and vertical array positions are shown in conjunction with the range-varying bathymetry. The time separation between the two tow sections is 5.5 h*

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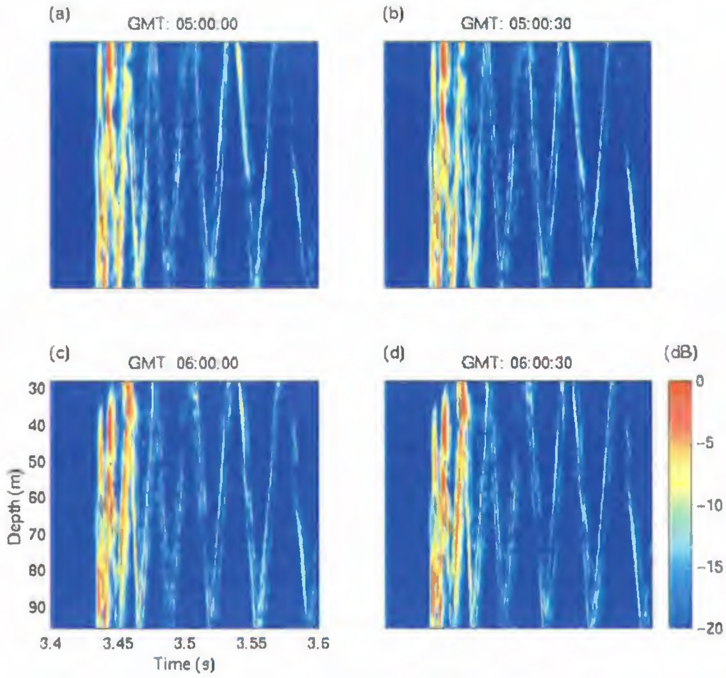


Figure 01-A/B.29 *Depth stack of matched-filtered acoustic signals in the frequency band from 150 to 850 Hz received at 4 different geo-times at 5-km range. The signals are similar at time differences of 30 s [compare (a)-(b) and (c)-(d)], but significant changes in the propagation conditions are evident for signals acquired 1 hour apart [compare (a)-(c) and (b)-(d)]. These changes appear as amplitude fading and perturbations in the arrival structure caused by changes in the underwater environment.*

received on a moored 64-element vertical array. The 1 s Linear-Frequency-Modulated (LFM) sweeps in the frequency band from 150 Hz to 1600 Hz were repeated every 30 s for up to 13 h. The propagation range was changed by re-deploying the vertical array at 700 m, 2, 5, and 10 km from the sound source over a 4-day period. Environmental data (current, water column temperature, sea surface wave height) were acquired contemporaneously in order to correlate changes in the received acoustic signals with changes in the environment. A 40-element Conductivity-Temperature-Depth (CTD) chain was towed continuously along the acoustic tracks by *R/V Gulf Challenger* (University of New Hampshire) measuring time and range sound-speed structures,

(Fig. 01-A/B.28). The sound-speed profiles are clearly both time- and range dependent especially in the upper 40 m of the water column. The source location (S) and 3 positions of the vertical array (VLA) are shown in conjunction with measured bathymetry.

The effect of sound-speed variability in time and range on the matched-filtered acoustic signal is illustrated in Fig. 01-A/B.29 for the 5-km track. The acoustic signals received at 30 s intervals [Fig. 01-A/B.29 (a)-(b) and Fig. 01-A/B.29 (c)-(d)] show high stability in arrival structure and amplitude distribution over depth. Significant changes in the acoustic signals appear within 1 h [Fig. 01-A/B.29 (a)-(c) and (b)-(d)] in terms of amplitude fading and perturbation of the arrival structure. This is particularly evident for the early arrivals indicating fluctuations in the individual multi-path arrivals of the signal. A direct measure of the similarity between the received acoustic signals is established by applying a correlation function (Fig. 01-A/B.30). The value of the correlation function is 1 for two identical signals and 0 for totally uncorrelated signals. One of the received acoustic signals is noted as a reference signal (received at time 0) with which subsequent received signals are correlated. This processing indicates that de-correlation times of the acoustic data as a function of frequency is approximately 1 h for frequencies below 500 Hz (Fig. 01-A/B.30). The acoustic signals de-correlate within minutes at higher frequencies although the propagation range is relatively short (5 km). These results demonstrate the impact of a time- and range-varying ocean on acoustic propagation and the influence on operational sonar systems if coherent processing of the signals are performed. The experience from ADVENT'99 also indicates that variability of several dB can be expected in the transmission loss of the ASCOT'01 data depending on acoustic frequency and propagation range.

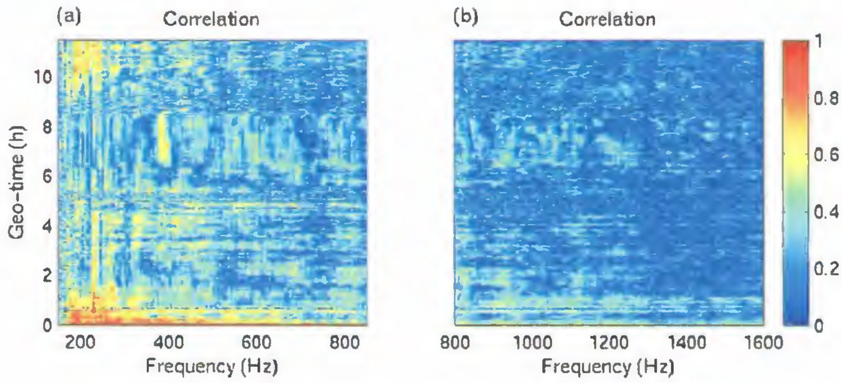


Figure 01-A/B.30 *Correlation between a reference acoustic signal received at 0 geo-time with subsequent received signals up to 12 h at the 5-km range. The correlation is normalized to 1 for identical signals and 0 for completely uncorrelated signals. Two acoustic transducers were used to cover the frequency band (a) 150-850 Hz and (b) 800-1600 Hz. Note the continuity in the correlation as the transmission is changed between the two transducers indicating high-quality acoustic data.*

Data fusion for prediction of undersea environment

Military decision-makers require advance knowledge of the impact of meteorological and oceanographic (METOC) conditions on their operations, platforms and weapon systems. The work conducted under this project is directed towards the design and implementation of automated decision support systems, which enable operational commanders to arrive at intelligent decisions more quickly and efficiently.

The REA information system architecture, (Fig 01-A/B.31) which follows the network-centric paradigm comprises sensor/data feeds, network-based geographic information systems (G.I.S.), decision support systems, and advanced visual display system. The work leading to and including some activities in 2001 focused on integration of geospatial information from a diverse number of sensors/platforms under a common G.I.S. architecture. The WIPE client-server G.I.S. system was used for automatic ingestion and integration of satellite imagery, numerical METOC model outputs, digital terrain elevation and gridded bathymetric fields. WIPE was configured to process imagery from a number of commercial satellites including: AVHRR, SeaWIFS, QuikSCAT, TOPEX/POSEIDON, GEOS, SPOT, LANDSAT, ERS-SAR, RADARSAT, DMSP/SSMI. Through exchange agreements and collaboration with several universities and government laboratories, numerical outputs from a number of METOC models were brought to SACLANTCEN for testing and evaluation. WIPE was configured to ingest outputs from the following METOC models: WAM, SWAFS, DIOPS, COAMPS, NOGAPS, HOPS, CUPOMS, and MFS. A unique capability of client-server systems is the ability to act as middleware between data-bases and applications/models which need access to the data. To demonstrate this concept WIPE was used as the middleware between two ocean acoustic models RAM and RANDI, and data generated by METOC model outputs and satellite imagery to predict propagation loss and ambient noise distribution in the ocean.

The major accomplishments of 2001 are:

- Web-based interfaces using HTTP/XML languages have been developed for querying the WIPE database for METOC parameters of interest relevant to specific operations. The nowcast/forecast METOC parameters for the Mediterranean and BALTIC regions are automatically retrieved from the FNMOC WEB-site and stored on WIPE on a daily basis.

- User friendly GUIs and rule-tables have been developed using HTTP/SQL languages for ingestion and editing of operations/platform types and critical METOC thresholds. The latter are quantitative values defining the limits beyond which operations/platforms become ineffective or unfeasible

- Web-based decision aids in the form of colour-coded maps and matrices have been implemented (Fig 01-A/B.32) which synthesize and present to the user the impact of the environment on the systems of interest. A traffic light scenario is adopted whereby the environmental impact is conveyed in terms of red-yellow-green colours, where green implies favourable, yellow implies marginal, and red implies unfavourable conditions.

Future activities

The follow-on work into 2004 involves the implementation of more complex decision support systems, which rely on knowledge-based production rule systems and fuzzy logic.

The first operational demonstration of the REA decision support systems will be in March 2002, during exercise Strong Resolve, which is a joint combined LIVEX conducted every four years, exercising NATO's ability to conduct two simultaneous operations, (Article 5 and non-Article 5 crisis). SACLANTCEN will support the REA component of SR02 Peace Support Operations (PSO) which will be conducted in the southeastern Baltic along the Polish coast.

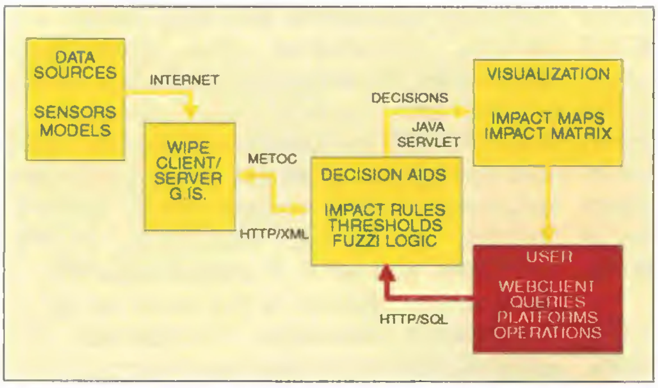
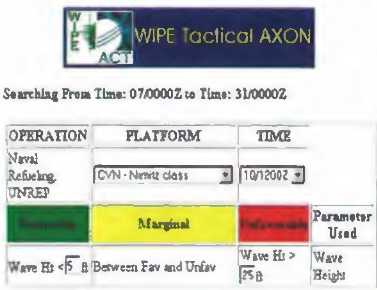


Figure 01-A/B.31 *System architecture.*



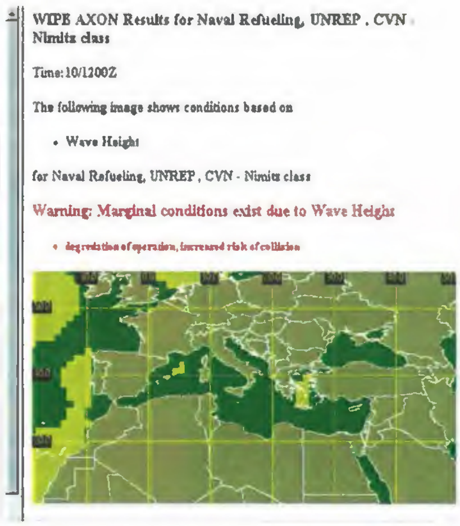


Figure 01-A/B.32 *Web-based decision aids.*

Prediction of directional ambient noise

Real-time range prediction is fundamental for all operational sonars and prediction is only possible with accurate knowledge of bottom reflection properties. To date this has been an awkward quantity to measure, requiring a receiver and separate displaced source. A new method developed at the Centre uses ambient wind and shipping noise as the distant source and a single vertical array as receiver.

Natural noise sources at the sea surface such as wind, rain and waves, combined with distant shipping provide an ideal acoustic plane wave spectrum for investigating the geo-acoustic properties of the seabed. The vertical noise directionality, in particular the differences between the up-going and down-going part, is closely related to the bottom properties.

A new method developed at the Centre uses ambient noise and a vertical hydrophone array to deduce the bottom reflection properties from the directionality. Theory shows that the simple ratio of up-to-down intensity on steered beams is, in fact, the power reflection coefficient of the seabed – a function of angle and frequency.

Experimental data have been collected with the Centre's 62m VLA at six sites including three south of Sicily, two near Elba and one on the New Jersey Shelf. Typically, stable solutions are found after averaging for a minute or so.

Figure 01-A/B.33 shows the array response at one of these sites south of Sicily, in which one can already see significant up-down differences. A plot of the differences is shown in

Fig 01-A/B.34, and this is interpreted as reflection loss *versus* angle and frequency.

One can already see a critical angle at about 30°, and the regular fringe pattern is caused by interference between paths to the seabed and to a single layer at about one metre depth.

The equivalent picture from a different site near Elba is shown in Fig 01-A/B.35 where the bottom structure is slightly more complicated.

Figure 01-A/B.36 shows that the bottom can be modelled as two sediment layers above rock with the upper layer being thin with high speed.

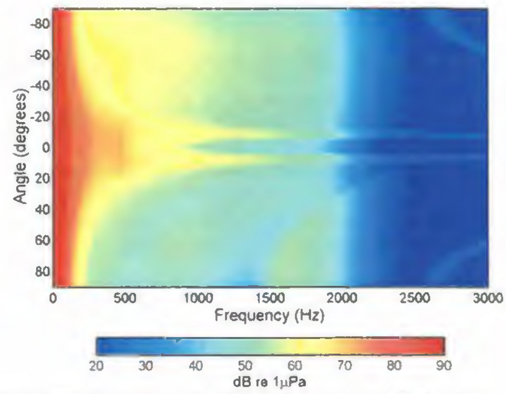


Figure 01-A/B.33 *Vertical directionality from a VLA showing directly the differences between up and down*

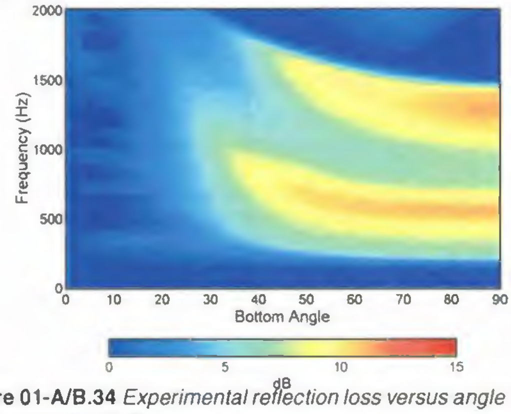


Figure 01-A/B.34 *Experimental reflection loss versus angle and frequency: Sicily.*

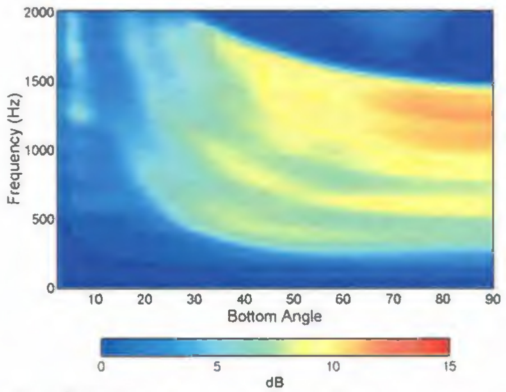


Figure 01-A/B.35 *Experimental reflection loss versus angle and frequency: Elba.*

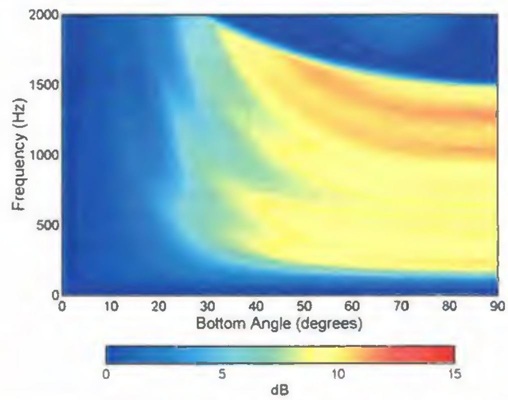


Figure 01-A/B.36 *Modelled reflection loss versus angle and frequency.*

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1

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Jürgen Sellschopp *received his diploma in physics at the Institut für Kernphysik, University of Kiel and his Ph. D. at the Institut für Meereskunde, University of Hamburg. From 1970 to 1976, he conducted research on sea state prediction, sponsored by the German Ministry of Defence. From 1976 to 1994, he was Head of Oceanography at the Forschungsanstalt der Bundeswehr für Wasserschall- und Geophysik in Kiel. His main research interests being the development of oceanographic instruments, at-sea experiments and the relationship between ocean acoustics and oceanographic variability. He was appointed Head of the SACLANTCEN Large Scale Acoustics and Oceanography Group, in 1994 and Head, Oceanography Department in 1999. In 1998 he was appointed Survey Director of NATO MILOC Rapid Response.*

Emanuel M.M. Ferreira Coelho*, hydrographic engineer in the Portuguese Navy and associate professor at the University Lusofona, Lisbon, was Head of the Oceanography Division at the Instituto Hidrográfico, Lisbon, until September 2001. Prior to his appointment as Senior Principal Scientist in the REA Thrust Area, coordinating the Littoral Ocean Modelling Programme, CDR Ferreira Coelho obtained his MSc (1991) and Ph.D. (1994) in physical oceanography, with a minor in digital signal processing, at the Naval Postgraduate School, California. He has coordinated and participated in a number of oceanographic experiments and studies dedicated to mesoscale and sub-mesoscale processes; developed software for the processing, interpretation and analysis of acoustic data and acoustic tomographic methods for observing near-inertial internal wave propagation over irregular (finite) topography and non-linear internal wave generation and propagation.*

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***Vittorio Grandi**, received his masters degree in Electronic Engineering from the University of Pisa. He joined SACLANTCEN in 1993 as Head of the Sensors Branch of the Engineering Technology Division, after many years in state and commercial industries, as analogue and digital designer. He has participated in numerous sea trials requiring analogue and digital system development for oceanographic and acoustic instrumentation.*

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***Francesco Spina** graduated in electronic engineering from the University of Genova in 1965. He worked for a short period with Elsag and joined the Centre in 1968 where he worked initially in the computing department in systems and applications software. Since 1995 he has been working in the fields of oceanography, seafloor classification and geographic information systems.*

***Richard Stoner** graduated from Birmingham University with a master's degree in underwater communication. His industrial career started in 1985 with GEC Sonar Systems Division, commissioning and developing passive towed array sonars for the Trafalgar class submarine. In 1988 he moved to Ferranti ORE as a research engineer working on payload design feasibilities for AUVs. In 1991, he joined the Acoustic and Sonar Group at Birmingham University, as trials coordinator and research engineer where his research focused on shallow water communication using HF wide band and parametric techniques. He has been Head of the Oceanography Branch of ETD at SACLANTCEN since 1997.*

Thrust 03 Mine Countermeasures (MCM)

Project 03-C: Mine-ship interaction (Manning days - 10)

3

Operational relevance

This work, which will contribute to rectifying a number of military shortfalls, focuses on techniques applicable to rapid or in-stride operations or situations in which mine hunting is ineffective, unavailable or inappropriate. In particular this work will study and where possible, demonstrate the feasibility of mine jamming.

Mine jamming

Joint Research Project partners[1] will participate in a trial planned for June 2002 for which the Centre will provide modelling and analysis support. The objective of the trial is to demonstrate some techniques that were not demonstrated in the 1998 trial, namely organic, environmental and signature jamming. The latter was demonstrated in the last trial but smaller more portable equipment will be used.

An experiment was conducted off the island of Palmaria to determine the most appropriate equipment for environmental jamming. Acknowledging the prevailing concern as to the environmental impact of this type of experiment, considerable effort was devoted to ensuring that appropriate marine mammal risk mitigation policies were complied with. Having established that optimum propagation is achieved in the specific environment of the experiment at 160 Hz, (Fig. 03-C.1) this frequency was used to calculate the safe distances for divers and marine mammals, (Fig 03-C.2).

[1] Participants:
MRSYS-N/M1 (BE); DREA Ship Silencing and Surveillance (CA); Danish Matériel Command (DE); Bundesamt fuer Wehrtechnik und Beschaffung Dept. SG III 2 (GE); COMFORDRAG (IT); Norwegian Defence Logistic Organisation/Sea; TNO (NL); Dstl, Bincleaves Technology Park (UK); Coastal Systems Station, Dahlgren Division (US).

Signature sensitivity study

Nations spend a great deal of time, effort and money on signature reduction to minimize the mine threat. NATO publications provide signature levels for various influences, however they do not give the rationale for particular signature levels and in some cases attainment of a particular level can be prohibitively expensive. The goal of this study is to determine the relationship between the signature levels and operational gain.

The first phase of this work will be a feasibility study to determine the current level of knowledge in the scientific community for the influences most likely to be exploited by a mine.

A workshop at SACLANTCEN in February 2001 found that NATO nations share the same concerns regarding the accurate assessment of risk from the mine threat to current signature levels and the degree of signature reduction needed to counter the future mine threat. While the problems are common to all nations, different nations have strengths in different areas so that collaboration could benefit all nations. Three specific areas of concern were identified by the workshop:

- NATO tactical publications are considered to be inadequate and are generally not used.
- Techniques to predict the change in influence levels with range are inaccurate.
- Lack of knowledge of environmental noise across all influences.

The study could benefit NATO nations. In the short term, by proposing improvements to NATO publications; in the medium term, by developing more accurate methods for assessing the risk from the mine threat; and in the longer term, by making measurements and developing models to improve understanding of environmental noise. Nations attending the workshop expected to gain from the study as well as having something to offer.

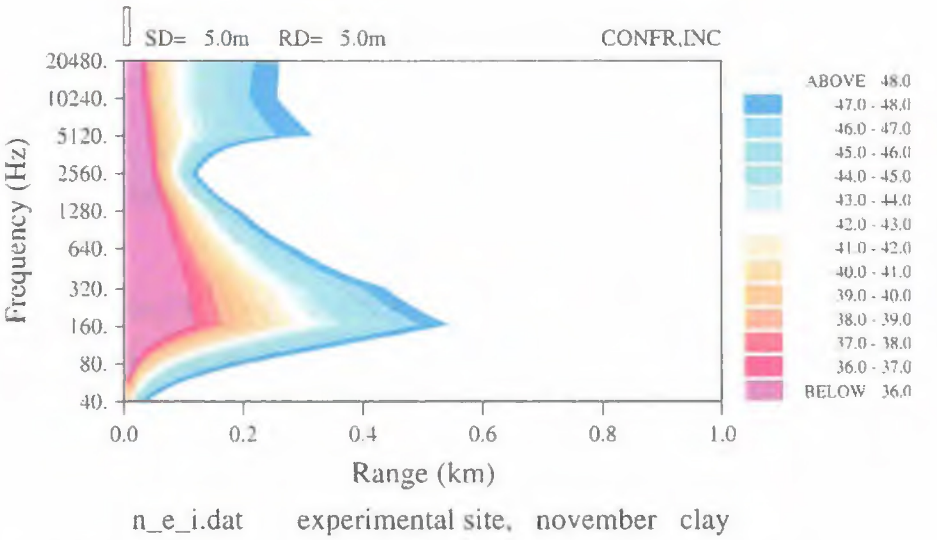

Figure 03-C.1 *Output from C-SNAP showing propagation as a function of frequency.*

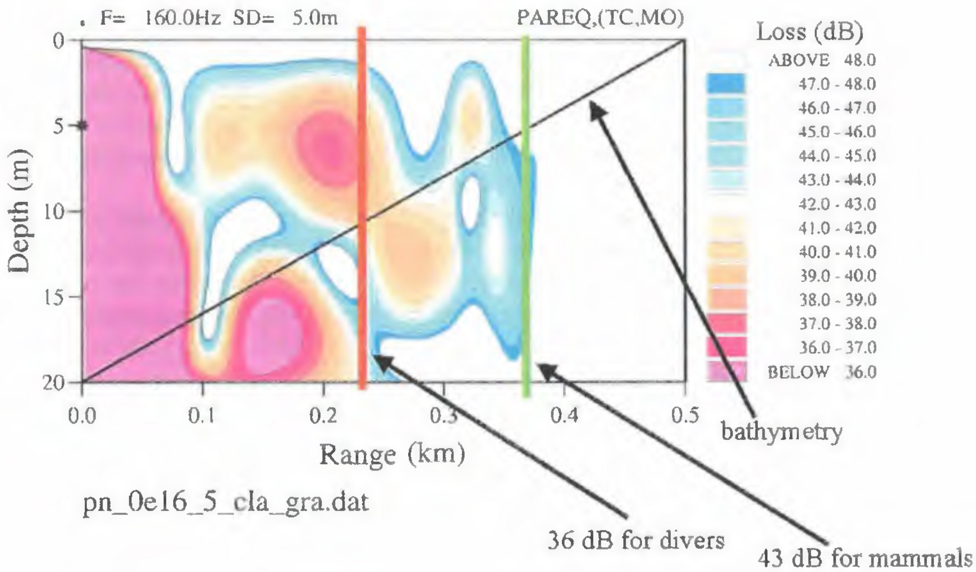

Figure 03-C.2 *Output from PAREQ showing propagation as a function of range.*

Project 03-E: Modelling of MCM related propagation, reverberation and target scattering

Operational relevance

Accurate computer models of scattering of sonar signals from seabed mines are essential for significantly improving the effectiveness of acoustic minehunting operations. The models improve the predictive capabilities for detection and classification systems, thus providing an essential component of predictive sonar performance models for MCM. Computer models also increase understanding of how various physical features in the mines and seabed affect the scattering of sonar signals, thereby enabling the design of acoustically stealthy mines to counter an adversary's MCM

3

Finite-element modelling of target scattering

The project has two objectives:

The development of a 3-D, high-fidelity, state-of-the-art, finite-element, structural acoustics code for modelling the scattering of acoustic waves from undersea structures, primarily mines. The models will compute both transient and steady-state target signatures. "High-fidelity" means high accuracy relative to the real world, which is achieved by using fully 3-D physics throughout the code (no engineering approximations).

Reliability of the software is being established in two ways:

- Validation ("Are the right equations solved?"), i.e., is the physics correct? The more complete the physics, the higher the fidelity. This will be accomplished by full-scale, at-sea experiments, to compare the model with the real world.
- Verification ("Are the equations solved correctly?"), i.e., are the numerical errors low? This is accomplished by comparing computed results with other, *independent* models or problems with known solutions. Two examples are shown in this report.

The primary application of this code will be for predicting the scattering of sonar signals from mines in, on or moored above the seabed.

Using the code to generate a data base of target signatures for real mines over a wide range of conditions:

- Different positions and orientations relative to the seabed.
- Different seabed conditions, especially those unavailable for experiments.
- Different designs for each type of mine.
- Ranges of uncertainty in mine design parameters.
- Mines that NATO doesn't have and hence can't measure experimentally.

This mine-signature database will be used as input to Projects 03-F and 03-G.

In addition, in 2002 and beyond, the code will be used to compute acoustic scattering from submarine-like structures, and possibly other military structures.

Code development

The project has been following a four-year code development schedule since late 1999, with completion expected near the end of 2003. Phase I, a structural code for modelling wave propagation in viscoelastic media, was completed on schedule in 2000[1]. Phase II, an acoustic code for modelling wave propagation in fluids, was completed on schedule in 2001; the development, verification and demonstration of that code comprise the remainder of this report.

Development of acoustics code

Software with sufficient capability to meet the requirements of this project (e.g., high-fidelity modelling of acoustically large and complex targets immersed in heavy, inhomogeneous fluid media) is not available either commercially or in any of the national laboratories. Therefore, the Centre has been working since 1999 with a unique, commercial, state-of-the-art, FE technology developed by the R&D Division of Altair Engineering (formerly COMCO) in Austin, Texas. The principal software package, ProPHLEX, is a suite of software development tools for developing customized FE codes. Using ProPHLEX, the Centre has created a commercial-quality FE acoustics code (Fig. 03-E.1).

The acoustics code can model wave propagation in regions of any complex shape and with inhomogeneous material properties. The FE mesh and other input data for the code are generated using the Altair-developed commercial software product, HyperMesh (Fig. 03-E.2). A capability for steady-state (i.e., cw or frequency domain) analyses was also developed.

Verification of acoustics code

In order to establish confidence in the reliability of a large software system, it is important to subject the code to as many tests as is practicable. A typical test problem is one in which a solution is available by some other, independent method, e.g., an exact analytical solution or an approximate numerical one. If the two solutions agree closely, one's confidence level (in both solutions) increases. Following are two successful tests of the acoustics code.

Propagation across the interface between two different fluids

This test simulates some of the acoustic conditions in the vicinity of the seabed, i.e., a flat, horizontal interface between water above and sediment below, with the speed of sound in the sediment being greater than in the water. A point source radiating a spherical pulse is located just above the interface. Figure 03-E.3 compares the FE solution with an independent numerical analysis.[2]

Scattering from a rigid sphere

This test problem provided verification of two other code capabilities: (i) scattering from a target (rather than radiation and propagation as in the above test), and (ii) Fourier analysis of the scattered wave to produce a steady-state (frequency domain) response.

Here we consider a single fluid, water, in which is immersed a point source that is radiating a spherical pulse (the same as in the above test problem) and a rigid sphere located a few wavelengths away from the source. Figure 03-E.4 shows a snapshot of the FE solution at an instant of time shortly after the pulse wave has scattered from the rigid sphere. Figure 03-E.5 shows the transform of the scattered wave plotted on a polar grid and compared with the exact analytical solution[3].

Demonstration of acoustics code: scattering from a rigid Manta mine on the seabed

The following example illustrates the general type of modelling that can be performed with the acoustics code. It also adds to the confidence in the code because specific details in the computed solution conform to expected results.

Figure 03-E.6 shows a mesh of a large hemisphere of water (above) and sediment

[1] 2000 Annual Progress Report pp.35-42

[2] Fast-Field-Program analysis by M. Porter, in Computational Ocean Acoustics, by F. Jensen, et. al.

[3] Electromagnetic and Acoustic Scattering by Simple Shapes, by Bowman, et. al.

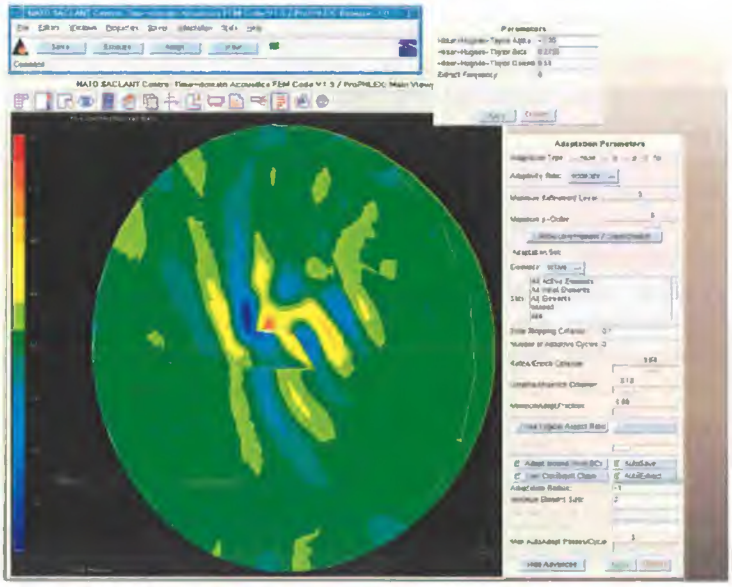

Figure 03-E.1 *ProPHLEX GUI showing a few of the available windows for controlling input data and analysis parameters and for graphically displaying a solution.*

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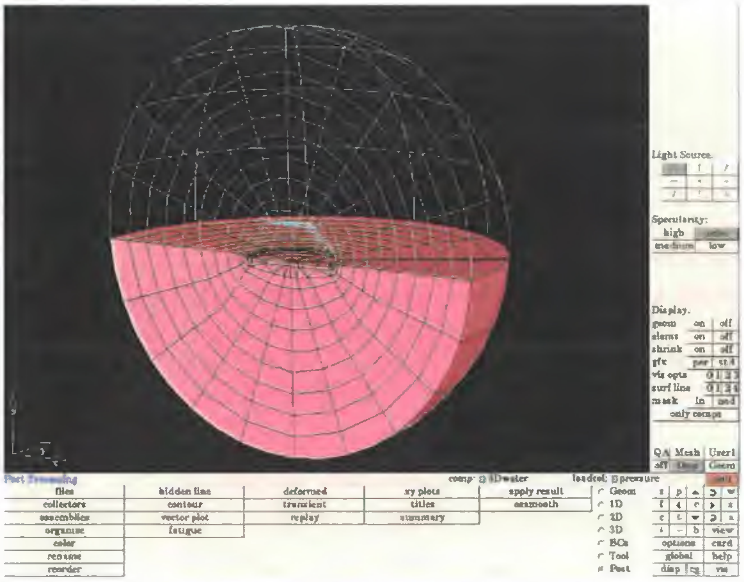

Figure 03-E.2 *HyperMesh GUI, showing some typical control panels for developing meshes, and a graphic of a partially developed mesh.*

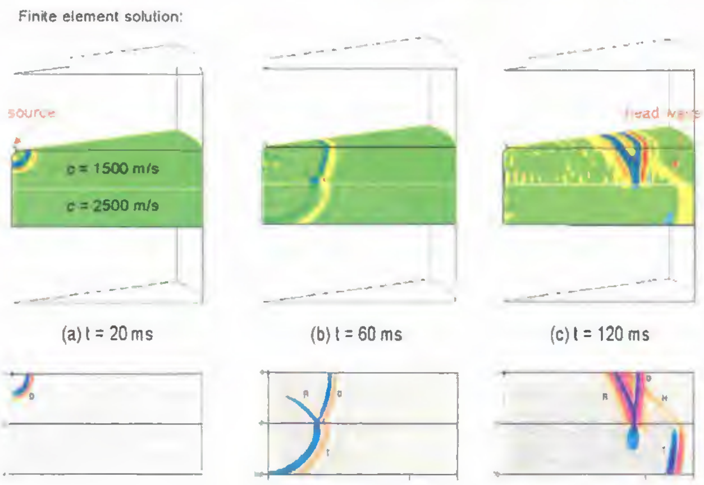

Figure 03-E.3 *Comparison of FE solution with an independent analysis at three instants of time: (a) before the spherical pulse reaches the interface, (b) shortly after it reaches the interface, and (c) further in time.*

(below) surrounding a rigid hole in the shape of a Manta mine, slightly buried in the sediment. The complete mesh of water and sediment is actually a sphere but only half is shown here in order to reveal mesh details in the interior. The mesh was prepared using HyperMesh. Note that interior structural components of the mine are excluded from the analysis because this is an acoustics code, which models wave propagation in fluids, not in elastic solids. The latter was illustrated by a similar demonstration problem in the 2000 *Annual Progress Report*, which showed elastic waves propagating through the internal features of the mine.

The acoustics code performed a transient analysis. Figure 03-E.7 shows two snapshots taken from the animated time history display of propagating contours of acoustic pressure.

Looking ahead

In 2002 ProPHLEX will be used to couple the elasticity and acoustics technology from the separate structural and acoustics codes, which have been described in this and last year's annual report. The integration of these two technologies will constitute Phase III, which will yield a coupled structural acoustics code. This will be the Centre's first operational structural acoustics code, a major milestone that we expect to be completed on schedule.

Bistatic synthetic aperture imaging of buried objects from an AUV

In 2001 we completed a preliminary analysis of the GOATS '98 AUV nose array data set, showing that the concept of synthetic aperture sonar could be extended to AUV platforms which measure the scattering from a target field illuminated by a remote source. In Fig. 03-E.8 the GOATS 98 experimental scenario is shown, where an MIT *Odyssey* AUV with an eight element nose array cut for 7.5 kHz executed a lawnmower pattern over a target field which included three 1.0 m diameter spheres S1, S2 and S3, the centres of which were buried at depths of 1.0, 0.5 and 0 m below the sand–water interface. This target field was insonified by a TOPAS parametric source operating at secondary frequencies between 2 and 20 kHz from a 10 m tower at a range of 34.5 m from the proud sphere S3, which was at the centre of the insonified region. In this configuration the flush-buried sphere S2 was insonified at a grazing angle of 17°, which was below the 22.9° critical angle of the bottom. The bottom was sandy with a compressional speed of approximately 1650 m/s.

The data acquired by the *Odyssey* nose array for 120 consecutive TOPAS transmissions is shown in Fig. 03-E.9. Three distinct types of arrivals are visible. The first, between (arbitrary) times of 0.028 and 0.033 s, are the direct, surface and bottom multiples of the direct arrivals from the TOPAS source. The amplitude of these arrivals is low because the AUV is out of the main beam of this highly directional source. The second returns, those of greatest interest, lie between 0.042 and 0.045 s, are the scattered returns from the flush buried sphere S2. The two largest returns, between 0.046 and 0.050 s, are the direct and surface multiples of the scattered field from the proud sphere S3. The fact that S2 can be seen on these stacked time series means that that there is potential for significant synthetic aperture gain for the detection of buried objects below the critical angle of the sediment, if time series such as these can be coherently combined to improve signal to reverberation ratio.

The physical aperture of the *Odyssey* nose array was 0.7 m, and with the vehicle travelling at 1 m/s and a TOPAS ping rate of 3.34 pings per second, the overlap between consecutive apertures was approximately 0.4 m, meaning that the forward velocity of the vehicle could be estimated by a correlation log procedure. In addition, the unknown TOPAS trigger time (which was removed painstakingly by hand in order to create Fig. 03-E.9) could be solved automatically. The resulting coherent aperture over 6.6 m of synthetic aperture is illustrated in Fig. 03-E.10.The superimposed hyperbola on the right was fitted to the scattered return of the proud sphere S3, which is used as a target of opportunity to anchor the position of the AUV in space. A target of opportunity is necessary because the AUV lacks the trigger time of the TOPAS and therefore cannot use two-way travel time to find its position relative to the targets.

