NATO SACLANT
UNDERSEA RESEARCH CENTRE

ANNUAL PROGRESS REPORT 2000

Pictures from an exhibition...

Some of the exhibits and a demonstration during the SACLANT MCM Development Shop Window organized by SACLANTCEN for SACLANT

Clockwise from top right:

Pluto GIGAS
MIT ODYSSEY
Pluto GIGAS (Italy)
Pluto GIGAS
SEAFOX (Germany)
Office of Naval Research
FAU Explorer
Source

Annual Progress Report 2000

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Annexes

"...conduct research in support of NATO's undersea operational requirements."

The year 2000 did witness significant progress in the quest for a stable funding regime, a dominant theme since 1998. Canada agreed to act as lead nation in a further review of the Centre's procedures and the *Scientific Programme of Work* by the Senior Resource Board Study Team. Intensive preparation and collaboration between HQ SACLANT, the Scientific Committee of National Representatives and the Centre, contributed to an explanation and demonstration of the vital role of the Scientific Programme of Work to the continued operational viability of NATO. The Senior Resource Board Study Team also recognized that the Centre has instigated an efficient and transparent financial management system and that further improvements were being evaluated, including the extension of ISO quality management, which at present is applied only to the R/V *Alliance*, to the Centre as a whole. The findings of the Study Team were confirmed during a visit by a Senior Resource Board delegation in June, the month in which the Military Committee visited the Centre. The visit by the Military Committee, originally planned to coincide with the 40th anniversary in 1999 and postponed due to the Kosovo crisis, represented a much valued and long awaited opportunity for the staff of the Centre to interact with the highest NATO military body, highlighting the importance of focusing on military requirements and the transmutation of scientific research into operational relevance today and in the future.

The quality of the scientific vision of SACLANTCEN has been tellingly demonstrated by the fact that several major projects in the *Scientific Programme of Work* have for several years addressed research recommended by the *Long Term Study of the Implications of New Technologies on Maritime Operations in 2015* (MO 2015). The study was completed under the directorship of SACLANT HQ in 2000, with important contributions by SACLANTCEN scientists.

The resource implications of relevant parts of MO 2015 and other high profile themes such as Defence Capabilities Initiative (DCI) and Concept Demonstration and Experimentation (CDE) are reflected in the *Medium Term Financial Plan 2002-2006*. Further integration will be in the forthcoming *Business Plan*.

The results of MO 2015 provided the impetus for the highly successful *MCM Development Shop Window*, sponsored and hosted by SACLANT, organized by the Centre and attended by 200 visitors from nations and commands and industry, with significant representation at flag level. Demonstrations, displays and presentations contributed to a valuable exchange of information and discussion of future concepts.

The NATO Maritime Rapid Environmental Assessment Concept of Operations, endorsed by the Military Committee in March 2000, designated the Centre, in collaboration with the REA Command and Support Centres, as the data-fusion site for future REA operations.
The Centre's Autonomous Ocean Sampling Network (AOSN) technology capability has been enhanced by a second experiment in the Generic Oceanographic Array Technology System (GOATS) series. Advances were demonstrated in AUV network technology, adaptive AUV sampling and AUV operations with REA and MCM components. GOATS was augmented significantly by the integrated Multi-scale Environmental Assessment Network System (MEANS). The potential for determining seabed properties *through-the-sensor* was demonstrated in a geo-acoustic inversion experiment on the Malta Plateau. Experimental results from a towed array rather than a fixed system demonstrated operational as well as performance advantages.

Progress towards the implementation of Synthetic Aperture Sonar (SAS) in an AUV was demonstrated with the production of SAS images from a towed body at sea. Additionally five years work on the impact of the environment on minehunting sonar, has included the development of a methodology for seabed classification through the inversion of multibeam data and the delivery of time domain, HF scatter and LF seabed penetration models. The Centre's planning and analysis of minehunting percentage clearance trials, a measure of how accurately NATO minehunters report their operational effectiveness, has proved to be very popular with the operational community.
Analysis of the 1999 tactical active sonar experiment revealed severe degradation of the performance of the cardioid array. Shortcomings in the array's mechanical characteristics have been rectified. A significant milestone was reached in the ASW programme with the placing of the contract for the buoys for the Deployable Underwater Surveillance System. The development of new techniques for the measurement of low frequency scattering and reverberation will enable adequate data acquisition for improved sonar performance prediction in shallow water.
There could be no clearer manifestation of the underlying support for the Centre throughout NATO, spearheaded by SACLANT, than the soon to be launched, state-of-the-art coastal research vessel *Leonardo*, the first Italian Public Vessel on a newly created Ministry of Defence register. This tangible evidence of the esteem with which the work of the Centre is perceived by SACLANT is fundamental to the continued ability of SACLANTCEN to attract the best scientific talent in NATO in order to be able to comply with the mandate of the North Atlantic Council.

Thrust 01 Rapid Environmental Assessment (REA)

1

Project 01-A: Rapid assessment of operational ocean parameters (Manning days -1)

Operational Relevance

Rapid Response, the third in the series of demonstrations of skills in rapid environmental assessment (REA) ended in 1998. A comparable demonstration bringing together research organizations and military command structures with common purpose will not reoccur until 2002 in support of Strong Resolve. REA methodologies continue to be developed in parallel with validation of the SACLANT concept of REA operations by the NATO MILOC community.

Exercise support for Linked Seas 2000

milestone

During Linked Seas 2000, for the first time, survey vessels were exclusively military. The REA commander controlled the survey, for which the plans had been designed by the military oceanography (MILOC) syndicate or, in the case of ocean sampling, by an ocean modeller.

SACLANTCEN supported the REA components of Linked Seas by embarking a group of scientists on *HMS Roebuck*, to conduct a survey using expendable bottom penetrometers (XBP), sidescan sonar and a device to measure bottom reverberation. The data were rapidly processed and fused into a decision aid (Figs. 01-A.1a and 01-A.1b).

Spread spectrum radios for line-of-sight communication were provided to the survey ships with computers and software, which automatically and transparently transfer data between all partners in the network until each holds the complete set of data. It is only necessary to load acquired data into the system. Survey data from the ships were thus concentrated on the Portuguese vessel *Dom Carlos*, from whence new information was transmitted twice daily *via* Inmarsat B satellite link to the shore-based data fusion centre. Acknowledgement messages confirmed transfer to every data originator. Although the Linux-based system RIAB[1], had been under development to the last minute, it performed flawlessly.

Ocean modelling for Linked Seas at SACLANTCEN was concentrated on support for the mine countermeasure forces, to whom excessive ocean currents would be a challenge. The Harvard Ocean Prediction System was initialized with data from the initial ship survey and forced with atmospheric model fields spanning 7 days of forecast. They were obtained from the Bundesamt für Wehrgeophysik in Traben-Trarbach, Germany. Two scientists from the Instituto Hidrografico in Lisbon, Portugal, at the Centre assisted with numerical ocean modelling. The currents produced by internal ocean dynamics and wind action were weak and therefore comparable with the strength of tidal currents in that area. Tidal currents computed by Instituto Superior Técnico in Lisbon with three hours time resolution (Figs. 01-A.2 and 01-A.3) were displayed on the web site of the data fusion centre (Fig. 01-A.4).

[1] REA in a box.

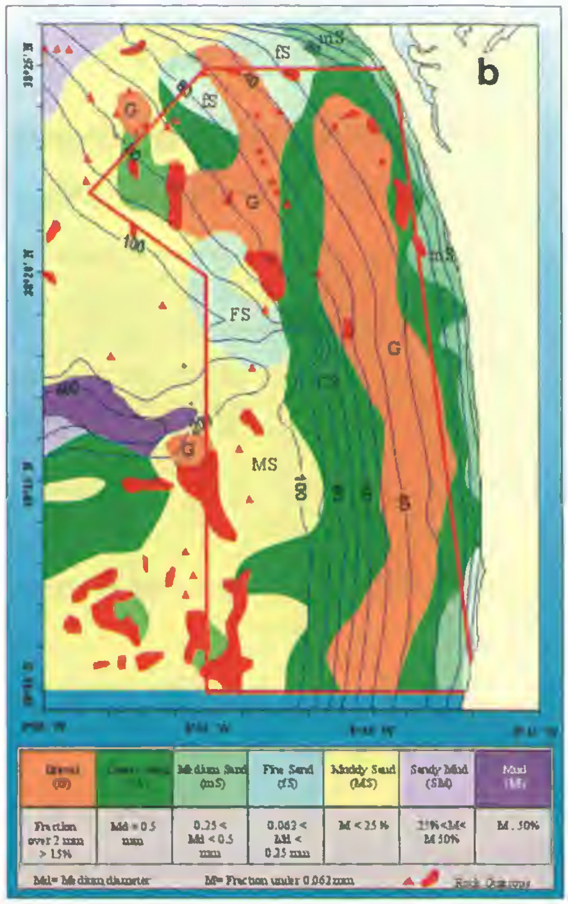


Figure 01-A.1a/b *Bottom classification results (from the SACLANTCEN team embarked on HMS Roebuck) indicating low probability for impact burial of sea mines in agreement with an existing map of sediment properties.*

Data fusion for Linked Seas 2000 was based in La Spezia, as in previous REA exercises. The fusion team was augmented by information technology specialists from France, Germany and the Netherlands. The majority of data was received and distributed by a server on the Internet, where access was restricted to authorized persons. As some data were not released for transmission through the Internet a restricted web site was also maintained on the NATO Intermediate Data Transfer System (NIDTS) (Fig. 01-A.5). Incremental backups of the unclassified data set were transferred regularly to NIDTS and merged with the restricted information. Following Linked Seas 2000, procedures for the maintenance of a REA data fusion centre were prescribed in a report[1].

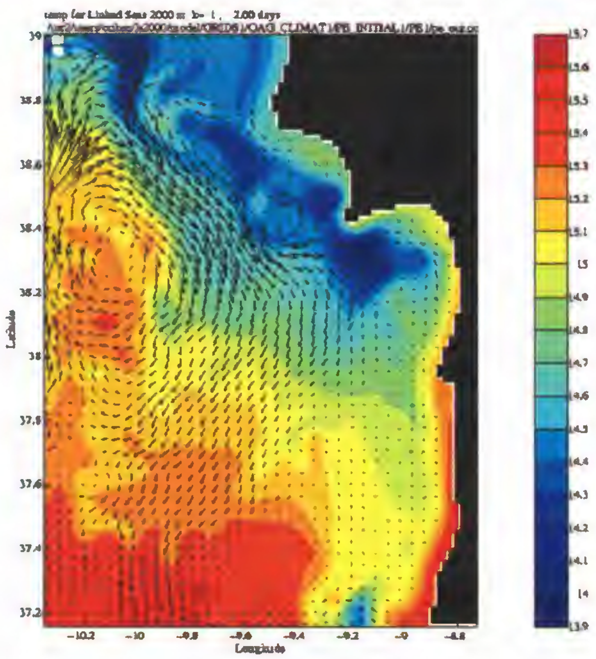


Figure 01-A.2 *Forecast of surface temperatures and currents in the Linked Seas 2000 model domain The Harvard Ocean Prediction system was initialized and updated with* in situ *measurements from survey ships and forced by atmospheric forecast fields provided by the Bundesamt für Wehrgeophysik.*

milestone

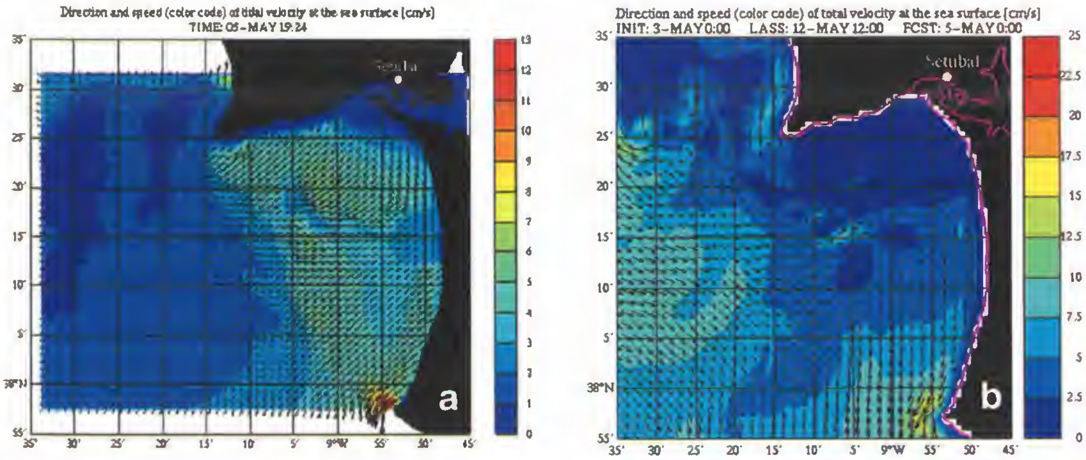


Figure 01-A.3 *a) Model result for the small (nested) domain of the Linked Seas exercise area. The colour scale indicates the strength of sub-tidal surface currents (time scales longer than those of tides). b) Tidal currents calculated by Instituto Superior Técnico from deep ocean tides and shelf topography. Forecast currents are the sum of sub-tidal and tidal currents.*

Multiscale Environmental Assessment Network Studies (MEANS)

In spring 1999, when the scientific programme of work for 2000 was already drafted, a Joint Research Project (JRP) was suggested (MEANS) to be carried out in conjunction with the existing JRP named GOATS (Project 01-B) to exploit ship time at night.