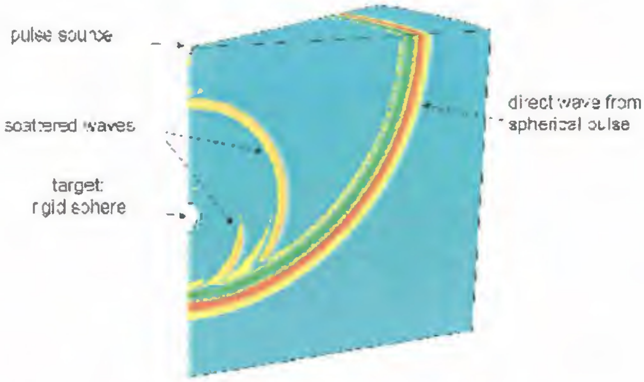

Figure 03-E.4 *Pressure contours from the FE solution, showing the direct wave from spherical pulse and waves scattered from rigid sphere.*

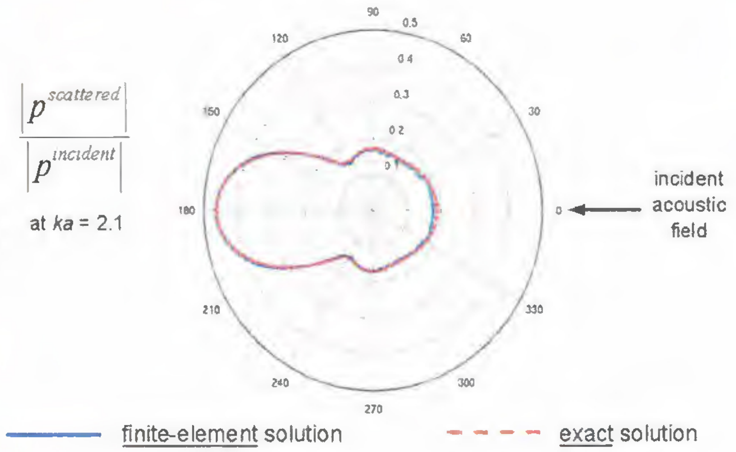

Figure 03-E.5 *Fourier transforming the scattered wave yields a steady-state response that is in excellent agreement with the exact solution.*

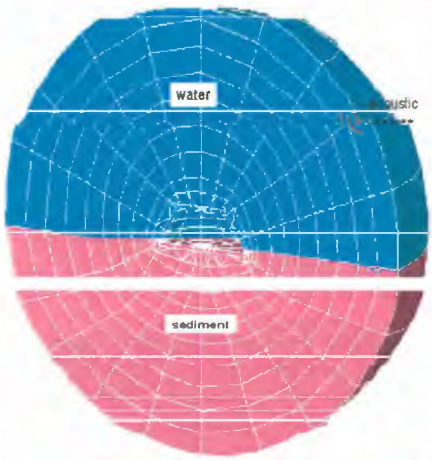

Figure 03-E.6 *Finite-element mesh of water and sediment surrounding a rigid hole in the shape of a Manta mine.*

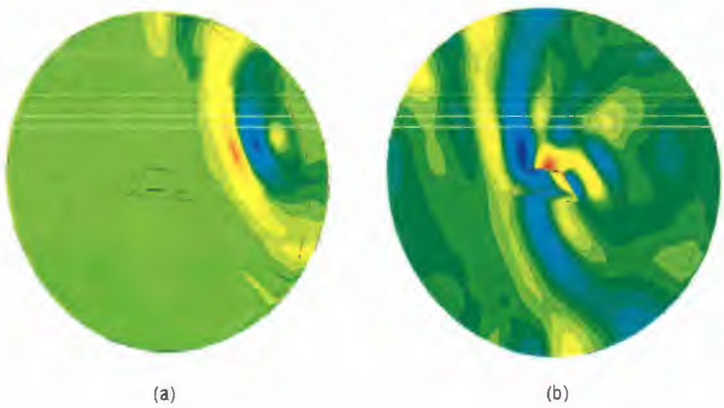

Figure 03-E.7 *Contours of acoustic pressure (a) before the wave strikes the mine and (b) as it begins scattering from the mine.*

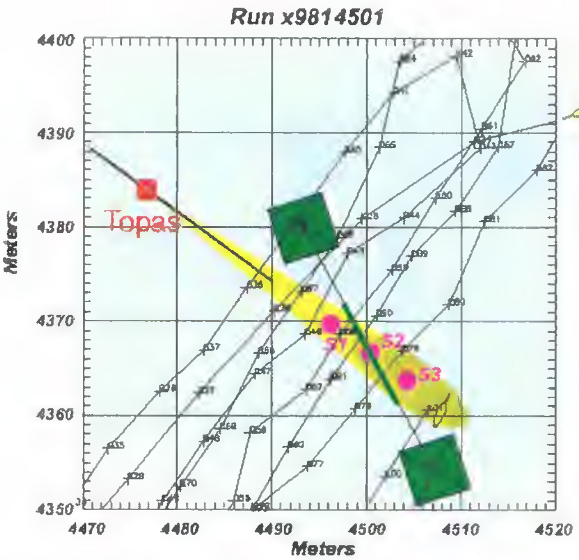

Figure 03-E.8 *The lawnmower pattern followed by the MIT Odyssey AUV as it sampled the scattered energy excited by the bistatic insonification of the target field by the TOPAS parametric array. The green boxes and the line connecting them represent the 128 element HLA which was used by other SACLANTCEN researchers to conduct target imaging using conventional nearfield beamforming.*

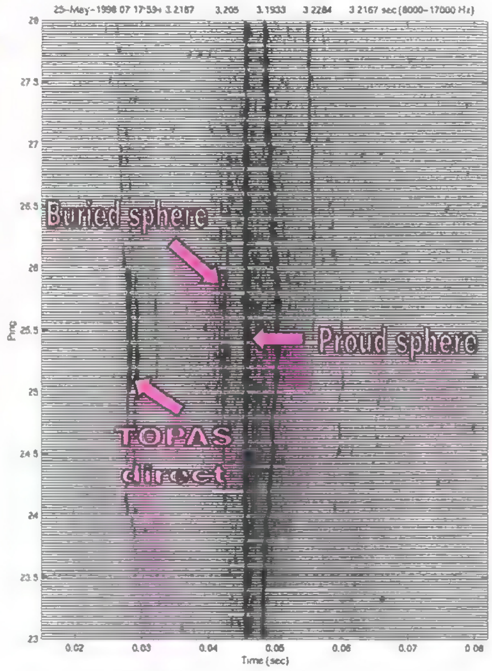

Figure 03-E.9 *Structure of the acoustic energy seen on the Odyssey nose array as a function of the file numbers shown on the AUV trajectory in Figure 03-E.9.*

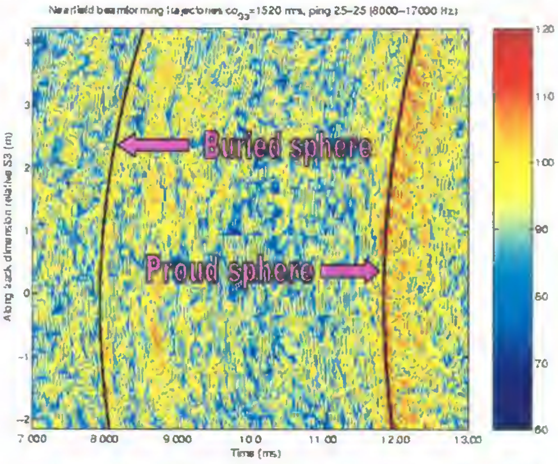

Figure 03-E.10 *Nearfield synthetic apertures of the scattered returns from the flush buried sphere S2 (left) and the proud sphere S3 (right) with the corresponding nearfield hyperbolas superimposed.*

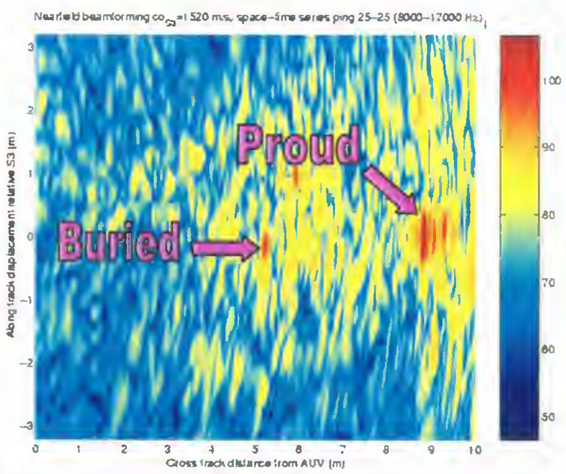

Figure 03-E.11 *Nearfield synthetic aperture image of the target field.*

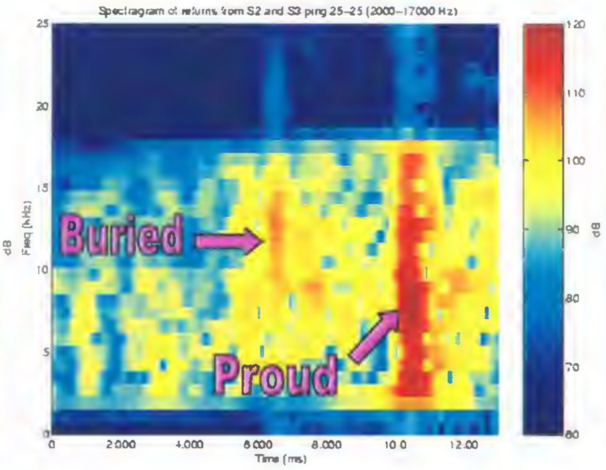

Figure 03-E.12 *A time-frequency spectrogram of the scattered returns from S2 and S3.*

However, once the position of a target of opportunity is known, then other scatterer positions *relative* to the target of opportunity may be imaged, under the assumption that the AUV's trajectory is straight and that its height above the image plane (seafloor) is known. The left-hand trajectory is that of a scatterer hypothesized to lie 3.55 m closer to the AUV along the AUV-S3 axis, and -0.2 m perpendicular to the AUV-S3 axis. This hypothesized location corresponds roughly with the known position of the flush buried sphere S2, and is seen to align coherently with the first scattered return from S2.

In Fig. 03-E.11 an image formed by coherently summing along all the hypothesized hyperbolae of possible target locations is shown. At a range of 8.8 m and a cross track displacement of 0.0 m (by definition) is the image of the proud sphere S3. At a distance of 3.55 m closer to the AUV, an image of the first return from the flush buried sphere S2 is found at a range of 5.25 m from the AUV and an along track displacement of –0.2 m.

To better understand the resonant nature of the scattered returns from the flush buried sphere S2 and the proud sphere S3, a spectrogram of these returns is illustrated in Fig. 03-E.12. Here it is seen that the flush buried sphere is most visible in the 8-15 kHz band, and appears to be composed of three distinct arrivals. The first arrival, at a time of 6 ms, has most of its frequency content between 4 and 9 kHz and is believed to be the "specular" return from the buried object, which is easiest to see at low frequencies since it is excited by an evanescent wave. The second return, at approximately 6.5 ms, is the strong return upon which is superimposed the left hyperbola in Fig. 03-E.10, and is assumed to be a first membrane wave multiple. The third return, at approximately 7.5 ms, is assumed to be a second membrane wave multiple. The finding that a flush buried sphere scatterers most strongly in the 8-15 kHz frequency band was an unexpected experimental result, which shows the value of the GOATS '98 data set.

Very low frequency acoustic propagation

SACLANTCEN conducted the SWEEP-2K experiment in September/October 2000 designed to validate numerical propagation model prediction of low-frequency acoustic signal reception at <500 m separations in very shallow water (< 100 m). The experiment simulated a ship radiating low-frequency tones, passing closely to a mine. Three experimental sites were chosen, at each of which, eight acoustic tracks were executed, changing acoustic source depth and frequency. Sound speed profiles were measured in the morning and afternoon for use in the prediction tool. The acoustic sound source has been calibrated using the experimental configuration and the processing of the acoustic signals received by a 4-element vertical array was completed during 2001. The acoustic data are available as transmission loss depending on experimental location, distance between source and receiver, source depth and frequency. Initial predictions of acoustic propagation for the 3 sites have been performed using *a priori* environmental information as input to the model. Fine-tuning of the environmental parameters is necessary in order to obtain acceptable agreement between model and data. A final report will be published in 2002.

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Project 03-F: Minehunting sonar performance model

3

Operational relevance

To provide NATO with an improved performance prediction tool for minehunting, particularly in shallow water, and to provide the sonar performance parameters required as inputs by the NATO MCM planning tool MCM EXPERT.

The aim of Project 03-F is to provide a tool that can be used by naval operators to provide the sonar performance parameters needed by MCM planning and evaluation tools - such as the standard NATO tool MCM EXPERT - and by scientists and engineers who need to predict the performance of minehunting sonars.

MCM Planning

The tool will be able to provide the parameter *p(y)* (cumulative probability of detection as a function of across track distance) or the values A (characteristic detection width) and B_d (characteristic probability of detection) which are required by planning tools such as MCM EXPERT. The tool will also be able to provide an estimate of mine case burial depth and the performance of minehunting sonars against buried mines.

The parameters p(y) or A and B_d are derived from single ping probabilities of detection and these, in turn, are derived from signal excess. An algorithm has been developed to calculate the single ping probability of detection from the signal excess, which has the potential to take into account reverberation statistics (if these are known). Algorithms for calculating the cumulative probability of detection from single ping probabilities have been evaluated. One of these algorithms, which takes into account some dependency between successive pings, is giving promising results. Another factor that needs to be included is the efficiency of the sonar operator (or computer aided detection algorithm), but this will require further investigation.

The input parameters required by the model include those of the sonar system, target, and the environment In operational use, the tool would be configured for a particular sonar type. In this case, the user would only be presented with the sonar settings that can be changed by the sonar operator (another use of the tool could be to optimize these settings). Generally, target parameters would be pre-set for a number of different mine types. Environment parameters could be customized to correspond to the data normally available, whether from a minewarfare pilot, charts, an environmental database, or the results of a rapid environmental assessment (REA). Figure 03-F.1 illustrates how the tool would be used for MCM planning.

Software Architecture

An important aim of this project is to create a modular "plug-and-play" architecture and a significant amount of effort has gone towards achieving this goal. This architecture allows sub-models to be added relatively easily and allows customization of the user interface. The benefits of this approach include:

- being able to update or replace sub-models when improved sub-models become available
- new functionality can be added relatively easily
- nations can replace sub-models with their own, if they wish
- the user interface can be customized for different types of user.

Software prototyping has been used to develop this architecture. The language chosen for the prototyping and the final tool is Java. The advantages of using Java include platform independence and the "introspection mechanism", which allows the software to determine the parameters required by each sub-model. The prototype software demonstrates the capability of being able to add new sub-models without having to change or re-compile any existing code and of providing different views of the environmental, sonar, and target parameters. Where the parameters shown in a view of, say, the environment do not match the parameters required by a sub-model, "adapters" are used to provide a mapping between the two. Figure 03-F.2 shows a typical display available in the prototyping software (in this case, the display shows propagation loss calculated using Bellskip, a derivative of the freely available model Bellhop).

Reverberation modelling

Where suitable sub-models exist that can be distributed within NATO (for example those in the APL-UW High-Frequency Ocean Environmental Acoustic Models Handbook), the project will use these. Initially, it was intended to use an existing national reverberation model, but it was subsequently ascertained that it was not possible to distribute this model freely to all NATO nations. Consequently, it became necessary for the project to develop its own high frequency reverberation model.

An existing public domain propagation model, called Bellhop, was used as the starting point for the reverberation model. Bellhop is a robust and efficient ray-based model which uses a variant of Gaussian beam tracing called geometric beam tracing to calculate eigenrays. The structure of the code has been changed substantially to allow reverberation to be calculated, but the fundamental technique for calculating propagation loss remains the same. A slight variation of the geometric beam tracing technique has been used to calculate other ray parameters needed to calculate reverberation, such as grazing angle and travel time.

Links to other SACLANTCEN projects

This project aims to make use of work being carried out under other projects at the Centre. Of particular relevance is the work being done on target modelling (Project 03E-2) and environmental assessment (Project 03H-1). An accurate model of the scattering from proud and buried mines is important for sonar performance predictions, and it is anticipated that the results obtained under Project 03E-2 will provide a robust target strength model. It is also anticipated that Project 03H-2 will be able to provide information on the statistics of bottom reverberation. This information can be used to calculate detection probability more accurately.

By incorporating sub-models developed within other projects into the performance tool it is hoped that, in the future, all NATO nations will be able to benefit from aspects of the Centre's work more rapidly than is currently possible.

Progress

The reverberation model was completed this year and has been incorporated into the prototype software. The project plan has been updated since the SPOW 2001 was produced. Due to the reallocation of resources from 03F-1 onto other projects during 2001, the project has been delayed. Under the current project plan, the beta test version of the minehunting sonar performance tool is scheduled for mid-2003, with the project then entering a final validation phase with completion by the end of 2004.

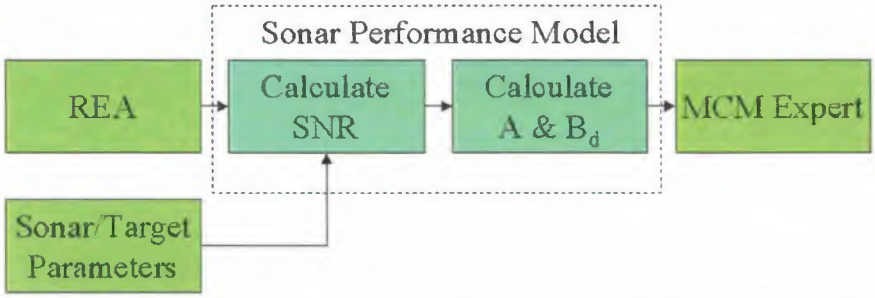

Figure 03-F.1 *Interfaces between the minehunting sonar performance tool and MCM EXPERT*

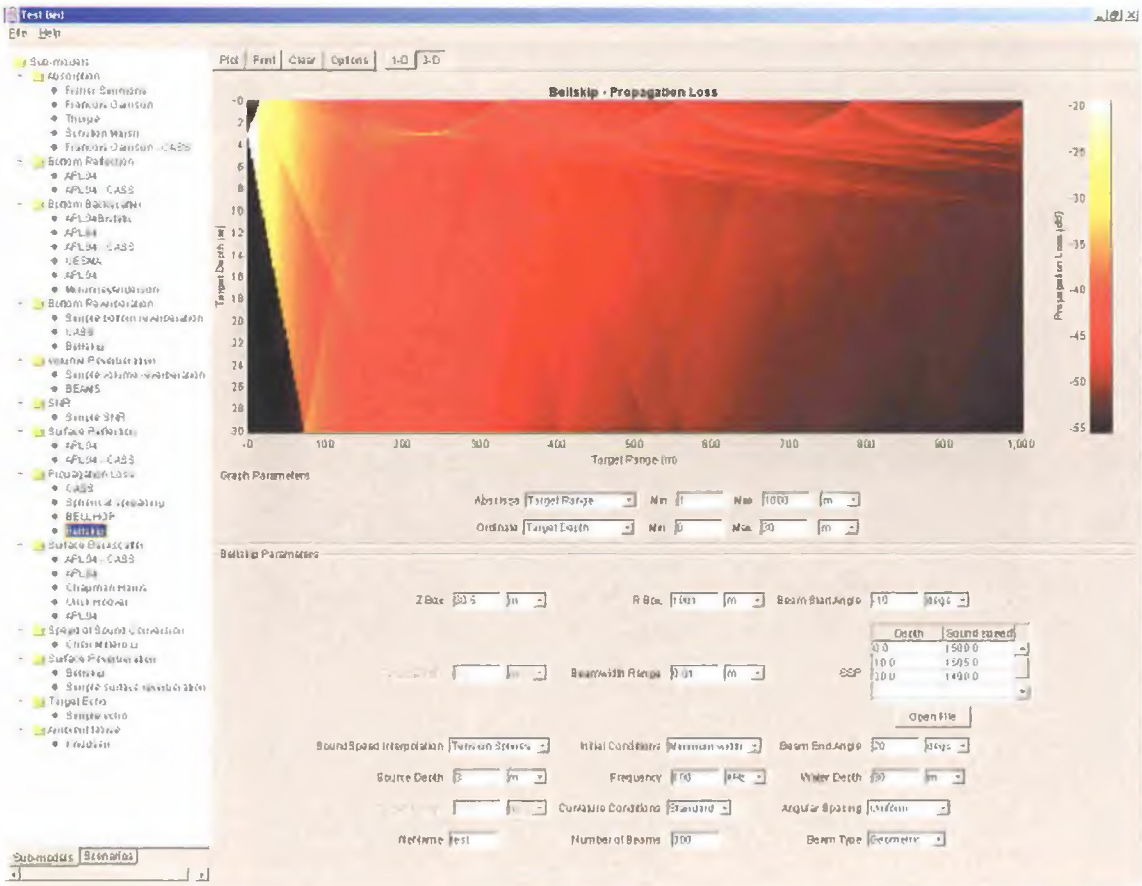

Figure 03-F.2 *Prototype software example showing propagation loss*

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Project 03-G: Advanced minehunting sonar concepts for unmanned underwater vehicles (Alliance days – 15, Manning days - 12)

3

Operational relevance

The countering of buried mines is a recognized capability shortfall, highlighted by the NATO study MO 2015, to which this project has actively contributed. Mine sweeping is the only existing active countermeasure against all types of buried mines. However, arming delays, ship counts and pressure sensors can reduce its effectiveness. Conventional minehunting sonars are ineffective against mines which are fully buried in sediment, where sound absorption is high compared to that in water. The Centre is studying specific, bottom penetrating sonars, which will, in the long term, be integrated with an Autonomous Underwater Vehicle (AUV). Due to critical angle effects, the range of such sonars is limited, especially in shallow and very shallow water, which makes the use of manned surface ships undesirable.

Buried mine hunting

Mine-sweeping is the only active countermeasure against buried mines. However arming delays, ship counts and pressure sensors reduce its effectiveness. As conventional minehunting sonar systems are ineffective against mines, which are fully buried in sediment, in which sound absorption is high, this project is intended to study low-frequency, bottom penetrating sonar, which will be integrated on an unmanned underwater vehicle (UUV).

At the low frequencies at which bottom penetrating sonar operates, the difficulty is to maintain sufficient resolution to reduce seafloor reverberation, which is the background against which the echoes of buried targets have to be detected. Previous work has demonstrated the effectiveness of scanned parametric sonar in detecting buried targets, due to their large bandwidth and comparatively narrow beam. The work on buried mines in 2001 was focused on the application of array signal processing techniques for improved detection and classification, of buried targets, using a 2-16 kHz parametric

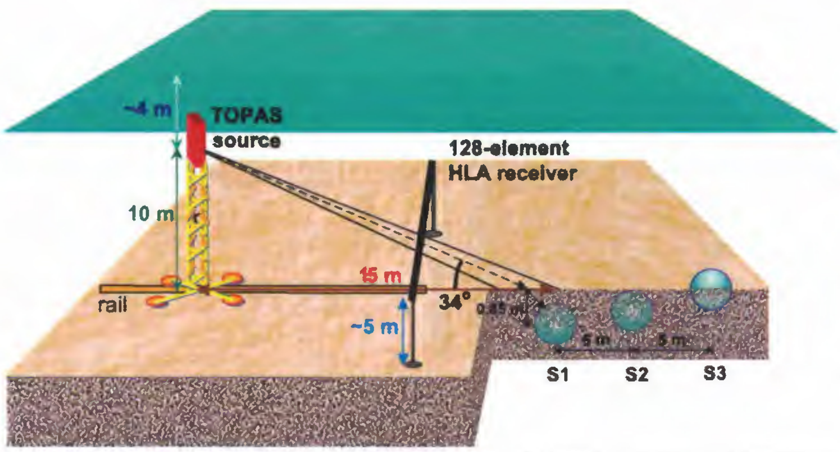

Figure 03-G.1 *GOATS'98 experimental configuration. The HLA array is perpendicular to and centred on the TOPAS rail.*

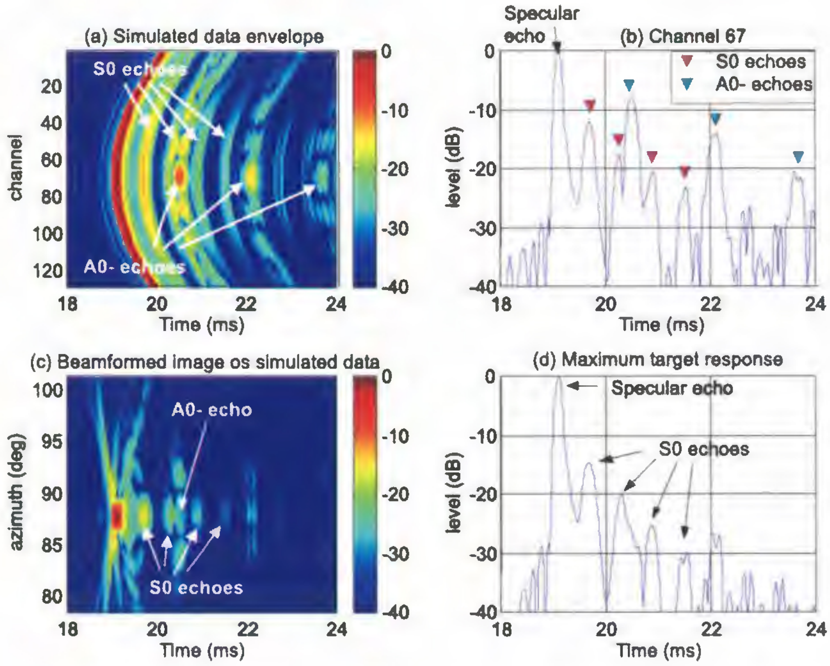

Figure 03-G.2 *Sphere S1 simulated data (bandwidth (1,12) kHz): envelope of HLA data (a), the envelope of channel 67 (b), beamformed image (c), beam of maximum target response (d).*

transmitter with a 12 m horizontal line array (HLA) and synthetic aperture processing. (Fig. 03-G.1)

Due to increased directivity, significant gains in detection are obtained at grazing angles above and below the critical angle of total reflection. An environmentally adaptive matched filter theory has been developed, which accounts for the change in absorption over the transmitted bandwidth. The adaptive filter provides significant gains with respect to conventional theory. The high-resolution images obtained in both cases allow straightforward discrimination between buried spherical and cylindrical shells. In addition, resonant scattering theory is shown to provide robust additional classification cues for the simpler case of the air-filled spherical shell. The issue of the spatial (i.e., azimuthal) coherence of the elastic waves of the buried spheres was addressed. The response of the deeply buried sphere S1 is presented. The echo received by each of the HLA hydrophones has been modelled by means of a T-matrix-based simulator, developed at the U.S. Coastal Systems Station. The raw simulated data (Fig.03-G.2 (a) and (b)) show the sphere specular echo and two main circumferential

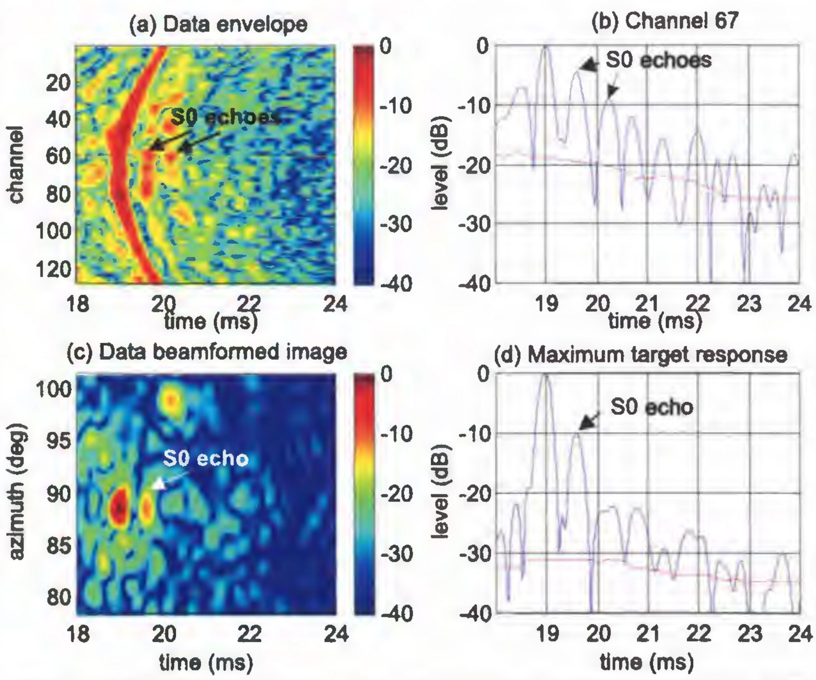

Figure 03-G.3 *Sphere S1 at-sea data filtered in the frequency range (3,7) kHz: envelope of HLA data (a), envelope of channel 67 (b), beamformed image (c), beam of maximum target response (d). The red dashed/solid curves show the average reverberation level before/after beamforming.*

waves, the supersonic S0 Lamb-type wave and subsonic A0- Lamb-type wave. Due to the target symmetry and the relatively low-frequency composition of the S0 wave, the spatial coherence of the S0 Lamb-type wave extends over a wide azimuth. Due to the higher frequency composition of the A0- wave, its azimuthal coherence is restricted to a narrower angular range. The different nature of the two waves in terms of spatial coherence explains the result of beamforming shown in Fig.03-G.2(c) and (d). There is still significant array gain for the S0 wave echoes, but not for the A0- wave echoes shown in Fig.03-G.2(b) and (d). From the study of the wave frequency composition, the main contribution of the S0 first two echoes, which are the echoes most clearly detectable in the model, was found between 3 and 7 kHz. Hence the at-sea data have been studied in this range as shown in Fig.03-G.3 (a) and (b). After beamforming shown in Fig.03-G.3 (c) and (d) the first S0 echo is 22 dB above the mean reverberation level. In summary, the use of a long HLA improves the detectability of both the target specular echo and those elastic waves that are spatially coherent for a wide range of azimuth angles.

Future work on buried mine hunting will benefit from a new 8-16 kHz 2D sonar array (4 rows of 16 receive elements spaced at 6.5 cm) which has been procured from Florida Atlantic University. Synthetic aperture sonar (SAS) will then be used to synthesize arrays the performance of which should exceed that of the HLA with more compact sonar design. It was initially planned to integrate this sonar in 2001 on the Ocean Explorer AUV procured for Projects 01A/01B. However, due to procurement delays, this integration has to be postponed till 2002.

Synthetic aperture sonar

Implementation of SAS on UUVs for large area, covert reconnaissance systems, is the primary objective of this project.

International competitive bidding for a wide-band high frequency transmitting and receiving sonar system to be integrated into a UUV was not undertaken due to continuing delays in the funding of the MCM Capability Package. Scientific work has continued using existing equipment in collaboration with other research institutions.

Results of InSAS'00 sea trial

High-resolution co-registered bathymetry and imaging is important for UUV-based MCM operations. A new approach to depth finding using interferometric sonar, based on direct time delay estimation was proposed and validated experimentally in 2000. The data used were from a joint experiment between GESMA, France and Qinetiq, UK carried out at the Lanvéoc rail facility. The sonar operates at 120-180 kHz with two receiving arrays of 32 elements, of length 26.7 cm at 21 cm intervals. Further improvements in the processing of the data, in particular the correction of roll-induced distortions in the bathymetric map, were achieved in 2001 (Fig. 03-G.4)

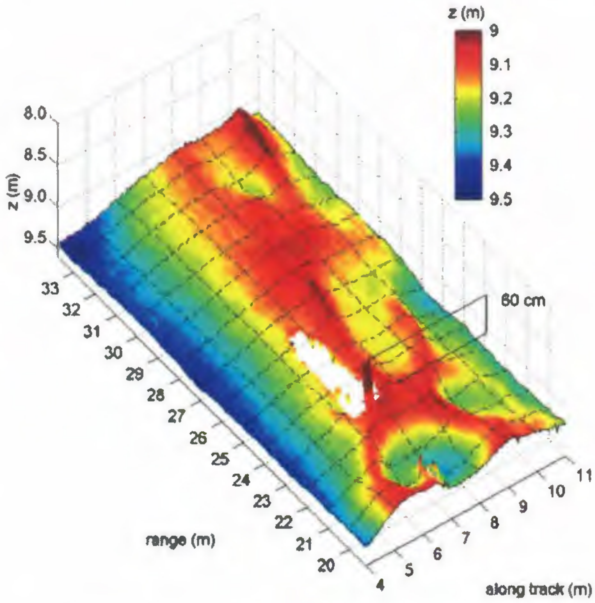

Figure 03-G.4 *InSAS bathymetric map of Brest area seafloor at the range interval around 25 m, with 5 cm along-track resolution and 25 cm across-track resolution. The echo of a 1 m diameter sphere and a scoured pit in front of the target are clearly visible. The bathymetry is omitted in areas where the correlation coefficient is less than 2/3 (e.g. in shadow zones).*

The data from the InSAS'00 experiment performed in November 2000, jointly with

Qinetiq, UK and FFI, Norway with the objective of furthering the understanding of InSAS, were analyzed in 2001. Qinetiq provided a 24 m underwater rail, a wideband interferometric sonar, and a motion system allowing controlled track-keeping errors to be generated. The receive array was similar to the one described above whereas the transmitter design was new. In addition to expertise in ocean engineering and logistic support for the trial, SACLANTCEN provided a strapdown inertial navigation system (INS) of the 0.1 nm/hr class. A significant gain in SAS performance, measured in terms of image quality and increased area mapping rate, was shown to result from the combination of accurate estimates of the sonar array attitudes, provided by a high grade INS, and linear sonar displacements provided by the data-driven micronavigation technique known as DPCA (Displaced Phase Centre Antenna). Fig.03-G.5 shows SAS images of several targets at 50 m range, demonstrating an azimuth resolution gain as high as 40, even in the presence of large track-keeping errors induced by the motion system. This was the first time an INS has been successfully used to focus an SAS. Multi-aspect SAS imagery from the MASAI'00 trial are shown in Fig. 03-G.6.

Autonomous UUV navigation

To assess the SAS performance achievable on an ocean-going platform, an aided inertial navigation system (AINS) was integrated on the MASAI (Multi Aspect Synthetic Aperture Imaging) towbody (Fig.03-G.7) and tested at sea in October/November 2001 during the MASAI'01 sea trial. The AINS consists of the high grade INS, a 1200 kHz Doppler velocity log, a pressure sensor and RTK GPS receiver on board the ship. The towfish houses the 100 kHz programmable sonar used for SAS research. In addition to SAS, a significant gain in navigational accuracy is expected to result from the combination, in an optimal Kalman filter, of a high grade INS and of DPCA micronavigation. The benefit for an AUV equipped with SAS (alternatively a specifically designed navigation sonar optimized for DPCA micronavigation) will be the increased range of autonomous navigation, between position updates (e.g. GPS fixes or landmark recognition). This is being studied using the aided inertial navigation software, provided by FFI, called NavLab. The InSAS'00 and MASAI'01 data sets are extremely valuable in this respect.

Preliminary results are shown in Fig. 03-G.8, where the ping-to-ping motion estimates obtained by the DPCA and the INS are compared (the INS results are plotted after removal of a low-order drift). The DPCA yaw estimate is seen to be much noisier than that of the INS. There is better agreement between both surge and sway estimates.

A preliminary evaluation of AINS performance was effected during MASAI'01. Figure 03-G.9 shows an *Alliance* track measured by GPS and two types of AINS. The mean speed of the ship was 4.4 kn. The total distance of the track was 5.2 kn. The blue line is the position of the ship given by the GPS, used for ground truth. The green line is INS position using GPS, DVL and depth sensor aiding. The red line is INS position using only the DVL, the depth sensor, and one GPS fix at the beginning of the run. The INS result with GPS aiding throughout is in good agreement with the GPS result for the straight parts of the track. Position error increases when the ship was turning due to the relative change in position between the towbody and the ship. At the end of the run, the position error is less than 1 m. On the other hand, the green line, which is more representative of a UUV, INS has a much larger position error. It was about 37 m (0.7%) at the end of the run. This is much larger than is expected for an aided inertial navigation system of such high quality and the possible reasons for this discrepancy will be investigated in 2002.

Effect of the sea surface interactions on SAS performance

Multipath is an important factor limiting the performance of sonar, including SAS, in shallow and very shallow water. The performance of DPCA micronavigation in multipath channels was experimentally assessed during MASAI'01. DPCA is based on the coherence of the seafloor backscatter at successive pings, which could be significantly degraded by sea surface

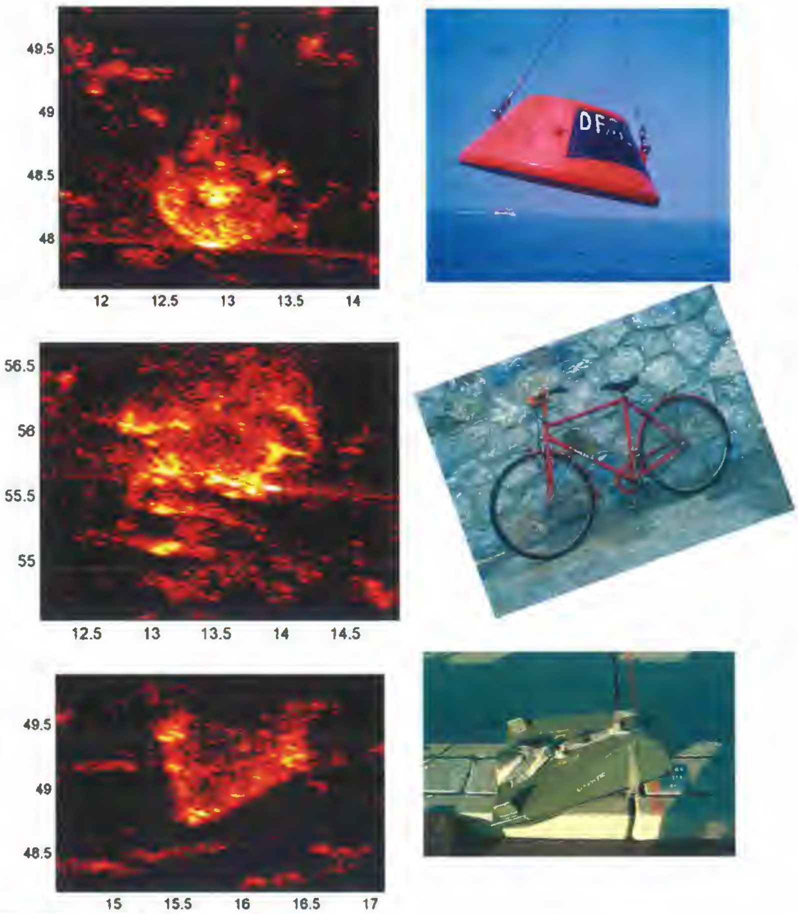

Figure 03-G.5 *SAS images from INSAS'00 data. Details of the echoes of a Manta mine, a bicycle and a Rockan mine at 50 m range are shown with the photo of the corresponding object.*

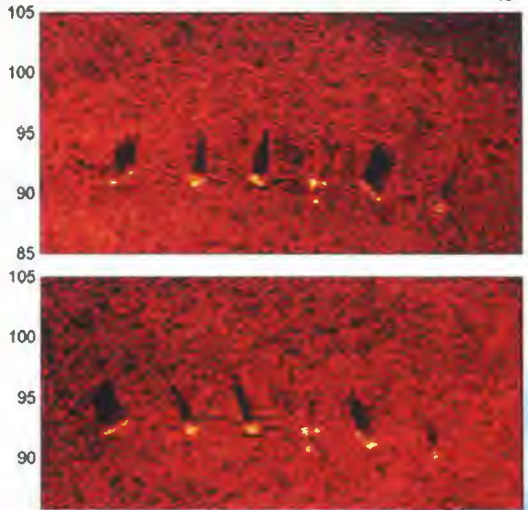

Figure 03-G.6 *Two different aspects of the target field at 90 m range during MASAI'00 trial.*

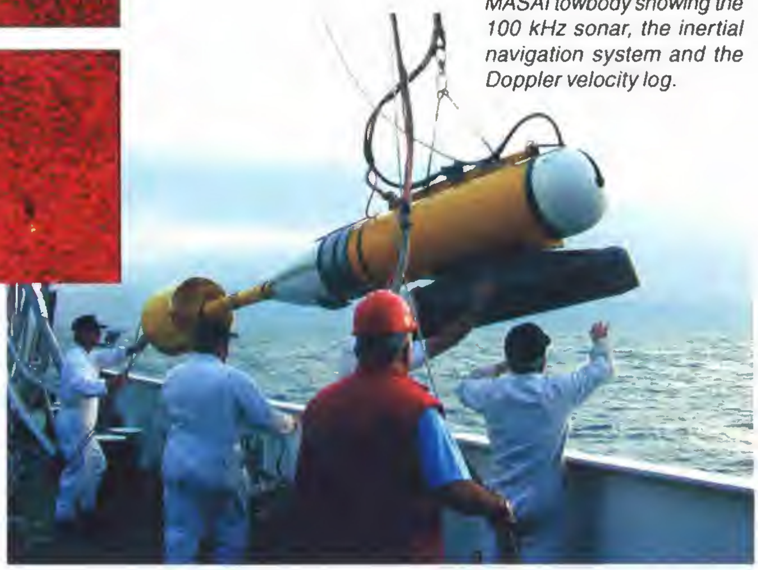

Figure 03-G.7 *Modified MASAI towbody showing the 100 kHz sonar, the inertial navigation system and the Doppler velocity log.*

interactions. The multipath structure was analyzed by deploying the sonar array vertically. Figure 03-G.10 shows received signal intensity as a function of grazing angle and range, at a depth of 32 m with a relatively calm the sea surface. The main returns can be identified as the direct backscatter from the seafloor (blue) and from the sea surface (green), and the surface-bounced seafloor backscatter (magenta). By deploying the sonar horizontally, at a fixed position and varying its position in the water column, the ping-to-ping coherence could be measured experimentally as a function of range and depth. The drop in coherence is due to the sea surface interactions, the ping-to-ping coherence of which is reduced by sea surface motion (Fig. 03-G.11).