The Naval Oceanographic Office at Stennis Space Center operationally runs a 3-D ocean model (SWAFS) of the Mediterranean Sea with a two day forecast. It is forced with meteorological forecast fields (COAMPS) from the Fleet Numerical Meteorology and Oceanography Center. It assimilates satellite sea surface temperature and *in situ* data of opportunity, mainly temperature profiles (XBT) taken by US navy ships. An unclassified version has been run in parallel since winter 2000. The unclassified model results are made available to NATO and hence to the MEANS JRP. The University of Colorado version of the Princeton Ocean Model (CU-POM) tailored to the Ligurian Sea uses the SWAFS output as initial conditions and continuously assimilates its result at the boundary of the Ligurian Sea domain (Figs. 01-A.6, 01-A.7). The Harvard Ocean Prediction System (HOPS) was applied in the Corsica Channel domain (Fig. 01-A.8) and in a small sub-domain at Elba with 225 m model resolution. The boundary values for the sub-domain were always taken from the results of the larger area, while the Channel domain was run with both options: with boundary conditions taken from CU-POM and with open boundaries.

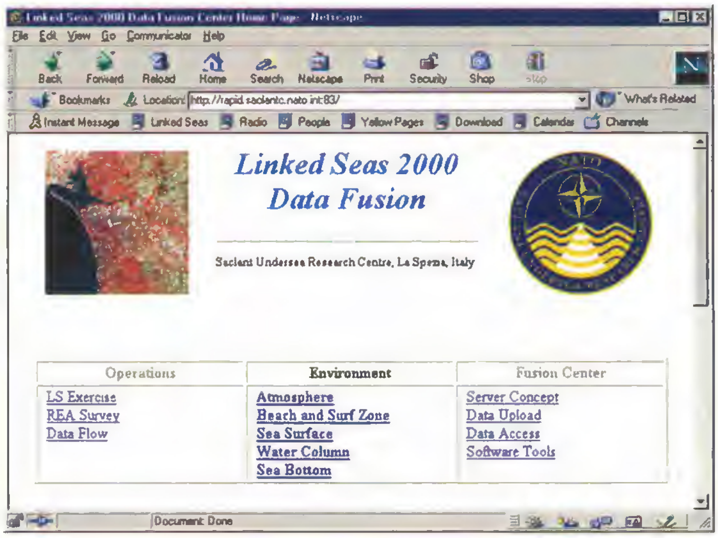


Figure 01-A.4 *The Linked Seas 2000 data fusion home page combines structured entries to environmental information with organizational and survey documentation and provides answers to technical questions.*

[1] SACLANTCEN SR-336

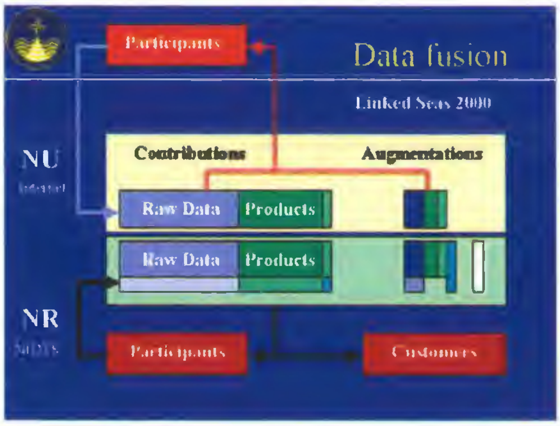


Figure 01-A.5 *Schematic diagram of data fusion. Contributions delivered at the fusion centre are immediately available to all contributors in the network. The fusion team prepares inventories, visualizations and combined products. It creates hypertext pages for optimal accessibility. The unclassified server content is mirrored to a restricted server and enriched with restricted and proprietary data.*

Dense sampling of temperature and salinity data by NRV *Alliance* prior to the GOATS experiment provided excellent initial values for the numerical models in the eastern Ligurian Sea. Limited radius night excursions of the *Alliance* during GOATS yielded sufficient data to prevent degradation of the model of the Channel domain. Satellite sea surface temperature images were useful for the assessment of the oceanographic situation and for track planning. Shipborne acoustic Doppler current profiler (ADCP) measurements were used for verification of the model results. The ocean model was also prepared to ingest data from autonomous underwater vehicles (AUV). The area in which AUVs were operated was however too small for their data to be of major value.

In the MEANS programme, data acquisition and processing at sea was conducted by Centre personnel. A SACLANTCEN ocean modeller went to Harvard University for participation in HOPS modelling. The Centre also took care of the model runs of CU-POM and of the arrangement of SWAFS and COAMPS fields. In MEANS it was successfully demonstrated that ocean models of different origin, maintained in different places can be compelled to interface for multiple nesting operational forecast. Whether nesting has an advantage against open boundary conditions must be decided separately for each ocean area under consideration.

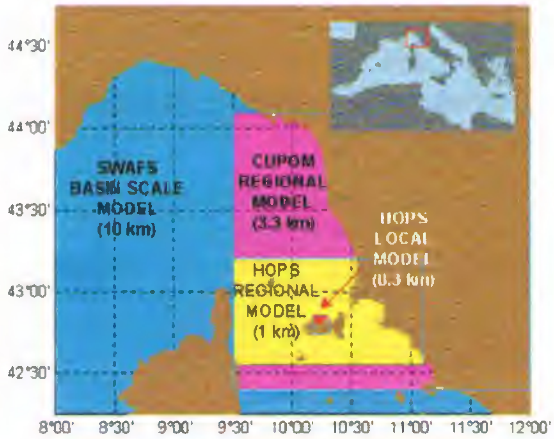


Figure 01-A.6 *Pre-defined model domains for the MEANS experiment. SWAFS covers the whole Mediterranean Sea. It relies on sparse* in situ *assimilation data. The CUPOM area was extended to double size towards the west. MEANS initialization took place in the pink and yellow area, with update sampling in the yellow area.*

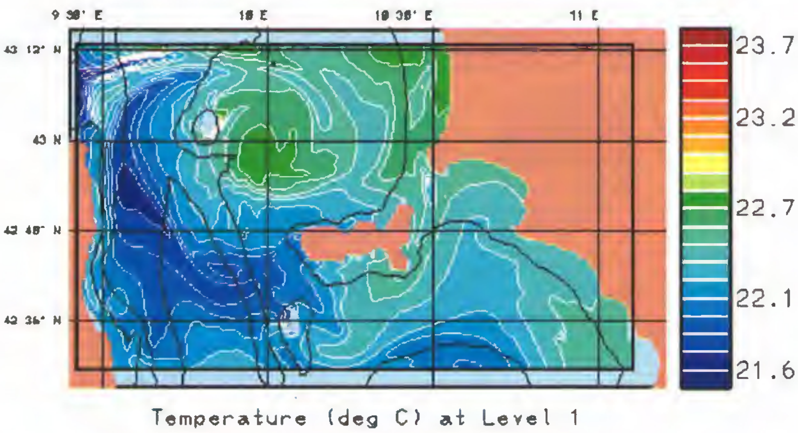


Figure 01-A.7a *The Corsica Channel domain was run with open boundary conditions (a) and with boundary conditions taken from the CU-POM output fields (b). While the main features are unchanged, warm and saline water from a coastal patch in CU-POM is sucked into the Capraia eddy when models are nested.*

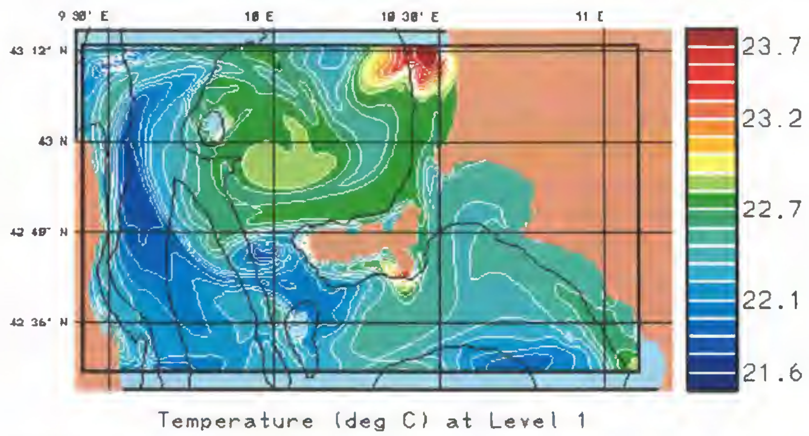
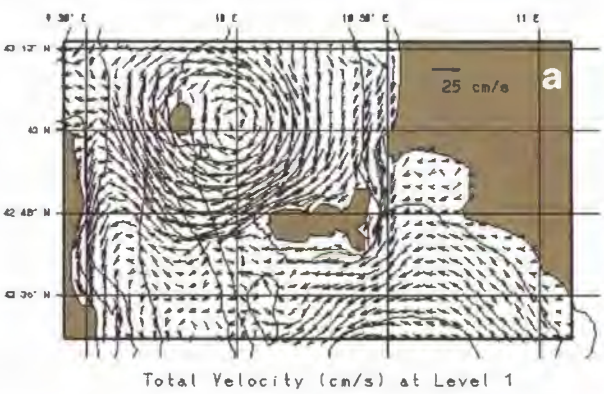


Figure 01-A.7b

A satellite-based ocean forecasting system for operational time scales uses a time series of satellite images of the area of interest as input to the forecasting system. Forecast fields are obtained in three consecutive phases. First, the space-time variability in the time series of satellite data is divided into space and time components. In a second phase, each



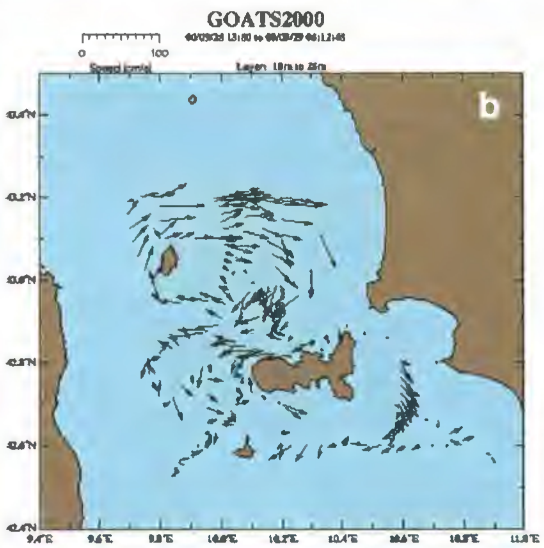


Figure 01-A.8 *The numerical model result of a clockwise rotating eddy (a) is verified by current measurements taken by NRV Alliance during her update surveys (b).*

component of the variability, spatial and temporal, is analyzed separately in order to isolate the deterministic part of the variability. Finally, artificial intelligence is employed to forecast the deterministic part of the time variability. A novel genetic algorithm and an evolutionary neural network have been developed for this purpose. The total forecast field is obtained by the combination of the deterministic spatial variability with the forecast time variability.

Satellite-based ocean forecasting systems

The availability of suitable *in situ* measurements for assimilation into ocean forecast models cannot be guaranteed under all circumstances. Satellites sometimes constitute the only way to discreetly monitor space-time oceanographic variability in coastal areas at acceptable spatial and temporal resolutions simultaneously. The ability to carry out ocean forecasts based exclusively on satellite remote sensing would constitute a great advantage.

In support of the GOATS/MEANS experiment, the forecasting system was implemented to obtain monthly mean sea surface temperature (SST) forecasts and estimates of surface currents of the eastern Ligurian Sea. A time series of monthly mean SST ranging from March 1993 to December 1998 has been acquired as input to the system. One-month-ahead forecasts of monthly mean SST fields were compared with data from 1999 for validation of the system performance. Results of one-month forecasts from the system were in excellent agreement with observations (Figs. 01-A.9, 01-A.10, 01-A.11).

Future work will be focused on the development of hybrid forecasting systems, in which the satellite based ocean forecast will provide surface fields to be assimilated into numerical and ocean thermal models. Partners in this effort are funded by the European Community.

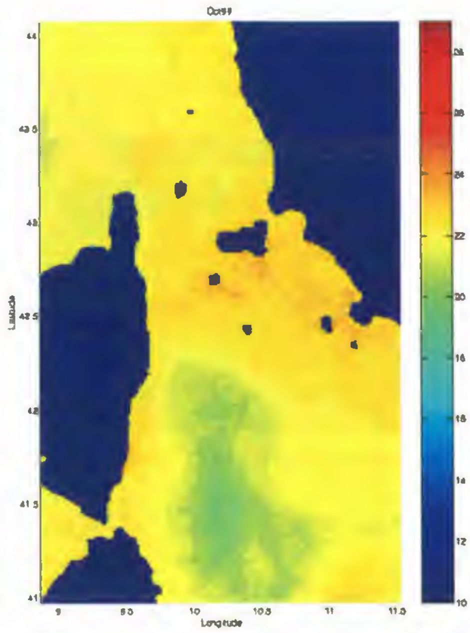


Figure 01-A.10 *Mean satellite sea surface temperature in October 1999.*

Sensor platform in trawl-safe real-time configuration

The SEPTR system – its full name is "Shallow-water Environmental Profiler in Trawl-safe, Real-time configuration" – is intended for extended duration deployments in areas where water column instruments are at risk from fishing trawlers. Real-time data return and control are achieved *via* two-way cellular or satellite communication.

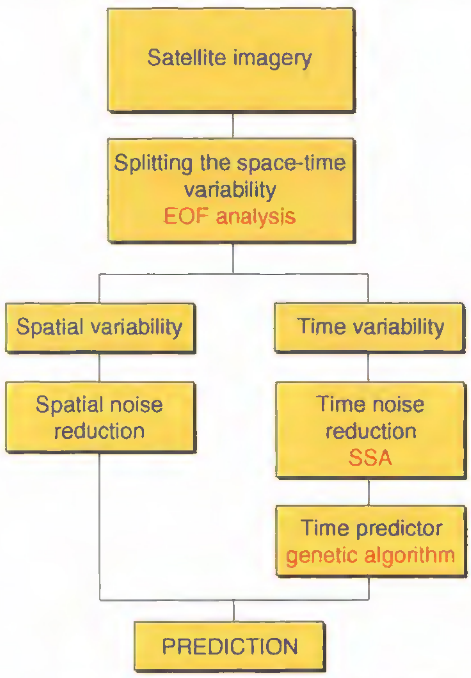


Figure 01-A.9 *Flow diagram for the prediction of the sea surface temperature field.*

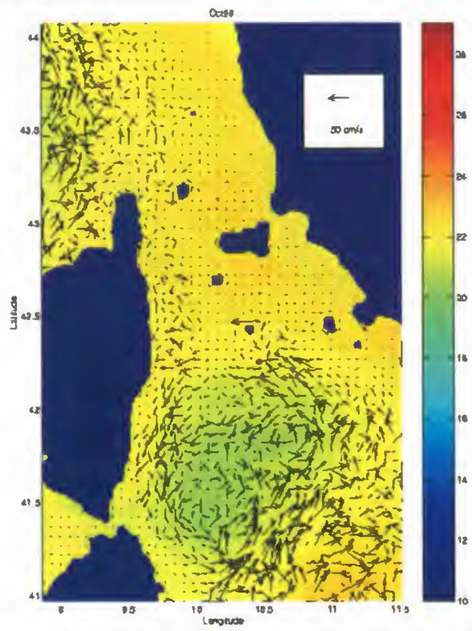


Figure 01-A.11 *One-month-ahead forecast of SST and surface currents for October 1999.*

The SEPTR design (Fig. 01-A.12 and 01-A.13) consists of a trawl-safe bottom platform, which houses an Acoustic Doppler Current Profiler (ADCP), wave/tide gauge, ambient noise sensor array, and buoyant water column profiler. The

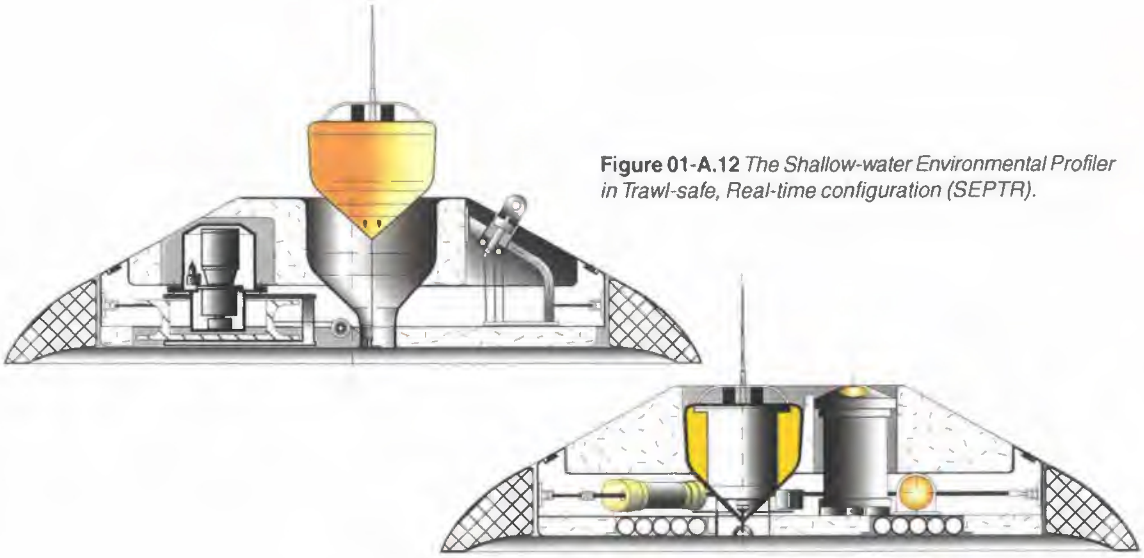


Figure 01-A.12 *The Shallow-water Environmental Profiler in Trawl-safe, Real-time configuration (SEPTR).*

profiler buoy and associated winch are designed for autonomous vertical profiling of CTD, optical and acoustic properties of the water column in depths down to 100 m. The buoy includes DGPS navigation and two-way communication for use while on the surface, acceleration, pressure and magnetic field sensors for surface wave measurements. The bottom platform includes an extended duration battery package in the recoverable barnacle-shaped housing. For recovery of the entire system, a messenger buoy is released either by a command through the normal communication channel to the profiler or by means of an acoustic transponder/release in the bottom platform.

If the platform becomes inverted the buoyant central housing can still be realeased through the bottom by command to a backup acoustic transponder system within the bottom platform. The system is designed for 360 profiles during a 3-month deployment in 100 m water depth, with current, wave/tide and noise measurements every hour. Two way communication of data, position and control allows profile results to be returned in real time, and operational commands such as profile schedules to be sent to the instrument (Fig. 01-A.14). Complete profiles are also stored on board the recoverable units.

problem

Critical subsystems were tested successfully in November 1999. System testing in 2000 resulted in minor modifications. The first operational test during the sea trial GOATS/MEANS 2000 was discontinued when sand fouled the spooling mechanism of the profiler buoy. The mechanical problems have been solved (Fig. 01-A.15). Tests will be continued as ship and engineering time permits. Given favourable conditions, a SEPTR will be deployed during the experiments in summer 2001. The Centre is committed to SEPTR operations during the exercise Strong Resolve 2002.

milestone

Figure 01-A.13 *The SEPTR can be deployed and recovered from a small vessel. Here the cover is opened showing the interior with flotation removed. The central part is occupied by the Acoustic Current Doppler Profiler (ADCP) with 4 transducers, the water column profiler with antenna and the messenger buoy for instrument recovery.*

Figure 01-A.14 *During operation only the profiler with antenna surfaces. Coloured differently it would be virtually invisible.*

problem

The REA cruise in November was cancelled. It had been planned for real-time support of a tri-lateral sea trial for multistatic submarine detection, for which the requisite equipment had not timely been in place. The 01-A cruise time was allocated to Project 01-B in exchange for a commensurate period in January 2001.

The Fusion Centre

Under the terms of the mutually advantageous Memorandum of Agreement[1] between the Centre and Commander, Naval Meteorology and Oceanography Command (COMNAVMETOCCOM), negotiated by Dr William Jobst (Deputy Director and Head of the Scientific Division 1998-2001), oceanographic/ atmospheric modelled products are made available to the Centre for value added oceanographic and acoustic research,(Fig 01-A.16).

Figure 01-A.15 *Divers observe the function of the SEPTR during a test deployment.*

Two commercial GIS systems, WIPE[2] and ESRI[3], utilizing client-server technologies, were procured and installed on a powerful Windows-NT dual-processor server, to host an array of geo-spatial information and provide on-line connectivity to satellite observations.

WIPE provides the framework for near-real-time image processing and GIS analysis using web-based technologies. WIPE can automatically ingest, post-process and browse data from a number of satellites.

In addition to the satellite imagery, data-bases containing the digital terrain models (DTM) and bathymetry are available for different regions at various horizontal resolutions. WIPE has also been configured to ingest and process information from the Naval Oceanographic Office (NAVO), Fleet Numerical Oceanographic Meteorological Center (FNMOC), University of Colorado (UC) and Harvard University (HU).

[1] "a) The Commander, Naval Meteorology and Oceanography Command (COMNAVMETOCCOM) desires to improve the coverage and resolution of US Navy gridded ocean models in the Mediterranean Sea, as well as the Black Sea and Baltic Sea, and to acquire ground truth data for testing and validation of related U.S. models in these areas.

b) Supreme Allied Command, Atlantic Undersea Research Centre (SACLANTCEN) desires to develop high resolution research models addressing littoral oceanography, sedimentation, biological processes and other projects within the Scientific Programme of Work (SPOW) assigned to SACLANTCEN."

[2] Web Image Processing Environment (WIPE)

[3] Environmental Systems Research Institute (ESRI)

The ESRI system supports the following data:

Scenario data	Status	Type	Area
Coast lines and bathymetry from various sources	*Loaded*	*Points, Lines, Polygons*	*North and Central Tyrrhenian sea South Ionian sea in S57, from ITHO, All Mediterranean from GEBCO*

SACLANTCEN data	Status	Type	Projects
Bathymetry acquired with EM3000 or the Atlas Multibeam	*Loaded*	*Polygons*	*01-B*
Bottom types	*Loaded*	*Polygons*	*01-B, 01-A*
Sediment thickness	*Loaded*	*Polygons*	*01-B, 01-A, 04-C*
CTD/XBT stations	*Loaded*	*Points*	*01-B, 01-A*
Side scan sonar images.	*Loaded*	*GeoTiff Images*	*01-B*
Sub bottom profiles	*Loaded*	*Images*	*01-B, 04-C*
Sea floor samples (cores, grabs)	*Loaded*	*Points*	*01-B*
Sea floor images	*Loaded*	*Images*	*01-B*
Mammal observations, strandings and related data including bibliography	*Planned*	*Points*	*06-C*
Water properties	*Planned*	*Grids*	

Figure 01-A.16 *From right to left: Dr William Jobst, Deputy Director, SACLANTCEN; Dr M.J. Carron, Chief Scientist, Naval Oceanographic Office, Stennis Space Center; Jan L. Spoelstra, Director, SACLANTCEN; RADM Richard D. West, Oceanographer of the Navy; CDR Brian Williams, SACLANTCEN Naval Adviser, meeting in November to discuss mutual benefits of the "enduring relationship" recognized in the Memorandum of Agreement.*

Figures 01-A.17 to 01-A.20 show Fusion Centre products. Figure 21 shows the flow of information to and from the Fusion Centre.

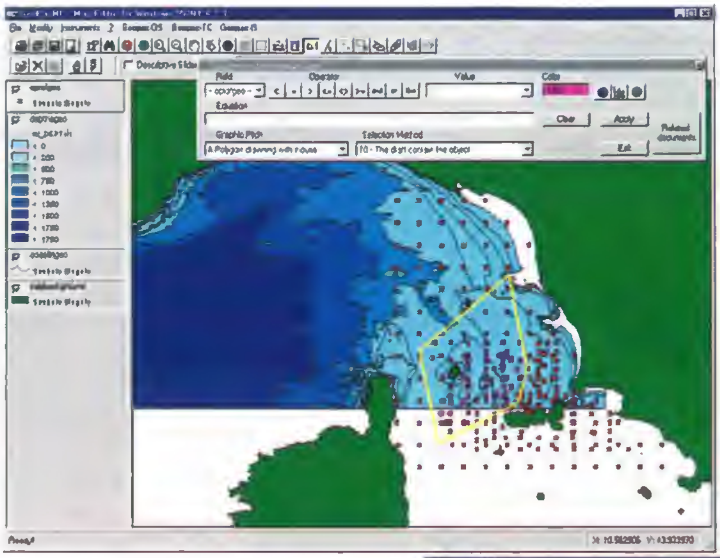


Figure 01-A.17 *ESRI GIS representation of CTD data sites in the north Tyrrhenian Sea with sub-sampling polygon.*