A simple model was developed to estimate the correlation of bottom returns. It is planned that more advanced modelling will be performed in collaboration with Projects 03-F and 03-H, to provide a real performance prediction capability for SAS in shallow and very shallow water.

Scattering

The algorithms for the analyses of 12 kHz interferometric sidescan sonar are ready and the work is expected to be completed following receipt of the data. The bistatic model for high frequency acoustic scatter has been developed and is shortly to be tested against existing data.

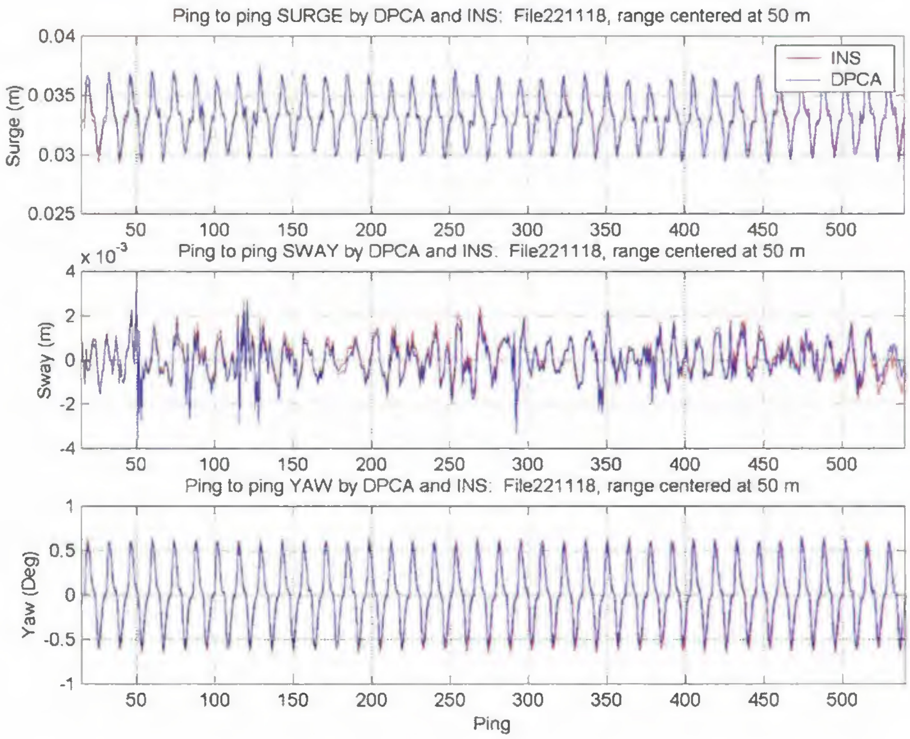

Figure 03-G.8 *Ping to ping DPCA motion estimates compared with the INS. A low order polynomial drift has been removed from the INS estimates.*

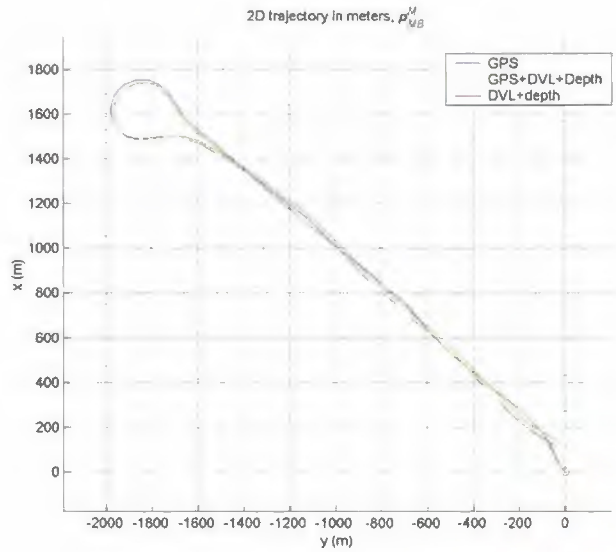

Figure 03-G.9 *Ship track for a closed loop run as estimated by GPS alone (blue), aided inertial navigation with continuous GPS aiding (green) and aided inertial navigation with initial GPS position fix (red).*

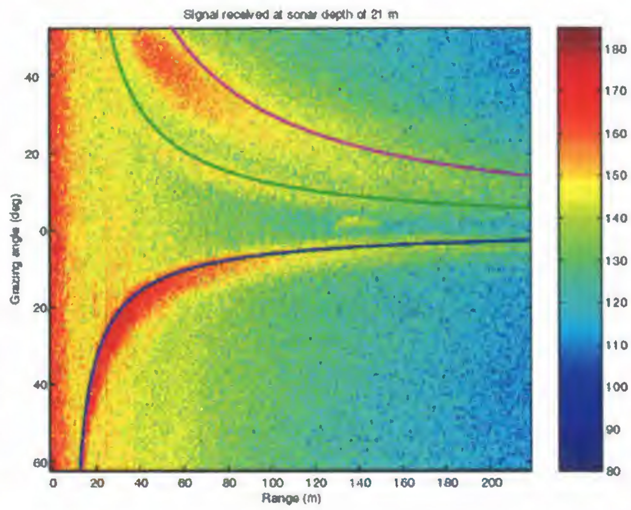

Figure 03-G.10 *Direct seafloor backscatter and sea surface interactions impingeing on a 2 m vertical array deployed in shallow water.*

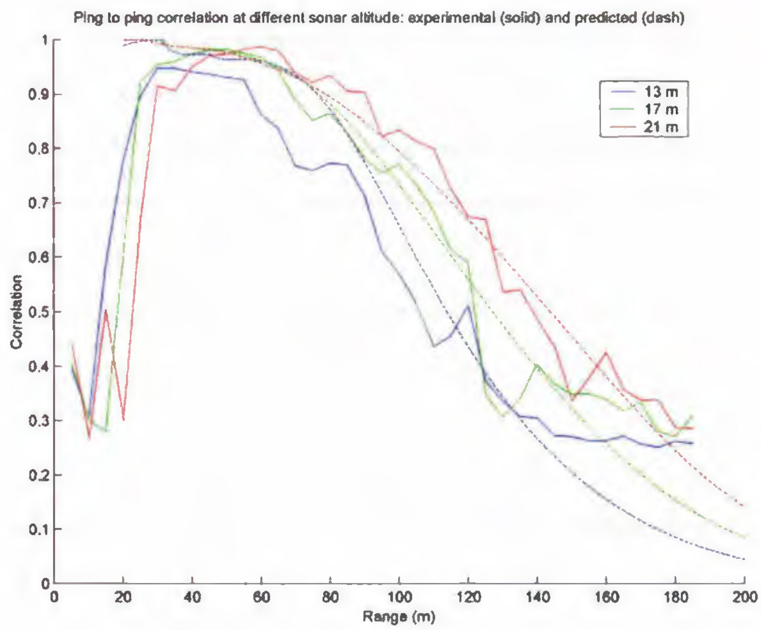

Figure 03-G.11 *Ping-to-ping coherence of seafloor backscatter for a horizontal array as a function of range and sonar altitude.*

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Project 03-H: Environmental support for minehunting systems (Alliance days – 24)

3

Operational relevance

Accurate knowledge of environmental parameters is a prerequisite for effective military operations. Evaluation of percentage of clearance during MCM operations is closely related to performance prediction results, which in turn lead to the assessment of remaining risk to follow on forces in a channel or area. The environment is the constraint on minehunting system performance, especially when detecting low contrast mines in cluttered environments. The objective of this project is to provide solutions to remotely retrieve the environmental parameters affecting minehunting performance by the most effective sensor combination on an UUV platform, expressed in terms of validated, robust and efficient algorithms. The performance of advanced sonar and navigation sensors is reduced in shallow and very shallow water by multi-path effects, water column property fluctuations and seabed properties. Simulation and at-sea experiments quantify the limits of micro-navigation and thus synthetic aperture sonar for minehunting purposes. This project will also produce a clutter estimator capability valid at minehunting frequencies and for new geometries (e.g. bi-static). It will enable detection performance predictions during mission in a quantitative manner for a wide range of favourable to unfavourable environments likely to conceal mines.

Maple'2001 experiment

milestone

The Maple'2001 experiment, which took place in July, off Halifax with the R/V *Alliance* and the Canadian Navy Research Ship *Quest* (Fig. 03-H.1) was an opportunity to quantify seabed properties and their effect on acoustic reverberation. The acoustic response of the seabed and the causes of acoustic fluctuation were measured simultaneously using numerous acoustic and non-acoustic sensors to retrieve seabed and water column properties. Algorithms developed for seabed segmentation/ classification and characterization were also tested. A wide range of seabeds was selected including those in which stealth mines are difficult to detect.

Seabed segmentation and classification

The MAPLE'2001 sea trial enabled the validation of the Centre SEafloor Segmentation Algorithm (SESAM) based on the analysis of the seabed angular backscattering information provided by common multibeam echosounders. SESAM requires low interaction with the operator and produces a high spatial resolution segmentation map at low computing cost. The algorithm was validated on data from two Centre multibeam echosounders: the 80 beam Atlas HYDROSWEEP MD multibeam echosounder operating at 49 kHz and the 120 beam SIMRAD EM3000 operating at 300 kHz. These data were acquired at three shallow water sites off the coast of Halifax (Canada). In parallel, ground truth data were acquired including data from two high frequency sidescan sonars, the Roxann system using signals from a monobeam echosounder, gravity cores, grabs, expendable bottom penetrometers, videos and stereo-photos. The confrontation between the segmented maps obtained using SESAM and the ground truth data validates the algorithm and confirms its ability to identify small variations of the seabed properties with spatial resolution approaching that of the relevant multibeam system. Figure 03-H.2 displays the bathymetric map and related segmentation map using data obtained with the EM3000 multibeam data from the site of St Margaret's Bay. In addition to SESAM, a new classification algorithm using

Figure 03-H.1 *Map displaying the three sites studied during Maple'2001. R/V Quest (forefront) and R/V Alliance (back) during a survey of the St Margaret's Bay site (Halifax, Canada), July 2001.*

signals from monobeam echosounders is currently being developed within project 03-H. It will complement the unsupervised segmentation algorithm for sidescan sonar images developed at SACLANTCEN during previous years under project 03-D.

Study of the impact of clutter on mine detection

Clutter is due to high amplitude, distinct scatters and causes the probability of false alarm to increase and consequently degrades detection performance. In order to reduce the impact of clutter, its impact on higher moment statistics need to be understood. These higher order statistics relate directly to probability of detection of an object for a given system and geometry and are not included in current sonar performance prediction models. So far, only qualitative estimates of detection performance based on seabed classes defined by ATP24 may be available to the operator. Apart form the appropriateness and the availability of this rough classification for an area of interest, it is system and geometry independent and does not relate easily to detection probability for a specific minehunting system. This project aims at developing and validating a clutter estimator that includes complex environmental inputs and, as an end goal, will allow the quantitative estimate of detection performance for realistic situation in shallow water. In parallel to the modelling work, the Maple'2001 experiment was an opportunity for measuring probability density functions on many different cluttered environment. The measurement was made using an environmental sensor package (ESP) destinated to be installed on the Centre AUV in 2002. The ESP prototype is a rudimentary yet effective towed system able to measure single look and single frequency reverberation levels using a single transducer. It is also featured with a video camera, a compass and a motion sensor. Figure 03-H.3 displays the ESP prototype before being deployed during Maple'2001 and 50 consecutive time series backscattered from the from the same cluttered seabed as the ESP is drifting. It illustrates the strong effect of clutter on detection and on the related probability distribution (PDF).

As a complement to the study of clutter, the Maple'2001 trial included the study of the performance of several high frequency sidescan sonars on calibrated mine like objects (Manta, Cylinder, MP80, Rock). Detectability and classification parameters were studied as a function of range, aspect and frequency. These data will be used to compare the performance of a real aperture against a synthetic aperture (SAS).

Effect of the environment on micronavigation applied to SAS

The objective is to establish the physical limits imposed by the environment on micronavigation techniques applied to Synthetic Aperture Sonar. As water depth decreases, multi-paths and sensor motion are expected to seriously affect long range viability of micronavigation techniques. Water column property fluctuations are expected to increase and have a direct impact. The coherence of the seabed response is also called into question. The study of the impact of water column fluctuation and its related impact on acoustic backscattering commenced during the Maple'2001 experiment. Backscattered time series for short pulse high frequency transmission (100 kHz) together with local currents and of sound speed profile variation were measured. These measurements will correlate the environmental properties with the performance of micronavigation applied to SAS using simulation and at sea data analysis. The end objective is a series of recommendations to project 03-G 'Advanced Minehunting Concept for UUVs'.

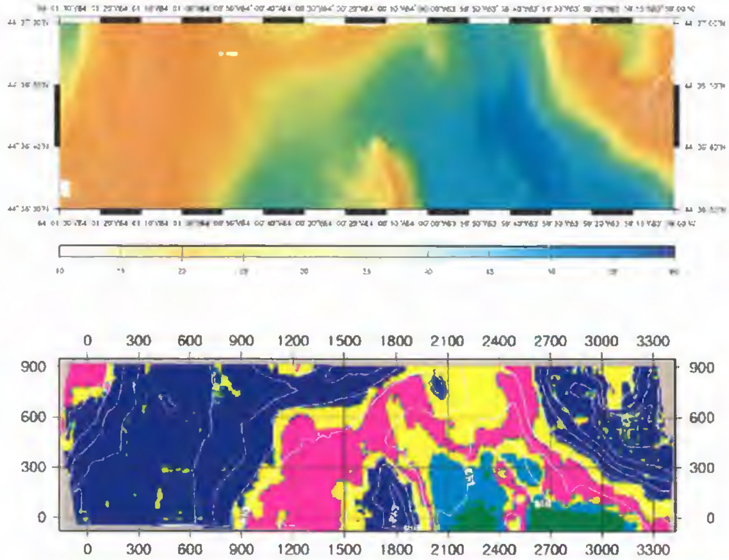

Figure 03-H.2 *Bathymetric map of a 2 mile by 0.5 mile area within St Margaret's Bay (top) with the corresponding segmented map of the area below. Note the rapid spatial changes in seabed types and the strong correlation between the bathymetry and the segmented areas.*

Figure 03-H.3 *Environmental Sensor Package prototype (ESP) was used during the Maple'2001 sea trial. The prototype is being deployed from R/V Alliance (B). Example of fluctuation of recorded backscattered signals from the same cluttered environment (C). Corresponding probability density function (PDF) of the cluttered environment that enables a quantitative assessment of the probability of detection (D).*

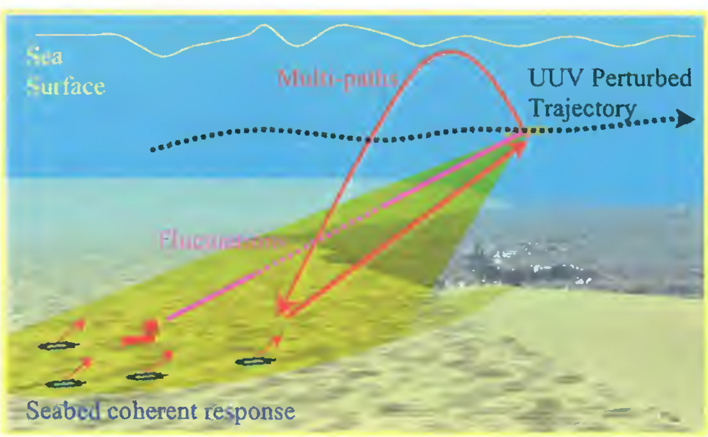

Figure 03-H.4 *Synopsis of the main physical phenomena affecting micronavigation and related synthetic aperture sonar imaging: sensor motion, water column fluctuation, multi-path and seabed coherent response.*

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Project 03-I: Systems and concepts for rapid MCM operations

3

Operational relevance

NATO's MCM capability is slow, overt and increasingly ineffective against low target strength mines and mines utilizing state of the art micro-processing. These shortcomings have a detrimental effect on all types of MCM operations but most especially on amphibious operations, which are characterized by very constrained timelines and the necessity to maintain the element of surprise. Furthermore, the threat posed by terrorist sea mining of NATO ports and SLOCs has been thrown sharply into focus by the events of 11 Sept 01. The MCM response to such a threat will need to be rapid and effective in order to re-establish the free flow of essential maritime traffic. This project examines how NATO can improve the speed and efficiency of MCM operations through the novel use of existing equipment, procurement of new systems and the development of new tactics in the short term. The final deliverable of this project will be a proposed set of systems with minimum acceptable operating characteristics and an outline Concept of Operations for the most promising sub-set of these recommended systems.

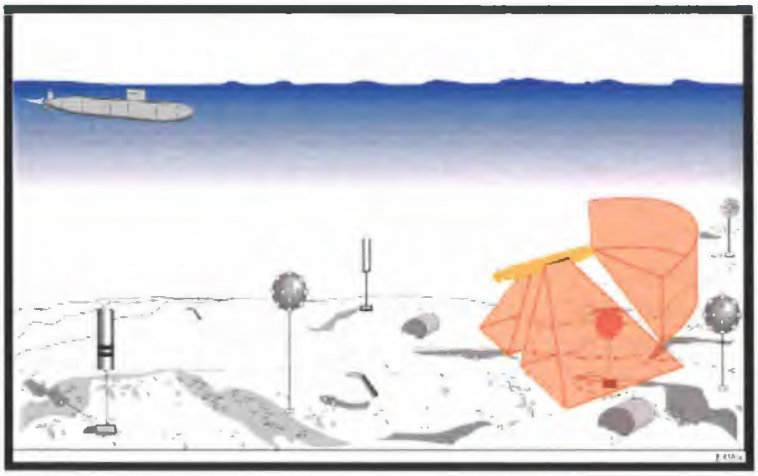

Figure 03-I.1 *AUVs will form a central part of and future Concept of Operations for rapid MCM.*

Work has centred largely around data collection from open and classified sources of information relating to MCM systems which are due to mature within the next 5 years. The development of new tactics and possible changes to NATO MCM doctrine have also been progressed and although these are still at the concept stage they show considerable promise for improvement to the speed of MCM operations at little to no cost. Of particular interest is the potential to reduce channel width and Mine Danger Area (MDAs)and therefore MCM effort, and the concept of planning on risk which will optimize the amount of MCM effort required for a particular operation.

AUVs have been identified as having the greatest potential for speeding up MCM operations throughout a range of applications. Any future Concept of Operations for rapid MCM will have AUVs as a central requirement (Fig. 03-I.1)

Participants in the September workshop[1] expressed their desire to support the project through information exchange and attending future workshops.

[1] Attended by CINGERFLEET (GE), COMINEWARCOM (USA), Office of Naval Research (USA), COMFORDRAG (IT), Centro Instrucao Tactica Naval (PO), Fleet Staff Author Group (UK), HMS Dryad MW Section (UK), CAPT MFP (UK), Maritime Warfare Centre (UK), EGUERMIN MW School (BE/NL), DERNAVOST/MWDC (BE), COMCMSERVICENL (NL), SACLANT, SHAPE, CINCEASTLANT.

The MW schools at HMS *Dryad* in the UK and EGUERMIN in Belgium have accepted tasking to conduct studies. The result of the workshop was an agreed list of systems and concepts and scenarios to be taken forward to the MOE and modelling phase of the project which will occupy the first three quarters of 2002.

Systems and concepts

- Channel width reduction/Mine Danger Area (MDA) evaluation and reduction – The reduction in the area which needs to be subjected to MCM operations will have obvious benefits with regard to time saving. Limitations which require further investigation are warship manoeuvering requirements (AAW, ASW) and the track keeping abilities of a wide range of possible follow on shipping.
- AUVs – Through the work being carried out at SLC and in several NATO nations AUV technology and its application to MW operations has made significant progress. Within the next 5 years AUVs will be able to conduct reliable, detailed, covert reconnaissance in advance of the main MCM force. This capability will markedly increase the speed and efficiency of MCM ops.
- One Shot Mine Disposal (OSMD) – The time taken to identify and classify mine like objects with present ROV systems represents a significant proportion of the time taken to complete an MCM operation, especially in high seabed clutter areas. OSMD systems have the potential to significantly improve this situation through reduced preparation, deployment, and countermine times.
- Increased processing capabilities – New sonar capabilities such as wide band sonar will present the operator with much more information over a larger area. This increase in workload will necessitate better Computer Aided Detection (CAD) and Computer Aided Classification (CAC) to ensure that all contacts are swiftly and adequately dealt with.
- Route Survey Database (RSDB) – Detailed survey of potential MCM operating areas will increase the speed of subsequent operations by providing a database of what has already been identified as non-mine and can therefore be disregarded.
- Rapid Environmental Assessment (REA) – A thorough and timely knowledge of the seabed and water column conditions in the area which is soon to be subjected to MCM operations is crucial to the efficient tasking of assets and, most importantly, in identifying areas of low clutter density where MCM operations can be conducted most rapidly.
- MCM planning and evaluation – The efficient tasking of scarce MCM assets to achieve no more than the required remaining risk and thus no more time and effort than is absolutely necessary can be achieved through the use of programs such as MCM EXPERT and DARE.
- Command Control Communications Computers and Intelligence Surveillance Reconnaissance (C4I/ISR) – More efficient C4I and better knowledge of the threat and the area of operations will contribute to the speed and effectiveness of MCM operations.
- Mine Jamming – In time constrained operations Mine Jamming can provide the extra small reduction in risk that can make an otherwise marginal remaining risk more acceptable.
- Target Setting Mode Sweeping (TSM) – Influence sweeping is generally more rapid than minehunting. It does, however have several drawbacks, not least of which is the inability to be able to say with a high degree of confidence that your sweep has been effective against an unknown mine threat. TSM can improve this situation by capitalizing on the signature information we can obtain from our own vessels which can then be simulated in the sweep to actuate those mines which are configured against that particular type of vessel.

Scenarios

- Sea Lines Of Communication (SLOCs)
- Operating areas

  Port break in/break out
- Ship To Objective Manoeuvre (STOM)
- Large area mine clearance

Work during 2002 will be aimed at developing the models and MOEs with which to validate the systems and concepts listed above and a start will be made on defining the minimum operating characteristics for each system. A mid project review workshop is scheduled for September 2002.

3

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LePage, K.D., Schmidt, H. Bistatic synthetic aperture imaging of proud and buried targets using an AUV. Proceedings of the GOATS 2000 Conference, SACLANT Undersea Research Centre, La Spezia, Italy, 21-23 August 2001, SACLANTCEN CP-46.

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Tesei, A., Zerr, B., Maguer, A. Multi-aspect and multi-frequency: A new paradigm for mine classification. UDT, Hawaii, 2001.

Wang, L., Bellettini, A., Pinto, M., Tesei, A., Chapman, S., Gade, K. Interferometric SAS and INS aided SAS imaging. InSAS'00.

Nicholas Gaze Pace was awarded the BsC and Ph. D. degrees at the University of Durham in 1967 and 1971 respectively. He was research fellow at the University of Bath 1971-1979, Lecturer in Physics since 1979 and Reader in Physics since 1999. Awarded the Tyndall Medal of the UK Institute of Acoustics in 1990, he is a Fellow of the Acoustical Society of America (1985) and of the Institute of Acoustics (1986).

Andrea Bellettini received his B.S. degree in Physics from the University of Milan and the Master degree in Mechanical Engineering from the Hokkaido University (Japan) with a thesis in nonlinear acoustics. His research interests include shock waves and tsunami propagation. He joined SACLANTCEN in 1999 working on minehunting sonar systems.

David Burnett received B.S. and M. Eng. degrees in Engineering Physics from Cornell University in 1962, an M.S. degree in Engineering Science from the California Institute of Technology in 1963 and a Ph.D. degree in Theoretical Mechanics from the Univ. of California, Berkeley, in 1969. He worked more than 28 years at Bell Laboratories (of Lucent Technologies; formerly part of AT&T), primarily in undersea R&D for the U.S. Navy, specializing in theoretical and computational mechanics (elasticity and acoustics). In the '80s and '90s he was a group technical leader for the development of 3-D structural acoustics finite-element codes for ASW applications. Dr. Burnett taught many courses in finite-element analysis in the Bell Labs In-Hours educational program. In 1983 he received the title of Distinguished Member of Technical Staff, and in 1996 the title of Fellow, Bell Labs' highest honour. Dr. Burnett holds several patents in the field of computational acoustics, and is the author of three books: an 844-page textbook Finite Element Analysis: From Concepts to Applications; a 230-page book of finite-element homework problems; and a 200-page manual on computational structural acoustics. He joined SACLANTCEN in 1998, where he leads the development of a finite-element structural-acoustics code for modelling scattering from undersea structures.

Gary Davies received his MA in Engineering Science from Lincoln College, Oxford in 1984. Subsequently, he joined a company specialising in sonar technology where his interest in sonar performance modelling began. After two years in Australia as Systems Engineer for the new Australian minehunting sonar, he returned to England in 1998 as head of a Research and Development Group for minehunting sonar systems and as the project manager of an experimental AUV-based sonar programme. He joined SACLANTCEN in 1999 where he has worked mainly on minehunting sonar performance prediction.

Glynn Field *joined the Admiralty Underwater Weapons Establishment, AUWE in 1971. During his early years he wrote finite element software to predict the dynamic behaviour of towed arrays. He later developed computer models to predict the hydrodynamic properties of flexible sonar domes. In 1981, he joined the Mine Warfare Department where he was responsible for research into Mine sensors. In 1985 he became responsible for work on Mine Algorithms and Simulation, including the Total Mine Simulation System, TMSS. TMSS has become the focus of international collaboration. Versions of TMSS are installed in Australia, Canada, France, Germany, Netherlands, New Zealand, Norway, Sweden, US and SACLANTCEN, where Glynn Field has been Project Leader of Mine/Ship Interaction since 1994.*

Lavinio Gualdesi *graduated from the Naval Academy, Livorno (IT) in 1967. He was awarded the naval architect masters degree at the University of Trieste. Having resigned from the Navy in 1978 with the rank of Commander (Engineering Corps), he contributed to the design for fibreglass mine counter measure vessels as the Technical Director of the Intermarine Shipyard in Sarzana.. He has been Head of the Underwater Technology Branch in the Ocean Engineering Group since 1982, working mainly on buoy technology and towed body design.*

Reginald Hollett *was born in Rochester, U.K., in 1952. He received a Ph. D degree in nuclear physics from the University of Bradford, U.K., in 1980. He was employed from 1980 to 1984 in the Marine Aircraft Systems Division of Marconi Avionics, specializing in performance of ASW sonobuoy systems. In 1984, he joined the SACLANT Centre and has since pursued research interests in underwater ambient noise, signal processing and mine counter measures.*

Finn B. Jensen *received the M.S. and Ph. D. degrees in engineering science from the Technical University of Denmark (TUD), Lyngby, in 1968 and 1971, respectively. From 1969 to 1973 he was an Assistant Professor in the Department of Fluid Dynamics at TUD. Since 1973 he has been employed at SACLANTCEN as a research scientist developing numerical models of sound propagation in the ocean; from 1981-1998 as Head of the Environmental Modelling Group with responsibility for the development and validation of acoustic and seismic propagation models; since 1999 as Project Leader, Computational Acoustics for activities related to propagation, reverberation and target strength modelling. Dr Jensen is a Fellow of the Acoustical Society of America, Editor of the Journal of Computational Acoustics and co-author of a 600-page textbook on Computational Ocean Acoustics published in 1993.*

Lucie Pautet *received the diplôme d'ingenieur de l'Ecole Centrale de Lyon in 1993, an M.S in Aerospace Engineering from Penn State University in 1994 and a Ph.D. in Applied Ocean Sciences from the University of California in 2000. She worked for a year at Thomson Marconi Sonar in Sophia Antipolis, France as a signal processing engineer before joining SACLANTCEN in 2001, where she is working on seafloor scattering with emphasis on the impact of fluctuations in the environment on propagation and scattering of acoustic signals.*

Marc Pinto *graduated from Ecole Nationale des Ponts et Chausées, Paris in 1983. He obtained the Diplôme d'Etudes Approfondies in probability theory in 1984 and a Ph. D. in solid state physics in 1992. From 1985 to 1993, he worked as research engineer on semiconductor and magnetic sensors, first at Schlumberger Research Laboratory in Montrouge, Paris and then at the corporate research Centre of Thomson-CSF in Orsay, Paris. From 1993 to 1997 he headed the Signal Processing Group of Thomson Sintra ASM, Brest (now Thomson Marconi Sonar). In 1997 he joined SACLANTCEN where he is leading minehunting sonar systems research.*

Eric Pouliquen *received the B.S. degree in physics from the University of Brest in 1988 and the M.Sc. and Ph.D. degrees in physical methods in remote sensing from the University of Paris 7 in 1989 and 1992, respectively. From 1989 to 1992, he was with IFREMER in Brest. From 1993 to 1995, he was a postgraduate research assistant at the California Space Institute of the Scripps Institution of Oceanography, San Diego. Since joining SACLANTCEN in 1995, he has been involved in a variety of projects in environmental acoustics.*

After graduating *as a siv.ing. from the University of Trondheim, Norwegian Institute of Technology in 1992, Per Arne Sletner worked as a special investigator (computer fraud) and trained police investigators at the Police Academy in Norway. Before joining the Environmental Acoustics Branch of the Engineering Technology Division in 1996, he worked for Geco Defence, Økokrim and Simrad Subsea.*

After receiving her Ph. D. degree in telecommunications from the University of Genova, Italy, in 1996, **Alessandra Tesei** joined SACLANTCEN initially as a consultant, working on the European Union funded MAST-III project Detection of Embedded Objects (DEO). Her main research interests are in statistical signal processing, acoustic resonance scattering modelling and analysis.

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After graduating from the University of Bath with a BSc in physics, **Luigi Troiano** was a design engineer for a multibeam imaging sonar system, at Ulvertech Ltd. Since joining SACLANTCEN in 1987 he has provided engineering support to scientific sea-trials in the fields of low frequency active sonar, mine countermeasures and environmental acoustics.

Liansheng Wang received the B. Eng. And M. Eng. Degrees in Underwater Acoustical Engineering from Harbin Engineering University, P.R. China in 1982 and 1985 respectively, and the Ph. D. degree in Physics for research studies into sound propagation in range dependent underwater channels from Bath University, England in 1989. He joined the Acoustic and Sonar Group, University of Birmingham, Birmingham, UK in 1990 as a research fellow and became a lecturer in 1996. His main research interests are in the areas of underwater propagation, parametric sonar and underwater acoustic communications. He came to work on the Advanced Mine Hunting Sonar Concepts project in the Signals and Systems Department at the Centre in May 2000.

Mario Zampolli graduated in Mathematics from the University of Bologna, Italy, in 1996. Between 1996 and 1997 he collaborated with the University of Bologna on research in boundary-element models for aerodynamics and on control theory. In 2000 he received a Ph.D. in Mechanical Engineering from Boston University, where his research focused on physical acoustics and acoustical micro-electro-mechanical systems (MEMS). In 2001 Dr. Zampolli joined the MCM department at SACLANTCEN, where he works on the development of a finite-element structural acoustics code for modelling scattering from undersea structures and performs experiments on the reduction of risk from sea-mines through acoustic environmental mine-jamming.

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Thrust 04 Tactical Active Sonar (TAS)

Project 04-A: Advanced shallow water tactical active and surveillance sonar (Alliance days – 27)

Operational relevance

To significantly advance ASW capabilities in shallow water by developing state-of-the-art technology into research equipment and prototype sonar systems and through research and development of advanced system concepts. These concepts include the coordinated, interoperable use of tactical and deployed multistatic sonar and the adaptation of sonar operations to exploit local environmental conditions using REA methods

4

CERBERUS'01 multistatic LFAS sea trial

Multistatically operating LFAS-equipped ships have the potential to improve submarine detectability by increasing detection range, area coverage, and signal excess. Deploying multiple sonar receivers increases the number of detection opportunities for each transmitted ping, which will result in better overall probabilities of detection, especially when it is possible to exploit the inherent diversity of multistatic geometries. Where one source-receiver sonar pair is faced with challenging detection conditions, another may be more favourably situated.

The increased number of detections from multistatic assets will lead to better target tracking and localization. Where one system loses a target track, another system can fill in the gaps. When multiple, simultaneous detections are made from several source-receiver sonar pairs, the resulting contact data can be associated, fused, and cross-fixed, yielding a more accurate localization of the target. This is attractive not only to achieve better localization, but also because it provides higher probability target tracks more quickly than a single system could, reducing the time to verify presence of a threat.

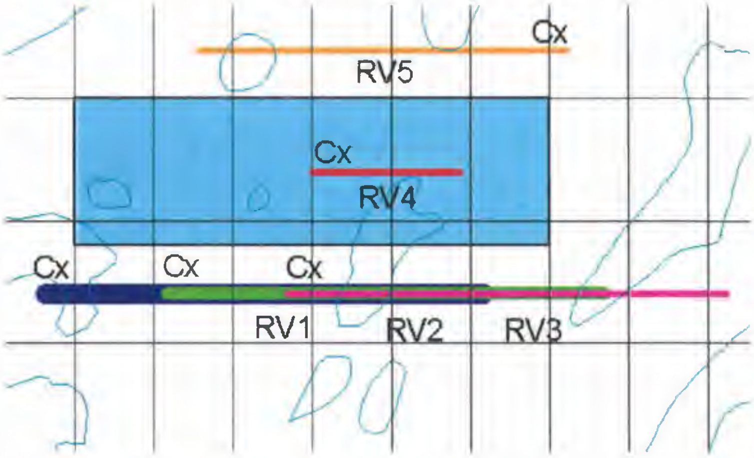
The objectives of CERBERUS'01 were to demonstrate the feasibility of coordinated, interoperable, bi/multistatic operations with LFAS sonar in a shallow water reverberation-limited environment. The sea trial was held during August 2001, in the Southwest Approaches to the United Kingdom, in shallow water (100-200 m). Each Joint Research Project partner[1] contributed assets, equipment and personnel to planning and execution, including three LFAS-equipped ships, a target submarine and naval support vessel.

The R/V *Alliance* was equipped with the LFAS system incorporating high power source and right/left-directional cardioid receive array. The United Kingdom provided a charter vessel, the M/V *Bremen*, equipped with their LFAS system including a broadband source. Germany provided R/V *Planet*, with their LFAS system which uses a right/left-directional twin line receive array. Germany also provided a submarine target and a surface support vessel to tow an echo repeater system. Figure 04-A.1 shows R/V *Alliance* and R/V *Planet* at the pier in Falmouth.

[1]Germany (FWG) and U.K. (DSTL/QinetiQ)

Figure 04-A.1 *R/V Alliance and R/V Planet at the pier in Falmouth, during CERBERUS'01.*

Figure 04-A.2 *CERBERUS'01 single standoff source scenario. The monostatic ship (RV1) is distant from the submarine (RV4), while the passive bistatic receiver ships (RV2 and RV3) are closer.*



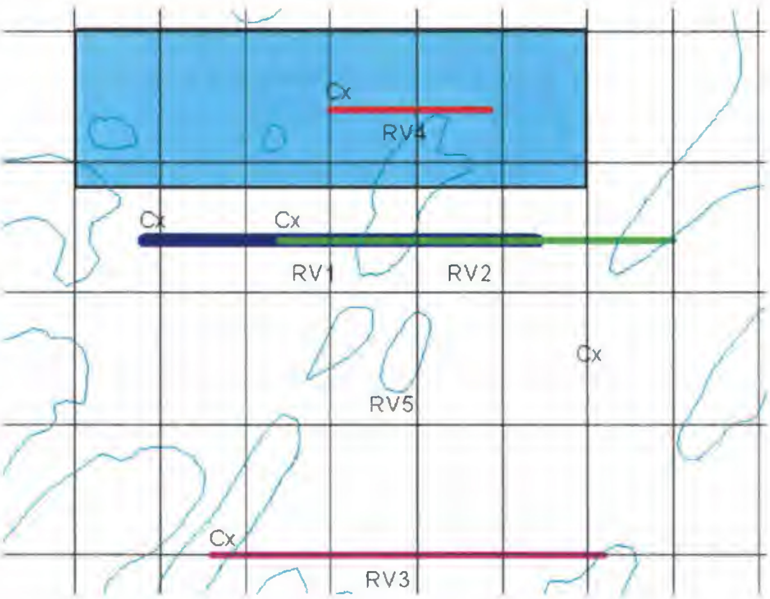


Figure 04-A.3 *CERBERUS'01 multi-source scenario. Three LFAS ships (RV1, RV2, and RV3) proceeding in line in the vicinity of the submarine target (RV4) are shown.*

The trial was successfully executed, despite several problems with scientific equipment. A large multistatic data set was acquired which will be analyzed to evaluate and quantify the advantages of multistatically interoperable LFAS systems. Approximately 41 experimental runs were successfully executed, with a variety of run geometries, sonar configurations and transmission sequences.