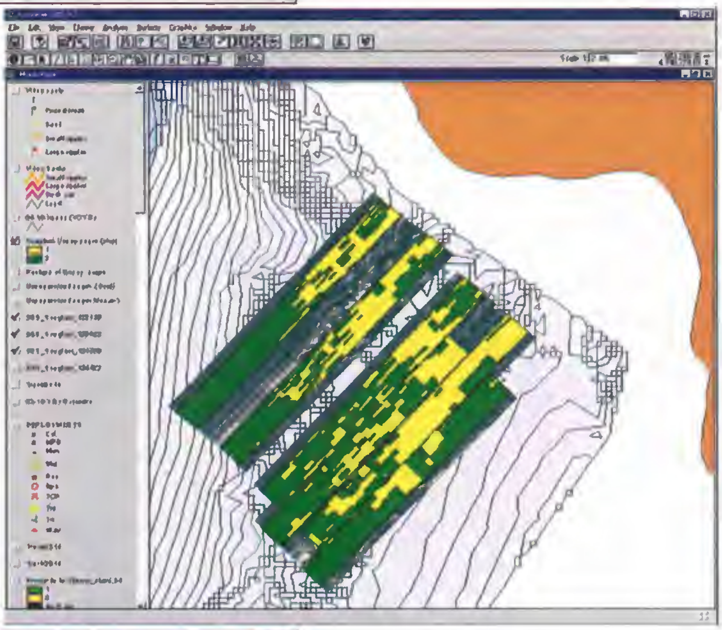


Figure 01-A.18 *ESRI GIS representation showing sea floor unsupervised segmentation from side scan sonar image (sand [yellow] and Posidonia [green]) superimposed on 0.5 m bathymetric contours.*

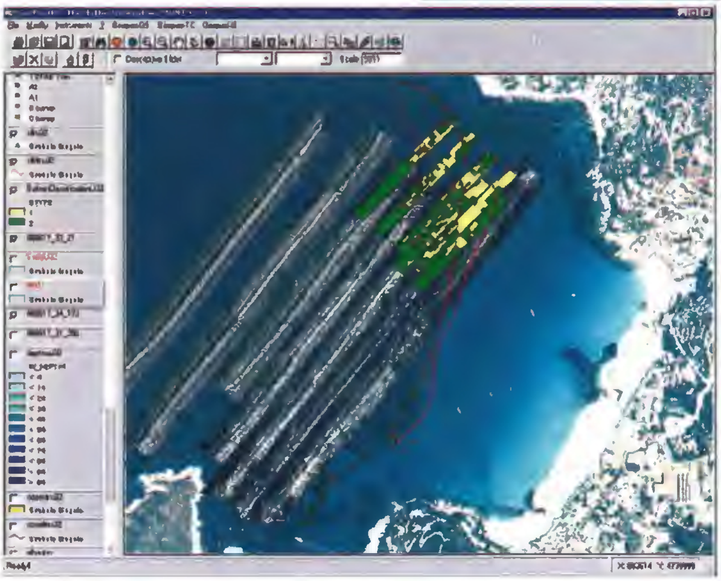


Figure 01-A.19 *ESRI GIS representation of the Gulf of Biodola, showing an aerial photo, side scan sonar, unsupervised segmentation, a ship track and locations of sea floor video images.*

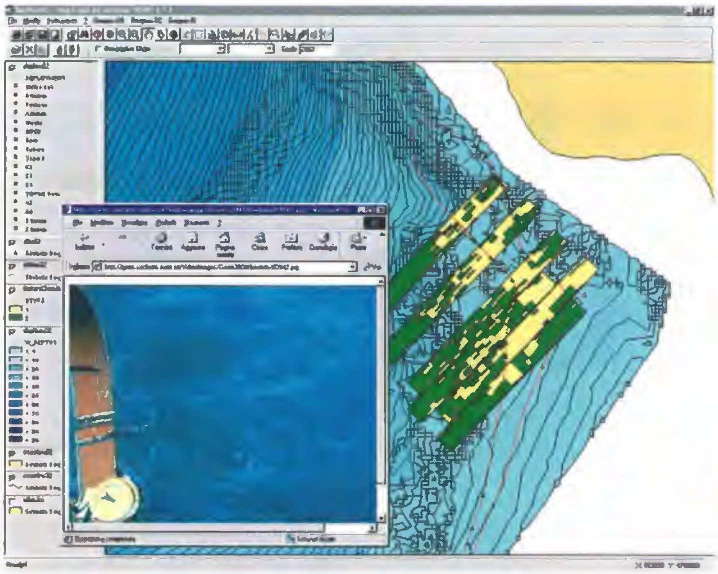


Figure 01-A.20 *ESRI GIS representation of bathymetry, unsupervised segmentation and video images locations, with one image displayed.*

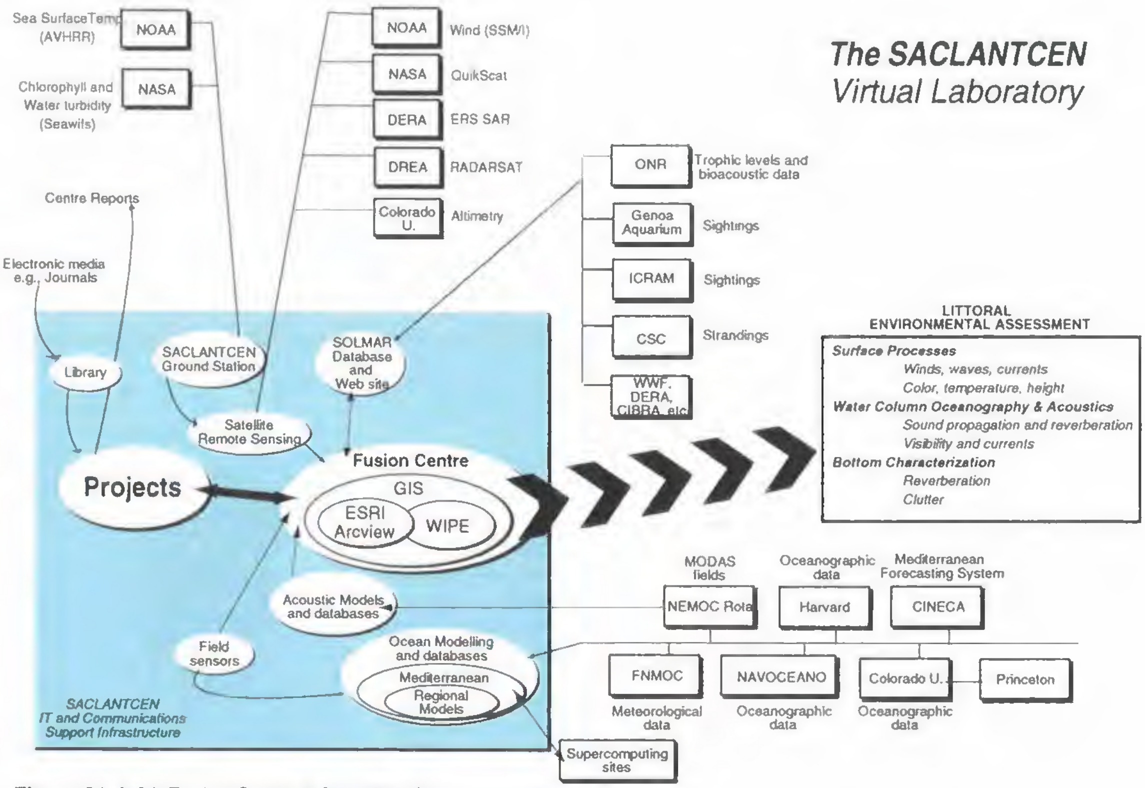


Figure 01-A.21 *Fusion Centre information flow*

Jürgen Sellschopp *received his diploma in physics at the Institut für Kernphysik, University of Kiel and his Ph. D. at the Institute 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.*

Alberto Alvarez Diaz *was awarded first and masters degrees in physics by the Universidad de Santiago de Compostela in 1991 and the PhD by Universidad de les Islas Balears in 1995, since when he has been appointed to academic positions at both universities (1990-1997) and the Taiwan National Central University (1997-1999). He joined SACLANTCEN in May 1999.*

Farid Askari *received the B.S. (1977) degree in Engineering from Purdue University, West Lafayette, IN., the M.S. (1979) and Ph. D. (1985) degrees, respectively, in remote sensing and physical oceanography from the Ohio State University, Raleigh, N.C. During 1988-1997 he was employed by the U.S. Naval Research Laboratory (NRL) Washington, DC as a research physicist and head of the Ocean Measurements Section between 1991-1993. Since 1980 he has been working in the areas of remote sensing, image processing and pattern recognition and has served as principal investigator on several international projects. Since joining the Centre in 1997 his research interests have included microwave imaging of the ocean surface, sensor fusion and development of tactical decision aids for rapid environmental assessment.*

Lakshmi Kantha *graduated with distinction as a Bachelor of Engineering from Bangalore University. He was awarded with distinction, the Master of Engineering degree by the Indian Institute of Science and a PhD by the Massachusetts Institute of Technology. He has held research and consultancy positions at the National Aeronautical Laboratory, Bangalore, MIT, Johns Hopkins University, Dynalysis of Princeton, Princeton University, the Institute for Naval Oceanography, NOARL, NRL and the Naval Oceanographic Office. Since 1991 Professor at the Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research, University of Colorado, Boulder, Lakshmi Kantha spent 2000 as a sabbatical year at the Centre. Professor Kantha has been a member of numerous boards, panels, working groups, committees and professional and academic societies and is the author of numerous papers and two books.* www-ccar.colorado.edu/~kantha.

Reiner Onken was awarded the degree of Diplom-Ozeanograph at Kiel University in 1982 and the Ph.D. (Dr.rer. nat.) in 1986, for a thesis entitled "Numerical simulation of the generation and the instability of mesoscale fronts" after four years as Research Assistant at the Institut für Meereskunde, Kiel, to which he returned as Research Assistant and Assistant Professor, following one year as Research Assistant at the Robert Hooke Institute, Oxford. He has been a principal scientist at SACLANTCEN since 1996, where he pursues his research interests of modelling, mesoscale, sub-mesoscale dynamics and large scale circulation of the Atlantic and Mediterranean.

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.

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Project 01-B: Rapid environmental assessment of operational acoustic parameters (Alliance days - 62, Manning days - 39)

1

Operational relevance

Provide detailed, accurate environmental information at short notice in near real-time

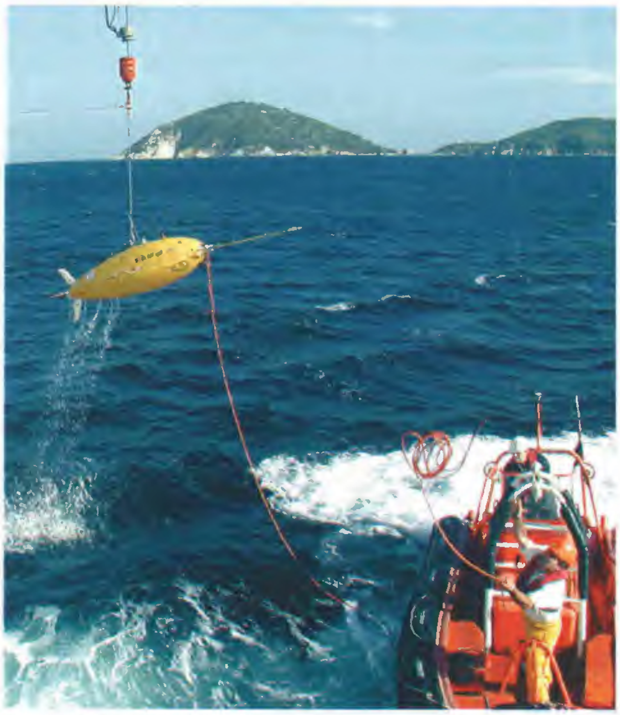


Figure 01-B.1 *The Ocean Explorer (OEX) vehicle developed by Florida Atlantic University, deployed to map the Gulf of Procchio with video camera and dual frequency (100/390 kHz) side scan sonar.*

Mapping and characterizing the seabed and ocean with autonomous underwater vehicles

Progress in underwater robotics has led to a new paradigm in ocean science and technology, the Autonomous Ocean Sampling Network (AOSN) consisting of a network of fixed moorings and/ or autonomous underwater vehicles (AUV) linked by acoustic communication. An example of AOSN is the Generic Oceanographic Array Technology System (GOATS), which was designed to study AUVs equipped with inter-vehicle synchronization, communication and navigation to achieve large spatial sampling for acoustic and non acoustic measurements. The GOATS concept, well suited to rapid environmental assessment in denied areas, was tested during GOATS 2000 off the Island of Elba in the autumn.

Following a proposal by the Office of Naval Research, the scope of GOATS was broadened to provide input data for oceanographic modelling in support of the Multi-Scale Environmental Assessment Network Studies (MEANS). The REA component of the experiment was in support of Project 01-B, the MCM component was in support of Project 03-G. MEANS was performed in cooperation with Project 01-A.

The Ocean Explorer (OEX)[1] equipped with a colour video camera and the Edgetech dual frequency DF-1000 side-scan sonar (Fig. 01-B.1) and the TAIPAN (LIRMM)[2] equipped with the Applied Microsystem CTD (Fig. 01-B.2), were

[1] Developed by Florida Atlantic University.
[2] Laboratory of Robotics of the University of Montpellier

Figure 01-B.2 *The TAIPAN vehicle developed by LIRMM measured salinity and temperature distribution in Biodola bay.*

deployed from R/V *Alliance*, to transect the bays to the east of Procchio, Island of Elba, to acquire side-scan sonar data and to measure currents, salinity (Fig. 01-B.3), density and temperature, as input to 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 was fused in the SACLANTCEN GIS database. The tiled side scan sonar images were processed with unsupervised segmentation algorithms that demonstrated the capability to distinguish quantitatively between different types of seabeds (Fig. 01-B.4), (i.e. sand, sand ripples and Posidonia).

Estimating seabed geo-acoustic properties with expendable/ deployable devices

Geo-acoustic inversion methods- "REA-through-the-sensor"

Sound propagation variability in shallow water can be attributed to a number of environmental factors, including surface wave-height conditions, water column sound speed properties, bathymetry and seabed type. To optimize sonar system performance, sound propagation prediction tools are used, which require as input the geo-acoustic properties of the seabed. When existing archived data are insufficient, techniques are needed to rapidly and easily assess seabed properties.

Matched Field Processing (MFP) geo-acoustic inversion infers seabed properties from acoustic measurements. Computer simulation is used to model the down-range acoustic response to different seabed types and search algorithms are applied to identify the environment which optimally correlates modelled with measured data. MFP inversion was used to predict seabed properties during Advent99, a series of joint SACLANTCEN, TNO-FEL experiments, which provided the basic tools and understanding of the limitations of MFP inversion, using a vertical array and laid the foundation for the method to be applied to measurements acquired with a more easily deployed towed array.

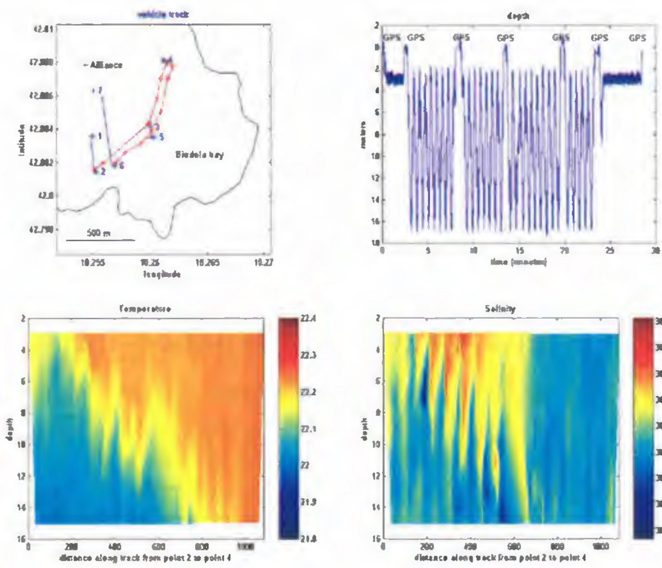


Figure 01-B.3 *The TAIPAN AUV equipped with the Applied Microsystem CTD measured temperature and salinity distribution in Biodola bay. The figure shows the horizontal and vertical tracks of one mission and the measured temperature and salinity fields.*

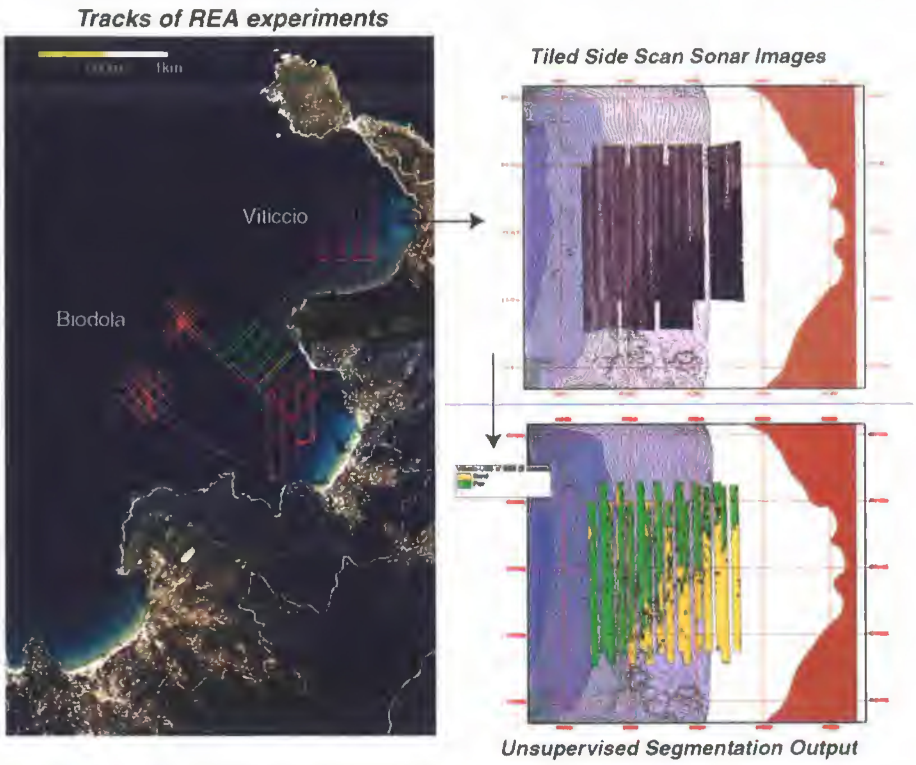


Figure 01-B.4 *The Ocean Explorer AUV equipped with side scan sonar and video camera performed several REA experiments in Biodola and Viticcio bays. The figure shows the tracks and one example of the tiling of side scan sonar images in Viticcio bay. The output of the unsupervised segmentation algorithm for the same mission clearly identifies the boundaries of the Posidonia field*

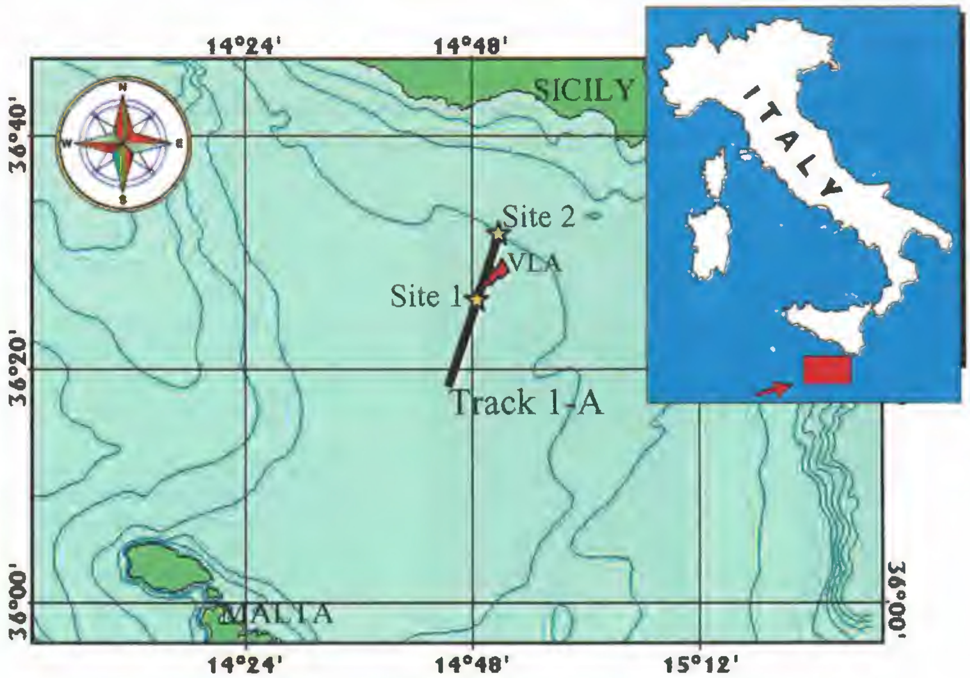


Figure 01-B.5 *Wind analysis.*

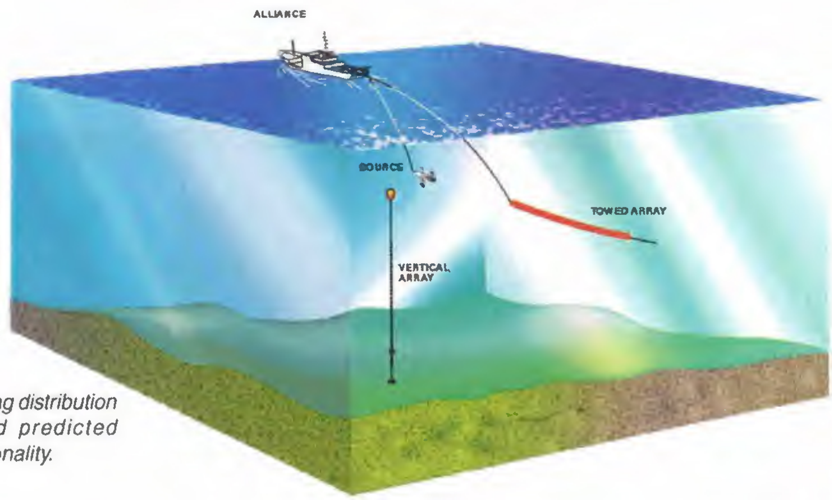


Figure 01-B.6 *Shipping distribution from Radarsat and predicted ambient noise directionality.*

The concept of determining seabed properties using Rapid Environmental Assessment-through the sensor was tested during MAPEX2000 which took place in March on the Malta Plateau. The experimental site for one of the acoustic tracks is shown in Fig. 01-B.5. The acoustic data from a vertical array (near Site 1 in Fig. 01-B.5) was inverted for seabed properties to compare with the results from the towed array.

Figure 01-B.6 shows the experimental configuration. A one-second, linear, frequency modulated sweep (200-800 Hz) was transmitted from *Alliance* at Site 1 on March 7, 2000. The vertical array was moored approximately 1 km from the sound source; the towed array spanned ranges of 300-554 m behind. The matched filtered arrivals on the towed array are shown on the left of Fig. 01-B.7. The first two arrivals in Fig. 01-B.7 due to the direct and surface bounces, contribute *no* information about the seabed. Other arrivals *have* interacted with the seabed and therefore contribute information.

The complex-PROSIM propagation model and a genetic algorithm were used to identify the environment that produces a pressure field that best correlates with the measurements. These tools are now part of the SACLANTCEN inversion package SAGA. The pressure field corresponding to the best environment found in the inversion is shown in the right panel of Fig. 01-B.7. The environments giving the best fit to the measured data are shown in Table 1 for the vertical and towed arrays. For practical purposes, inversion results using the vertical and towed arrays are the same.

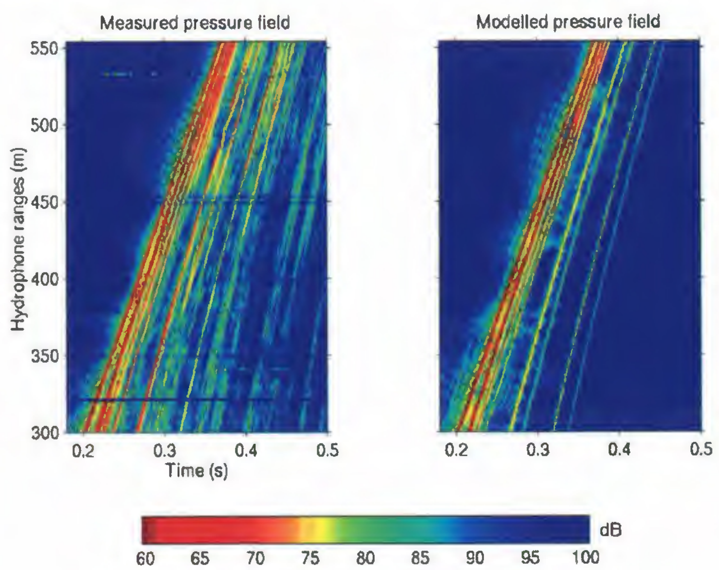


Figure 01-B.7 *Site of track 1-A from the MAPEX2000 experiments on the Malta Plateau. Site 1 and Site 2 are locations of geo-acoustic inversion and VLA gives the vertical array location.*

1

Array type	c_{sed} (m/s)	c_{bottom} (m/s)	h (m)	α (dB/λ)	ρ (g/cm^3)
Towed	1560	1653	19	0.1	1.3
Vertical	1554	1643	19	0.1	1.9

Table 1 *Seabed parameters using a vertical array and through-the-sensor (towed array). Values shown are sediment compressional sound speed c_{sed}, sub-bottom compressional sound speed c_{bottom}, sediment thickness h, attenuation α and density ρ.*

MAPEX2000 results illustrated performance advantages of the towed array system in addition to the operational advantages (compared to a fixed system). The shallow water area on the Malta Plateau has several seabed types determined from data collected during MAPEX2000 and other SACLANTCEN experiments[3]. A fixed system requires either a spatially homogeneous (in range) seabed or the estimated properties will represent averaged quantities over the acoustic track. When the source was at Site 2 (Fig. 01-B.5), the seabed properties had changed significantly and the water depth had decreased from 130 to 100 m. In Table 2, the inversion results for the towed array acoustic data at Site 2 are shown with the seabed properties of Site 1. The seabed near Site 2 has a softer sediment layer with sound speed less than the water column. The seabed type near Site 2 has no critical angle until the sub-bottom is reached, approximately 9 m below the water sediment interface, a feature which strongly influences acoustic propagation characteristics.