One of the principal test scenarios placed a transmitting monostatic LFAS ship at long range from the target (Fig. 04-A.2). The other two LFAS units were closer to the target and receiving only bistatically (no active transmissions). Real-time observation and detection monitoring during these tests indicate that there is potential in using LFAS units in this configuration to extend detection range and increase area coverage.

Another main test scenario placed the ships closer in formation, moving together, with all three LFAS units actively transmitting (Fig. 04-A.3). Various transmission sequences were designed and tested for LFAS system interoperability, which was achieved through ping interleaving and frequency band allocation. Real-time observation and detection monitoring indicate that valuable data has been acquired for research into multistatic crossing fixing, data association, fusion and tracking. Analysis will focus on evaluating improvements in detectability, tracking, and localization.

CERBERUS demonstrated the feasibility and potential of real-time exchange of encrypted sonar data between ships. Each LFAS sonar system generated a set of echo-contacts for each source-receiver pair, per ping. These contacts, the output of an automatic detection scheme include submarine echoes and a large number of false alarms (clutter) for each ping. Each ship packaged this information into a common format for transmission *via* high-speed spread spectrum radio/data link to the other platforms. A customized geographic information system (GIS) which automatically displayed the contact data in real-time was installed on all platforms (Fig. 04-A.4).

This was a first attempt to perform "visual fusion" of the multistatic contacts using overlays on a common geographic screen. The radios had sufficient throughput capability to handle the large amount of information transmitted, but at times were limited in link availability at certain ranges and bearings due to antenna installations and atmospheric conditions. This was an important first step in demonstrating the concept of multistatic contact sharing that will be developed further with more robust GIS capabilities and more reliable radio links.

The successful execution of the CERBERUS'01 multistatic sea trial was the project's most significant accomplishment of 2001. The collected data will be analyzed at least through

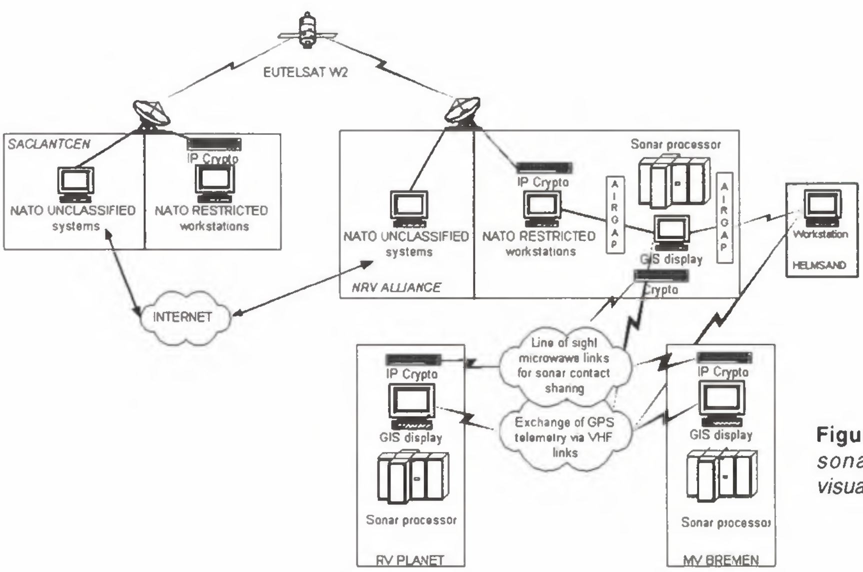


Figure 04-A.4 *The ship-to-ship sonar contact sharing and visualization setup.*

2002 in the evaluation of LFAS multistatic performance and in the future development of multistatic data fusion/tracking algorithms.

Multi-ping tracking and fixed-feature removal

The reduction of a large number of false alarms and fixed reverberation clutter can be accomplished by associating the sonar's received echo objects over time. A multi-ping tracker has been developed which can make these associations from a single source-receiver sonar pair, either monostatic or bistatic. It has been tested with data from the BACCHUS'98 sea trial. Fig. 04-A.5 shows beamformed and matched filtered data for a single ping. Reverberation and clutter are visible, resolved to either the right or left side by the cardioid array. The data are normalized and post-detection integration is applied (using the Page test), forming detection objects (targets and target-like false alarms). Objects are defined here as a group of samples that, above some threshold, are connected in range or beam direction. The data mass-centre of these objects can be formed and these correspond to a stable representation of the object. The data mass-centres are much less susceptible to multi-path variations or feature highlight interference than the individual data samples. Because objects are formed over beam and range direction, they inherently imply a form of two-dimensional range/beam interpolation estimation. Figure 04-A.6 shows the data after the forming of the detected objects.

The data mass centres of the sonar objects can be calculated. These are stable, and can be used to follow the consistency and motion of underwater features over pings. The tracking algorithm associates the mass centres of objects over sequential transmissions using an M-of-N criteria, and determines their stability. For objects that show sufficient consistency (i.e., they pass the M-of-N test) an estimate of the object speed is made. If an object does not contribute to a successful track association, the object is removed from the data. In addition, objects may be removed that contribute to a successful track association where the velocity formed track near zero. This part of the algorithm is known as fixed feature removal, and is successful in reducing fixed, zero-doppler clutter due to discrete bottom reverberation features. Figure 04-A.7 shows the resulting data image with random and fixed clutter removed using this multi-ping tracking algorithm. This algorithm development was a significant accomplishment because it will directly support and feed into the future development of a multistatic fusion tracker, which will not only associate detection objects between pings, but also between different source-receiver sonar pairs.

Clutter consistency and localization

In order to fully exploit the advantages of multistatic systems and develop the necessary data association and fusion algorithms, it will be necessary to understand the statistics and stability of fixed reverberation clutter. Fixed features on the ocean bottom can produce reverberation clutter that negatively impacts sonar performance by increasing the number of false alarms. In order to develop clutter classification and removal algorithms, the consistency of the clutter in time, range and geometric aspect (both monostatically and bistatically) must be assessed. In addition, the localization accuracy of these features by sonar systems must be known before appropriate clutter cross-fixing schemes can be devised.

A study was made of clutter from the DUSS '97 experiment south of the Island of Elba (Italy) during which a multi-static system of surveillance buoys (3 receivers, 1 source) was deployed.

The data contains measurements from three receiving stations positioned on a straight line at approximately 2 n.mi spacing. The first station, a (quasi-) mono-static element, is the *Alliance*, which deployed a source and a receiver buoy. The two other buoys were bistatic receiver buoys. The positions of the stations were determined by differential GPS.

The reverberation returns from Montecristo Island were studied. The detections were clustered into objects and projected on a geographical map. Even though the returns from

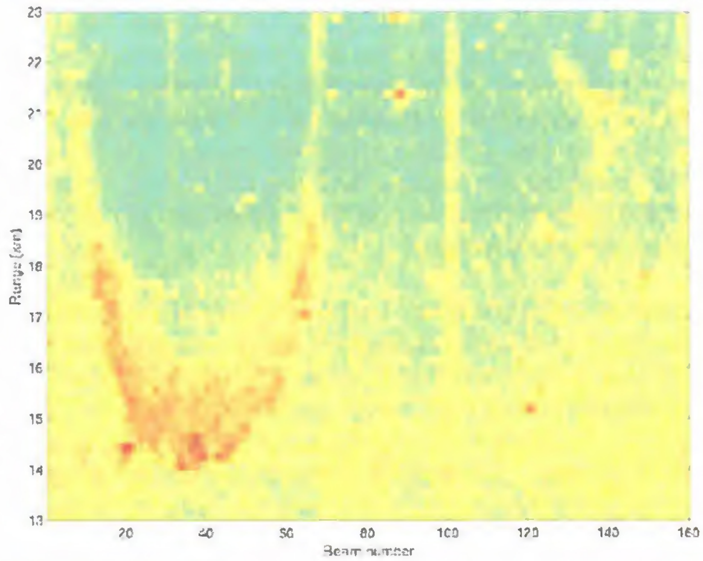


Figure 04-A.5 *Cardioid beamformed and matched filtered data from the Bacchus trial South-East of Sicily. The 160 beams cover 360°.*

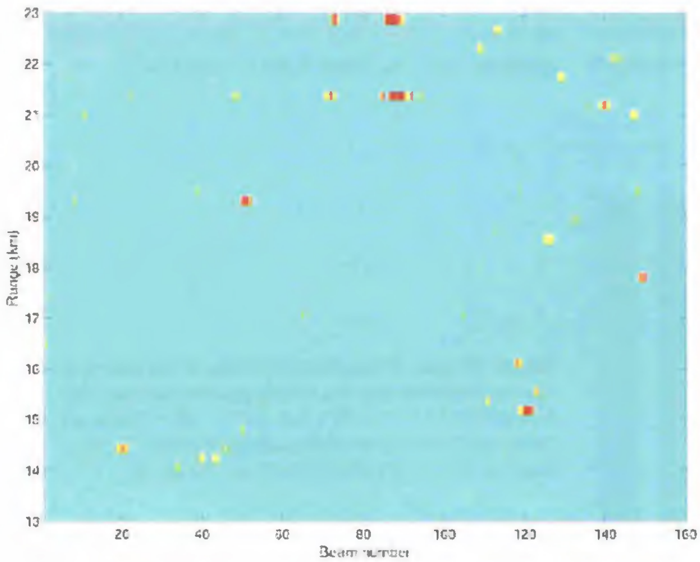


Figure 04-A.6 *Data of Fig. 4, after normalization and Page test detection.*

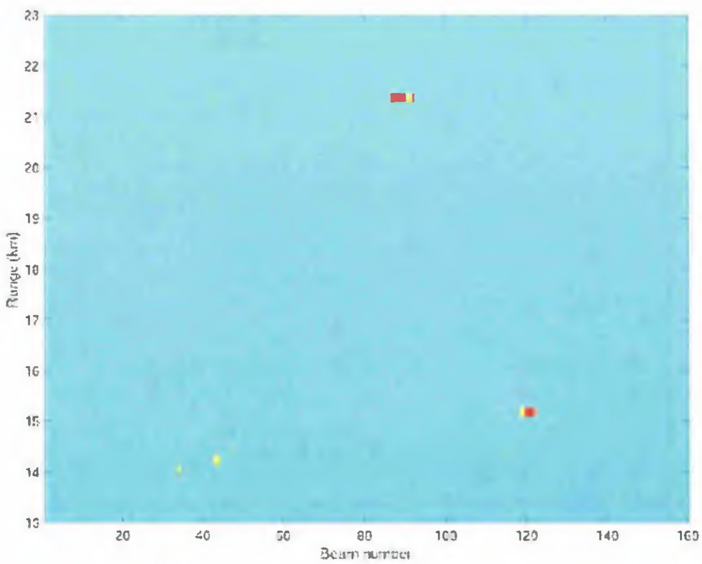


Figure 04-A.7 *Data of Fig. 5, with all non-trackable and fixed feature objects removed.*

the island form large objects (several kilometres), they were successfully represented by single points, which were the mass centres of the detected range-bearing cells. The buoys inherently give accurate range estimations of the reverberation features and the calculation of the mass centres improved the estimation of their azimuthal location.

Another important factor for the accuracy of the localization of sonar contacts is the orientation of the sonar receiving array. The buoys contained compasses, which contained errors that were corrected using the sound arrival of Echo Repeater transmissions. Because the first buoy was connected to the moored ship, it experienced strong azimuthal motion induced by coupling with the ship's motion. The corrections for the movements of this particular buoy were therefore not as good as for the other two.

The results of one run are plotted in Fig. 04-A.8. Figure 04-A.9 shows the cross-fixing accuracy. For each ping the distances between the detections of the three buoys are plotted. The distances between the localized detections of the buoys vary from a few hundred metres to two kilometres. The larger distances are mainly due to buoy 1's poorer localization performance. The distances between detections for buoys 2 and 3 are, for most pings, below 500 m. The distances to buoy 1 detections fluctuate heavily mainly, because the compass corrections for this buoy are not accurate.

This analysis shows the importance of having accurate array orientation information in the localization of clutter objects. It also shows the potential of using the mass centre calculation as a way to localize the objects of a multistatic system prior to data fusion methods.

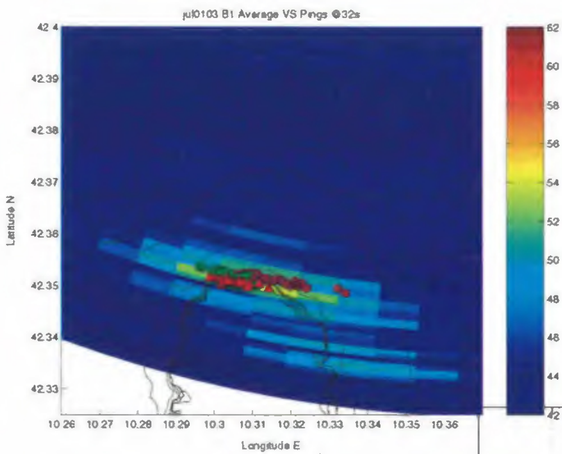


Figure 04-A.8 *The centre of gravity of the detected objects is plotted over the average sonar reverberation background for the entire run. Buoy 1 detections are indicated by the brown circles, those of buoy 2 by green squares and those of buoy 3 by red triangles.*

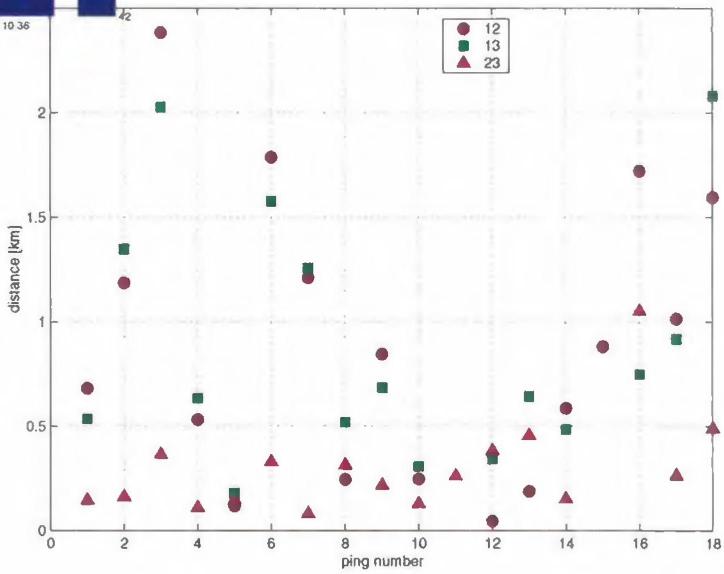


Figure 04-A.9 *The cross-fixing accuracy is shown by plotting the distances between the localized detections of the three buoys. The distance between the detections of buoy 1 and buoy 2 are plotted as brown circles, those of buoy 1 and buoy 3 as green squares and those of buoy 2 and buoy 3 as red triangles.*

Broadband processing evaluation

The use of broadband sources, receivers, and signal processing methods have been seen as one way to improve the performance of active sonar systems, particularly in harsh reverberation-limited shallow-water conditions. Broadband may be used to reduce reverberation, or alternatively, to allow for frequency-band selectivity. This has been studied using data from the MERCURY'99 sea trial.

Range resolution in active systems is inversely proportional to twice the bandwidth of the transmitted signal. The ensonified bottom or volume cell decreases with increasing bandwidth and as a result the intensity of reverberation is reduced. The theoretical enhancement in signal excess is proportional to 10xlog(BW). To verify this result experimentally, a detection scheme is designed based on multiple matched filters with varying bandwidths (Table 1). The maximum available bandwidth is 2400 Hz. Reverberation levels are calculated for each bandwidth. The results are shown for two linear frequency modulated (LFM) signals of duration one and six seconds. The theoretical expectations agree with the estimates based on real broadband data from Mercury 99 (Fig. 04-A.10).

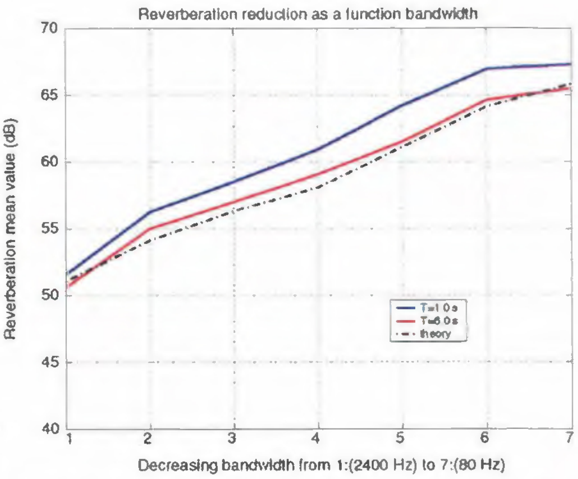


Figure 04-A.10 *Reduction of reverberation levels as a function of processed bandwidth.*

Sub-band	Bandwidth (Hz)	Centre frequency (Hz)
1	2400	2200
2	1200	1600
3	720	1600
4	480	1480
5	240	1360
6	120	1300
7	80	1300

Table 1 *Sub-bands with varying bandwidth and centre frequency used in a multiple matched filter scheme to optimize detection.*

Although, in principle, bandwidth increase reduces reverberation, in practice, the detection performance of active detection systems drops from its maximum performance when system bandwidth increases beyond a critical point (system, target and environment dependent). This phenomenon occurs as increasing system bandwidth over-resolves the target, either due to significant frequency variation in the reverberation spectra or because the target is situated in a partially reverberation and partially ambient noise limited environment.

This suggests that the utilization of wide bandwidth signals in conjunction with sub-band processing techniques may be suited to optimum bandwidth(s) selection and implementation of incoherent processing schemes to exploit frequency diversity.

Figure 04-A.11 shows the normalized matched filter output for the two LFM signals of one and six seconds duration, for the seven sub-bands shown in Table 2. Due to favourable propagation conditions and run geometry, a target is clearly identified at 8.9 km in all cases. However, the detection output varies as a function of bandwidth and signal duration. These variations are better expressed in terms of signal-to-noise ratio (Fig. 04-A.12a), which shows the measured SNR (solid line) as a function of bandwidth (Table 1). The full bandwidth does not offer the optimum performance for reasons mentioned earlier. It is also shown that detection output degrades with bandwidth reduction, as small bandwidths do not offer significant reverberation reduction. For this particular data set, the best performance is obtained for bandwidths on the

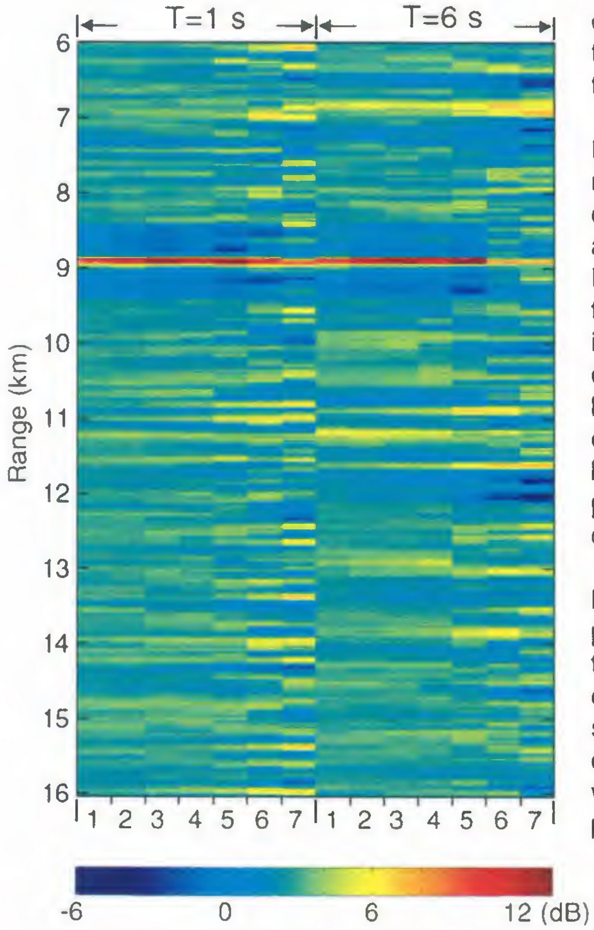


Figure 04-A.11 *Normalized matched filter output for two pulses (1 and 6 seconds) and seven different frequency sub-bands (as defined in Table 2).*

order of 200 Hz that belong to the low octave of the spectrum. Similar results are observed for the T=6 s case (Fig. 04-A.12b).

Detection performance may become more robust by applying incoherent sub-band combination that reduces ping-to-ping variations and rejects poor-performing frequency regimes. In Fig. 04-A.12, the dashed horizontal line shows the SNR levels for the incoherent method that incorporates all available sub-bands and the dotted horizontal line the SNR values for the best performing sub-bands. The performance of the latter adaptive incoherent scheme, besides the stability it offers, demonstrates performance comparable to the single band case.

Multiple bandwidth processing schemes may provide significant gains for spatially varying targets, in frequency varying reverberation environments. Such analysis and procedures steer broadband detection methods towards environmental adaptive implementations that will be useful from an operational and a scientific point of view.

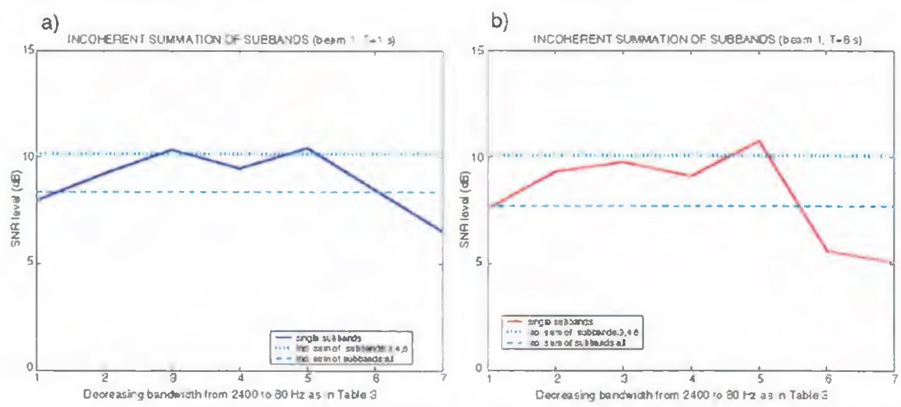


Figure 04-A.12a/b *Echo signal-to-noise ratio for different sub-band processes and incoherent combinations (Pulse duration 1 s).*

Advanced active sonar technology

During the past several years the Centre has invested in an LFAS capability upgrade including the procurement of a right/left-directional towed cardioid array, a high power broadband (two-octave) source, and an increased real-time processing capability. Although the cardioid array has been successfully modified to improve mechanical performance, some problems were experienced during CERBERUS'01 with the electronics and telemetry. Work was initiated with the appropriate industrial contractor to remedy these problems.

The broadband transmission capability is achieved with the combination of two high power sources, one LF and on HF, each covering one octave of frequency bandwidth. The HF source was successfully used again during CERBERUS'01. Work was started on outfitting the LF source with an appropriate towbody and deployment configuration from *Alliance*. The integration and first use of both sources will be in 2002.

A contract for the procurement of the Deployable Undersea Surveillance System (3 receivers and 1 source buoy) was signed. The contractors have finalized the design and have started manufacturing for delivery in 2002.

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Project 04-C: Shallow water acoustic reverberation and propagation: adaptation to large bandwidths (Alliance days – 36)

Operational relevance

Low frequency (1 – 4 kHz) active sonar systems in shallow water must contend with seafloor reverberation, which limits and confounds the ability to detect and classify small submarines. NATO systems under development are beginning to rely on frequency diversity, which recognizes that the frequency of optimum system performance varies according to environment. Which frequency operates best in which environment is a function of a number of parameters including the bottom scattering function, which remains poorly understood. The current NATO 'database' for bottom scatter is a single coefficient, independent of frequency and area. The goal of this project is to study techniques for extracting the major controlling environmental factors for use in numerical models for sonar system design, performance prediction and optimization in shallow water, by furthering understanding of acoustic interaction with the seabed and sea surface and validation of rapid environmental assessment (REA) techniques and physics-based acoustic models.

4

Unique numerical analysis tools and experimental techniques have been developed to extract local (within a few 100 m) geoacoustic and scattering properties of the seabed. Bottom sound speed and bottom layering are determined by wide-angle reflection loss measurements. Mono- and bi-static scattering properties (interface and volume scattering from the seabed) are obtained by a direct path measurement technique. The two techniques are self-consistent as the geoacoustic properties are used to infer scattering properties of the seabed. Range-dependent seabed properties can be achieved by repositioning the measuring equipment as the reflection and scattering measurements are local.

The second of three experiments in a Joint Research Project[1] *Boundary 2001* and *GeoClutter 2001* were conducted off the east coast of the US and Canada: the STRATAFORM area (New Jersey Shelf) and Scotian Shelf (Figure 04-C.1). Measurements of reflection loss and scattering properties of the seabed were acquired in two areas. An example of the received raw time series *versus* reduced time and range during the reflection loss measurements is shown in Fig. 04-C.2. The arrival time has been corrected to produce a constant arrival time of the first arrival for all ranges. The seabed properties are inferred by characterizing the red hyperbolae superimposed on the raw time series. The hyperbolae identify reflection from individual seabed layers. Preliminary layering and layer velocities based on analysis of Fig. 04-C.2

[1]Defence Research Establishment Atlantic, Applied Research Laboratory (Pennsylvania State University), Massachusetts Institute of Technology, Naval Research Laboratory

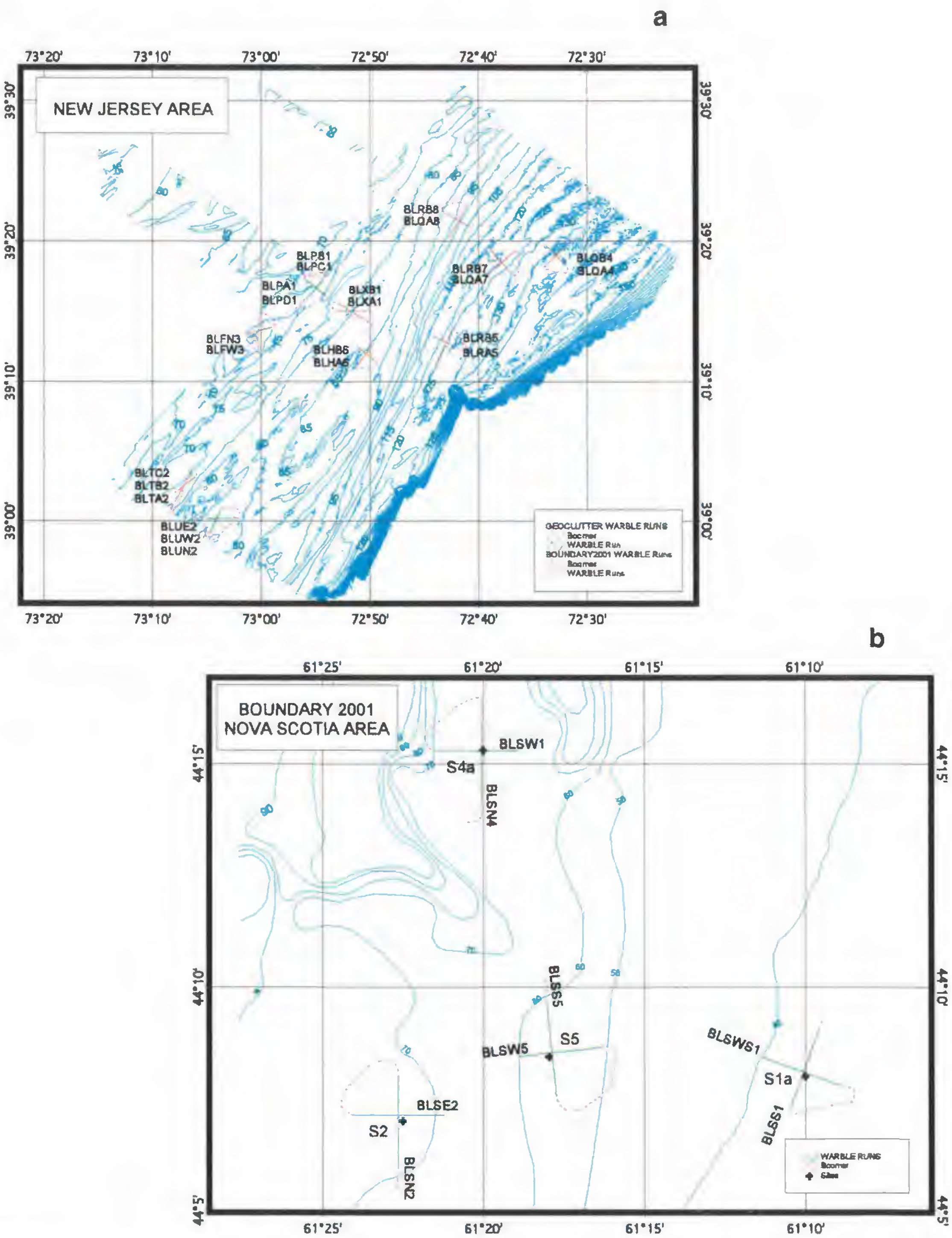

Figure 04-C.1 *Boundary 2002 and GeoClutter 2002 experimental areas: (a) STRATAFORM area on New Jersey Shelf, and (b) the Scotian Shelf.*

indicate a bottom with 20-m sandy sediment layer overlying a 10-m high-speed gravel layer. Below the gravel layer, the velocity returns to sand-like properties [Fig. 04-C.3 (a)]. The preliminary layering structure of the bottom is in close agreement with a seismic survey performed in the same area [Fig. 04-C.3 (b)]. The reflection loss data were acquired in the frequency band 300 to 10000 Hz. Further analysis is necessary to fully characterize the seabed properties in the experimental area.

Seabed scattering measurements were made in the same area as the reflection loss measurements. The beam time series of the monostatic geometry is shown in Fig. 04-C.4 (beam 1 is towards the sea surface and beam 22 towards the bottom). The water-bottom interface scattering contribution is seen starting at 0.04 s in beam 22 rising with time to beam 14 at 0.2 s. Following this main branch, a smaller arrival appears probably caused by scattering from the base of the gravel layer [Fig. 04-C.3 (b)]. Data acquired in the frequency band 600-3600 Hz, will be useful in determining the scattering kernel for a combined sand-gravel-sand bottom.

In addition to the monostatic geometry, acoustic signals were also received on the 96-element DUSS array. The reverberation data acquired were beam-formed in the horizontal plane resulting in azimuthal variability of the reverberation level. The DUSS array response is shown in Fig. 04-C.5 at 1800 Hz at two different sites. The data at Site N2 are relatively noisy and require further processing, but some clutter events are present. At Site 1 there are several strong clutter events that may be caused by buried river channels in the experimental area.

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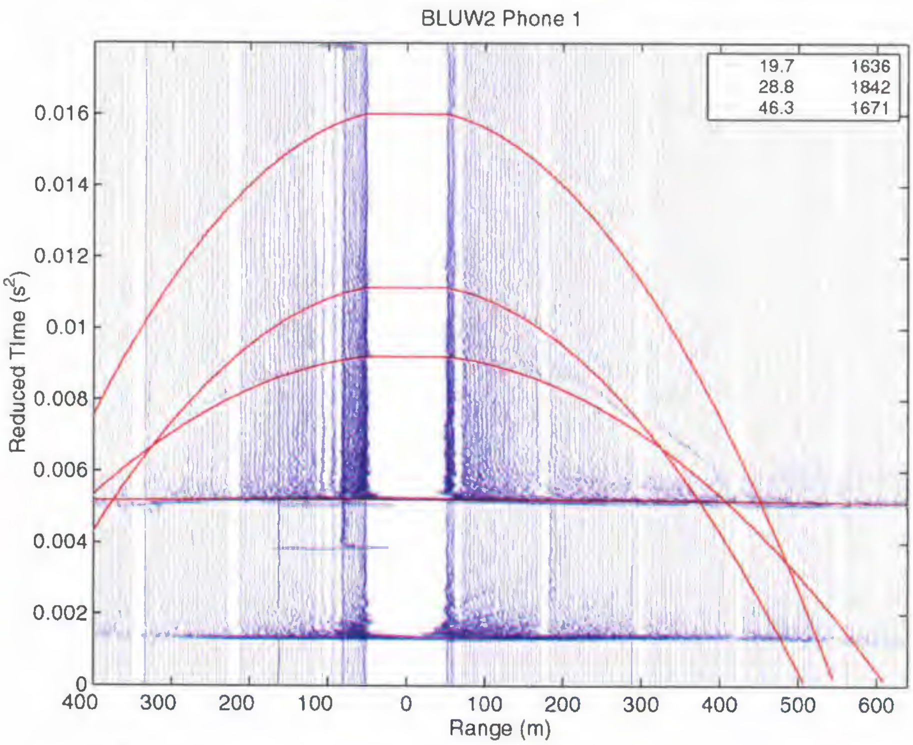


Figure 04-C.2 *Raw time series data with fitted hyperbolae (red lines). Preliminary layer thicknesses and interval velocities are shown in the legend.*

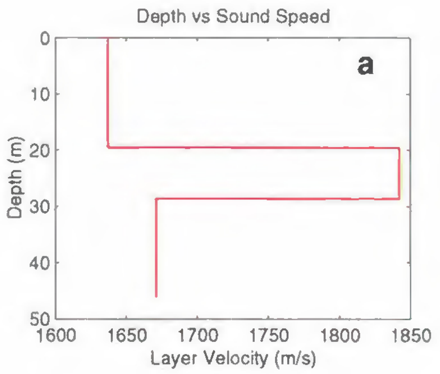
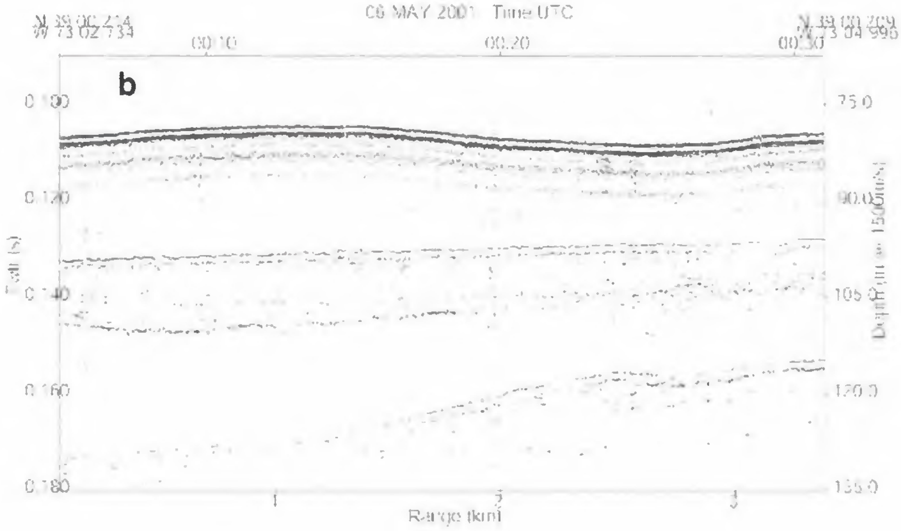


Figure 04-C.3 *Preliminary interval velocities (a) based on the analysis of data shown in Fig. 04-C.2 and (b) a seismic survey in the area of the acoustic experiment.*



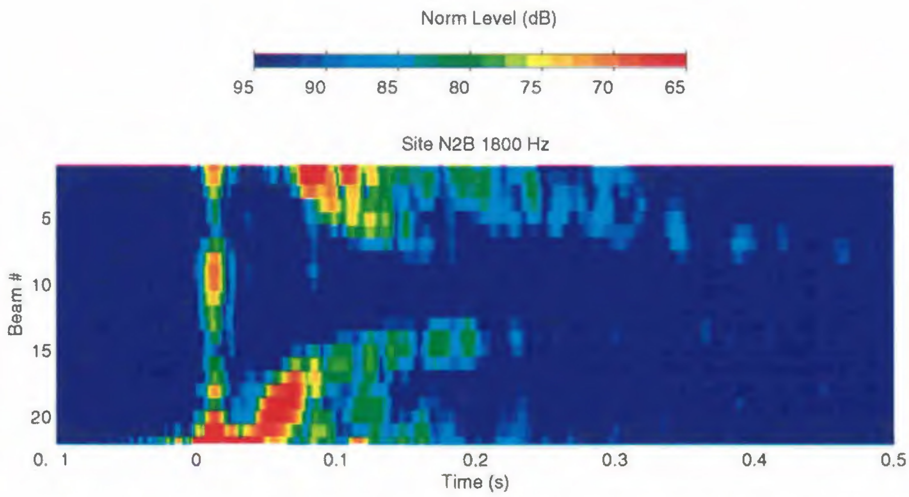


Figure 04-C.4 *Measured beam time series at 1800 Hz; the quantity shown is the ratio of received level and source level in dB. The water and source depth are.80 and 56 m, respectively. Time t=0 is the pulse initiation; the pulse is observed on all beams on the direct blast due to clipping.*

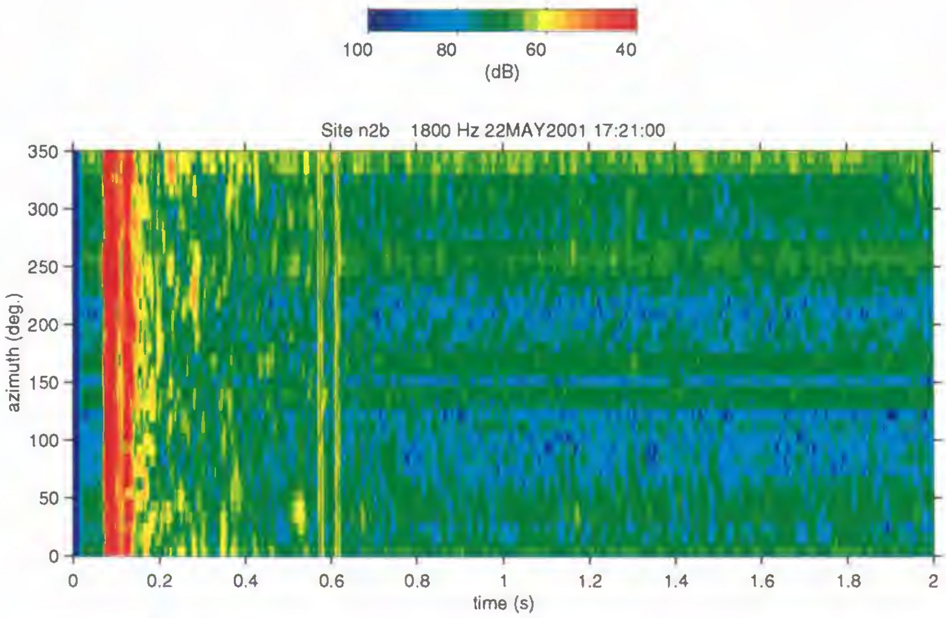


Figure 04-C.5a *Reverberation level at 1800 Hz received on the SACLANTCEN DUSS array at two experimental sites.*

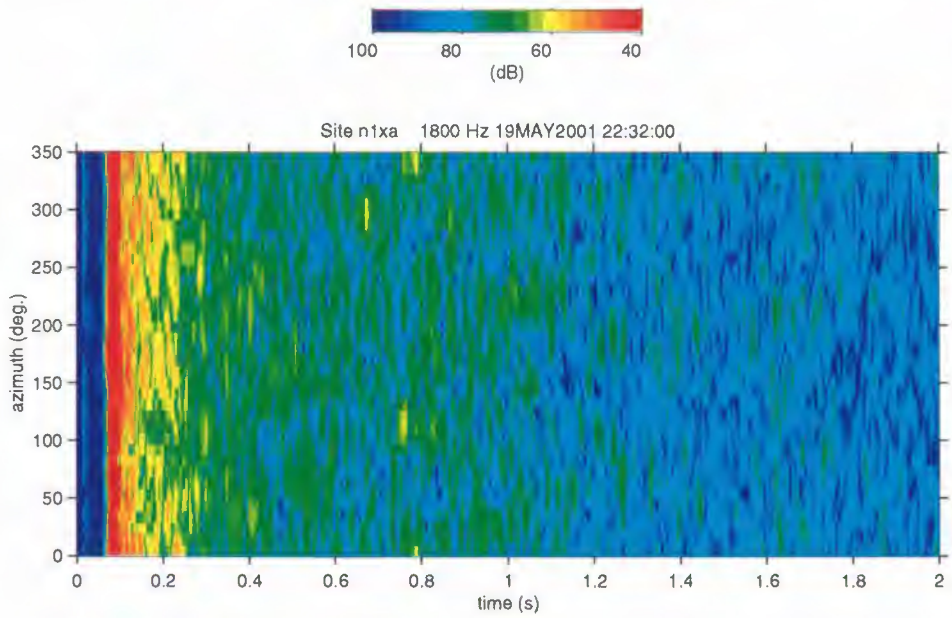


Figure 04-C.5b *Reverberation level at 1800 Hz received on the SACLANTCEN DUSS array at two experimental sites.*

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Project 04-D: High-fidelity propagation, reverberation and target scatter models for ASW

Operational relevance

Broadband propagation and reverberation models are required to determine the performance prediction and system concept assessments related to low-frequency active sonars. The models improve the predictive capabilities for both detection and classification systems, thus providing an essential component of predictive sonar performance models for ASW. Computer models also increase understanding of how various physical features of the ocean and the seabed affect the propagation and scattering of sonar signals. The models, once developed, can provide data for ASW planning aids, thereby significantly improving the effectiveness of acoustic ASW operations.