Location	c_{sed} (m/s)	c_{bottom} (m/s)	h (m)	α (dB/λ)	ρ (g/cm^3)

Table 2 *Seabed parameters at the two sites indicated in Fig. 01-B.5. These properties were estimated using through-the-sensor (towed array) technique.*

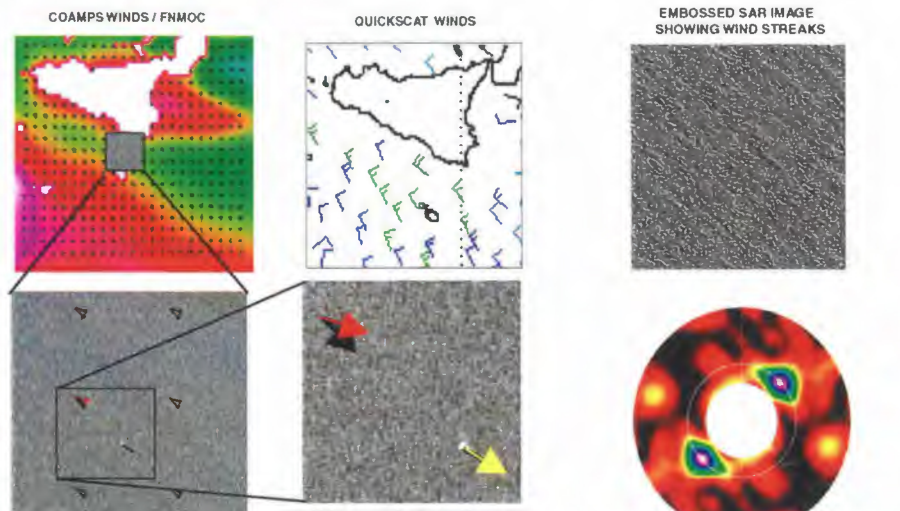
In the examples shown, *a priori* knowledge of the area was not assumed (the same procedure was used for data collected at Site 1 and Site 2). By not requiring manual adjustments to finding the seabed properties, the method is well suited as a survey technique for large area coverage. The good agreement between the inversion results between the data collected on the vertical and towed arrays is a valuable "sanity-check" for the through-the-sensor approach, illustrating the potential of the technique.

Fusing satellite sensor data to predict sea state shipping densities and oceanographic parameters

In order to test and validate inversion/detection algorithms, critical to ambient noise modelling and prediction, data from the Canadian RADARSAT/SAR (swath width 50 to 500 km; orbit frequency 1 to 4 days) and NASA's QuickSCAT Scatterometer (swath width 1600 km; orbit frequency 1 day) were used during two separate experiments.

QuickSCAT provides measurements of the surface wind vector over 25 $\times$ 25 km cells with an accuracy of 2 m/s and 20°. Higher resolution (1-3 km cells) wind vectors can be extracted from RADARSAT when used as an imaging scatterometer. For wind-retrieval, we utilize a

[3] SACLANTCEN SR-311, SR-340.



WIND COMPARISONS

SOURCE	WIND SPEED (M/S)	WIND DIR
COAMPS	10.2	286
SAR	11.6	299
[illegible]	10.3	297
QUICKSCAT	9.5	283

Figure 01-B.8 *The configuration for the MAPEX2000 experiments. NRV Alliance towed the sound source and receiver array; simultaneously the vertical array received the transmissions and the data was relayed back to Alliance by radio telemetry.*

modified scatterometer algorithm previously tuned for C-band vertical polarization (VV) ERS/SAR to account for the (HH) polarization configuration of RADARSAT. The SAR-derived wind fields are compared (Fig. 01-B.8) with *in situ* measurements acquired by the R/V *Alliance*, model outputs from the Coupled Ocean Atmosphere Prediction System (COAMPS) and QuickSCAT scatterometer measurements. The excellent agreement and consistency of the SAR-derived results with other fields show the potential of SAR for delivering high-resolution operational wind fields in the coastal regions. Work continues in optimizing the fusion of ancillary information with SAR imagery for wind direction extraction, when SAR imagery lacks signatures of wind-induced phenomenon.

RADARSAT-SAR employs electronic beam steering to image the surface using: Standard, Wide, ScanSAR-narrow, ScanSAR-wide, Extended-high, and Extended-low beam modes. Each mode offers flexible choice of incidence angles, spatial resolutions and swath width. We assessed the ship detection capability of the SCANSAR and STANDARD beam modes during the MAPEX-2000 and BOUNDARY-2000 field campaigns. We found that while ships could be detected visually in SCANSAR imagery, in spite of its extended swath width (300 km), it was not the recommended mode for automatic ship detection due to poor radiometric resolution, signal saturation under high winds and distorted statistics. The STANDARD beam S6 was found to be the optimum imaging mode because of its high spatial-radiometric resolution and lower clutter levels at the higher incidence angles. Using wake orientation as a basis for estimating ship heading, SAR-derived headings were nearly identical to *in situ* measured headings. In the absence of a visible wake, it was possible to assign a ship heading (with 180° ambiguity) based on the orientation of the ships largest dimension. This method yielded headings

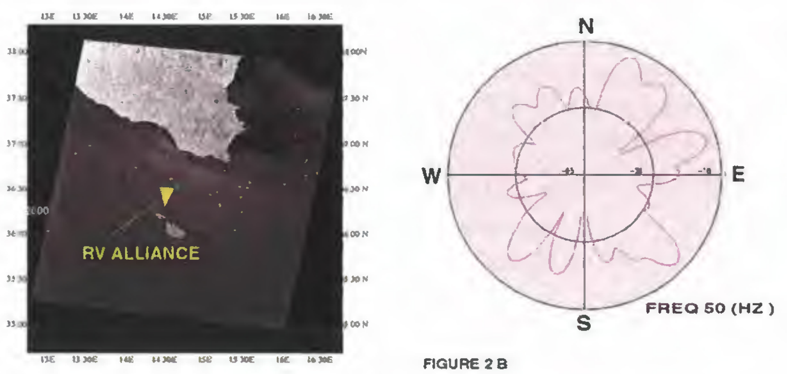


Figure 01-B.9 *The matched filtered pressure field received on the towed array is shown in the left panel. The right panel shows the modelled, matched filter output for the environment having the highest correlation with the measured data.*

that were within 5° of the *in situ* measured headings. On the basis of hard target response obtained from the R/V *Alliance*, the ship-size tended to be overestimated by at least a factor of 2 and 1.4 respectively, using SCANSAR and STANDARD imagery. More observations are needed, however, because of the sensitivity of this parameter to azimuth viewing angle.

Work continues in assimilation of satellite-derived parameters (Fig. 01-B.9) into ambient noise prediction models such as RANDI. During both MAPEX-2000 and BOUNDARY-2000 field campaigns, array of hydrophones were deployed for measuring the horizontal and vertical directionally of the ambient noise field. Future plans call for the comparisons of the in situ measurements of the directional ambient noise field with RANDI model predictions.

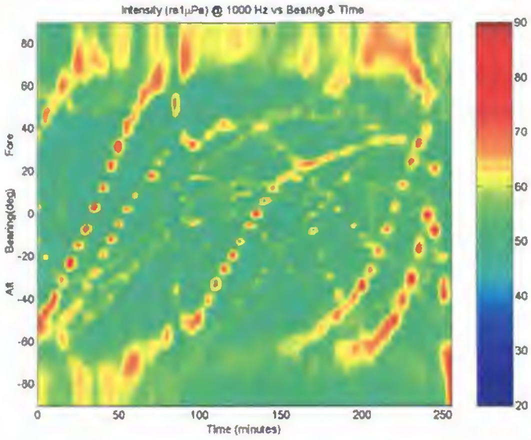


Figure 01-B.10 *Ships passing in the night.*

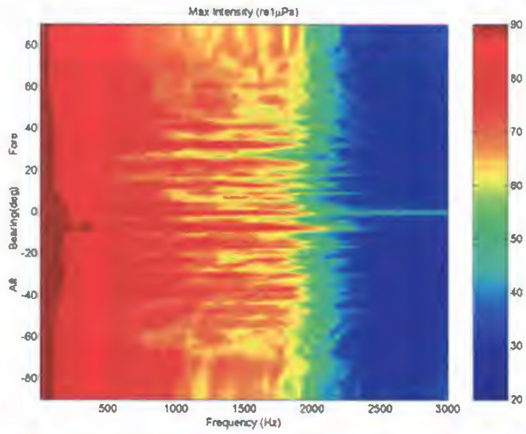


Figure 01-B.11 *Maximum over time.*

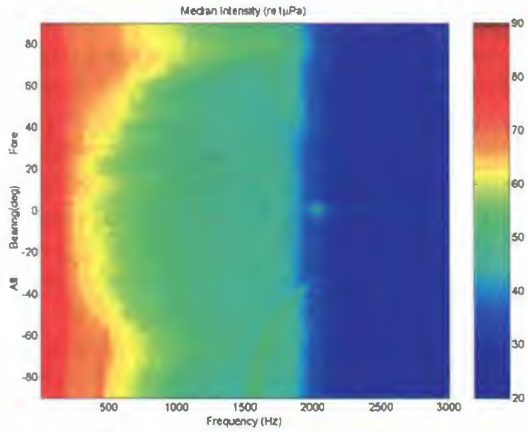


Figure 01-B.12 *Median over time.*

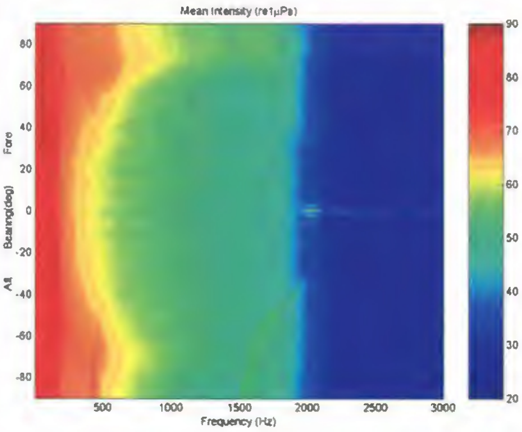


Figure 01-B.13 *Mean over time.*

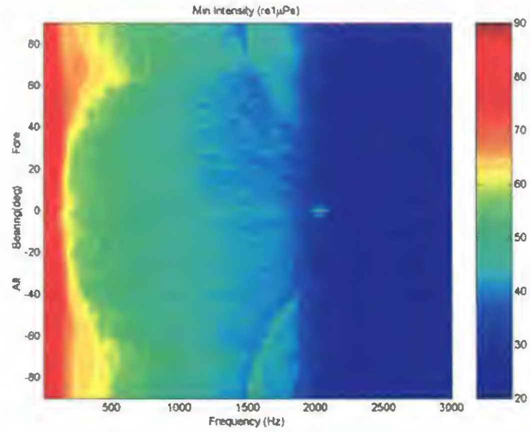


Figure 01-B.14 *Minimum over time.*

Predicting ASW and MCM performance from propagation ambient noise and reverberation

Ambient noise directionality measurements and predictions

During February and March, a series of experiments as part of MAPEX2000 was carried out on the Malta Plateau between Sicily and Malta. One of the objectives of these experiments was to test the idea that satellite SAR (synthetic aperture radar) images of shipping and sea surface roughness could be used to improve predictions of ambient noise. Towed array measurements of directional ambient noise were made over a period of several hours on two occasions, coincident with the twice daily RADARSAT orbit. Noise measurements were collected with the 256 element towed HLA for 5 s every 5 min on the calm sea day (and 10 s every 10 min on the rough sea day). Using frequency domain beamforming based on averaged cross-spectral-density, the data were reduced to a function of beam angle, frequency and time. From a statistical study of the several-second-average over hours (max, min, median, mode etc) it is possible to separate the nearby individual ships from the more slowly varying background. A number of deductions about individual ships are possible (spectra, absolute levels, aspect dependence). The smooth background spectrum *versus* angle can also be deduced. Surprisingly, the minimum noise over the several hours, a frequency and angle dependent background, appears not to depend on weather conditions. The self-noise of the *Alliance* in rough weather is clearly visible.

Geoacoustic inversion of ambient noise

In shallow water, the coherence and vertical directionality of ambient noise depend on the noise source distribution and environmental parameters such as bathymetry, sound speed profile and bottom reflection properties. In general one would require a detailed model to predict noise knowing the environment (including wind and shipping). Nevertheless, in principle, geoacoustic parameters can be inferred by inversion of the measured noise directionality or coherence. Earlier techniques require uniform source distributions and absence of shipping. Recent work at the Centre has concentrated on a simple approach where the reflection loss is found directly by comparing the upward with the downward going noise as measured by a vertical array. Modelling and parameter searching is minimized, and the method does not require a detailed knowledge of the noise source distribution. This is particularly useful in the Mediterranean where shipping densities are high and the source distribution may change over a period of hours.