4

Propagation model developments

SACLANTCEN maintains a suite of computer codes to model sound propagation and reverberation in the ocean. In addition, software packages are available for automated matched-field inversion of acoustic data and for modelling the scattering from targets in ocean waveguides. This suite contains numerical models to cover most of the environmental conditions and acoustic frequencies relevant to the Centre's research programme.

Acoustic models developed at the Centre and externally developed models significantly modified by Centre staff are shown in Fig. 04-D.1, which is reproduced from a review of more than two decades of acoustic modelling at the Centre

Broadband signal simulation in shallow water

Broadband models have become indispensable tools for acoustic data analysis and sonar system predictions. These models are used for Monte Carlo studies of acoustic signal fluctuations, tomographic time-domain inversions, wideband geoacoustic inversions with global search algorithms, the design of underwater acoustic communication systems and testing signal processing algorithms.

Much work has gone into the development of computationally efficient cw propagation models for use in ocean acoustics. These standard techniques, based on ray, mode, wave-number integration and parabolic equation solutions of the wave equation, can be straightforwardly extended to broadband signal simulations *via* Fourier synthesis of a spectrum of cw solutions. Clearly the computational effort in each model increases with the number of frequency samples required.

For many practical applications, the computational effort involved in using broadband models is still excessive and more efficient solution approaches are continuously being developed. The accuracy and

Transmission Models

1. *Wavenumber Integration Solutions:* SAFARI/OASES
1. *Normal Mode Solutions:* COUPLE, C-SNAP, KRAKEN, PROSIM, SNAP-RD
2. *Parabolic Equation Solutions:* PAREQ
3. *Ray Solutions:* BELLHOP

Inversion Models

A. *Inversion using Genetic Algorithms:* SAGA

Reverberation Models

A. *Normal Mode Solutions:* BISTAR, C-SNAP-REV
B. *Parabolic Equation Solutions:* PAREQ-REV

Target Scatter Models

2D modeling suite: FAWCETT

Figure 04-D.1 *List of current holdings of acoustic models at SACLANTCEN.*

computational speed of GRAB, PROSIM, C-SNAP and RAM were compared in three different shallow-water test environments, with propagation out to 10 km and a signal bandwidth of 10–1000 Hz.

An illustrative test problem is shown in Fig. 04-D.2 consisting of a symmetric upslope/downslope where the water depth varies from 200 m at the deep ends to 100 m at mid range. This geometry corresponds to a bottom slope of 1.15°. The sound-speed profile is downward refracting and taken to be unchanged along the track. The bottom is a homogeneous fluid half-space with the properties given in Fig. 04-D.2.

We consider a broadband pulse emitted by a source at 100 m depth and calculate the received signal on a hydrophone at 20-m depth and at a range of 10 km. The emitted signal is a Ricker pulse with centre frequency of 500 Hz covering the band 10–1000 Hz. As the received signal at 10 km is found to have a total time dispersion of nearly 2 s, we know that a frequency sampling of 0.5 Hz is required to avoid signal wrap-around in the Fourier transformation ($\Delta f = 1/T$). Hence 1981 frequency samples must be computed to synthesize the received signal at 10 km.

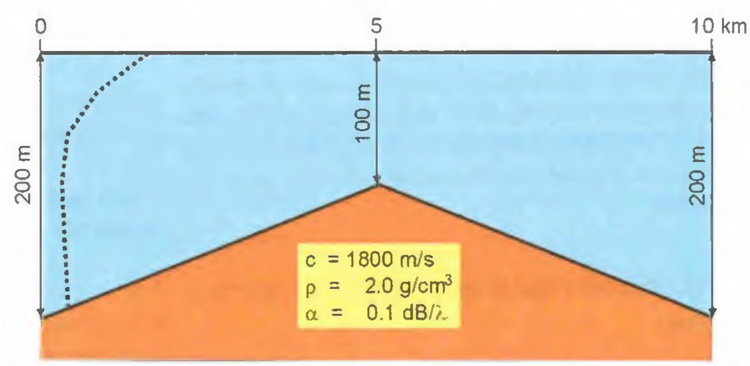


Figure 04-D.2 *Shallow water test environment for broadband models.*

Results in Fig. 04-D.3 show the multipath signal structure typical of shallow-water waveguides. The early arrivals correspond to ray paths near the horizontal and hence with the shortest path length to the receiver. Steeper rays bounce repeatedly between surface and bottom and may arrive up to 1 s later, corresponding to an added path length of 1.5 km between source and receiver.

All four models accurately predict the arrival times of individual pulses, but not the detailed signal shapes. Taking RAM to be the most accurate of the four models, it is clear from Fig. 04-D.3 that GRAB and C-SNAP provide the correct signal shapes (two strong arrivals followed by two weak arrivals, and so on). The PROSIM model is less accurate due to inherent approximations associated with adiabatic mode theory.

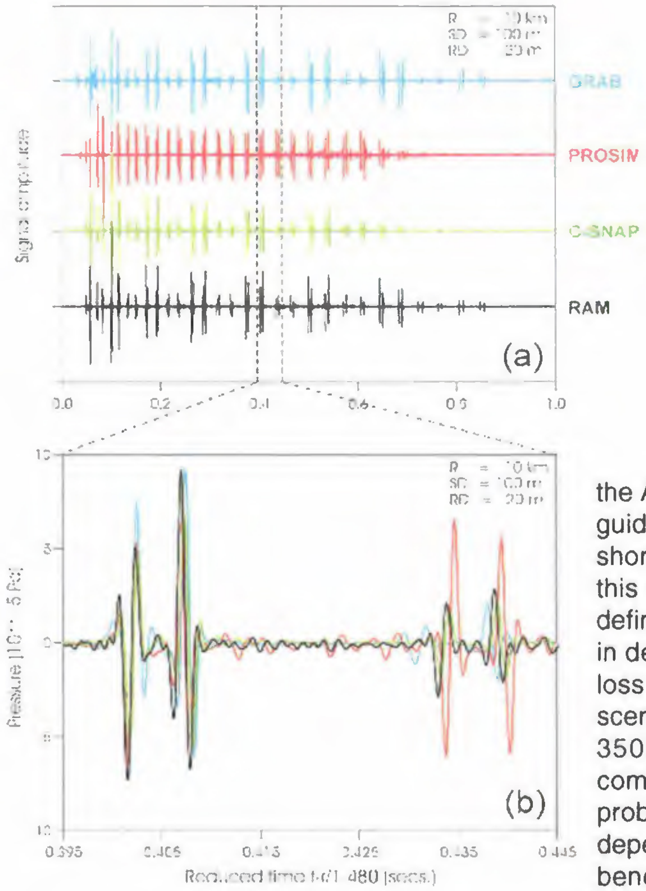


Figure 04-D.3 *Comparison of broadband pulse solutions from four numerical models. The source signal is a Ricker pulse with centre frequency 500 Hz.*

The computation times on standard PC equipment vary from 10 min for GRAB and PROSIM to 20 h for C-SNAP and RAM. More narrow-band signals can be computed faster, with the computation time being directly proportional to the signal bandwidth. Only the ray model GRAB is practical for broadband signal simulations above 1 kHz.

Performance assessment of the LYBIN-2.0 propagation loss model

The Allied Environmental Support System (AESS) is the standard sonar performance prediction system used by NATO Commands. The system includes environmental databases, acoustic models, system specific data, tactical decision aids, and various support facilities for data manipulation. The AESS is a powerful tool for optimizing the use of ships and sensors in complex tactical scenarios.

SACLANTCEN has previously performed an assessment of the acoustic models included in the AESS version 6.0, with the aim of providing guidelines for best model choice and identifying shortfalls in current model implementations. To this end, a suitable set of test problems was defined covering typical operational scenarios in deep and shallow water. AESS propagation-loss predictions were generated for each test scenario, for two sonar frequencies (500 and 3500 Hz) and for several source/receiver combinations. Reference solutions to all test problems were obtained with the GRAB range-dependent ray trace model, which, in turn, was benchmarked against other models from the SACLANTCEN model library.

As a follow-up to the above study, SACLANTCEN was tasked to perform a similar assessment of a new propagation model LYBIN, developed by the Norwegian Navy, and proposed for inclusion in the standard AESS model set.

LYBIN is a complete sonar performance prediction model, but it is only the acoustic transmission part that has been tested. That part is a range-dependent ray model, which, however, only allows for varying bathymetry along the propagation track. Hence, in the current implementation of LYBIN, ocean sound-speed structure and bottom-loss properties are assumed to be constant along each track.

The LYBIN model is clearly designed for speed and it provides acoustic field predictions at all frequencies in a matter of seconds on a standard PC. It is the accuracy of the field predictions that has been assessed by comparing LYBIN transmission-loss curves with those generated by the GRAB and PAREQ reference models.

Typical results of the validation procedure are illustrated in Fig. 04-D4. In the upper graph we show the test environment and associated ray traces for two different source depths. The lower graph shows the prediction results obtained from LYBIN (red curves) compared to the GRAB and PAREQ models for both a low-loss bottom (dashed curves) and a high-loss bottom (full curves). Note the excellent agreement between the various predictions for both bottom types.

The general conclusion of this study is that the range-dependent ray-trace model LYBIN developed by the Norwegian Navy, is indeed a valid alternative to existing propagation models in the AESS. The LYBIN model has a prediction accuracy similar to the GRAB 'reference' model but is considerably faster.

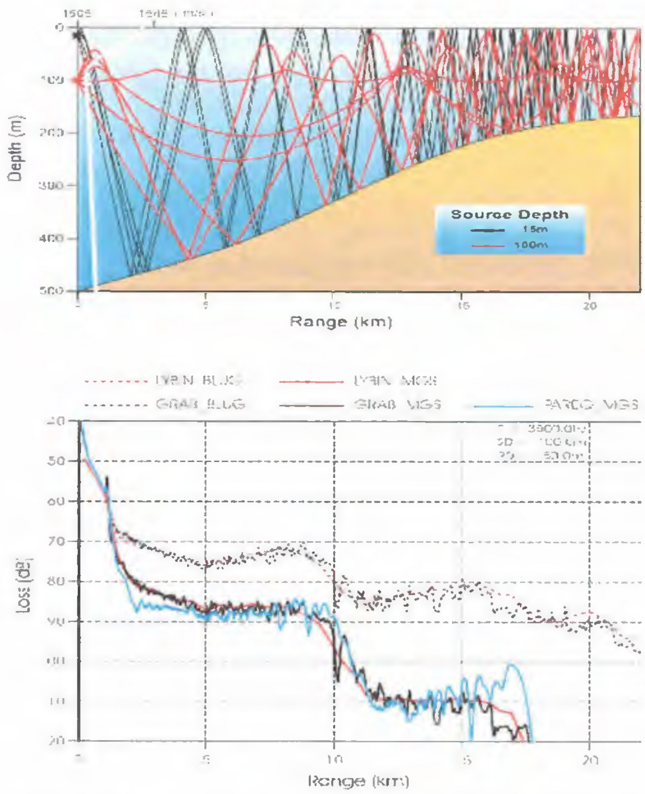


Figure 04-D.4 *Comparison of LYBIN results with predictions from the GRAB and PAREQ models for upslope shallow water test environment. Dashed curves are for a hard bottom and continuous curves for a soft bottom.*

Bistatic reverberation model development

The development of advanced codes for the prediction of scattering and reverberation in complicated environments is one of the focal points of this project. Year 2001 represents the fourth out of a planned five-year schedule for this activity. Three codes have resulted from this project, OASES volume scatter, which is a sediment volume scattering extension to Schmidt's SACLANTCEN developed OASES code, R-SNAP, which is a range-dependent monostatic reverberation prediction model built upon the SACLANTCEN developed C-SNAP code, and BiStaR, which is a bistatic extension to R-SNAP. At this point both R-SNAP and OASES volume scatter have been benchmarked, while the BiStaR code is partially complete. In this progress report we concentrate on the use of R-SNAP over the last year to help understand data sets, and also briefly describe some of the work that has gone into the time domain Green's function estimator that both R-SNAP and BiStaR use to rapidly and accurately generate time-domain Green's functions for range-dependent waveguides.

Using R-SNAP for data interpretation

In 2001 the R-SNAP model has been exercised to study scattering from river channels buried beneath the sediment, shelf break features and deterministic scatterers. In addition the theoretical underpinnings of the bistatic extension to R-SNAP, BiStatic Reverberation (BiStaR) have been derived and implemented in a first version of the BiStaR code.

During April and May 2001 we participated in the *Geoclutter* and *Boundary Characterization* cruises off the eastern coast of the United States and Canada. During the cruise the R-SNAP model was exercised to help understand the physical mechanisms which might be the cause of several

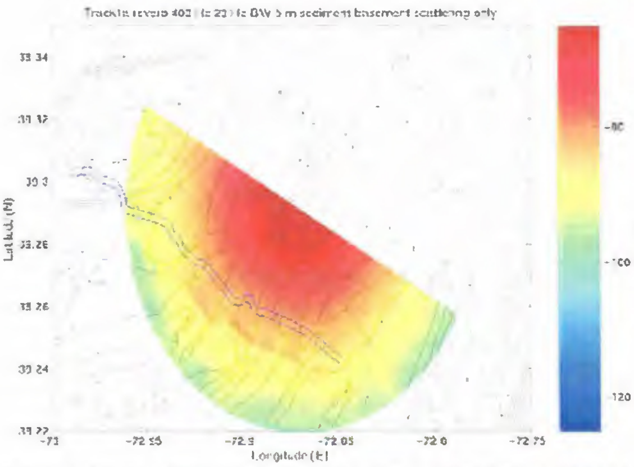


Figure 04-D.5 *Reverberation rose for a buried river channel computed using the R-SNAP model. Reverberation from a rough sediment-basement interface is seen to be excited over the buried channel by the slower-travelling higher-order modes.*

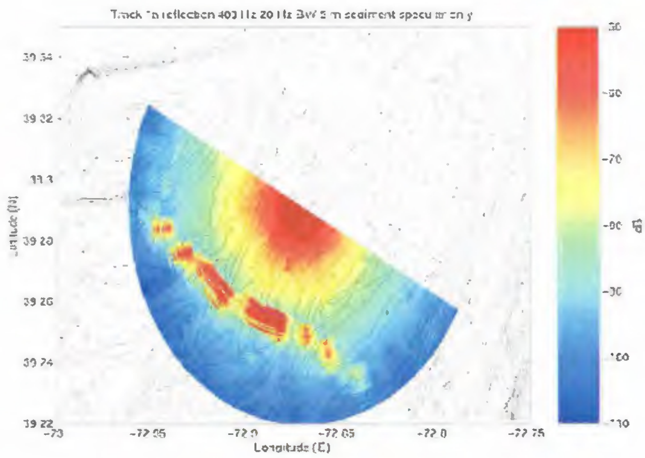


Figure 04-D.6 *Deterministic scattering rose for a buried river channel computed using the R-SNAP model. Here the buried channel gives a spectrum of returns from most of the modes, resulting in a smeared reflection structure which is markedly different from the reverberation prediction of Fig. 04-D.5.*

unexplained reverberation features. One of the central hypotheses of the Geoclutter experiment, advanced by the *Geoclutter* Chief Scientist Nick Makris of MIT and the bottom morphology expert John Goff of UTIG, was that features buried beneath the relatively flat bottom relief of the New Jersey continental margin might be correlated to clutter events in the reverberation. Clutter events are defined as spikes or relatively confined features in the reverberation which are target like in their nature. MIT and UTIG made available their highly detailed bottom and subbottom morphology for use in running the R-SNAP model, which can accept range dependent environmental inputs. In addition, theoretical and software extensions to the R-SNAP model were made to allow the model to compute backscatter from deterministic features such as abrupt changes in bathymetry and buried river channels. In Figs. 04-D.5 and 04-D.6 the reverberation and deterministic reflection off a notional buried river channel 5-m deep, 200-m wide and buried beneath 3 m of fast sediment are shown. These results indicate that the R-SNAP model is a powerful tool for predicting the scattering and reflection from proud or buried features in range dependent environments.

The R-SNAP model was also exercised to help better understand anomalous reverberation off of the New Jersey continental margin. In Fig. 04-D.7 beam data from the continental margin is shown with a range-independent reverberation prediction super-imposed, showing that the measured reverberation is 5-10 dB higher than the prediction at ranges between 15 and 20 km from the source. This increase in measured reverberation is also coincident with a sharp increase of the water depth as the acoustic propagation moves beyond the shelf break. When the R-SNAP model was run with the high resolution bathymetry of the continental margin of the same beam, a range-dependent reverberation prediction was obtained which contained much of the structure of the observed reverberation enhancement, if not at the correct levels (Fig. 04-D.8). Knowing that the slopes of the continental margin are extremely rough, the model indicates that the scattering strength of the margins is at least 25 dB higher than that of the outer shelf. When these 25 dB are added to the scattering strengths from the shelf, the red curve, which is in good agreement with the data, is obtained.

Benchmarking the range-dependent Green's function

Much of the effort that has gone into the R-SNAP and BiStaR models is in efficiently estimating the time-domain Green's function which connects the source to the scatterers and the scatterers to the receivers. The Range-Dependent Narrow-Band Approximation (RDNBA) was benchmarked against Fourier synthesized solutions obtained with the Centre's Coupled SACLANTCEN Normal mode Acoustic Propagation model (C-SNAP.) In Fig. 04-D.9 the performance of RDNBA and the commonly used adiabatic approximation are shown relative to the benchmark Fourier synthesized solution for an upslope wedge at 25 Hz. The RDNBA is shown to out-perform the adiabatic approximation in the sediment. In Fig. 04-D.10 the performance of RDNBA and the adiabatic approximation at 100 Hz for a steep downslope wedge (12°) are compared to the Fourier synthesized benchmark solution. In this case the RDNBA is seen to outperform the adiabatic approximation in the lower third of the water column.

The performance of RDNBA for estimating the time series over the buried river channel on the New Jersey shelf (Fig. 04-D.11), indicates that it is the highest order modes with the slowest group speed which interact most strongly with the change in the sediment-basement depth associated with the river channel, between ranges of 4 and 4.2 km. The quality of the time domain Green's function is important for the accuracy of the predictions shown in Figs. 04-D.5 and 04-D.6.

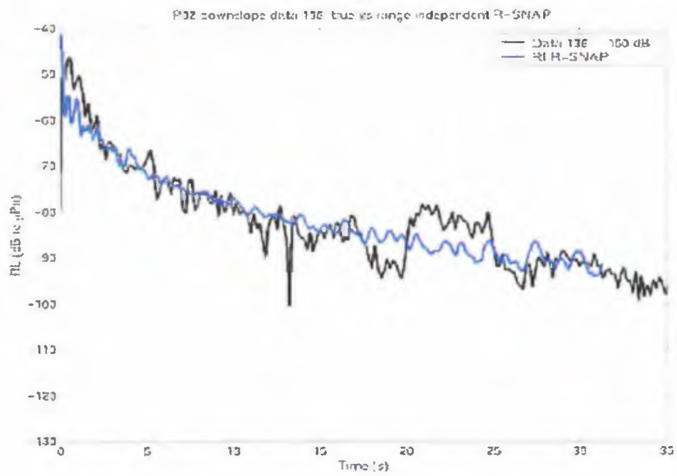


Figure 04-D.7 *Data-model comparison of reverberation off the New Jersey shelf break. The black curve is the data and the blue curve is a range-independent coherent reverberation prediction computed using R-SNAP. The data show an enhancement at 20 s (consistent with a range of 15 km) which is actually coming from a range off the shelf break (data courtesy John Preston PSU.)*

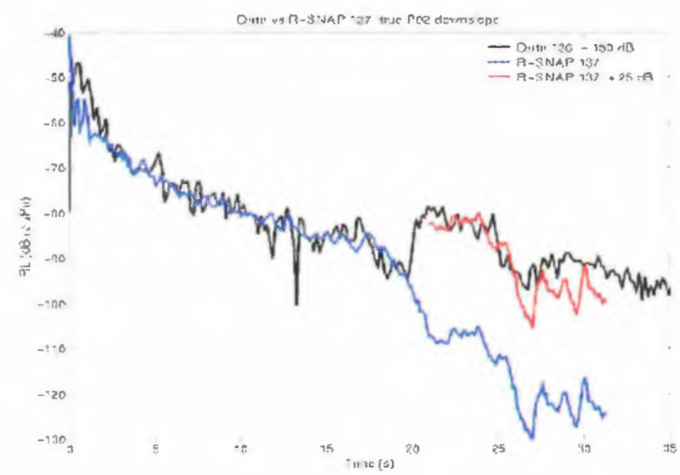


Figure 04-D.8 *Range dependent data-model comparison for the same downslope reverberation feature where the high-resolution bathymetry of the New Jersey shelf break has been used for R-SNAP model inputs. When a uniform scattering strength is used for the R-SNAP prediction, the blue curve is obtained, which correctly predicts the structure but under-predicts the level of the measured data. If a scattering strength enhancement of 25 dB is assumed to accompany the rubble-strewn slope of the shelf break, then the red curve is obtained.*

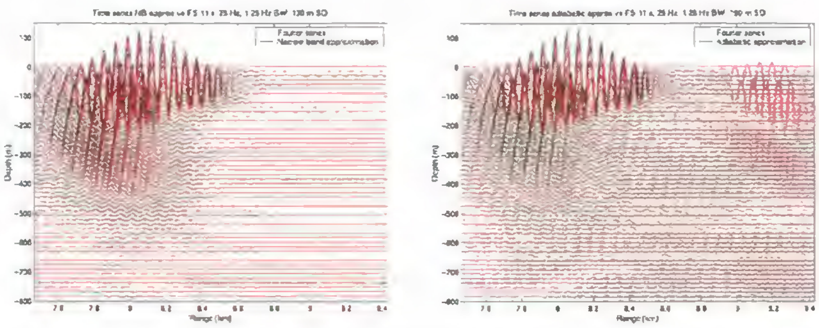


Figure 04-D.9 *Comparison between Range Dependent Narrow Band Approximation (RDNBA, red, left panel) and adiabatic approximation (red, right panel) and Fourier synthesis (black curves, both panels) for an upslope environment at 25 Hz. Below depths of about 190 m the RDNBA produces a better estimate of the time domain Green's function.*

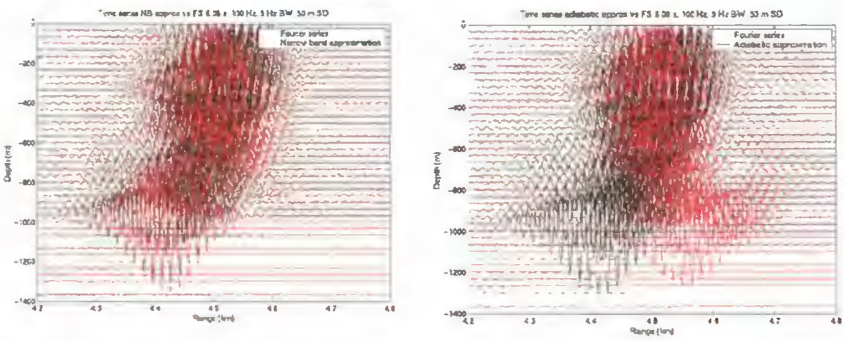
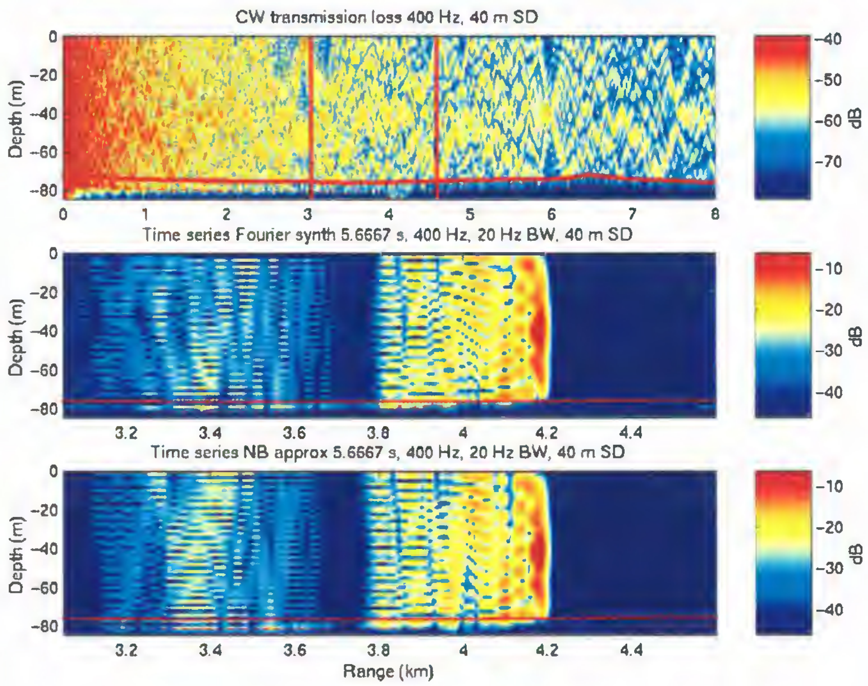


Figure 04-D.10 *Comparison between RDNBA (red, left panel) and adiabatic approximation (red, right panel) and Fourier synthesis (black curves, both panels) for a downslope environment at 100 Hz. The RDNBA correctly estimates the wavefront curvature whereas the adiabatic approximation does not.*

Figure 04-D.11 *Time series over a buried river channel (seen in the TL plot below at a range of 4 km) determined by Fourier synthesis (middle panel) and RDNBA (bottom panel.) RDNBA is an efficient way to approximate the time domain Green's function from the source to the scatterers, and back again.*



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Project 04-E: Sonar performance model for multistatic reverberation limited situations

Operational relevance

Although modern targets behave as weak scatterers it is almost inevitable that there will be bright spots or 'glints' in their directional response. One of the benefits of multistatic sonars is that they can take advantage of these glints by planting receivers at many aspects. With multiple source-receiver pairs it is also possible to view the target against a number of reverberation backgrounds, and therefore pick the best signal-to-noise ratio. On the other hand additional sources bring potential interference and mismatch between source and receiver. Meanwhile the multiple simultaneous geometries create problems of data presentation and recombination in the form of a meaningful tactical display. These phenomena are complicated, and special purpose models are required to predict the performance of multistatic sonar systems. These models will support the development of multistatic ASW tactical planning aids.

4

Experimental work under Project 04-A includes investigations into the performance of multistatic sonar with towed arrays in complex environments. In Project 04E a special purpose multistatic model is being designed and built to facilitate interpretation of these results. There are several phenomena that are important to model faithfully in the context of multistatics. Firstly, one expects a higher chance of detecting bright target glints if the receivers are widely distributed. Secondly, the range- and azimuth-dependent reverberation background will be more or less favourable according to the positions of the receivers. Multiple sources add the complication of mutual interference and therefore regions of low detection probability. In addition, sources may not be ideally matched to some or all of the receivers.

The approach taken here is to break the scenario down into bistatic pairs and then perform complete target, reverberation and ambient noise calculations for each. Propagation loss is tabulated, along with vertical arrival angle and travel time, using an 'off-the-shelf' propagation model such as PROSIM or GAMARAY. Any model can be used as long as it provides intensity, angle and delay. Target echo is then calculated taking account of target orientation and environmental variations. Reverberation includes 'geo-clutter' from ridges and the like and diffuse reverberation from sea surface, bottom and volume. Computation times are of the order of seconds on a PC for ranges of 60 km.

An important issue is that of fidelity or accuracy *versus* computational efficiency. The design philosophy is to avoid embedding approximation or stringency in the code. Instead the user is able to control the trade-off himself without having to delve into the detailed physics.

An example of a beam-time plot for two receivers with a single source is shown in Fig 04-E.1.

The same information can be seen as a geographic plot in Fig 04-E.2.

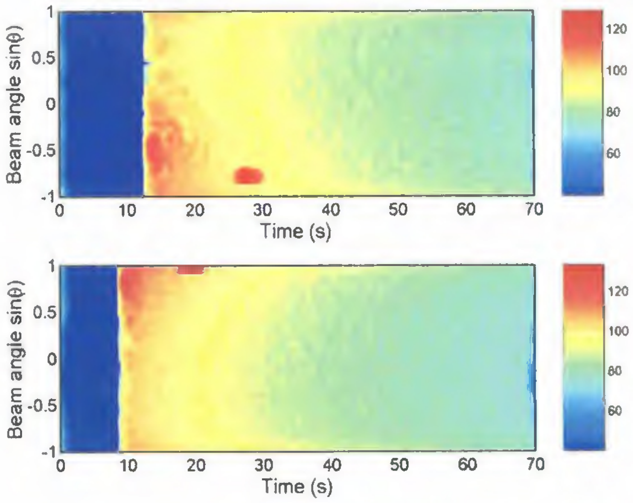

Figure 04-E.1 *Simulated beam-time plots for two receivers with a single source.*

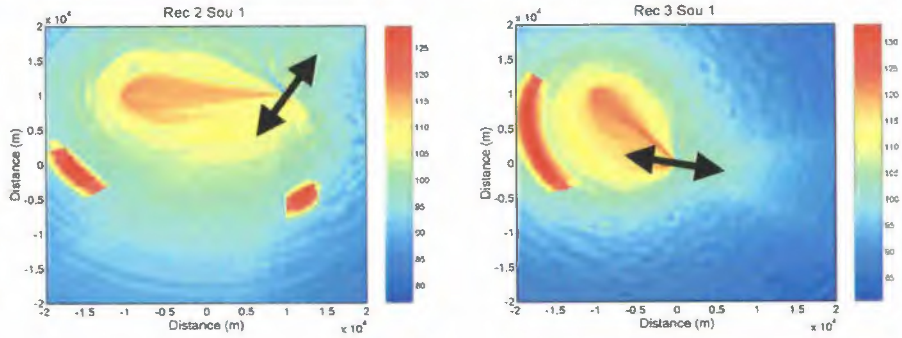

Figure 04-E.2 *Simulated geographic plots for two receivers with a single source.*

The black arrows indicate the horizontal array orientations in the two cases, and now one can see the large lobe pointing from each receiver towards the single source, which is at top left (forward scatter and direct blast). On the left of the left hand frame we see a bright spot from a target at that location. On the right of the same frame we also see a clear ambiguous beam response to the same target. This result falls out quite naturally from this approach. In the right frame a different receiver array sees the same target in the true position but at endfire. Consequently the beam is wider and there is no separate ambiguous response.

If we add another source, firing in sequence with the first, then both receivers detect echoes and reverberation from both sources, as in Fig 04-E.3.

We see the bright leading edge of the first arrival from the two sources in each picture, but the relative delays between first and second source depend on receiver position. A clearer picture can be seen from the geographic plot in Fig 04-E.4.

The left hand two frames show the same scenario as in Fig 04-E.2, still taking the first source as our time reference, but with the addition of serious interference from the additional source (the semi-elliptical red shape in the top frame, and the echo in the bottom corner) that could easily mask desired target echoes. Similar effects are seen in the two right hand frames where we now synchronize to the second source which is at the top right. Because this is the same location as the top receiver the top right frame is essentially a monostatic sonar with minor interference at bottom left.

These displays are designed to show ASW operators, operational analysts and trials planners where their best detection opportunities are likely to be.

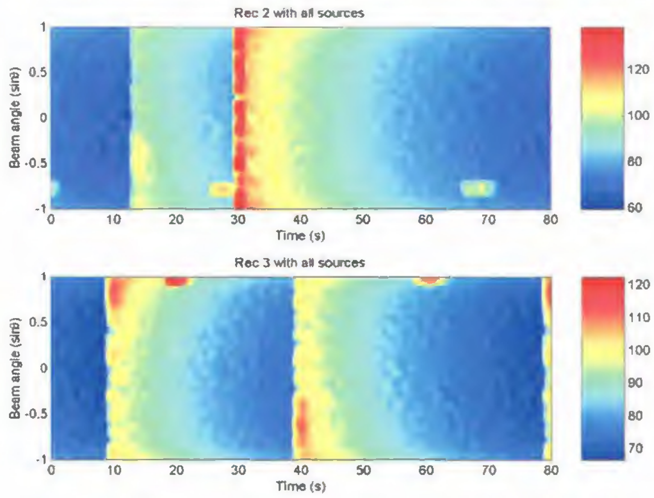

Figure 04-E.3 *Simulated beam-time plots for two receivers with two sources.*

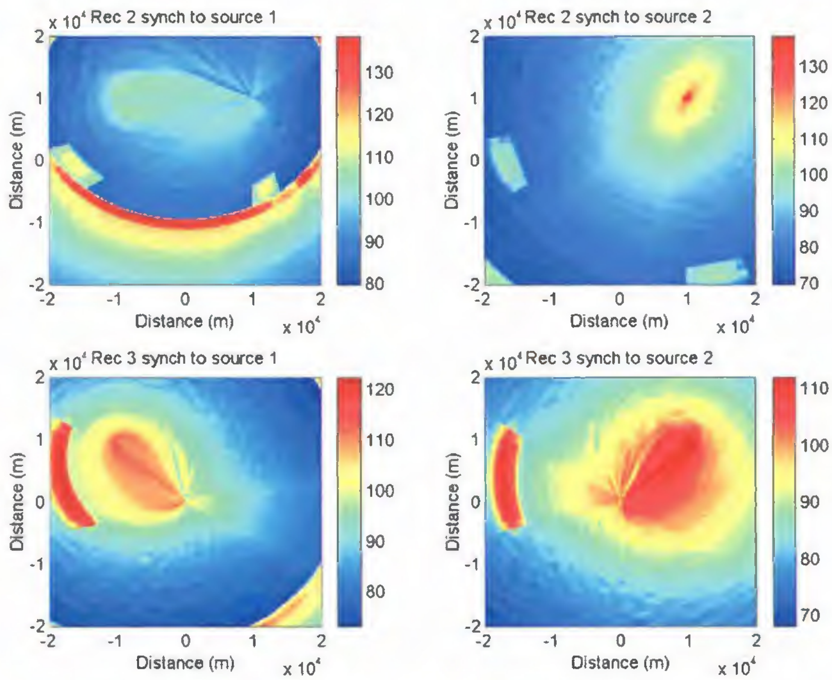

Figure 04-E.4 *Simulated geographic plots for two receivers with two sources.*

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Project 04F-1: Sound Oceanography and Living Marine Resources (SOLMAR)

Operational relevance

To support NATO peacetime operations by providing tools to determine areas of low environmental impact to conduct acoustic trials. Specifically, this project addresses the SACLANTCEN staff instruction 77-01 in the field of marine mammal acoustic risk mitigation, which applies to all acoustic experiments carried out by SACLANTCEN.