Measurements were acquired during two cruises at several sites with the 64-element VLA south of Sicily and north and south of Elba (Advent99 and MAPEX2000bis). An example of the array response *versus* beam angle and frequency is shown in Fig. 01-B.14 and the corresponding reflection loss *versus* angle and frequency in Fig. 01-B.15.

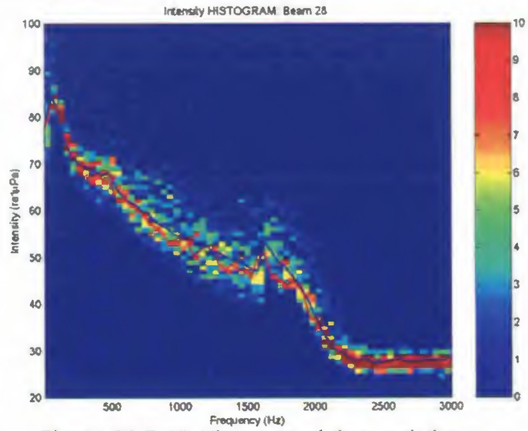


Figure 01-B.15 *Histogram of time variation as a function of frequency.*

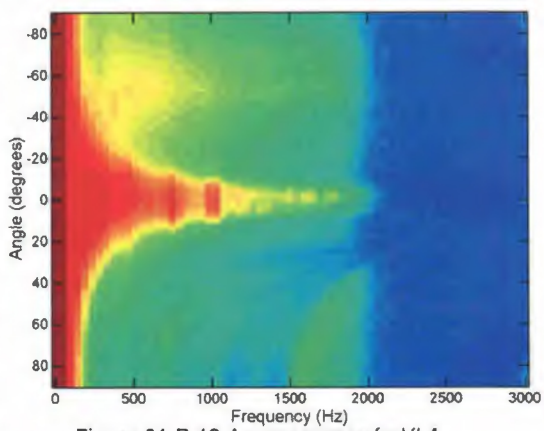


Figure 01-B.16 *Array response for VLA.*

Work is in progress on the most recently acquired data (November 2000). The four sites visited include mud, silt and rock bottoms in a variety of weather conditions, including flat calm.

The layered structure of the bottom manifests itself as interference fringes roughly following a frequency × sin(θ) law which can be seen in Fig. 01-B.15 and the theoretical curves of Fig. 01-B.16.

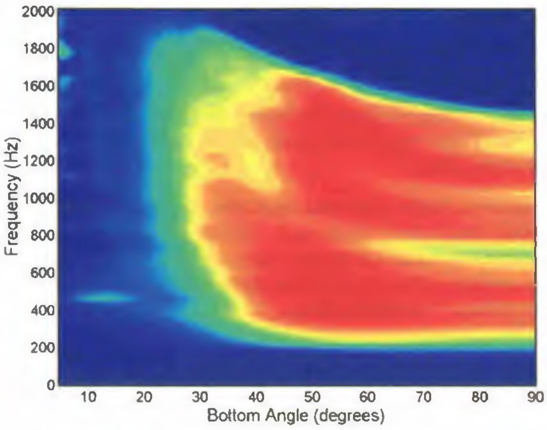


Figure 01-B.17 *Inferred reflection loss.*

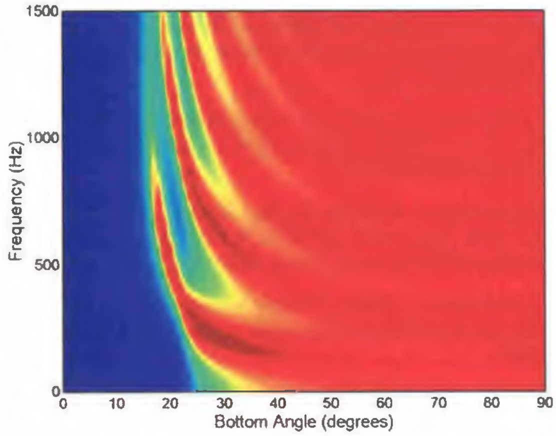


Figure 01-B.18 *Theoretical reflection loss for three-layer bottom (no correction for angle resolution).*

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Robert C. Tyce *received the Ph. D. in Applied Physics/Applied Ocean Sciences from the University of California Scripps Institution of Oceanography in 1976. Between 1976 and 1978 he worked for Hydroproducts/Tetratech on remotely operated vehicles. From 1978 until 1983 he worked jointly for the Marine Physical Laboratory at Scripps Institution of Oceanography and the NASA Jet Propulsion Laboratory, transferring technology on sonar and radar remote sensing. Since 1983 he has been Professor of Ocean Engineering and Oceanography at the University of Rhode Island. As head of the URI Ocean Mapping Development Center and Associate Director of the NSF/URI/Industry sponsored Ocean Technology Center, he worked with industry sponsors on commercial development of oceanographic hardware and software. In 1997/1998 he worked at SACLANTCEN as a Research Fellow, on sabbatical leave from URI, developing instrumentation for rapid environmental assessment.*

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. As engineering coordinator with specific responsibility for magnetic detection and the SWEEP buoy system, he has participated in numerous sea trials requiring analogue and digital system development for oceanographic and acoustic instrumentation.*

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.*

Enzo Michelozzi, *Environmental Acoustics Branch, Engineering Technology Division, graduated from the Institute of Electronics in Florence, in 1961 and in geophysics at the University of Pisa in 1972. He was employed at OTE (Spatial Electronics Laboratory), Florence, from 1961 to 1964. Since joining the Centre in 1964 he has specialized in the design, development and use of a wide range of research instruments, conducting extensive ocean and seafloor experiments in seismo-acoustics. He is co-author of numerous SACLANTCEN reports and contributions to the open literature.*

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. He is currently a member of the Acoustics Department at SACLANTCEN and his research interests include underwater acoustics and signal processing.*

Benoit Zerr *received the Ph.D. degree in electrical engineering from the University of Haute Alsace, Mulhouse, France in 1989. From 1982 to 1983 he worked as hardware engineer at TELMAT SA, Mulhouse, France, designing and implementing hardware for digital telecommunications. From 1986 to 1994, he was a research and development engineer at the Groupe d'Etudes Sous-Marines de L'Atlantique (GESMA), Brest, France. Since 1995, he has been a scientist at SACLANTCEN. His research interests include image processing, automated reasoning, data fusion, computer graphics and underwater acoustics. Dr. Zerr is a member of the IEEE Oceanic Engineering Society and the IEEE Systems, Man and Cybernetics Society.*

Thrust 03 Mine Countermeasures (MCM)

Project 03-C: Mine-ship interaction

3

Operational relevance

During a short term operation, reduce the risk to a target transiting a minefield, containing unknown mine mechanisms, to less than 5%.

Mine Jamming[1]

It has been demonstrated that it is possible to jam *unknown* threat mines. Specific mine algorithm knowledge is not required. The unknown mine logic was provided by one of the Joint Research Project partners[2].

It is important to establish that the mine presents a threat to the target in order to show that the countermeasure has had an effect. Figure 03-C.1 illustrates the performance of one mine against a frigate. The figure shows horizontal distance from the mine on the x-axis and water depth on the y-axis. The colours represent the probability of actuation of more than 20,000 mine/target encounters.

Using the same algorithm and the same method of presentation Figure 03C-2 demonstrates either that a crude sweep signature is relatively ineffective or that the mine's sweep rejection algorithm works well against this type of sweep signature.

The results of using this same unsophisticated sweep signature to protect a target are shown in Fig. 03-C.3.

Total Mine Simulation System (TMSS) models have been developed to evaluate organic MCM techniques. Figure 03-C.4 shows a generic model that will form the basis of organic jamming simulation using a target's degaussing coils.

Target Sweeping Mode Planning

Traditionally, influence sweeping has exploited weaknesses in a mine's design and has assumed a known mine threat. This is commonly termed minesweeping mode (MSM).

NATO nations have developed an influence minesweeping capability against an unknown mine threat by configuring the sweeping equipment to emulate the characteristics of a ship's influence signatures. This sweeping concept is termed target sweeping (or simulation) mode (TSM).

The objective of mine countermeasures (MCM) operations planning is to minimize the risk to

---

[1] The original project plan, which provided for a joint trial in Panama City in November 2001 has been revised to allow the trial to coincide with the MCMFORNORTH deployment scheduled for June 2002.

[2] Denmark, Germany, Italy, the Netherlands, United Kingdom, United States.

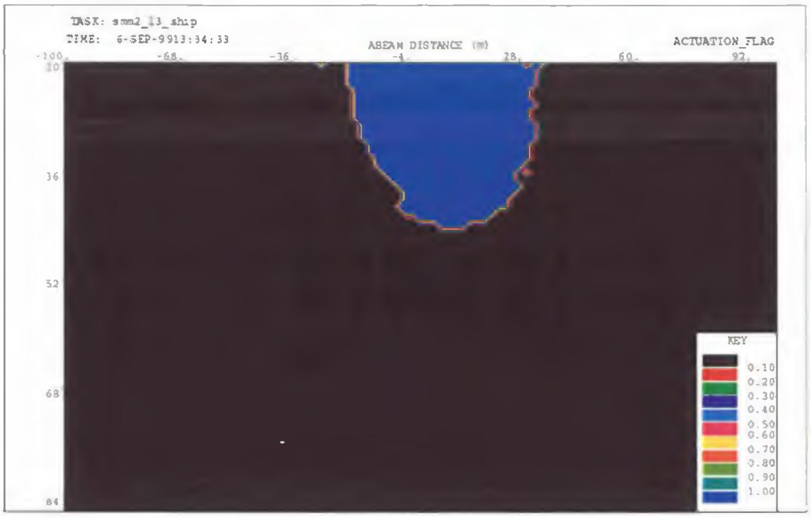


Figure 03-C.1 *Modelled data demonstrating the performance against a target.*

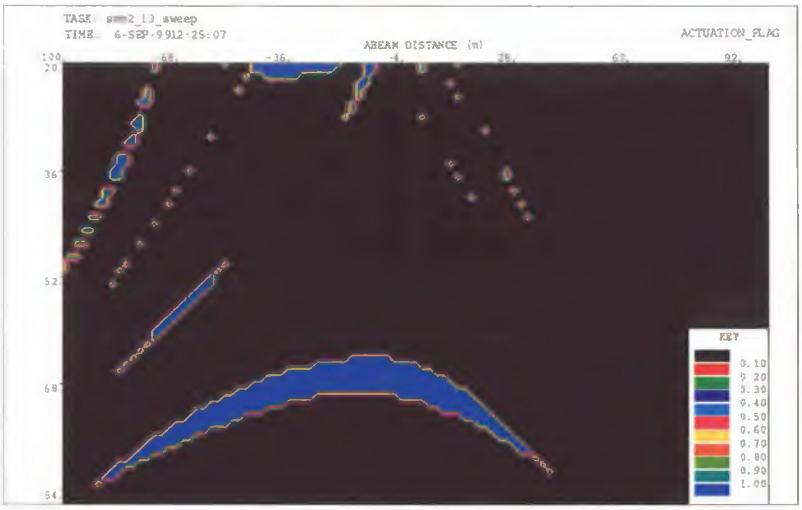


Figure 03-C.2 *Modelled data demonstrating that this mine is particularly difficult to sweep.*

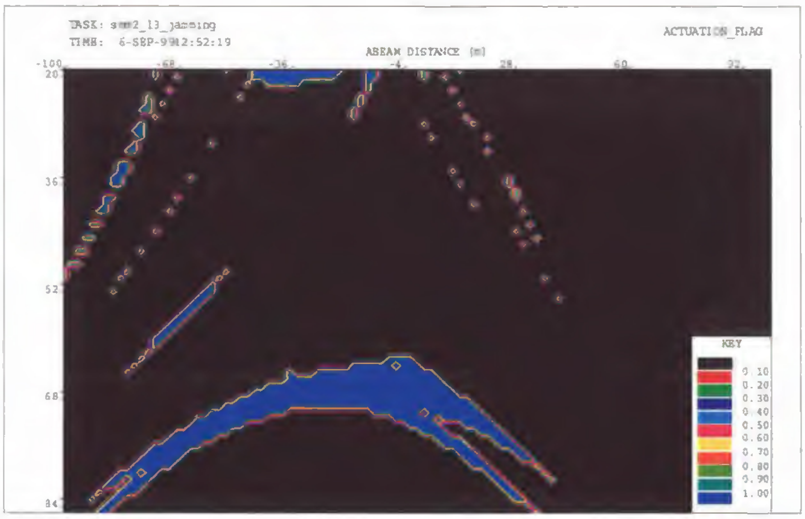


Figure 03-C.3 *Modelled data demonstrating that this mine was successfully jammed.*

subsequent target shipping whilst also minimizing the time taken and the risk to the MCM forces. The current NATO doctrine for the planning and evaluation of influence minesweeping operations is based on *a priori* knowledge of the performance, (in terms of sweep width and actuation probability), of the minesweeping system against the threat mine type(s). As it is not possible to quantify sweep performance against an unknown mine threat, this approach may no longer represent an optimum tactic for the employment of a TSM minesweeping system.