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The main scientific goal is to develop a cetacean density prediction capability and to develop and evaluate on-site acoustic risk mitigation procedures and tools. This is accomplished by incorporating ocean characteristics and cetacean presence data into an integrated Ocean Physical/Biological Information System (OPBIS) followed by the development of a cetacean prediction framework. Controlled acoustic exposure experiments are carried out with cetaceans of opportunity to investigate the impact of active acoustic devices on the target species. Trained visual observers, passive and active sonar and the use of non-acoustic sensors, such as motion-recording tags, allow the collection of unique data sets designed to improve understanding of the impact, or lack of impact, of sound on cetaceans.

The SOLMAR project was initiated in response to the recommendations of SACLANTCEN panels on Bioacoustics and Marine Mammal Environmental and Risk Mitigation Procedures, convened 15-19 June 1998[1] in response to a description of an unusual mass stranding[2] of Cuvier's beaked whales, *Ziphius cavirostris*, in Kyparissiakos Gulf, Greece. The R/V *Alliance* was conducting sonar trials in the Gulf during the time of the stranding, transmitting signals in the 450-700 Hz and 2.8-3.3 kHz ranges at source levels of 226-228 dB re 1 μPa at 1 m. Analysis of acoustic data from the sonar trial detected sperm whales >3 km from the ship, with no obvious short-term changes in vocal behaviour. However, ignorance of the sounds produced by Ziphius prevented acoustic analysis for this species. The panels concluded that an acoustic link could neither be clearly established nor eliminated as a cause of the strandings, primarily because of the lack of appropriate anatomical data. On 15-16 March 2000, a similar stranding of 17 cetaceans including 9 Ziphius and 5 other beaked whales took place in the Bahamas as a naval task force moved through the area, with 5 ships transmitting sonar sounds. Some of the ships used AN/SQS-53C sonars transmitting 2.6 and 3.3 kHz signals at source levels of 235+ dB re 1 μPa at 1 m, and some used AN/SQS-56 sonars transmitting 6.8-8.2 kHz signals at source levels of 223 dB re 1 μPa at 1 m[3]. These powerful sonars are of a sort that has been used for decades by many Navies.

[1] SACLANTCEN M-133.

[2] *Nature*, **392**, 1998: p.29

[3] U.S. Department of Commerce and U.S. Department of the Navy. Joint interim report, Bahamas marine mammal stranding event of 15-16 March 2000. December 2001.

Analysis of the tissue from the four well preserved beaked whales yielded the following results:

- The four dead whales from which specimen samples could be collected showed signs of inner ear damage and one showed signs of brain tissue damage. While the causal mechanisms of tissue damage are unknown, evidence points to acoustic or impulse trauma. Review of passive acoustic data ruled out volcanic eruptions, landslides, other seismic events, and explosive blasts, leaving mid-range tactical Navy sonars operating in the area as the most plausible source of the acoustic or impulse trauma. [p. 47]

Similar tissue damage was observed from beaked whales stranded in Madeira during a NATO naval exercise in May 2000.

The earliest stranding recorded for Cuvier's beaked whale is from 1804, but no mass strandings were reported until 1963, since when there have been progressively more mass strandings, totalling > 20 events. Only recently have tissues been analyzed for clues as to the cause of stranding, but about half of the stranding reports mention the presence of surface warships in the area at the time of the strandings.

The accumulating evidence supports the decision made in 1998 by SACLANTCEN to establish an environmental policy to reduce the risk to marine mammals from powerful sonar transmissions, and to establish a research programme with appropriate goals.

The SACLANTCEN risk mitigation policy is multi-layered. It first establishes an exposure level above which risk mitigation must be applied. Depending upon response data, this may differ according to species. For example, sperm whales in the area of the Greek Ziphius stranding showed little change in behaviour, suggesting that sperm whales may be less sensitive to that exposure than Ziphius. The current risk mitigation level is a received level of 160 dB re 1 μPa.

Two methods are being developed to reduce the possibility that marine mammals will be exposed to this level. A database of marine mammal distribution is being developed and oceanographic factors are being studied to predict the presence of different species to assist the planners in selecting areas and times least likely to have high densities of sensitive animals during sonar trials.

At sea, observers scan for marine mammals and passive acoustic monitoring is used to listen for animal vocalizations. A low-power whale-finding sonar is being developed to improve the probability of detecting submerged animals that may not be vocalizing. Each Sirena cruise attempts to improve visual monitoring, increase the ability to detect animal sounds, and test the whale-finding sonar concept.

During 2001, two sea trials were conducted to acquire environmental information and to evaluate techniques and methods for effective acoustic risk mitigation. Experimental emphasis was on continuing data acquisition with respect to deep diving cetaceans, in particular sperm whales and Cuvier's beaked whales.

Sirena 2001 was the third of a series of interdisciplinary measurements in the Ligurian Sea, a deep basin located in the northwestern Mediterranean Sea bounded to the north by the Italian and French Riviera, to the south by the northern coast of Corsica and to the southeast by the shallow water shelf of the Tuscan archipelago. It is open to the Mediterranean Sea along its western boundary.

During *Sirena 2001*, two sperm whales were tagged with a compact recording device, to acquire multi-sensor data for better understanding of behaviour during deep diving and when exposed to sonar sound. The animals were simultaneously tracked with a passive sonar system deployed from R/V *Alliance*.

A Senior Scientist[1] at the Woods Hole Oceanographic Institution, on sabbatical at the Centre has been developing capabilities to tag deep diving cetaceans in the Ligurian Sea, to record sounds heard and made by the whales

[1] Peter Tyack

in conjunction with their movement patterns. The goals of this research are twofold:

- Assist tests of the SACLANTCEN whale-finding sonar
- Develop methodology for controlled exposure experiments with deep diving whales including sperm whales and beaked whales

Assist tests of the SACLANTCEN low power whale-finding sonar

The WHOI-developed whale tag has sensors to measure sound, pressure, and three-axis accelerometers and magnetometers. The hydrophone on the tag measures the received level of acoustic signal at the whale. The non-acoustic sensors measure depth and orientation. When the R/V *Alliance* uses its whale-finding sonar to ping on a tagged whale, the tag verifies received level at the whale and provides information on the aspect. When a tagged whale is detected by sonar returns, this capability will allow the research team to calculate the Target Strength of the whale as a function of depth and aspect.

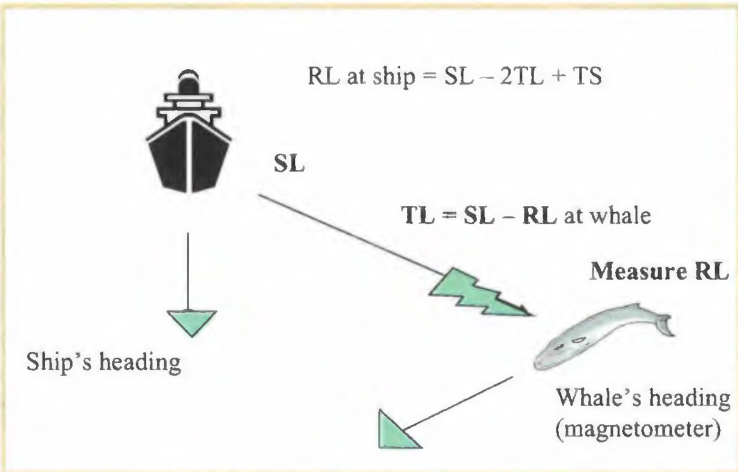

Figure 04-F.1. *Method for determining Target Strength of a "Dtagged" whale as a function of aspect with respect to the whale-finding sonar.*

During Sirena '00 and Sirena '01, the research team used the whale-finding sonar to ping on a "Dtagged" sperm whale. Acoustic data from the towed array is integrated with tag data in order to measure the whale's orientation with respect to the sonar source. As the whale was vocalizing, the directionality of the whale as a source can be measured.

Develop methodology for controlled exposure experiments with deep diving whales including sperm and beaked whales

The most important topic involves testing responses of whales in the exposure range established by policy as safe. The Cuvier's beaked whale is so difficult to sight and so little is known about their vocalizations, that no techniques are available to reconstruct the distribution of these animals prior to a stranding event. Even when it is possible to calculate how sonar sounds propagated before a stranding event, critical information is lacking to determine the association between received levels at the animal and concomitant risk of stranding. As strandings indicate a high level of risk, a risk mitigation threshold should mark a low level of risk. While the beaked whales examined in the Bahamas stranding showed signs of auditory injury, the injuries were of a type from which terrestrial mammals usually recuperate. The animals are thought to have died from the stranding event. It is not known whether the behavioural events leading to the stranding are only triggered by injury, or whether adverse behavioural effects could occur at received levels lower than those required to produce injury.

A workshop at the May 2001 meeting of the European Cetacean Society reviewed an experimental technique to resolve the dose:response relationship between noise and marine mammal behaviour. Controlled Exposure Experiments (CEE) involve the selection of a research subject in the wild, so that the behavioural results are ecologically valid. CEEs optimally use a quiet ship such as the R/V

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Alliance, which has little influence on the subject. The experiment requires a method to track the baseline behaviour of an individual animal, then monitor responses to controlled exposure of sound. The experiments should occur in a graded series, starting with received levels at the animal so low as to pose very low risk. Once the first level is well tested, if no adverse effect is detected, the level can be increased by a small increment and similarly tested. These experiments should not increase to levels high enough to pose a risk of auditory damage, but should be limited to studying behavioural effects at lower levels.

The Centre is committed to investigating the impact of active acoustic devices on the target species. In the case of beaked whales, where there may be a sudden transition to flight, it will be critical to develop experimental protocols to reduce the risk of adverse impact of the experiment. This suggests initially testing CEE on a deep diving marine mammal thought to be at less risk. Sperm whales, *Physeter macrocephalus*, are more common than beaked whales, yet there are no known cases of sperm whale strandings associated with sonar exercises. Sperm whales tracked at the time of the Ziphius stranding in Greece showed no obvious modification of vocal behaviour. Initial CEEs with sperm whales, are designed to test whale responses and the definition of experimental protocols for future work with beaked whales.

One key to CEEs involves the need for measurements that are sensitive to the behaviour of animals throughout the dive. This is particularly difficult for deep diving marine mammals that may dive for an hour or more. In addition, CEEs need to interpret whether behavioural changes observed, pose an adverse impact or not. Next to nothing is known about the behaviour of beaked whales, so breakthroughs are required simply to define baseline behaviour. The "Dtag"[1] allows the following measurements:

- Calibrated hydrophone: measures whale's own vocalizations and sounds impingeing on it
- Pressure: measures depth of dive

  3-axis magnetometer: measures orientation of the whale with respect to the Earth's magnetic field
- 3-axis accelerometer: measures acceleration and orientation of the whale with respect to gravity

As the tag can measure received level of a stimulus at the whale and behavioural response, it is well suited to experimental tests to correlate acoustic exposure with behavioural response.

During Sirena '00 and '01, the research team used the passive array on the R/V *Alliance* to find and track vocalizing sperm whales. Once the team has identified a subject for tagging, the ship approaches the whale, for a visual sighting. Once the whale is sighted at the surface, the workboat is deployed to close on the whale for tagging using a 13 m carbon fibre pole (Fig. 04-F.2).

Our approach for CEEs has been to plan to obtain several dives of baseline behaviour before exposing a whale to man-made sound, monitor responses during about an hour of exposure, then monitor the whale post-exposure until it returns to baseline. This requires 5-8 hours, depending upon how long the whale

Figure 04-F.2 *Tagging team attaching "Dtag" to sperm whale in the Ligurian Sea. R/V Alliance in background.*

[1] Designed by Peter Tyack and Mark Johnson of Woods Hole Oceanographic Institution.

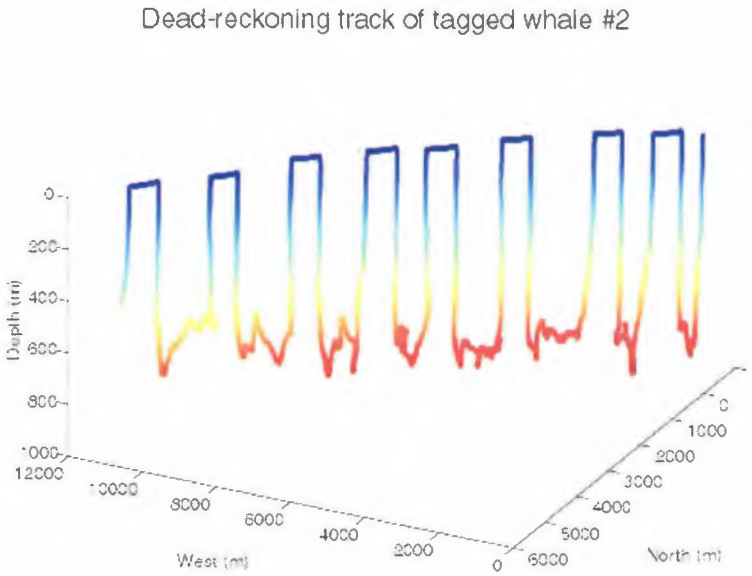

Figure 04-F.3 *Three-dimensional track of a tagged sperm whale. Dots on the surface indicate visual sightings. Depth is indicated by the colours on the whale track.*

takes to resume baseline behaviour. The tagging team goal of 5-8 hours for tag attachment was achieved during Sirena.

The Sirena cruises have shown the added value of merging tag data with visual sightings and with acoustic data from the towed array on the *Alliance*. The visual and acoustic monitoring from the ship allow estimation of the range to the whale in real time, which is important for predicting received level at the whale during the exposure portion of CEEs. The combination of data sets also enables 3D tracking of the whale's movements, which is an important response parameter. Figure 04-F.3 shows the 3D track of a whale tracked during Sirena '01.

The tag data have yielded rich data sets on the behaviour of diving whales. The acceleration and magnetometer data yield pitch, roll, and heading of the whale, and the derivative of pitch yields a clean record of the fluke strokes of the whale. This offers the possibility to model the energetic cost of the dive. As sperm whales dive, they produce clicks with inter-click intervals suggesting that the whale is echo-locating on a horizontal layer at depth. At foraging depth, they produce fast series of clicks considered to indicate that the whale is tracking a squid prey. The tag data allow tracking of these foraging events. The data can be used to develop a behavioural model, balancing the benefit of successful foraging against the cost of the dive.

The depth-of-dive data provides clear illustrations of responses of whales to disturbance. Figure 04-F.4 shows the dive pattern of a whale as the workboat approached to photograph the tag placement. Sperm whales usually surface for a long series of blows to ventilate carbon dioxide built up over a dive and to replenish oxygen. This whale, however, took short dives on each of the two occasions when the workboat approached. Even though these dives are obvious on the dive record, they were not obvious to observers on the workboat, who could not determine the depth to which the whale dived. The magnetometer data show that the whale turned as it dived, probably rolling upside down to look up at the workboat.

These results have stimulated strong interest in the scientific community, with an article in *Science* and an invited plenary talk to the Society for Marine Mammalogy. The project is now poised to start similar work on the baseline behaviour of beaked whales. The first step will involve learning how to tag these elusive animals. The project is also ready to plan CEEs with sperm whales.

The observation of sperm whale diving behaviour during foraging, supports the need for a detailed 3-D description of the oceanic state. During Sirena 2001, 3-D fields of modelled temperature and sound-speed were available for the first time through MODAS (Modular Ocean Data Assimilation System).

MODAS was developed at NRL SSC and is a modular toolkit for estimating present and future conditions of the ocean. It can acquire and quality-control input data of various types, use satellite data to refine climatological temperature and salinity in the oceans, merge *in situ* measurements with a "first guess" field to produce a "best guess" of the present condition of the ocean.

MODAS fields were made available by the US Navy NEMOC (Naval European Meteorology and Oceanographic Center) in Rota, Spain, which received on a daily basis XBT's from R/V *Alliance* and provided every second day the 3-D MODAS fields for the Ligurian Sea. The support from NEMOC was complemented by daily SeaWIFS satellite images.

Figure 04-F.5 demonstrates the application of MODAS data for the understanding of sperm whale presence. This picture shows the visual detection of sperm whales in the western Mediterranean Sea (red dots) overlaid on the depth of the13.8° isotherm extracted from the MODAS field (red is deep an blue is shallow). The sightings are in the area where the 13.8° isotherm is shallower, a clear indication that sperm whale presence may be correlated with oceanic upwelling.

The second sea trial of 2001 was dedicated to the presence of Cuvier's beaked whales in the vicinity of the Genova Canyon, in the northeastern Ligurian Sea, which forms a boundary for the predominant circulation. The canyon axis is oriented northeast–southwest, with two main canyons at the head. The canyon slope is very steep from the shelf break to a depth of 1200 m. East of this region is another large, wider canyon with a wide shelf to its south. There are also several seamounts. The western part of the valley has a steep slope to 1200 m bisected by several small canyons.

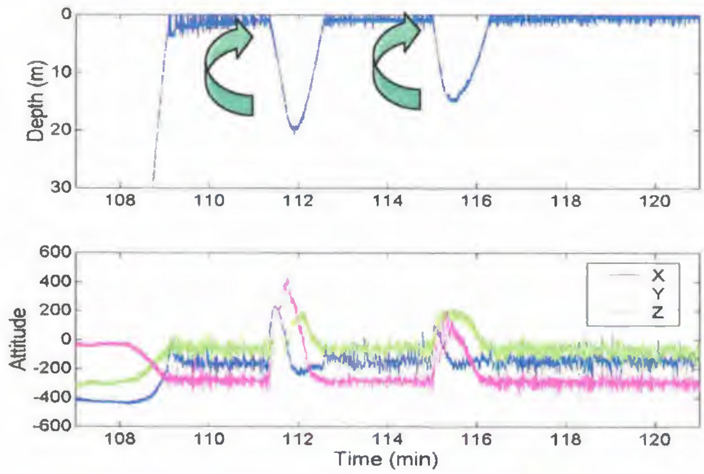

Figure 04-F.4 *Tagged whale dives in response to approach of workboat.*

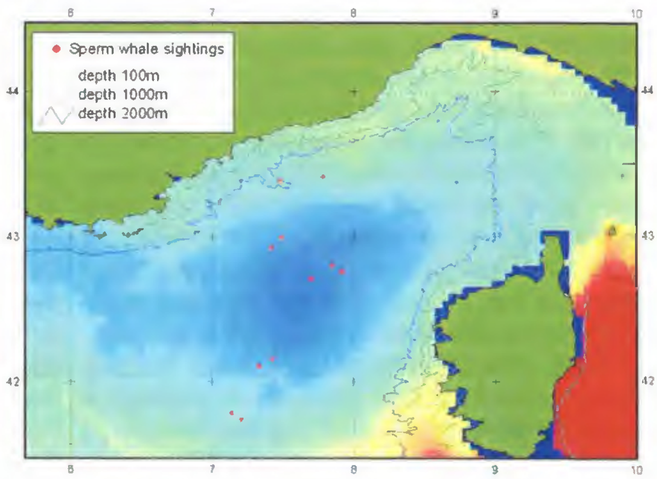

Figure 04-F.5 *Composition of visual sightings of sperm whales (red dots) and depth of 13.8° isotherm (red is deep and blue is shallow)*

Thrust 04 Journal papers and SACLANTCEN reports

Berni, A. The SACLANTCEN satellite communications facility: system setup and operations, SACLANTCEN SM-387 (NATO RESTRICTED).

Bondaryk, J.E. Benefits and limitations of active sonar for marine mammal risk mitigation, (i) SACLANTCEN SM-390, (ii) *Journal of the Acoustical Society of America*.

Bondaryk, J.E. Passive acoustic methods for marine mammal risk mitigation, SACLANTCEN SM-382.

Bondaryk, J.E., D'Amico, A. Low-power active sonar for marine mammal risk mitigation, (i) SACLANTCEN SM-379, (ii) *IEEE Journal of Oceanic Engineering*.

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4

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***Stephane Jespers** was born at Etterbeek (Brussels, Belgium) in 1956. He received the MS in Electrical Engineering (option Telecommunications and Hyperfrequencies) from the Universite Catholique de Louvain in 1979. He then became Assistant to Professor VanderVorst and conducted statistical atmospheric impact studies on radio and television signals depolarization and attenuation at 12 and 35 GHZ using radiometers and the European OTS satellite signals. In 1983, at SACLANTCEN he developed submarine target strength measurement techniques in support of Very Low Frequency Activated Towed Array Sonar concept studies. Later he conducted VLF Active Sonar statistical performance analysis and finally led the design of an advanced real-time Active Sonar receiver prototype. In 1990, he was hired by Objectif SA Paris to lead at DCN/Le Brusc the design and experimentation of a LF multi-function Sonar Intercept demonstrator for French SSNs and SSBNs. He then specialized in various Array Processing techniques, with application to towed array shape retreival and Synthetic Aperture Sonar (SAS). In 2000, as Head of Department at SACLANTCEN he is heading the ASW thrust area, in which the main focus is performance improvement of LFAS and deployable systems in shallow water, with emphasis on environmental limitations and impact of sound on marine life. Stephane Jespers is a member of the IEEE, Signal Processing and Communications Societies. He is a member of the UDT conference Technical Programming Committee. He is an ex officio member of NATO/RTO/Sensors and Electronics Technology.*

4

***Joseph E. Bondaryk** received his Ph.D. in Oceanic Engineering from MIT and WHOI in 1994. Subsequently, he was a Research Engineer and Lecturer in the MIT Department of Ocean Engineering and a Principle Scientist at Engineering Technology Center, Inc. He has over twelve years of practical government and corporate experience with radar and sonar systems in the areas of signal and array processing, ocean and structural acoustics and target detection. His current project is marine mammal risk mitigation for high power sonar systems.*

***D. Vance Crowe** headed home to the East Coast of Canada after receiving MSc in Electrical Engineering from McMaster University, Ontario, Canada in 1973. He immediately started work in acoustic ASW at the Defence Research Establishment Atlantic (DREA). He worked on many projects: passive towed arrays, low frequency active sonar, high-speed signal processing and directional acoustic sensors. He has participated in and lead many multi-platform multi-national sea tests of R&D sonar systems. He worked at DREA until taking a leave of absence in September of 2001 to join the Centre, where in the ASW Department, he will lead one of the projects to develop the concepts of multi-static acoustics using towed LFAS and active deployed underwater surveillance systems (DUSS).*

Angela D'Amico *received a Master's degree in Marine Science from the College of William and Mary, Williamsburg, Virginia. She has worked in underwater acoustics since 1977. From 1985 until joining SACLANTCEN in 1997, she worked at the Space and Naval Warfare Systems Center, San Diego, CA, as an Office of Naval Research program manager in Multistatic Active Surveillance. During her tenure at SSC, she was awarded the US Department of the Navy award for Meritorious Civilian Service in the field of Multistatics in 1996. She also received two awards for outstanding contributions to the USN Critical Sea Test/Low Low Frequency Active program (1995, 1996). At SACLANTCEN, she has worked on the Low Frequency Active program and currently is leader of the Sound, Oceanography and Living Marine Resources (SOLMAR) project. The focus of her research is to understand the effects of anthropogenic noise in the marine environment in support of SACLANTCEN's Acoustic Risk Mitigation Policy. Ms. D'Amico is the scientist in charge of a multi-year, multinational at-sea measurement program, "SIRENA", which employs Dual Use Technology to acoustically detect and localize cetaceans. She is responsible for the functional design of the SOLMAR data base which contains cetacean sighting and stranding information for the Mediterranean Sea.*

Doug Grimmett *received the B.S. degree (1987) in electrical engineering from the University of Utah and masters degree in acoustics (1995) from the Pennsylvania State University. From 1987 to 1997 he worked with the SPAWAR Systems Center (and its predecessors) in San Diego, California, on signal and information processing in the area of bi/multistatic active sonar. In 1998 he joined SACLANTCEN where he leads the Advanced Shallow Water Tactical Active and Surveillance Sonar project.*

Georgios Haralabus *received the B.S. degree (1987) in mathematics from Aristotle University in Greece and the M.S. (1989) and Ph.D. (1993) in signal processing from Duke University. After serving as a sonar control petty officer in the Hellenic Navy, he joined SACLANTCEN in 1995, where he is working on broadband signal processing problems.*

Peter Louring Nielsen *received the M.S. Mech. Eng. from Aalborg University in 1989 and the Ph.D. from the Technical University of Denmark in 1993. From 1993 to 1996 he was employed at the Technical University of Denmark on a European Union funded MAST-II project concerning development and validation of numerical models for sound propagation in the ocean. He joined SACLANTCEN in 1996 working on numerical modelling and experimental data analysis of time variability of received broad-band acoustic signals in shallow water. His interest is in numerical modelling of sound propagation in the ocean and geoacoustic inversion techniques.*

Chris Harrison received his MA in Natural Sciences from Clare College, Cambridge in 1968. Subsequently, at the Scott Polar Research Institute, Cambridge he studied radio propagation in ice and spent two summer seasons in the Antarctic, completing his Ph.D in 1972. He started work in acoustics at Admiralty Research Laboratory, Teddington and spent two years, from 1976 to 1978, as Exchange Scientist at Naval Research Lab, Washington where he worked on long distance reverberation and three dimensional propagation theory. Since 1978 he has worked as an acoustics consultant, mainly under contract to the UK MOD and DERA, in a software company, which is now a part of British Aerospace. One of his interests was the software generation of realistic waveforms for testing sonar systems in the laboratory. He joined the Centre's Acoustics Division in March 1999 where he has worked on rapid environmental assessment (REA) topics, particularly ambient noise directionality.

Charles W. Holland received the MS and Ph. D. degrees in acoustics from the Pennsylvania State University in 1985 and 1991 respectively. In 1985, he began working for Planning Systems Inc., Virginia, on various projects including geoacoustic modelling, seafloor classification techniques, high frequency seafloor acoustic penetration and low to mid frequency bottom loss and bottom scattering measurement/modelling techniques. One of the models which he developed, treating reflection from a stochastic layered seafloor, is employed in the AESS NATO performance prediction systems. From 1995-1996 he served as Chairman of the Critical Sea Test Bottom Interaction Working Group, a consortium of scientists from universities, government laboratories and private industry. Since 1996 he has been a project leader at SACLANTCEN, leading research activities in shallow water low frequency propagation and reverberation.

4

René Laterveer received the Ph. D. in theoretical physics from the University of Amsterdam in 1993 on a subject in elementary particle physics. From 1992 to 1995 he was at TNO Physics and Electronics Laboratory in the Hague, the Netherlands, working on active low frequency sonar. He has been a SACLANTCEN since 1996.

Kevin LePage joined SACLANTCEN as Senior Scientist in 1997. His investigation of the predictable characteristics of reverberation time series, using a variety of theoretical approaches, resulted in the development of two models, which are useful for the prediction and interpretation of reverberation data. In a synergetic effort, Dr. LePage has been involved in the collection, analysis and interpretation of data collected during the SCARAB 98 and GOATS 98 experiments. Previously he was Senior Scientist at Bolt, Beranek and Newman, in Cambridge, Ma. He received his Ph.D. in Ocean Engineering from MIT in 1992.

***Mark Prior** received his B.Sc. in Physics from Birmingham University in 1988, after which he joined the Admiralty Research Establishment, Portland. As part of his work researching underwater acoustic propagation, he studied for an external Ph.D .in underwater acoustics with The Institute of Sound and Vibration Research at the University of Southampton, completing his Ph.D. in 1996. Remaining with A.R.E. through its transition to the Defence Research Agency and then the Defence Evaluation and Research Agency, he studied many aspects of underwater acoustic modelling with his main emphasis on propagation loss modelling and model validation using mathematical benchmarks and measured acoustic data. He joined SACLANTCEN in January 2001 and has worked on multistatic sonar modelling and the deduction of seabed properties from ambient noise.*

***T. Martin Siderius** received his B.S. degree in Physics from Western Washington University in 1986. He worked as an engineer for Baird Corporation (Bedford, MA) from 1986-1987 and for Bio-Rad (Cambridge, MA) from 1987-1990. In 1992 he received the M.S. degree and in 1996 the Ph.D. degree both in Electrical Engineering from the University of Washington. In 1996 he joined the staff at the University of Washington Applied Physics Laboratory. In 1997 he joined SACLANTCEN to work on geoacoustic inversion and signal processing techniques.*

***Marcel van Velzen** received a masters degree in theoretical physics from the University of Amsterdam in 1987 and until 1989 worked at the Netherlands National Institute for High Energy Physics (NIKHEFH). From 1989 to 1998 he was at the TNO Physics and Electronics Laboratory in the Hague, the Netherlands, where he worked on Synthetic Aperture Satellite Radar processing and from 1991 worked on real-time processing and data analysis for the Netherlands Low Frequency Active Sonar program. In 1999 he started at SACLANTCEN as a senior scientist working in the areas of signal processing and data analysis related to Active Sonar.*

***Walter Zimmer** received his Ph.D. (Dr.rer.nat.) in physics at the Institute for Theoretical Physics, University of Regensburg, Germany in 1978. From 1978 to 1982, he worked at the operation research department of the Industrie Anlagen Betriebs Gesellschaft (IABG), Munich, in the field of air-to-ground reconnaissance performance modelling. From 1982 to 1987, he was principal scientist in the SACLANTCEN Signal Processing Group working on high-resolution beam-forming techniques. In 1989 he became responsible for the real-time implementation of the active and passive sonar systems.*

Thrust 05 Command Support (COS)

Project 05-C: Command and operational support

Operational relevance

Prototype operational and tactical planning aids

Assist operational commanders in determining which forces must be committed to accomplish a particular ASW or MCM mission and provide tactical advice on how best to use the forces committed. In the past, studies were specific in terms of scenario, geographical area, threat, objectives and force composition. Such studies are no longer appropriate given the transformation of NATO's defence posture and the need for crisis response. The present approach is to produce computer-based decision aids applicable to any situation. Due to the versatility of these decision aids, they can also be used to support higher-level force requirement studies, such as the Defence Requirements Review.

Support to ASW and MCM components of NATO exercises

Quantitative analysis and assessment techniques accelerate the development of experimental tactics (EXTACs) and planning aids. A further benefit is the concomitant flow of information and expertise between the operational community and the Centre.

5

Underwater warfare operational planning software

The objective of this task is to provide decision support aids to commands and nations for crisis planning of underwater warfare operations. Activities have concentrated on ASW operations.

PLANET

PLANET (Planning Expert Tool), sponsored by SACLANT, the latest of a series of operational and tactical decision aids, is a sophisticated decision support tool for use by ASW planners, which allows selection and analysis of ASW forces in specified areas. The development of PLANET is guided by a Steering Group, consisting of military and operational ASW specialists, from nations and commands.

PLANET:

- Is applicable to area search, force screening, safest route and barrier operations
- Contains high resolution maps incorporating information from an extensive acoustic database for areas of strategic importance
- Allows selection of generic sets of NATO ASW ships, submarines, MPAs and helicopters, which can be edited by the user
- Applies sophisticated OR algorithms including reactive targets
- Incorporates an interface to browse environmental and acoustic data
- Provides rapid reports of results

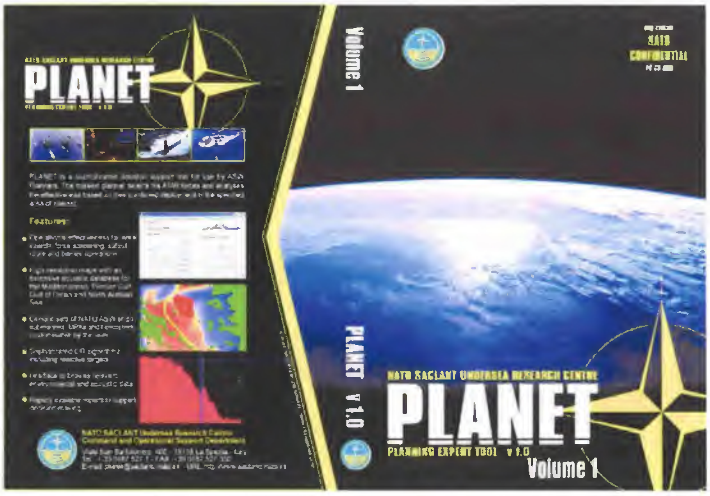

Figure 05-C.1 *PLANET version 1.0.*

The major accomplishments of 2001 are:

- Specialist Steering group meeting in July (reviewed pre-release PLANET version 1 and advised on modifications).
- Testing of acoustic data sets for two areas.
- Production of PLANET version 1: official release date January 2002 (Fig. 05-C.1).
- PLANET has been selected as the prototype tool for the capture of the ASW Operational Planning requirements for the MCCIS Roll 4 Enhancement ASW Segment
- Meeting at SACLANT with MCCIS development team (June)
- Steering Group meeting in October (recommended release of PLANET version 1).

The original project plan called for release of PLANET version 1 at the end of 2000. This release was postponed on the advice of the Steering Group due to problems observed with the ASW sensor performance predictions.

The problems were resolved in 2001 and submitted to the Specialist Steering group of acoustic and non-acoustic experts from nations and commands, who meticulously examined the proposed solutions. It was concluded that the PLANET model under review was suitable for the intended use. At the July Specialist Steering group meeting it was recommended that PLANET version 1 be released at the end of 2001.

ASW tactical planning aids

Area Search Tactical Planning Aid (ASTPA)

The aim of the ASTPA model is to:

- Provide the commander at sea with a search tactic that can be used by allocated ASW units to meet the military objectives
- Optimize ASW tactics and sensor deployment
- Improve procedures for determining the effectiveness of area search with realistic parameters, sensors and doctrines

The development of ASTPA is controlled by the *Area Search and Screening Working Group* (AS2WG) under the aegis of the MTWG.

The major accomplishments of 2001 are:

- AS2WG scientific panel meeting in April (model results compared and discrepancies discussed)
- Rapid Application Development (RAD) of user interface demonstrated (Fig. 05-C.2)
- AS2WG meeting in October (emphasis on modelling of environment and target tactics).
- Linked real-time range-dependent sonar prediction module completed (Fig. 05-C.3)

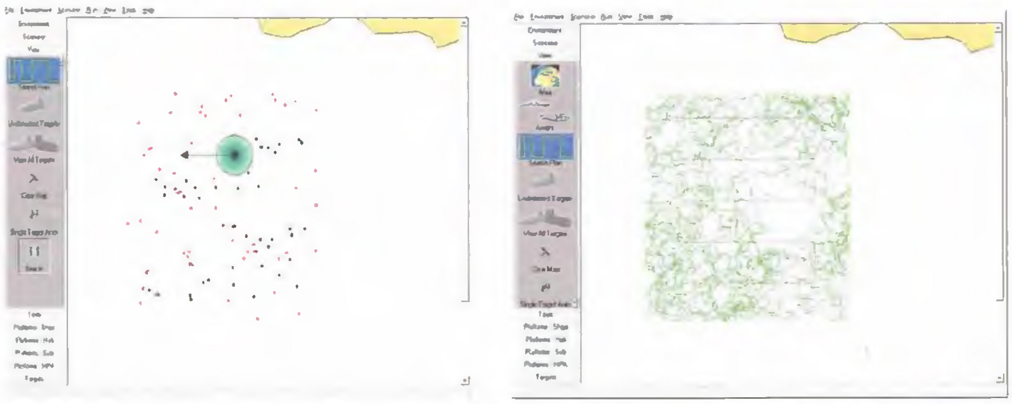

Figure 05-C.2 *User interface, showing ladder search, with associated target tracks and Bayesian threat distribution.*

It was not possible to comply with the original project plan which called for completion of alpha-prototyping and phase two modelling design by the end of 2001 as manpower was transferred from ASTPA to PLANET in order to solve the problems identified by the PLANET Steering Group.

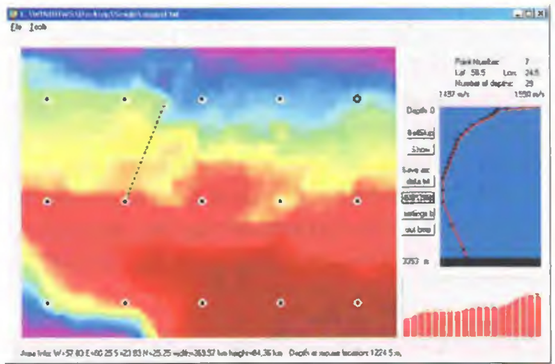

Figure 05-C.3 *Sample real-time range-dependent sonar prediction module (BELLSKIP) output, for use by ASTPA.*

Emerging requirements

The objective of this sub-task is to support NATO commands and activities on an *ad hoc* basis by providing expert consultation and analytical assistance, subject to resource availability. Three activities of this type have been performed during 2001:

- At the request of the Permanent Analysis Team (PAT), analysis of EXTAC 176 (ASW Sector Screen) as part of the DOGFISH analysis objectives
- At the request of SACLANT, support to the requirements capture for the Mine Warfare segment of the Maritime Command and Control Information System (MCCIS) Roll 1 enhancement.
- At the request of COMNAVSOUTH, support to the analysis of the exercise DESTINED GLORY 2001.

Support to MCM EXPERT algorithms (EXTAC 857)

Mine Countermeasures Exclusive Planning and Evaluation Tool (MCM EXPERT) is an experimental, PC based software tool for the planning and evaluation of NATO MCM operations. MCM EXPERT was developed by the NC3A and incorporates algorithms developed by an *ad hoc* Working Group from NATO agencies, commands and national research laboratories. SACLANTCEN is responsible for the standard NATO method to calculate the threat posed by mines to a defined target vessel. The software is now maintained by the NATO Integrated Software Support Centre (ISSC). SACLANTCEN continued to support the MCM EXPERT User Group (MEUG) meetings. A revised edition of MCM EXPERT Planning and Evaluation Methods was published. The following algorithms were developed by SACLANTCEN and will be incorporated into MCM EXPERT (V 4.0) scheduled for release at the end of March 2002:

- The planning of MCM operations based on an 'acceptable' level of remaining risk to follow-on shipping.

- The convolution of a general minehunting / minesweeping *p(y)* curve with a normal distribution.
- An heuristic method for providing a seed to the non-uniform coverage planning function.

Support to DARE (EXTAC 858)

In 1998 the Centre sponsored its first NATO Experimental Tactic (EXTAC) - DARE (Decision Aid for Risk Evaluation) which assists Maritime Mine Countermeasures (MCM) commanders to assess the risk to follow-on traffic/naval operations arising from uncountered mines after the completion of a MCM operation. The software has continued to be supported by resolving queries arising from its use during operations and exercises. The tactic has now been issued to 11 nations and commands. Training in the concept and use of DARE was provided to the military in the UK, the US and at the BE/NL Minewarfare School (EGUERMIN).

Electronic Minefield Referee (EMIR)

EMIR simulates the interaction between a synthetic minefield and surface and sub-surface exercise participants. During the exercise planning phase 'paper' minefields are coded into the EMIR software using the dedicated Planner software. During the exercise a laptop computer is installed on participating units, which contains the EMIR software with the embedded coded minefields. Throughout the exercise the EMIR software checks the position of the participating unit, compares it to the position of the minefields and provides a warning if a mine is deemed to have detonated and damaged the unit. For surface units, it is possible to connect a GPS unit to EMIR. EMIR was used during exercise BLUE GAME (see below) and during the UK's Joint Maritime Courses (JMC). An improved version of the program is currently under development.

Support to NATO meetings

Specialist support has been provided to the following NATO meetings during the year:

- Maritime Tactical Working Group (MTWG)
- Naval Group 2 (NG2)
- Naval Group 3 (NG3)
- NG3 Specialist Team for Remote Controlled Influence Minesweeping (ST-RCIMS)
- NATO Mine Warfare Conference
- MILOC Conference
- Mine Warfare Data Centre Interoperability Workshop
- Mine Warfare Working Group (MWWG)

Defence Requirements Review

This is an ongoing effort to support the NATO Bi-SC Defence Requirements Review (DRR) Working Group in areas relating to undersea warfare. The mission of the Working Group is to identify, for the planning period under consideration, the military force levels, readiness, structures and capabilities required by the Strategic Commands to execute their missions. The SACLANTCEN contribution to this process during 2001 involved:

- Evaluating and providing generic NATO ASW sensor performance
- Reviewing environmental data for mine hunting.

Exercise support

The overall aims of the Centre's participation in NATO exercises are:

- To facilitate the flow of information and expertise between the Centre and the operational community and Commands including SACLANT, SACEUR and their subordinate commands.
- To provide expert assistance to the NATO maritime analysis agencies: the Permanent Analysis Team (PAT) at Northwood, UK and the Independent Maritime Analysis Team (IMAT) at Naples, IT.

- To present Centre scientists with the opportunity to test new concepts in an operational situation and for naval forces to receive experience and training in the use of these new techniques.

Exercise Support comprises participation in the planning, analysis (and sometimes conduct) of exercises and in the provision of specialized exercise support tools.

MCM exercise planning and analysis

During 2001, COS have continued to be involved in the planning and analysis of minehunting 'Percentage Clearance' Trials. These trials were originally conceived in 1997 as a method of determining how accurately NATO minehunters can report the results of their operations within a "controlled" environment. The planning, execution and analysis of these trials has been continuously developed by SACLANTCEN and currently a number of minehunting performance parameters are evaluated, including the capability for environmental assessment, contact errors and sonar detection and classification performance. The data are used as an aid to quantifying the operational effectiveness of NATO's two MCM Immediate Reaction Forces, MCMFORNORTH and MCMFORSOUTH. During 2001, PC Trials were carried out during Exercises ALCUDRA, DAMSEL FAIR and TU MINEX (MCMFORSOUTH), BLUE GAME (ABNL) and ANGLER (MCMFORNORTH). For exercises ALCUDRA and TU MINEX, COS personnel embarked on the MCM Command Ship and carried out the analysis immediately after each vessel completed minehunting operations.

In addition to preparing contributions to the formal analysis reports, COS personnel have debriefed the results of PC Trials to the Minewarfare Working Group (MWWG), the MCM EXPERT User's Group and to NATO MW Officers attending MW courses and visiting the Centre. The results obtained always generate considerable interest and discussion and have already been used as a basis for changes to NATO's MW tactical publications. By combining the results from several trials, statistically significant performance data have been obtained for use in NATO's Defence Requirements Review (DRR) studies.

Specific exercises supported by COS during 2001 are:

DAMSEL FAIR 2001

DAMSEL FAIR is the NATO southern region MW exercise that took place in May 2001 in Doganbey, TU. COS provided support for the PC Trials, which were completed by 4 ships of MCMFORSOUTH.

BLUE GAME 2001

BLUE GAME is the NATO FPB / MW exercise held annually in the Skageraak, Kattegat and the Baltic. In addition to the PC Trials (4 units from ABNL), COS provided support for the planning of the exercise including EMIR being fitted to all participants. COS provided a brief at the exercise pre-sail conference (PSC) and carried out the analysis in conjunction with the PAT.

TURKISH MINEX 2001

COS personnel embarked on the MCMFORSOUTH Command Ship TCG SM PA^A for 6 days to carry out the analysis of the PC Trials and to debrief the 5 MCMFORSOUTH participants. The opportunity was taken to sea ride whilst one minehunter operated in the PC Trials' area. A summary presentation was given at the PXD.

ALCUDRA 2001

COS personnel embarked on the COMTEMECOM Command Ship SPS DIANA for 7 days to carry out the analysis of the PC Trials and to debrief the 3 MCMFORSOUTH participants. A summary presentation was given at the PXD and the results formally published in the Exercise ALCUDRA-01 Analysis Report.

ANGLER 2001

COS supported the planning of the PC Trials and carried out the analysis at the MW HQ. The

4 units from MCMFORNORTH that completed the PC Trials were debriefed individually and a summary presentation given at the PXD.

BELL BOTTOMS 2001

BELL BOTTOMS is a synthetic MW exercise held in early December biennially at the BE/NL MW School, Ostend, BE. COS representatives attended the exercise and supported the analysis led by CINCGERFLEET. The specific SACLANTCEN analysis task concerned the use of the DARE tool by the participants and some useful information was obtained for improvements to the tool.

ASW exercise planning and analysis

COS Dept have continued to develop the SACLANTCEN Track Analysis and Reconstruction Software (STARS) as part of the ASW exercise support task. This is aimed at supporting the COMNAVSOUTH initiative of near real-time ASW analysis and feedback. In the past, in-depth analysis of exercises took place only after data records of all units had been received and reconstruction had been completed. The results were fed back to the participants in the form of a report at some later date. Now, with the data available during the exercise *via* signal and the reconstruction and analysis software available on lap-top computers, in-depth analysis and feedback is possible during the exercise. It has been demonstrated during DOGFISH 2001 and DESTINED GLORY 2001 that feedback during the exercise enhances its training value.

DOGFISH 2001

COS Dept made a significant contribution to the analysis by carrying out all the necessary reconstruction, contact validation and missed opportunity analysis for submarine *versus* submarine and ship *versus* submarine engagements.

DESTINED GLORY 2001

COS Dept supported the Maritime Feedback Team (MFT) and Maritime Central Analysis Team (MCAT) at HQ NAVSOUTH. The analysis efforts focused on the reconstruction and validation of ASW engagements of the exercise during the exercise. Operational feedback was provided by signal to the participating units within a short period of time of the event occurring. This was the first time all participating ASW units (surface, sub-surface and air) received feedback on their performance during a NATO exercise. This analysis approach will be further developed and improved during subsequent exercises.

Thrust 05 journal papers and SACLANTCEN reports

Redmayne, J.C.J MCM EXPERT planning and evaluation methods revised edition, SACLANTCEN M-131

CD-ROM

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Redmayne, J.C.J. Spanish MCM Force Commander exercise ALCUDRA-01 Analysis Report

Redmayne, J.C.J. Exercise BLUE GAME 2001 analysis report, PAT 3109/43

Simcock, P.C., Yip, H. Exercise DOGFISH 2001 analysis report, IMAT

Simcock, P.C. Exercise DOGFISH 2001 analysis report, PAT 3109/44E

Thrust 06 Exploratory Research (EXR)

Project 06-B: Focused Acoustic Fields

Operational relevance

High frequency phase conjugation applied to multipath mitigation in shallow water provides higher fidelity in acoustic data communications and the enhancement of target echo-to-reverberation ratios in active sonar signal processing.

Analysis of data acquired in 2000 has resulted in two major accomplishments following the feasibility demonstrations during extensive trials in 1996-2000.

Target echo enhancement and reverberation reduction

A probe source (PS) in the vicinity of a vertical receive array (VRA) ensonifies the wave-guide. The dispersed signal with its multipath structure is received on the source/receive array (SRA), time-reversed, and retransmitted by the same transducers. The extent to which this retransmitted energy refocuses at the PS (as observed by the VRA) is used as a measure of the ability to carry out phase conjugation processing. Figure 06-B.1 shows the multipath structure received by the SRA for a 2 ms PS pulse from a range of 8 km at 40 m depth. Also shown is the SRA retransmission observed by the VRA where the highly dispersed signal has refocused in time and space.

The potential of a reduction in reverberation through time reversal focusing was investigated by carrying out the focusing procedure described with recording the backscatter (reverberation) received by the SRA after the retransmission. Figure 06-B.2 displays the power (dB) observed on each element of the SRA for 8 s after retransmission with the time series of instantaneous power from a single (mid-array) element. The reverberation from a simple broadside transmission and the time-reversal transmission are compared. The dip in the time-reversal return at ~6.3 s corresponds to the range of the PS, demonstrating that focusing the transmission mid-water column and at this range leads to a reduction in the returning reverberation.

Underwater acoustic communication using focused acoustic field

In a communications context, the severe multipath shown in Fig. 06-B.1 leads to serious intersymbol interference. However, the retransmission from the SRA received at the PS location is relatively free of dispersion. By using this SRA waveform as a canonic transmission time series, information can be coded into the phase of each symbol. Although the transmission is very complicated at the SRA, its structure is simple and easily decoded at the receiver located at the PS position.

Time reversal was applied to the communications problem and shown to be an effective technique that counters the inter-symbol interference caused by multipath dispersion. A substantial advantage of time-reversal self-equalization over one-way single source communications and to a lesser extent, advantage over one-way broadside (nearly

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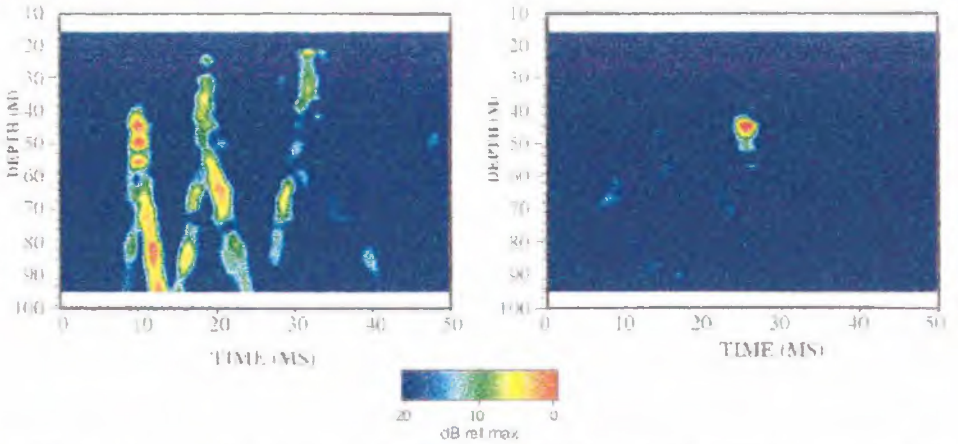


Figure 06-B.1 *The multipath structure received by the SRA and the SRA retransmission observed by the VRA where the highly dispersed signal has refocused in time and space.*

single mode) communications was demonstrated.The series of FAF experiments conducted in shallow water were implemented at centre frequencies of 450 Hz and 3500 Hz. If the ocean does not change significantly during the two-way travel time, the phase conjugate field will refocus irrespective of the complexity of the medium with the *caveat* that excessive loss in the system degrades the focus. During these experiments, communication sequences were transmitted and measured which took advantage of the temporal and spatial focusing properties of the FAF.

Phase shift keying (PSK)

PSK encodes digital information in the phase of a transmitted pulse. As shown in Fig. 06-B.3, one pulse or symbol, can encode one or more bits. For our experiment the pulse length, T, was 2 ms. Using binary phase shift keying (BPSK), one bit of information (1 or 0) is encoded on each symbol, and has two possible phases 180° apart (*e.g.* 0° and 180°). Quadrature phase shift keying (QPSK) encodes 2 bits (00, 01, 10 or 11) per symbol and has four possible phases (0°, 90°, 180° or 270°). Signal constellations can be created for any arbitrary M-ary PSK (MPSK) system. Higher constellations increase the probability of bit error. Bit error occurs when the phase of a symbol is incorrectly decoded back to digital information. Increasing M or shortening the length of the pulse T can achieve greater data transfer rates. Using BPSK encoding a data rate of 500 bits/s was achieved.

Digital information is encoded as a time series composed of many symbols. This sequence of pulses, ready for transmission, is called a communication sequence. For statistical analysis of bit error, thousands of symbols must be received and decoded. The BPSK sequence pictured in Fig. 06-B.4 is composed of symbols with two possible phases that are 180° apart (±1 in amplitude). The 8 symbol long sequence encodes the 8 bits: 0 0 1 0 0 1 1 1.

Though much progress has been made in ocean acoustic telemetry in the past 30 years, reliable high-speed communication has remained elusive. Coherent underwater acoustic communication systems, such as adaptive channel equalization, have become the favoured method to deal with the inter-symbol interference (ISI) caused by time-varying multipath environments. The application of the time-reversal methods for underwater acoustic communications has already been suggested and some calculations for the 3500 Hz pulse with a kilohertz bandwidth have demonstrated the temporal multipath recombination and side-lobe suppression needed for underwater communications. Time-reversal communication sequences were transmitted and measured during the experiment. As a comparison to TR, single source and broadside communication transmissions were also made.

Time-reversal self-equalization

Time-reversal self-equalization is a 2-way method of communication that takes advantage of the focusing ability of the time-reversal mirror.

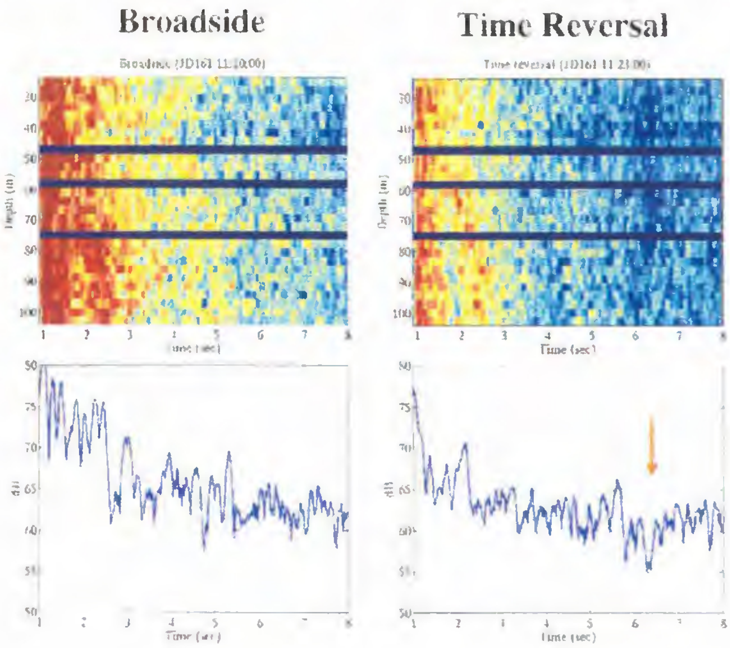


Figure 06-B.2 *The power (dB) observed on each element of the SRA where the reverberation from a simple broadside transmission and the time-reversal transmission are compared.*

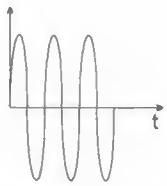


Figure 06-B.3 *One pulse (symbol).*

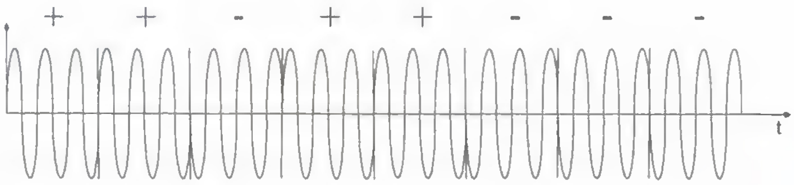
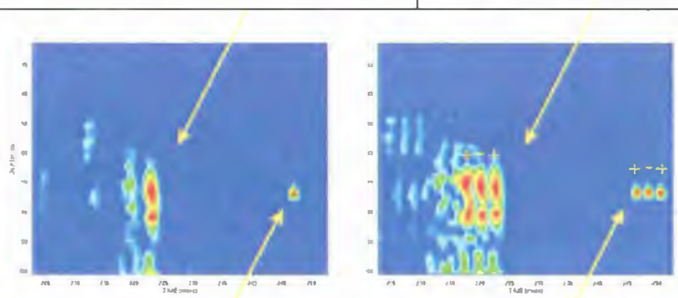


Figure 06-B.4 *An 8 bit communication sequence encoded by BPSK.*

Basic Symbol: The measured channel response from a 2 ms CW probe source has been time-reversed and displayed below.	Create a communication sequence by overlapping the basic symbol. For example, 010 have been BPSK encoded on three bits as a phase change of +-+ (90, 270 and 90).



Single bit TR focus received at the original PS range and depth.	At the PS range and depth, three received pulses the phase information of which can be readily decoded.

Figure 06-B.5 *The creation of a time-reversal self-equalization communication sequence.*

A channel is excited by a probe source and its channel response is recorded on the TRM and time-reversed as shown in the left panel of Fig. 06-B.5. This entire channel response represents the basic symbol we will use in PSK encoding. For example in BPSK encoding, the channel response is encoded with ±1 polarity (0° or 180°). The entire channel response is copied every 2 ms, with the copies substantially overlapping each other as shown in the right panel. After retransmission the individual symbols compressed nicely back to their original 2 ms duration.

Basic 1-way ocean communication is carried out by a single source transmitting to a receiver. Measurements of a single element of the SRA transmitting communication sequences to the VRA were made. Single source transmissions are the most prone to the negative effects. The acoustic energy is spread vertically at the receiver.

Broad-side transmission

Broadside transmission is another method of one-way communication, which uses all the elements of the SRA to transmit simultaneously the communications sequence. Broadside transmission approximates single-mode excitation. The ocean wave-guide supports the transmission of a discrete set of modes. For the purpose of communication, transmitting a single mode would suppress dispersion and therefore ISI. Exciting exactly a single mode in shallow water experiments has proven quite difficult and requires more complicated feedback control systems. A simple broadside is about as effective at exciting the first mode as trying to shade the array with the first mode shape. PSK communication sequences were transmitted using a full broadside of the 29 sources of the TRM. While broadside transmissions can suppress dispersion, the acoustic energy transmitted is incapable of breaking out of the shape of the first mode.

Range independent communication results

The communication experiments were performed in the fixed-fixed configuration with the VRA and SRA operated remotely. A 2 ms CW probe source signal was received at the SRA and time reversed, thereby creating the basic symbol for the communication sequence as described above. A random data sequence was generated and encoded using time-reversal self-equalization. BPSK communication results are shown in Fig. 06-B.6. For comparison, broadside and single source one-way communications experiments were also measured.

The in phase and quadrature plots on the right are an indication of the robustness of the communications process. With no noise or ocean variability, one would expect only two dots on the real axis at plus and minus one. Preliminary analysis suggests successful decoding with the best results from the time reversal process. The PS depth was considered the target depth for communication.

Range dependent communication results

All the communication sequences were performed in 5 and 10 s bursts. Examples of a TR, broadside and single source communications are shown in Fig. 06-B.7.

We have shown that TRM can provide an effective means of communication in shallow water environments at ranges of 10 km. Furthermore TR foci were measured up to ranges of 20 km at 3500 Hz. Because of its low probability of intercept properties it has potential applications in ship to submarine or submarine-to-submarine communication scenarios.

FAF and autonomous underwater vehicles

Figure 06-B.8 shows an experimental configuration for time-reversal self-equalization with an AUV as probe source and summarizes the salient issues and advantages of TR communications.

Shallow water environments, especially those which are range dependent, are characterized

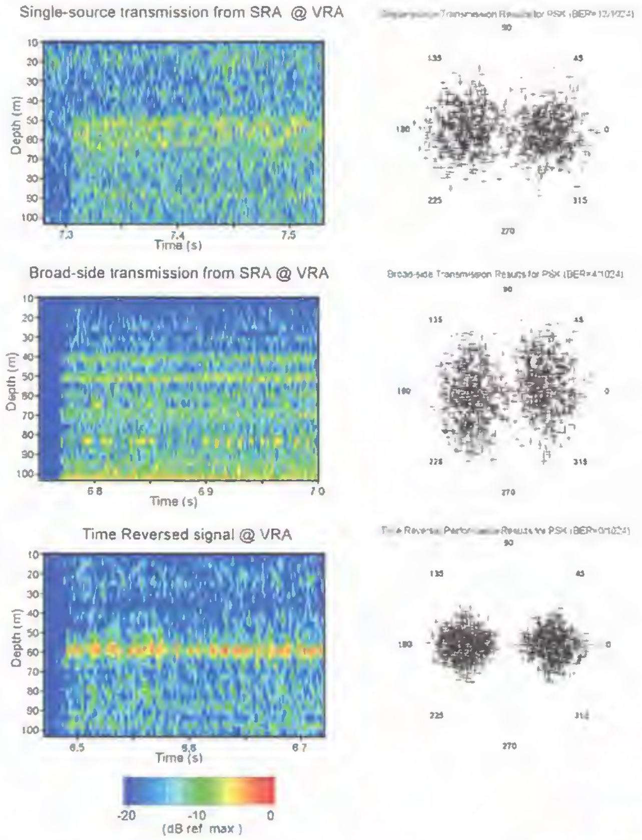


Figure 06-B.6 *Range independent: An example of time reversal communication result compared to the other one-way transmission control examples (single-source and broadside). Bit error rate is denoted as BER the data rate was 500 bit/s.*

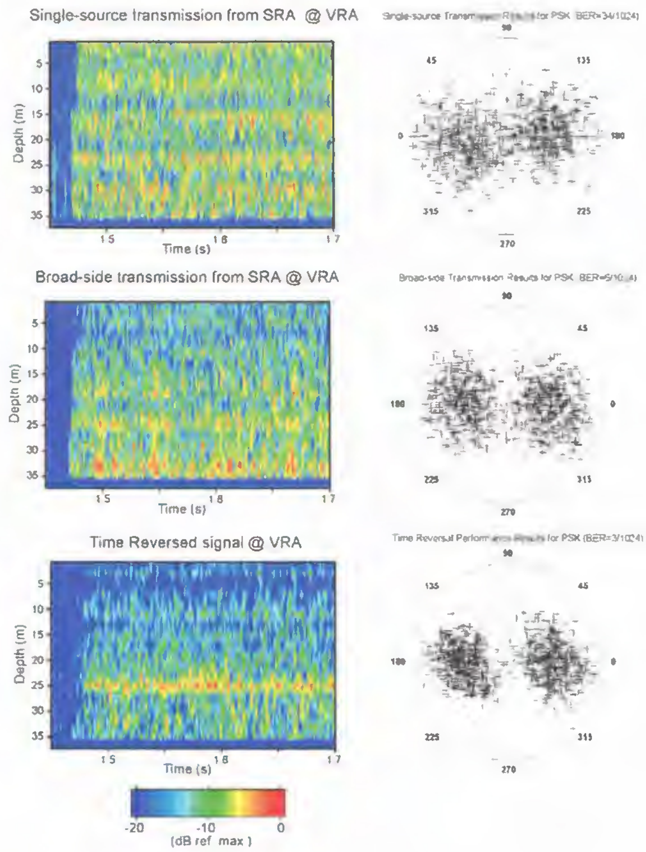


Figure 06-B.7 *Range dependent environment: An example of time reversal communication result compared to the other one-way transmission control examples (single-source and broadside). Bit error rate is denoted as BER.*

as time varying and dispersive. Advanced coherent communications techniques can be used to counter the ISI. When the AUV communicates to the source receive array, the SRA has access to the computing power and spatial diversity necessary for multichannel adaptive equalization. Alternatively, conventional beamforming (CBF) could be used in conjunction with single channel adaptive equalization. This is the same communication scenario as discussed for range dependent single source communications.

However, when the SRA is communicating with the AUV, the latter is limited in processing power and lacks spatial diversity. It has been shown that using time-reversal self-equalization it was possible to transmit information that counteracts dispersion and propagates acoustic energy to the PS depth and range. Therefore time-reversal self-equalization acts as a pre-processor overcoming the AUV's limitations.

The results also suggest that self-equalization could be used in conjunction with existing adaptive equalizers as a pre-filter. This would reduce the number of taps (filter weights) an adaptive equalizer would require. If the AUV has access to an adaptive equalizer it could extend the period of time the TRM can communicate between PS pings.

A TRM can be deployed from the payload of an AUV to communicate with its operator. This is the reciprocal experimental set-up where the AUV has the spatial diversity necessary for TRM communications. As the AUV is in shallow water a short array is adequate to span the water column.

Time Reversal Mirror (TRM)	Autonomous Underwater Vehicle (AUV)
• Not power limited • Fast computer processing • Spatially diverse reception • CBF + channel equalization • Multi channel equalization	• Conducts covert operations • Calibrates TR with PS ping • Transmits communications with PS • Receives communications from TRM

Figure 06-B.8 *Experimental configuration for TR communications with AUV.*

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***Piero Guerrini**, Head Systems Engineering Group, Engineering and Technology Department, received his Masters degree in electronic engineering from the University of Genova. Since joining the Centre in 1981 he has applied his extensive experience in the design of acquisition systems to underwater acoustics research.*

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Annual Bibliography of SACLANTCEN reports with abstracts

SM-329

Onken, R., Sellschopp, J.

Water masses, sound velocity structure and circulation between the eastern Algerian Basin and the Strait of Sicily in October 1996..

The investigation is based on data collected between the eastern Algerian Basin and the Strait of Sicily and in the southern Tyrrhenian Sea. The major pathways of water masses are identified by the core method and geostrophic currents are derived from the objectively analyzed density field.

Between the Sardinia Channel and the Strait of Sicily, the large-scale circulation of Modified Atlantic Water (MAW) and Winter Intermediate Water (MIW) is found to be cyclonic. Inflow into the gyre occurs via the Sardinia Channel by means of a boundary current attached to the Algerian coast and from the northern Tyrrhenian. The outflow is accomplished via the Strait of Sicily and to the Tyrrhenian. The Levantine Intermediate Water (LIW) flow resembles that of MAW/MIW in the southern Tyrrhenian, but is opposed in the Strait of Sicily and off Tunisia. Outflow to the Algerian Basin occurs south of Sardinia. In the eastern Algerian Basin the flow direction of all water masses is eastward close to the Algerian shelf. Farther offshore, MAW flows mainly southwest whereas the LIW is opposed to that supporting northward transport along the Sardinian shelf. The large-scale flow of all water masses is perturbed by mesoscale eddies. The impact of topographic obstacles is investigated.

SM-377

Max, M.D., Fawcett, J., Hollett, R., Thomason, B., Berkson, J.

Acoustic propagation and geoacoustic models for the Ragusa and West Malta Plateau geoacoustic terranes off SE Sicily.

In January 1996, acoustic and geophysical measurements were made at sites in the Strait of Sicily as part of a programme to develop methods of rapid geoacoustic and acoustic characterization of shallow water areas. Geoacoustic Terrane Analysis seeks to identify seafloor areas of similar geological, and hence geoaoustical character and then to derive by measurements and modelling the best general frequency and range dependent geoacoustic profile for each geoacoustic terrane. The geophysical measurements, performed as part of the geoacoustic terrane analysis programme, included swath mapping sonar, side-scan sonar, uniboom and sparker subbottom profiling, underwater television imaging and seafloor sampling. The acoustic measurements were made with explosive and controlled sources received by elements of a moored vertical line array at ranges up to 17 km.

The geophysical measurements showed that the seafloor in the northern Malta Plateau consists of two distinct bottom types having different geoacoustic properties. The eastern province, the Ragusa Terrane, is a ridge of rough seafloor consisting of patches of exposed rock with a discontiguous veneer of marine sediment generally less than 1 m in thickness. The western province, the West Malta Plateau Terrane, is an area of smooth seafloor underlain by a sedimentary sequence of 3-6 m of marine mud over partially consolidated sediments and limestones.

At a site in the Ragusa Terrane with an average water depth of 85 m, acoustic propagation measurements in the 50 to 2000 Hz band made using explosive sources revealed an optimum frequency of transmission of 100 to 400 Hz, in agreement with acoustic model simulations using the geoacoustic profile. At a site in the West Malta Plateau terrane with water depth 130 to 143 m, CW source propagation measurements at eight frequencies in the band 300 to 75000 Hz were in agreement with modelling results.

SM-378

D'Amico, A. Bergamasco, P. Zanasca, S. Carniel, E. Nacini, N. Portunato, V. Teloni, C. Mori, R. Barbanti

Correlation of oceanographic, biological and physical parameters with marine mammal presence in the Ligurian Sea.

In support of its acoustic risk mitigation policy, NATO SACLANT Undersea Research Centre (SACLANTCEN) is sponsoring a *series of sea trials, entitled "Sirena" to acquire a multi-year integrated oceanographic, biological and hydrographic data set, the goal being to explain, based on these parameters, why marine mammals were found in specific locations. By understanding how ocean dynamics affect the distribution and behaviour of whales and the organisms forming the food web upon which the whales feed, it may be possible to conduct acoustic exercises in areas of low cetacean density, thus avoiding operating in marine mammal hot spots. The first two Sirena multidisciplinary cruises were conducted in the Ligurian Sea in the late summer during 1999 and 2000. The focus of this analysis is to determine whether remotely sensed satellite data can indicate nutrient rich regions in areas where the oceanography is known and to determine if these regions of higher productivity, coupled with knowledge of cetacean presence from all available sources, could be used as an indicator of mammal presence for acoustic risk mitigation purposes. For the two years of data analyzed here, cooler sea surface temperature data positively correlated with high levels of chlorophyll production as seen by remotely sensed images. This data correlated well with measured sub-surface values of the same parameters. Coincident sightings of three species of marine mammals indicated that fin and sperm whales generally preferred the deep, nutrient rich portion of the basin and the Cuvier's beaked whales preferred a submarine canyon where there was a frontal influence.*

SM-379

J.E. Bondaryk, A. D'Amico

Low-power active sonar for marine mammal risk mitigation.

The NATO SACLANT Undersea Research Centre is sponsoring the development of tools and procedures to implement risk mitigation policies for the use of high power, underwater, acoustic sources. A sea trial, called Sirena 2000, was conducted in the Mediterranean Sea in August 2000 to assess the performance of a low-power active sonar concept for the detection and localization of marine mammals. This paper describes a feasibility study that includes the design of the system and data resulting from its operation. Using this system, it was possible to make an in situ Target Strength measurement of Striped Dolphin, Stennela coeruleoalba, of – 20.3 dB re 1?Pa, 1 m with a standard deviation of 4.7 dB.

SM-380

Zimmer, W.M.X., Johnson, M.P., D'Amico, A., Tyack, P.L.

Combining data from a multi-sensor tag and passive sonar to determine the diving behaviour of a sperm whale (Physeter macrocephalus).

This paper reports on the diving behaviour of a sperm whale tagged and tracked on 6 September 2000, during the SIRENA 2000 cruise in the Ligurian Sea. A total of about 4½ hours of acoustic and non-acoustic sensor data were recorded when a sperm whale was tagged with a WHOI-developed tag with a hydrophone, motion and pressure sensors. The animal was simultaneously tracked with a passive sonar system deployed from the NRV Alliance. By combining data from the tag and passive sonar, we were able to reconstruct a three-dimensional track of the whale, along with its orientation and vocal behaviour. While it was tagged, the whale carried out 3 deep dives to a depth of about 900 m in an area with a bottom depth of about 2600 m. The inter-click intervals of the diving whale were not consistent with ranging on the bottom, but were consistent the hypothesis that the whale was possibly echolocating on some target(s) near the depth at which it dove to feed. This study demonstrated an ability to track subtle3 changes in the behaviour of diving whales. This ability is important for three areas: (1) basic research, (2) studies of the responses of these animals to controlled exposures of manmade noise and (3) studies to infer the biological significance of behavioural disruption.

SM-381

Holland, C.W.

Direct observation of the angle of intromission in marine sediments.

High porosity marine sediments like silty clays have the curious property that the speed of sound through its bulk medium is lower than that of the interstitial pore fluid. When a high porosity sediment is at the water sediment interface, classical theory predicts that there is an angle at which the reflection coefficient is zero, and there is total transmission of sound into the seafloor. This angle is called the angle of intromission and has not been directly observed at the seafloor to the author's knowledge. Data from a new measurement technique show this phenomenon with remarkable clarity. Measurements of the angle of intromission in the coastal region of Italy indicate that the properties of the surficial high porosity sediments are surprisingly constant over large areas. A simple, but robust inversion method is shown for which the sediment sound speed and density can be directly obtained.

SM-382

Bondaryk, J.E.

Passive acoustics methods for marine mammal risk mitigation.

The objective of SACLANTCEN's Sound Oceanography and Living Marine Resources project is to demonstrate Dual Use Technology for acoustic detection and localization of marine mammals. Tools and procedures developed will assist in the implementation of acoustic risk mitigation policies for the use of high power acoustic sources underwater. A sea trial, designated Sirena '99, was conducted in the Mediterranean Sea in August 1999 using a number of advanced arrays to assess the performance of various passive acoustic detection and localization methods. The techniques of beamforming, target motion analysis, multi-path ranging and trilateration of arrivals are described, exemplified and evaluated in the context of acoustic risk mitigation.

For risk mitigation procedures to be effective, the range from the source to any marine mammals must be accurately known. While ranging is almost always possible for a visual detection to the accuracy of the observer, passive acoustic localization is seldom possible. Bearing information from a towed line array is useful as cue to visual observers, but is not particularly useful in itself for mitigation. TMA localization is possible for single animals that vocalize regularly, but it is problematic for groups and sporadic vocalizers. Longer arrays with narrow beams are recommended to reduce the contact time required for TMA localization. Multi-path ranging can work where the SNR is high enough to see multiple arrivals and wherever the vocalizations themselves and the water depth allows clear *separation of arrivals. This technique tends to be limited to medium deep water, 1000 m, and species that make loud wideband clicks. While trilateration of time-of-arrival information works consistently for any species with simple equipment, sensor configurations and SNR often limit its practical application, particularly for mitigation of a moving source.*

SM-383

LePage, K.D., Schmidt, H.

Bistatic synthetic aperture imaging of proud and buried targets from an AUV.

The use of Autonomous Underwater Vehicles (AUV's) for the detection of buried mines is an area of current interest to the Mine Counter Measures (MCM) community. AUV's offer the advantages of lower cost, improved operator safety, stealth and potentially improved coverage rates over more traditional mine hunters. However, AUV's also come with their own set of challenges, including acoustically significant error in navigation, and communication difficulties with the mother plat form and each other. In the case of bistatic detection scenarios, AUVs will therefore have difficulty knowing to sub-wavelength scales where exactly in space t hey are, and the exact trigger time of sources on other platforms, be they ships or other AUVs. However, the potential improvement in detection and coverage rates offered by bistatic sonar concepts makes resolution of these issues a high priority. In this report the problems of inaccurate navigation and source timing information are addressed for the GOATS'98 data set. In this experiment, conducted off Marciana Marina during June 1998, a MIT AUV with a SACLANTCEN nose array and acquisition system was used together with a TOPAS parametric sonar to explore issues of buried target detection using AUVs. In this report solutions to t he navigation and timing problems are proposed which enable the effective use of bistatic Synthetic Aperture Sonar (SAS) concepts for the detection of buried objects in the low frequency regime of 2-20 kHz.

SM-384

Ferla, C.M., Isoppo, C., Martinelli, G., Jensen, F.B.

Performance assessment of the LYBIN-2.0 propagation-loss model.

A new acoustic model LYBIN has been proposed for inclusion in the AESS model set. In order to determine this model's prediction accuracy and computational efficiency, SACLANTCEN was tasked to test LYBIN on exactly the same set of propagation problems used earlier for validating the current set of AESS models (ASTRAL, MOCASSIN, PE, PROLOS, RAYMODE, SUPERSNAP). The general conclusion of this test is that the range-dependent ray-trace model LYBIN, developed by the Norwegian Navy, is indeed a valid alternative to existing propagation models in the AESS. The LYBIN model has a prediction accuracy similar to the GRAB 'reference' model but is considerably faster.

SM-385

Bondaryk, J.E., Mazzi, M.L.

Automated passive acoustic detection of marine mammals.

The NATO Undersea Research Centre is sponsoring a project entitled Sound, Oceanography and Living Marine Resources, the objective of which is to demonstrate Dual Use technology for detection and localization of marine mammals. Tools and procedures developed will assist in the implementation of acoustic risk mitigation policies for the use of high power acoustic sources underwater. This report details the design and performance of an automated marine mammal detector for use with passive acoustic data. Included are descriptions of the vocalizations of marine mammals in the Mediterranean Sea. The performance of the detector was evaluated with data from the Sirena 2000 sea trial and found to be comparable to human monitored systems. The result of this analysis is a map of marine mammal acoustic presence in the Ligurian Sea during summer.

SM-386

Pinto, M.A., Hollett, R.D., Bellettini, A., Chapman, S.

Bathymetric imaging with wideband interferometric synthetic aperture sonar.

A new approach to interferometric sonar is presented, based on time delay estimation using short-term correlation of the seafloor backscatter. It is most suited to signals with large relative bandwidths and long interferometric baselines compared with the acoustic wavelength, that is, to the case in which the conventional processing has known limitations. The theoretical accuracy of the depth estimates is derived and validated using both Monte Carlo simulations and data from a trial carried out on an underwater rail in very shallow water. The interferometric sonar operated between 120 and 180 kHz with two 32-element receiving arrays of length = L 26.7 cm and a vertical baseline of D = 21.7 cm. The approach is extended to interferometric synthetic aperture sonar (InSAS) and experimental results are presented at range intervals around 25 m, 50 m and 75 m in 12 m water depth. It is shown that the increase in spatial resolution provided by the SAS processing considerably improves the accuracy of the depth estimates. A solution to the micronavigation problem based on the Displaced Phase Centre Antenna (DPCA) technique is presented which also corrects roll-induced distortions in the InSAS bathymetric map.

SM-387

Berni, A.

The SACLANTCEN satellite communications facility: system setup and operations.

The execution of the SACLANTCEN Scientific Programme of Work increasingly demands integration between scientists and systems at sea and ashore during scientific experiments and naval exercises.

One example is the Rapid Environmental Assessment (REA) thrust area, to characterize the environment interactions of the littoral and their potential effects on military operations, through the integration of oceanographic models and fusion of data from various sensors and platforms. Communications and Information Systems (CIS) are used to exchange information in the shortest possible timeframe between naval units, military commands, and data fusion centres. Other thrust areas, such as Antisubmarine Warfare (ASW) and Mine

Countermeasures (MCM) can however benefit from a general-purpose CIS architecture to implement more advanced concepts that require collaboration between systems and distributed data processing (e.g. multistatic sonar).

In the past SACLANTCEN has relied on commercial dial-on-demand satellite services to provide the necessary communication links, at the maximum data rate of 64 Kb/s. To satisfy all present and foreseen communications requirements (up to the data rate of 512 Kb/s) a new satellite communications (SATCOM) facility has been put in service, which provides with real-time capability for two-way computer-to-computer transmission of data to/from NRV Alliance regardless of location in the ACLANT Area of Responsibility.

The computer-to-computer link has been implemented using Commercial-Off-The-Shelf (COTS) components: Very Small Aperture Terminals (VSAT) have been installed onboard NRV Alliance and at SACLANTCEN, and satellite channel capacity is provided by commercial providers, through geostationary satellites.

This document describes the architecture and technical specifications of the new SATCOM facility, the applications that can be supported and their relevance in support of REA, ASW and MCM research. The aspects of information and communications security (e.g. to support classified communications) are also addressed.

SM-388

Canepa, G., Pace, N.G., Pouliquen, E.

Field measurements of bistatic scattering strength.

An experiment to measure bistatic scattering strength at 118 kHz was carried out in Bay of Biodola (Island of Elba, Italy). The experimental configuration and results are described. The scattering strength is calculated taking into account the instantaneous scattering area that depends on the pulse length, the beam pattern and the seafloor bathymetry. The scattering strength is presented as a series of contour plots. A full set of results is available from the authors.

SM-389

Pinto, M.A., Belletttini, A., Hollett, R., Tesei, A.

Real and synthetic array signal processing of buried targets.

Results from two field experiments aimed at investigating the detection and classification of buried targets are presented. In both experiments a 2-16 kHz parametric source was used. In the first experiment the source was used in combination with a 12 m horizontal line array and in the second with a 1.4 m vertical line array which was displaced horizontally along an underwater rail to form a 10 m x 1.4 m two dimensional synthetic aperture sonar (SAS). To increase the SAS integration time, the parametric source was electronically scanned in azimuth during the displacement along the rail, as in spotlight mode. It is shown that both arrays allow important signal to reverberation gains, enhancing the detection of sub-bottom echoes.

A new, environmentally adaptive, matched filter which further improves the signal to reverberation ratio while allowing discrimination between proud and buried targets is presented and validated experimentally. The use of resonant scattering for target classification of buried objects is discussed, in the particular case of spherical shells.

SM-390

Bondaryk, J.E.

Benefits and limitations of active sonar for marine mammal ship collision avoidance.

As part of the Sound Oceanography and Living Marine Resources (SOLMAR) project, the NATO SACLANT Undersea Research Centre is investigating a low-power, active sonar concept for the detection and localization of marine mammals to implement risk mitigation policy for underwater acoustic sound sources. Active sonar also has been identified as a possible candidate for marine mammal, collision-avoidance systems for ships and ferries. A preliminary design illustrates the benefits and limitations of such sonar. The benefits include wide area coverage, good performance against all species, day, night and poor weather operation, exact animal position and tracking capability. Limitations are imposed by summer sound velocity profiles, low and aspect-dependent Target Strength of animals, and interference from own ship noise. A concept feasibility test system detected striped dolphin, Stennela coeruleoalba, at 600m, during the Sirena sea trial, conducted in the Ligurian Sea in August 2000.

SM-391

Harrison, C.H.

Noise measurements during MAPEX2000.

During MAPEX2000 some simultaneous ambient noise measurements with an HLA and satellite SAR images were collected. The aim was to predict shipping and wind noise from the satellite radar and to compare results with acoustic measurements. This report takes the acoustic data alone and investigates differences in noise directionality and shipping densities in fair and rough weather conditions. Directionality and various statistics are studied as a function of frequency and time (several hours). In addition, picking one ship at a time it is possible to study its aspect dependence as it passes the HLA.

SR-335

Chotiros, N.P., Lyons, A.P., Osler, J., Pace, N.G.

Normal incidence reflection loss from a sandy sediment.

Acoustic reflection loss at normal incidence of a sandy sediment, in the Biodola Gulf on the north side of the island of Elba, Italy, was measured in the band 8 - 17 kHz, using a self-calibrating method. The water depth was approximately 11 m the sand pure with a mean grain diameter of 0.2 mm. The measured reflection loss 11 dB, ±2 dB is consistent with measurements in the published literature. The computed reflection loss for an interface between water and a uniform visco-elastic media with the same properties was 8 dB, ±1dB. The theoretical and experimental values do not significantly overlap, which leads to the conclusion that the visco-elastic model is inappropriate. The Biot model is suggested as a better alternative but more work is needed to ascertain the appropriate parameter values.

SR-343

Siderius, M., Nielsen, P.L., Gerstoft, P.

Range-dependent seabed characterization by inversion of acoustic data from a towed receiver array: results from MAPEX2000.

The MAPEX2000 experiments were conducted in the Mediterranean Sea in March 2000, to determine seabed properties using a towed acoustic source and receiver array. Towed systems are advantageous because they are easy to deploy from a ship and the moving platform offers the possiblity for estimating spatially variable (range-dependent) seabed properties. In this paper, seabed properties are determined using a matched field geo-acoustic inversion approach with measured, towed array data. Previous research has successfully applied matched field geo-acoustic inversion techniques to measured acoustic data. However, in nearly all cases the inverted data were collected on moored, vertical receiver arrays. Results here show that seabed properties can also be extracted by inverting acoustic measurements from a towed array of receivers and these agree with those inverted using data received simultaneously on a vertical array. These findings imply that a practical technique could be developed to map range-dependent seabed properties over large areas using a towed acoustic system. An example of such a range-dependent inversion is given for two sites from the MAPEX2000 experiments.

SR-344

Holland, C.W.

Shallow water coupled scattering and reflection measurements.

The characteristics of shallow water reverberation are often controlled by interaction with the seabed. This interaction includes both reflection and scattering processes. New techniques for measuring shallow water reflection and scattering have been developed that are coupled. The coupled nature of the measurements implies not only that they are conducted at the same locations, but that the measurements of the reflection provide significant keys for unravelling the scattering data. In particular, very high resolution geoacoustic data are extracted from the reflection data, which provide crucial inputs for the modelling of the scattering data. 1-6 kHz reflection and scattering measurements from the Malta Plateau illustrate the advantages of the coupled measurement approach.

SR-347

Askari, F., Scevenels, S.

High resolution wind mapping with RADARSAT SAR imagery.

This article assesses the capabilities of RADARSAT SAR imagery for high-resolution wind mapping. The mapping technique couples a scatterometer model function with two-dimensional image analysis and other fusion techniques for inverting the SAR back-scattering cross-sections into wind vectors. The SAR-derived results are compared with shipboard in situ measurements, coarse resolution winds derived from the coupled ocean atmosphere prediction system (COAMPS) model, special sensor microwave imager (SSM/I) and QUICKSCAT satellite measurements. The sensor-to-sensor comparisons show good overall agreement. The largest discrepancies are associated with measurements from the SCANSAR imaging mode, where antenna calibration is a suspect.

SR-348

Laterveer, R., Bongi, S.

Reverberation consistency: DUSS-97 data.

The use of low frequency active sonar in shallow water leads to large numbers of reverberation detections which can overload automatic tracking and classification algorithms.

We study the stability of reverberation returns from the DUSS97 multi-static experiment using fixed buoys.

The main conclusion is that to associate detections over station and time accurate geographical mapping of the data is essential. Therefore fixed buoys should have accurate calibrated compasses.

SR-349

Tesei, A., Maguer, A., Fox, W.J.L., Lim, R., Schmidt, H.

Measurements and modelling of acoustic scattering from partially and completely buried spherical shells

The use of low frequency sonars (2-15 kHz) is explored to better exploit scattering features of buried targets that can contribute to their detection and classification. Compared to conventional mine countermeasures sonars, sound penetrates better into the sediment at these frequencies, and the excitation of structural waves in the targets is enhanced. The main contributions to target echo are the specular reflection, geometric diffraction effects and the resonance response, with the latter being particularly important for man-made elastic objects possessing particular symmetry such as bodies of revolution. The resonance response derives from elastic periodic phenomena such as surface circumferential waves revolving around the target.

The GOATS'98 experiment, performed in a joint effort by SACLANTCEN and MIT off the island of Elba, included controlled monostatic measurements of scattering by spherical shells, which were partially and completely buried in sand, as well as suspended in the water column. The analysis is mainly addressed to a study of the effect of burial on the dynamics of backscattered elastic wave families, which can be clearly identified in the target responses, and is based on the comparison of measurements to appropriate scattering models. Data interpretation results are in good agreement with theory. This positive result demonstrates the applicability of low-frequency methodologies based on resonance analysis to the classification of buried objects.

SR-350

LePage, K.D.

Modal travel time, dispersion and approximate time series synthesis in range dependent waveguides.

A comprehensive theory for monostatic reverberation in range independent environments has been developed which makes use of the narrow band approximation to approximate the temporal Greens function to and from bottom scatterers. Here the propagation theory required to extend this treatment to range dependent environments is developed. The key is to extend the idea of model group speed and dispersion to range dependent environments. It is found that such an extension is easily obtained under the single scattering approximation, the parabolic approximation for one-way propagation in range dependent waveguides, and the WKB approximation for the forward propagated modal amplitudes. Results show that the effective {\em range dependent} slowness and dispersion properties of the individual modes vary from almost adiabatic for gradual range dependence of the waveguide at low frequencies, to completely non-adiabatic at higher frequencies and/or in waveguides with stronger range dependence. The theory is used to generate snapshot s of pulse propagation in shallow water waveguides which are compared to snapshots obtained through actual Fourier synthesis. The results show that while the narrow band approximation for range dependent waveguides has limitations in its ability to recreate the fine details of the benchmark results, all the important features in the pulse propagation, including the penetration of energy into the bottom at ranges where modes cutoff, are faithfully reproduced. The results give confidence that the narrowband approximation approach for modelling reverberation using a modal basis in range independent environments may be extended to rang e dependent environments without sacrificing accuracy or any of the intuition which is one of the features of the approach.

SR-351

Soares, C., Siderius, M., Jesus, S.M.

Source localization in a time varying ocean environment applied to the ADVENT'99 data.

Matched-field processing (MFP) is a technique that has been developed for source localization in an ocean waveguide. MFP is possible due to the complexity of the acoustic field in the ocean. Classificat MFP involves the correlation of the field measured with an array with the field predicted by a propagation model for a set of hypothesized source positions. This requires the knowledge of the propagation environment. Moreover, the environment may be highly time-variant in opposition to the assumption of time-invariance.

SR-352

Van Velzen, M.

Evaluation of the Page test on active sonar data.

The length of the echo return from a submarine in low frequency active sonar data depends on the environment and the dimensions and aspect of the submarine. It is therefore unlikely that fixed length post-detection integration techniques, such as the moving average filter, give the best performance. An adaptive algorithm, the Page test, calculates the echo extent by detecting the start and end of deviations from the background statistics, which are assumed Chi squared after normalization and integrating the energy over this extent.

The performance of the Page test and moving average filter are compared to no post-detection integration. Then the performance of the Page test is compared to the performance of the moving average filter for optimal window length. The sensitivity to its most important parameter, the bias, is also investigated. In the evaluation, more than 200 pings of shallow water active sonar data from 2 different runs at different centre frequencies were used.

It is shown that the Page test and the moving average filter enhance detection performance compared to no post-detection integration at all. The Page test performance is comparable to the moving average filter with optimal window length (about 60 m). This means that the Page test determines the optimal integration length from the data adaptively and is applicable to different environmental and tactical situations. It is concluded that the Page test can be considered a robust adaptive post-detection integration algorithm for low frequency active sonar data.

SR-353

Haralabus, G.

Time bandwidth analysis of *Mercury 99* broadband data.

An analysis of active, broadband detection in littoral waters was conducted based on Mercury99 data. Detection performance, reverberation, and ambient noise variations were examined with respect to the processed bandwidth, frequency and time-bandwidth product. This work constitutes the first step toward the ultimate goal of developing a detection algorithm adjustable to environmental conditions and the characteristics of broadband source(s) and receiver(s). Four linear frequency signals with different slopes (or time-bandwidth product) were examined (bandwidth 1 to 3.4 kHz, signal duration 1 to 6 s). For the particular data set, target detection by means of false alarm reduction was redundant due to high signal-to-noise (SNR) ratio. The objective was to identify the frequency regime(s) for which, in the particular environmental conditions, the SNR ratio was maximized. For this purpose various matched filter schemes based on selected sub-bands are devised. It was found that, especially for the short pulses, detection performance was enhanced at low frequency sub-bands between 1.2 and 1.5 kHz. However SNR variability observed for short and long signals. Reverberation and ambient noise intensity were examined as a function of time-bandwidth (TB) product. It was found that in most cases the 10·log(B) rule of reverberation reduction as a function of increasing is valid. Incoherent processing methods are shown to enhance detection by excluding frequency regimes with poor performance and to offer performance stability by simultaneously combining more than one matched filter outputs with significant detection output.

SR-354

Jensen, F.B., Ferla, C.M., LePage, K.D., Nielsen, P.L.

Acoustic models at SACLANTCEN: an update.

SACLANTCEN maintains a suite of computer codes to model sound propagation and reverberation in the ocean. In addition, software packages are available for automated matched-field inversion of acoustic data and for modelling the scattering from targets in ocean waveguides. This suite contains numerical models to cover most of the environmental conditions and acoustic frequencies of interest to the Centre's research programme at the present time.

SR-355

Bellettini, A., Pinto, M.

Accuracy of synthetic aperture sonar micronavigation using a displaced phase centre antenna: theory and experimental validation.

The Cramér-Rao Lower Bounds (CRLBs) on the cross-track translation and rotation of a Displaced Phase Centre Antenna (DPCA) in the slant range plane between two successive pings (known as DPCA sway and yaw in what follows) are computed, assuming statistically homogeneous backscatter. These bounds are validated using experimental data from a 118-182 kHz sonar, showing an accuracy of the order of 20 microns on the ping-to-ping cross-track displacements.

Next, the accuracy required on the DPCA sway and yaw in order to achieve a given SAS beampattern specification, specified by the expected SAS array gain, is computed as a function of the number P of pings in the SAS. Higher accuracy is required when P increases to counter the accumulation of errors during the integration of the elementary ping-to-ping estimates: the standard deviation must decrease as $p^{1/2}$ for the DPCA sway and $p^{-3/2}$ for the yaw.

Finally, by combining the above results, the lower bounds on DPCA micronavigation accuracy are established. These bounds set an upper limit to the SAS length achievable in practice. The maximum gain Q in cross-range resolution achievable by a DPCA micronavigated SAS is computed as a function of the key SAS parameters. It is found that, for P » 1, the optimum SAS spatial sampling factor is 4, in the sense that it allows maximum Q. These theoretical predictions are compared with simulations and experimental results.

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B Ship Management Office

NRV *Alliance, Leonardo* and T Boat *Manning*

R/V Alliance

Eight major scientific experiments were undertaken during 2001 (231 operational sea-days)[1], including four off the east coast of the United States and Canada and one in the Southwest Approaches to the UK. The vessel departed La Spezia on 7 April and returned on 11 September, having covered a distance of 18,642 nautical miles. During the 5 month deployment, port visits were made to Ponta Delgada, Washington, Norfolk, Boston, Halifax and Falmouth (UK), during which a number of receptions were held for distinguished visitors and personnel from defence and research organizations in the United States and Canada.

Maintenance

The meticulous, comprehensive and continuous maintenance programme by the crew in conjunction with focused investment will ensure continued operational availability of the *Alliance* into the second decade of the millennium.

Charter

One 6- day charter was undertaken to the Italian Navy.

Research Vessel Operators' Committee

The Ship Manager continues to participate in and contribute to the *Research Vessel Operators' Committee* (RVOC). The International Safe Ship Management Code (ISM) continued to be high on the agenda.

T-Boat Manning

Manning contributed 98 sea-days to the *Scientific Programme of Work.*

R/V Leonardo

The Ship Management Office's resources have been dedicated primarily to the construction of the *Leonardo*. Regular progress meetings were convened at the prime contractor, *McTay Marine Ltd.*, UK. The hull, having been sub-contracted to *Investrem*, Gdansk, Poland, was delivered to the UK in November and is in course of fitting out. The majority of factory acceptance tests for main and auxiliary machinery and systems have been successfully accomplished. Much of this hardware is in storage at the shipyard ready for installation in accordance with the *cardinal date programme*. System integration and fitting out this small vessel will present a significant challenge to the shipyard as space is limited in the various compartments; the enthusiasm and design engineering expertise of the shipbuilders are commendable and they are focused on timely delivery with a high standard of finish. Contract delivery date for the vessel, which will, subject to ratification of a *memorandum of understanding* by the Italian Government, be the first Italian public registered vessel, is now scheduled for 30 June 2002. Commissioning is planned for 6 September 2002 in La Spezia.

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[1] 200 days in 2000. Marstans prescribes 108 sea days per annum for frigates, the vessel type closest to the *Alliance*.

The *Leonardo* under construction

Chris Gobey entered the Britannia Royal Naval College, Dartmouth in 1963. His subsequent career included a period of loan service with the Royal New Zealand Navy, one year as commanding officer of HMS HECATE in the Falklands, South Georgia and Antarctica, deputy leader of a joint services expedition to the northern ice cap of Chile and Superintendent of Surveying Equipment at Taunton. He has been Head of the Ship Management Office at SACLANTCEN since 1986.

C Science and Technology Supporting Initiatives Office

Project	Activity	Return	Partner
04-F (SOLMAR)	Thesis on optical measurement	one man/year	DIPTERIS
	Biological oceanographic data acquisition	data analysis and cruise participation	ICRAM
	Oceanographic data acquisition and participation in experiment by Magnaghi	7 ship days, data acquisition/analysis	IIN, IOF, UNINA, (CNR)
	Letter of intent including emergency management	environmental advice on protected marine species	ICRAM
03-C(MCM) 01-A (REA)	Memorandum of understanding on ocean engineering and other infrastructure	*Alliance* chartering, ocean engineering developments	INFN
01-A(REA) 01-B(REA) 03-C(MCM)	Memorandum of agreement covering bottom characterization and mapping, oceanographic data collection and modelling	electronic charts, conversion of data to hydrographic standards	IIN
01-B(REA) 03-C(REA)	Letter of intent on research in underwater object detection and characterization	bottom characterization for AUV test site; wreck localization	MIT, SAT
01-A(REA) 01-B(REA)	Thesis in support of SEPTR development	one man year	DIPTERIS
ETD	CTD calibration (renewal)	one man/year	Idronaut S.r.l.

The ETD oceanographic instrumentation calibration service was provided to the navies of Italy, Portugal, Spain and Turkey; Italian laboratories (CNR, ENEA, INFN), universities and regional organizations, Spanish oceanographic institutions and in the spirit of the *Partnership for Peace* programme was offered to the Slovenian *National Institute of Biology* (CTD calibration).

ENEA:	Ente delle Nuove tecnologie, Energia ed Ambiente
ICRAM:	Istituto Centrale della Ricerca scientifica e tecnologica Applicata al mare
CNR:	Comitato Nazionale delle Ricerche
ISDGM:	Istituto per lo Studio della Dinamica delle Grandi Masse
DIP.TE.RIS:	Dipartimento per lo studio del territorio e delle sue risorse - Università di Genova
IOF:	Istituto per lo studio della Oceanografia Fisica
UNINA:	Università di Napoli Partenopea
INFN:	Istituto Nazionale Fisica Nucleare
CONISMA:	COnsorzio Nazionale Interuniversitario Scienze MArine
IIM:	Istituto Idrografico della Marina
SAT:	Sovrintendenza Archeologica della Toscana

__Federico de Strobel__ graduated from the University of Rome, Italy, with a degree in electronic engineering with acoustic specialization. Since joining the Centre in 1969, he has worked mainly in buoy technology, oceanographic instrumentation and CTD calibration at different levels of responsibility from scientist in the physical oceanography group to Head of the Ocean Engineering Department. In 1999, he became the head of the SACLANTCEN Science and Technology Office. He has spent sabbaticals at Woods Hole Oceanographic Institution, Woods Hole, MA and Scripps Institution of Oceanography, La Jolla, CA. He teaches "oceanographic measurements" at the Italian Navy Hydrographic Institute and the University of Genoa. Dr de Strobel received the Marine Technology Society's International Compass Award in 1992.

D Organization and staff members with effect from 1 January 2002

DIRECTORATE

Director :	J.L. Spoelstra (NL)
Deputy Director :	W.J. Jobst (US) (until 31 Jan 2001) K. Pye (UK) (from 1 April 2001)

OFFICE OF THE DIRECTOR

Naval Advisor	Cdr B. Williams, USN
Security Officer	Cdr G. Piaggio, ITN
Planner/Coordinator	D. Bennett (US)
Administrator (Health & safety)	R. Molteni (IT)

FINANCE OFFICE

Controller:	L. Parise (IT) (until June 2002)
Fiscal Officer:	M. Newman (US) (until February 2002) E. Stewart (US) (from April 2002)
Internal Auditor:	G. Lambie (UK)

PERSONNEL & ADMINISTRATION OFFICE

Head, PAD	R. Albini (IT)
Logistics & Supply	U. Varlese (IT) (until November 2002)
Information Services	A.W Green (UK)

INFORMATION TECHNOLOGY OFFICE

Head, ITO	R. Seynaeve (BE) (until February 2001) M. Leonard (BE) (from May 2001)
Senior ADP Systems Spec	P. Colucci (IT)
ADP Security Officer	Lt W. Smiley (USN) (until July 2002) CWO D.W. Oslon (USN) (from August 2002)

SHIP MANAGEMENT OFFICE

Head, SMO	C. Gobey (UK) (until August 2002) D.I. Sage (UK) (from 1 Sep 2002)
Senior Engineer/Materiel	A. Spairani (IT)
Research Vessel Captain	A. Iacono (IT)

CHIEF SCIENTIFIC DIVISION

Chief Scientific Division (twinned post): K. Pye (UK) (from April 2001)
Scientific Division Coordinator LCDR J. Staveley (UKN)

RAPID ENVIRONMENTAL ASSESSMENT DEPARTMENT (REA)

Senior Principal Scientist, Head, REA	R. Tyce (US) (from September 2001)
Senior Principal Scientist	E. Ferreira-Coelho (PO) (from Sept 2001)
Principal Scientist	F. Askari (US)
Principal Scientist	E. Bovio (IT)
Senior Scientist	M. Ferla (IT)
Senior Scientist	R. Onken (GE)
Senior Scientist	R. Signell (US)
Scientist	A. Alvarez (SP)
Scientist	D. Conley (US)
Scientific Specialist	F. Spina (IT)
MILOC Survey Officer	D. Schaa (Civ. GE) until July 2001
MILOC Survey Officer	U. Paul (Civ. GE) From July 2001

COMMAND AND OPERATIONAL SUPPORT DEPARTMENT (COS)

Senior Principal Scientist, Head, COS	P. Simcock (UK) (from July 2001)
Principal Scientist	J. Redmayne (UK)
Principal Scientist	E. Verhoeff (NL) (from January 2002)
Senior Scientist	H. Yip (CA)
Scientist	G. Arcieri (IT) (until December 2002)
Scientist	M. Meyer (GE) (from September 2001 until June 2002)

ENGINEERING TECHNOLOGY DEPARTMENT (ETD)

Head, ETD	O. Bergem (NO) (until July 2002)
Principal Engineer (Head,STO)	F. de Strobel (IT)
Principal Engineer (Head,ENG)	P. Guerrini (IT)
Senior Engineer	L. Gualdesi (IT)
Senior Engineer	E. Michelozzi (IT)
Engineer	V. Grandi (IT)
Engineer	B. Miaschi (IT)
Engineer	P. Sletner (NO)
Engineer	R. Stoner (UK)
Engineer	L. Troiano (UK)
Head, Acquisition Branch	P. Boni (IT)

LITTORAL ANTI-SUBMARINE WARFARE DEPARTMENT (ASW)

Senior Principal Scientist, Head, ASW	S. Jespers (BE)
Senior Principal Scientist	A. D'Amico (US) (until October 2001)
Senior Principal Scientist	M. Carron (US) (from January 2002)
Principal Scientist	D. Grimmett (US)
Principal Scientist	V. Crowe (CA) (from September 2001)
Principal Scientist	C. Harrison (UK)
Senior Scientist	C. Holland (until Sepember 2001)
Senior Scientist	P. Nielsen (DA)
Senior Scientist	S. Coraluppi (US) (from February 2002)
Senior Scientist	M. Van Velzen (NL)
Senior Scientist	R. Laterveer (NL)
Senior Scientist	K. LePage (US) (until August 2002)
Scientist	J. Bondaryk (US) (until May 2001)
Scientist	O. Gerard (FR) (from November 2001)
Scientist	M. Prior (UK)
Scientist	G. Haralabus (GR)
Scientist	M. Fallat (CA) (from November 2001)
ASW Programme Officer	CDR B. Egenberg (NO)a(until July 2001)
ASW Programme Officer	LCDR P. Mathias-Jones (UKN) (from July 2001)
Scientific Specialist	R. Hollett (UK)
Scientific Specialist	W. Zimmer (GE)

MINE COUNTERMEASURES DEPARTMENT MCM

Senior Principal Scientist, Head, MCM	N. Pace (UK)
Senior Principal Scientist	F. Jensen (DA)
Senior Principal Scientist	M Pinto (FR)
Principal Scientist	D. Burnett (US)
Principal Scientist	G. Field (UK)
Principal Scientist	T. Akal (TU) (until December 2001)
Principal Scientist	M. Stevenson (US) (from April 2002)
Senior Scientist	G. Davies (UK)
Senior Scientist	E. Pouliquen (FR)
Senior Scientist	L. Wang (UK)
Scientist	P. Munk (DA) (from January 2002)
Scientist	M. Zampolli (IT) (from June 2001)
Scientist	L. Paulet (FR) (from October 2001)
Scientist	A. Bellettini (IT)
Scientist	A. Tesei (IT)
MW Programme Officer	CDR O. Molino (ITN)
Naval Scientist	LCDR J. Law (UKN) (from January 2001)

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E Visitors and meetings

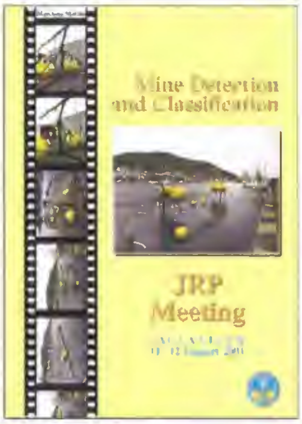
In addition to the six–monthly visits by members of the Scientific Committee of National Representatives, the Centre received some 350 visitors who spent some five hundred man-days discussing the Scientific Programme of Work; the minutiae of Joint Research Projects or attending scientific, technical or other meetings, some of which are identified below.

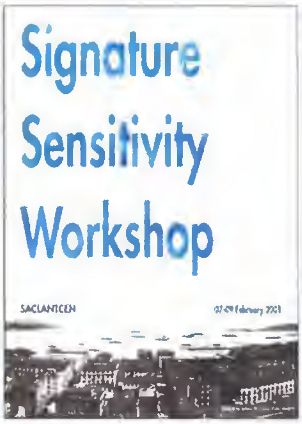
January	GOATS Workshop	
	5th Mine Detection and Classification JRP Meeting	
	Mr Nils Holme Mr Kenneth Peebles	Chairman, RTB Director, RTA
	Dr Chryssostos Chryssostomidis Prof. Andrea Caiti	MIT, US University of Pisa, IT
February	General William F. Kernan	Supreme Allied Commander, Atlantic
	Signature Sensitivity Workshop	
	METOC Meeting	USN Officers from COMSUBGRU Eight and NEMOC
	NATO VSWMCMWG	
	Dr Mark Trevorow	DREA, CA
	Dr Mirjam Snellen and Dr Dirk Simons	TNO, The Hague, NL
March	ITN Officers from Naval Academy, Livorno	
April	ITN Officers from the Hydrographic Institute, Genoa	
	Dr David Dittmer, Ms Julia Thibault and LT Jill Quinton	US Center for Naval Analysis (CNA)
	RADM Duncan E. Miller, CAN	Chief-of-Staff, SACLANT
	Dr Steve Piacsek and Dr Alex Warn-Varnas	NRL, Stennis Space Center, US
	CDR Harald H. Weiss, GEN and CDR Christopher Real, USN	SACLANTREPEUR
	Dr Tsih C. Yang and Dr Kwang Yoo	NRL, Washington, US
	Dr Edward McDonald	NRL, Washington, US
	03-I Project Definition Workshop	
	Dr Annalisa Griffa	CNR, S. Teresa, IT
May	CAPT Angelo Agliata, ITN	Director of Italian Navy Hydrographic Institute, Genoa, IT
	Dr Nadia Pinardi,	University of Modena, IT
	Mr Roy Ladner	NRL, Stennis Space Center, US
	Cerberus 01 Planning Meeting	
	Dr Germana Peggion	NRL Stennis Space Center, New Orleans, US
	RADM Frits M.P. 't Hart, NLN	Assistant Chief of Staff, Strategy, SACLANT
June	NATO Military Budget Committee	
	Mr Jon Downing and Mr Sean Chapman	DERA, UK
July	CDR Peter Van Mierlo, NLN	COMNAVSOUTH
	PLANET Specialist Steering Group Meeting	
	Prof. W.A. Kuperman Prof. H. Schmidt Dr M.B. Porter	MPL, Scripps, US MIT, US SAIC, US
	Dr Julie Pullen	NRL, Monterey, CA, US
August	Dr B.E. McDonald	NRL, Washington, US
	Dr Phil Schwarz	NRL, Washington, US

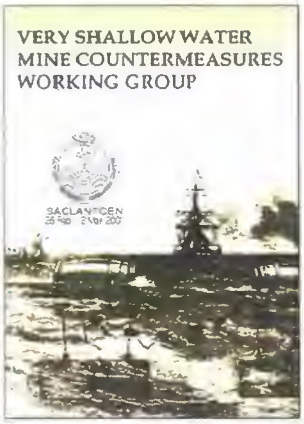
	GOATS JRP Conference	
	Mr D. DelBalzo	NRL SSC, US
September	SIRENA 01 Pre-cruise brief	
	ADRIA 02 Field programme coordination	
	MAPLE 2001 post-cruise brief	
	NATO Senior Resource Board	
	Dr Alex Warn-Varnas, Dr Richard A. Allard and Dr Dale L. Bibee	NRL, SSC, US
	Dr Robert C. Gisiner	ONR, Arlington, US
	Dr Orest Diachok	NRL, Washington, US
	REA meeting	NDRE, Norwegian Meteorological Inst., NORNAVTRAINEST, NORNAVY MAT COMMAND and SACLANT
	NATO R&T Agency Information Management Meeting	
	Group of ITN Submarine Officers for meeting on use of Towed Arrays on Submarines	
October	SIRENA 01 Post Cruise Meeting	
	Project 03-I Workshop – Systems and concepts for rapid MCM operations	
	79th SCNR Meeting	
	5th Operational Planning Software Steering Group Meeting (PLANET)	
	9th NATO Areas Search & Screening Working Group Meeting (AS2WG)	
	Visit from the Greek Hydrographic Office	
November	NATO Non-Acoustic Detection Meeting	
	6th Mine Detection and Classification Meeting	
	Ms Susan Parks and Ms Stephanie Watwood	Woods Hole, US
December	Dr Henry Perkins and Dr Mark Hulbert	NRL, Stennis Space Centre, US
	Prof. Andrea Caiti, Prof. Mario Innocenti and Mr Francesco Paralli	University of Pisa, IT
	Prof. Antonio Capone, Mr Mario Sedita, Mr Giorgio Riccobene and Mr Rocco Masullo	INFN, IT

The Senior Resource Board visited the Centre in September

Visit of the Nato Military Budget Committee to SACLANTCEN in June


Mine Detection
and Classification
JRP
Meeting


Signature
Sensitivity
Workshop
SACLANTCEN

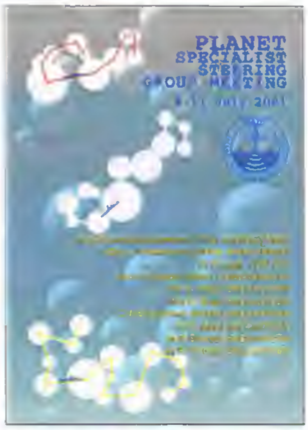

VERY SHALLOW WATER
MINE COUNTERMEASURES
WORKING GROUP
SACLANTCEN

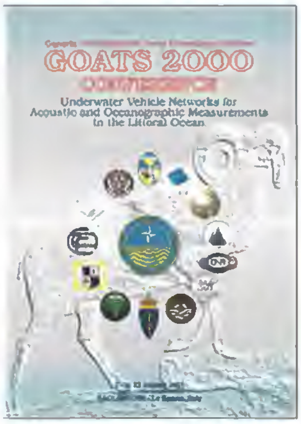

WELCOME
TO
SACLANTCEN
La Spezia


WELCOME
to
SACLANTCEN
La Spezia
BI-SC 2002 BUDGET
PRE-SCREENING MEETING
19 - 23 March 2001


PRESENTATION ON ALLIANCE
COMMUNICATIONS
6 April 2001


DERA
SACLANTCEN


PLANET
SPECIALIST
STEERING
GROUP MEETING


GOATS 2000
Underwater Vehicle Networks for
Acoustic and Oceanographic Measurements
in the Littoral Ocean


ADRIA 2002 - 2003
FIELD TRIALS PLANNING WORKSHOP
PARTICIPATING INSTITUTIONS
SACLANTCEN 24 - 25 SEPTEMBER 2001


PROJ. 03 - I WORKSHOP
SYSTEMS AND CONCEPTS
FOR RAPID MCM OPERATIONS


79th
16-19 October 2001
SCNR


5th
OPERATIONAL PLANNING SOFTWARE
STEERING GROUP MEETING


9TH NATO
AREA SEARCH & SCREENNING
WORKING GROUP
John Batchelor


6th Mine Detection and Classification
J R P Meeting
6th
Sestri Levante 29-30 November 2001

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F Scientific Committee of National Representatives and National Liaison Officers

BELGIUM *National Representative*	**LCDR Carl Gillis, BENA** ACOS STP-FP/Cap/S, Brussels
CANADA *Acting National Representative* *National Liaison Officer*	**Mr Warren C.E. Nethercote** Deputy Director-General, Defence Research Establishment Atlantic, Dartmouth, Nova Scotia **Dr. Dale Ellis** Defence Research Establishment Atlantic, Dartmouth, Nova Scotia
DENMARK *National Representative* *National Liaison Officer*	**Rear Admiral Niels Mejdal, DANA** Defence Command Denmark, Vedbæk **Mr Bjarne Damsgaard** Danish Defence Research Establishment, Copenhagen
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GREECE *National Representative* *National Liaison Officer*	**Dr Theodoros Kardaras** Hellenic Navy Hydrographic Office, Holargos, Athens **CDR Radamanthis Fountoulakakis, HENA** Hellenic Navy General Staff A' Branch – Section A3-I, Holargos, Athens
ITALY *National Representative* *Alternative National Representative* *National Liaison Officer*	**RADM Dino Nascetti, ITNA** Stato Maggiore Marina, 4° Reparto S.P.M.M., Rome **CAPT A. D'Andrea, ITNA** NAVARM, Ministero della Difesa Marina, Rome **CDR Fernando Cerrutti, ITNA** MARISTAT, Ministero della Difesa Marina, Rome

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National Liaison Officer	**CAPT Gijs J. Van Beeck Calkoen, NENA** Director of Naval Research and Development, Royal Netherlands Navy, The Hague
NORWAY *National Representative*	**Mr Jarl Johnsen** Norwegian Defence Research, Establishment, Horten
POLAND *National Representative*	**CAPT Andrzej Felski, PLNA** Akademia Marynarki Wojennej Gdynia
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National Liaison Officer	**Eng. CDR H. Ba?aran, TUNA** Arastirma Merkezi K.ligi, Deniz Harp Okulu K.ligi, Istanbul
UNITED KINGDOM *National Representative*	**Dr. Kevin Port** Dstl Analysis, Winfrith Technology Centre, Dorchester
National Liaison Officer	**Mr Jon Downing** Director of Equipment Capability (Underwater Battlespace), Ministry of Defence, London
UNITED STATES *National Representative*	**Dr Eric O. Hartwig** (Code 1001) Director of Research (acting) Naval Research Laboratory, Washington D.C.
Alternate National Representative	**Dr Steven E. Ramberg** (Code 01) Director (acting) Office of Naval Research, Arlington, VA
National Liaison Officer	**CDR Scott M. Tilden, USNA** (Code 321B) Office of Naval Research, Arlington, VA

SECGEN NATO *Representative* *Acting Representative*	**RADM Guillermo Leira, SPNA** Deputy Assistant Secretary General, Defence Support, NATO Headquarters, Brussels **CAPT (Ret) Arcangelo Simi** Head, Naval Armaments Section, Defence Support, NATO Headquarters, Brussels
NAMILCOM *Representative*	**COL Adam Sowa, PLAR** Logistics, Armaments & Resources Division, IMS, Staff Officer for Research and Technology, NATO Headquarters, Brussels
SACLANT *Representative* *Representative* *Liaison Officer* **SACLANTREPEUR** *Observer* **SHAPE** *Liaison Officer*	**RADM David M. Crocker, USNA** (HC-50) Deputy Assistant Chief of Staff, Policy SACLANT Headquarters **CDRE Per Ottesen, NONA** (HC-80) Deputy Assistant Chief of Staff, Resources SACLANT Headquarters **COL Donald I. Blackwleder, USAF** (HC-54) SACLANT Headquarters **CDR Christopher Real, USNA** Assistant for Long Term Armaments Planning NATO Headquarters, Brussels **CAPT Saverio Fanelli, ITNA** Chief Oceanographic Officer, Joint Operations Branch, IJX/OJE, SHAPE

G Personnel by category and nationality

Country	Scientific complement (31Dec 2001)	Total scientist man years (1959-2000)
Belgium	1	94.10
Canada	3	99.11
Denmark	2	141.11
France	4	159.05
Germany	2	131.03
Greece	1	31.00
Italy	6	244.02
Netherlands	4	129.09
Norway	1	102.00
Portugal	1	12.04
Spain	1	2.05
Turkey	1	38.00
UK	9	317.03
USA	7	378.03
Total	43	1882.06

Visit of General William F. Kernan in February

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