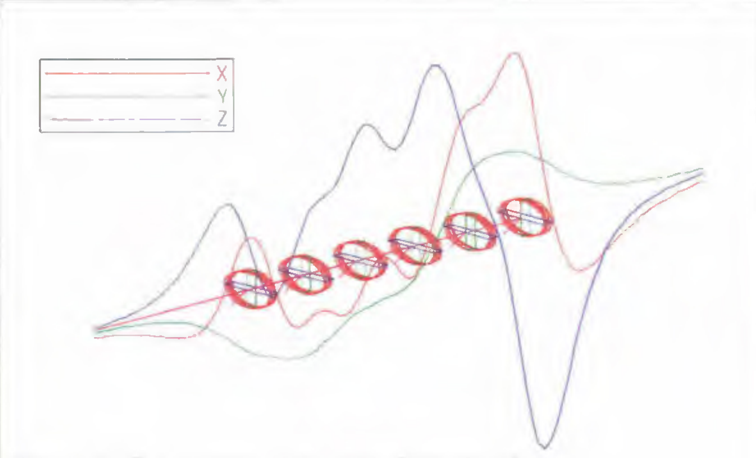


Figure 03-C.4 *Models have been developed to demonstrate organic mine jamming.*

The aim of this study is to investigate whether the underlying assumptions of NATO algorithms remain valid for TSM and to develop methodologies for the optimum employment of TSM minesweeping systems and the evaluation of the risk reduction to the target vessel.

During 1999, a technical solution was developed, which is an extension of the NATO MCM planning and evaluation procedures implemented in the MCM EXPERT tool. The planning algorithm uses either exhaustive search or simulated annealing to optimize the minesweeping effort. The selection of technique depends on the number of possible combinations in the scenario and the speed of the PC. The evaluation algorithm determines the remaining risk as a function of the *aggregate actuation width* of the mine against the target vessel (Fig. 03-C.5).

The algorithms were originally implemented in EXCEL 97 VBA for development and testing. A PC-based stand-alone prototype TSM planning and evaluation software tool written in Delphi (Figure 03-C.6) is now fully developed and documented completing (in September) the Project 03-C TSM Planning Phase 3 activity of the SPOW 2000. The help files are comprehensive and contain full documentation of the algorithms and software.

The software *Planning and Evaluation for TSM* (PET) has been delivered to the nations participating in the MCM EXPERT User's Group.

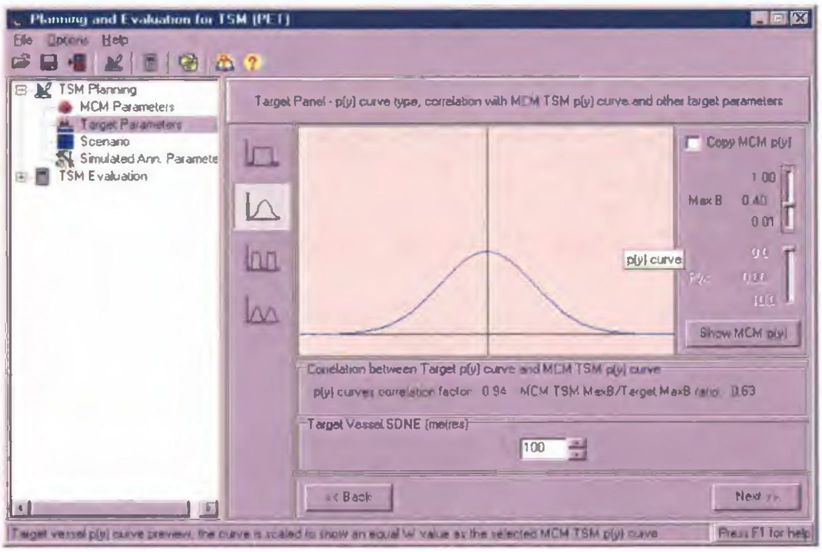


Figure 03-C.5 *TSM evaluation: the risk to the target plotted against the aggregate actuation width of the mine against the target.*

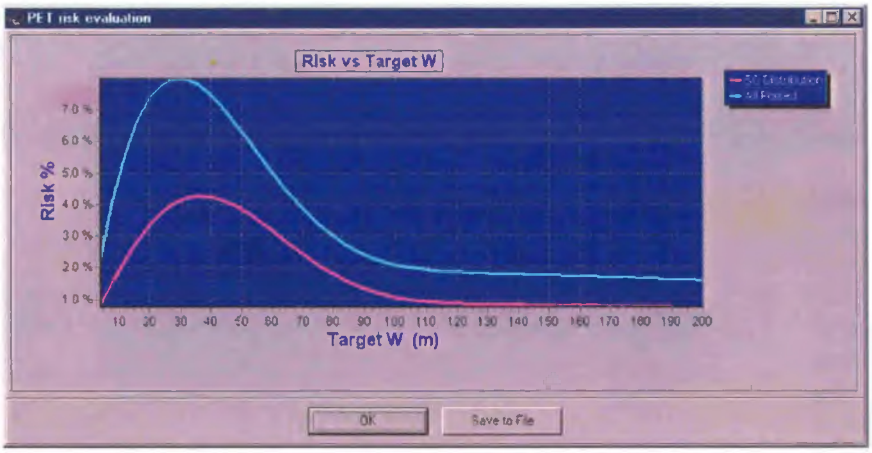


Figure 03-C.6 *Example of prototype TSM planning and evaluation software user interface.*

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. One of his many responsibilities was 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.

Project 03-D: Environmental impact on MCM sonar design and performance (Manning days - 25)

3

Operational relevance

An increased understanding of high frequency acoustic interaction with the seabed in shallow water to support MCM modelling requirements.

In shallow water at high frequencies, the rapid spatial changes in water column and seabed properties are of significance in the understanding and prediction of high-resolution sonar response, particularly synthetic aperture sonar (SAS). Of particular concern are the levels and spatial coherence of high frequency acoustic signals scattered from the seabed in high-energy environments. Understanding of near critical angle penetration of the seabed and scatter from buried targets is essential to optimal design of sonars for countering a buried mine threat. The need to map seabed areas where mines are likely to become buried is necessary for planning purposes and is being addressed through the inversion of acoustic data particularly that from wide swath sonars.

milestone

A five-year effort to address the complexities of the impact of the environment on the high frequency acoustics employed in MCM sonars concluded in 2000. The objectives were to deliver models and advice to other projects within the MCM Thrust of the Scientific Programme of Work. Major outputs of the project are:

- the time domain model of the effect of the seabed on a bottom interacting sonar (BORIS)
- the methodology for inversion of multibeam data for seabed segmentation
- models for high frequency scatter from the seabed and lower frequency penetration into the seabed.

Supporting studies:

- High Frequency Reverberation,
- Stereo Photogrammetry of the Microtopography of the Seabed

have advanced fundamental understanding of the importance of small scale topography and the volume structure of the seabed on acoustic scattering. A major experimental effort allowed modelling of the impact of wave induced fluctuations on the performance of synthetic aperture sonar to be validated.

The Joint Research Project with DERA *Wideband acoustic interaction with the seabed* was concluded in April 2000. Three data acquisition cruises with the *Manning* provided data on acoustic backscatter from a variety of seabed types in the frequency range 120-180kHz. A major feature of these experiments was the acquisition of high resolution environmental data which has allowed the relationships between acoustic backscatter, the microtopography of the water/seabed interface and the structure of near surface spatial volume fluctuations to be further understood. Such work provides the necessary basis for theoretical advances in this important area of high frequency acoustic scatter. Future exploitation of AUV technology will require a good knowledge and understanding of bistatic scatter coefficients and mechanisms. During March/

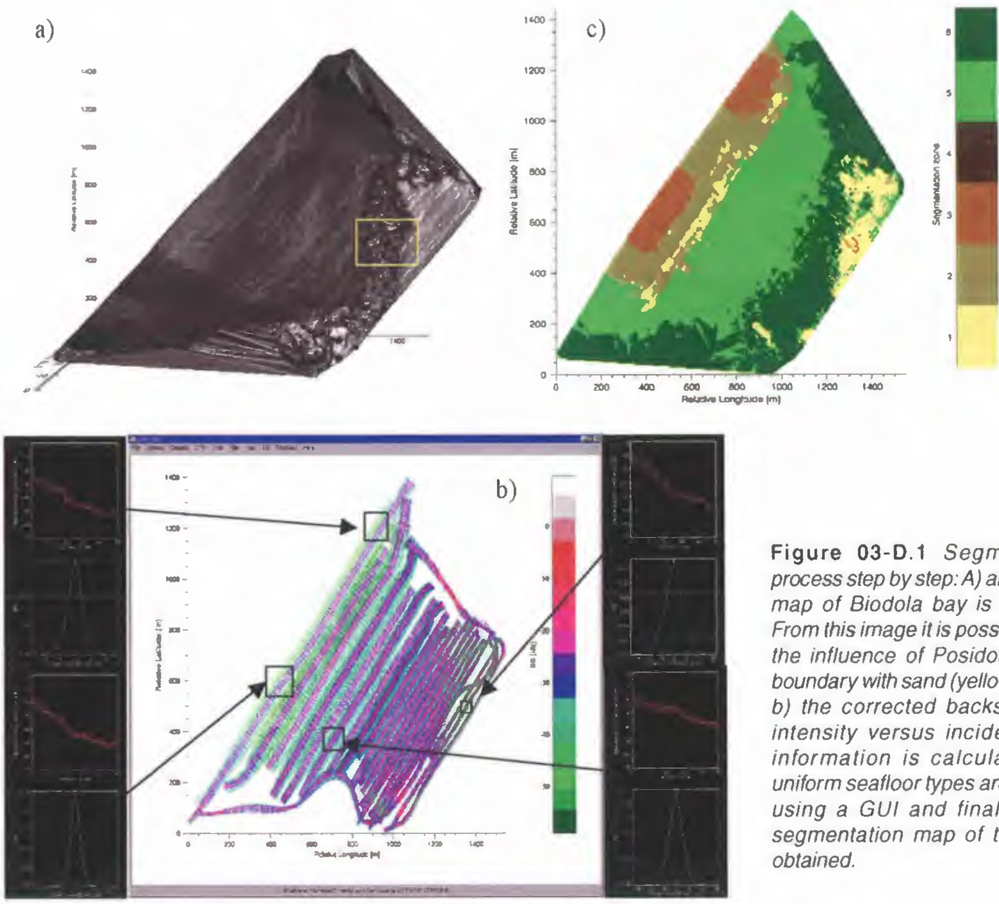


Figure 03-D.1 *Segmentation process step by step: A) an accurate map of Biodola bay is obtained. From this image it is possible to see the influence of Posidonia in the boundary with sand (yellow square); b) the corrected backscattering intensity versus incident angle information is calculated rout uniform seafloor types are selected using a GUI and finally, c) the segmentation map of the site is obtained.*

April, the shortage of bistatic scatter coefficient data was addressed through an experiment in Biodola Bay, Elba during which bistatic scatter coefficients from a well-characterized seabed were measured.

Bistatic scatter coefficient measurement requires coverage of incident, scatter and azimuth angle. Directive acoustic sources were pan and tilt mounted on a tower and the scatter measured using an omnidirectional hydrophone mounted on a pole deployed from the *Manning* while underway, to provide the requisite coverage of angles. Continuous knowledge of the geometry was obtained *via* triangulation using a ranging pinger on the tower with real time kinematic (RTK) GPS. Complementary measurements of the angular dependence of backscatter were obtained from the raw data facility of the EM3000 and the seabed finescale topography data from stereo photography. The water depth was about 11 m and the source depth 3 m. A display on the bridge was designed to provide guidance on range and azimuth for valid data acquisition.

A detailed survey using multibeam sonar at 300kHz was undertaken in support of this experiment and of GOATS 2000. This provided a good test of the seabed segmentation algorithms based on calibrated angular dependence of acoustic backscatter, with knowledge of local incidence angles from concurrent bathymetry. The segmentation algorithm is supervised and divides the seafloor into uniform zones, which can be classified according to ATP-24 definitions, using sensor fusion or ground truth on a limited number of spots. New generation bathymetric sonar, readily adaptable to an AUV, was used for the rapid acquisition of high resolution data, including bathymetric and backscattering intensity:

- To produce an accurate and robust bathymetric map of the site (Fig. 03-D.1a).
- To obtain backscattering *versus* incident angle information for each data point (see Fig. 03-D.1b).
- To select zones where the backscattering

versus incident angle result is uniform and calculate the Backscattering *versus* Incident Angle (BIA) function that is characteristic of each zone (Fig. 03-D.1b)

- To select a limited number of BIA to produce a filtered segmentation of the seafloor. In Fig. 03-D.1c, yellow, dark green and light green are known to be sandy, Posidonia and sparse Posidonia zones respectively.

Progress has been made in quantifying the effects of small scale seabed topography in conjunction with millimetric scale spatial fluctuations in seabed volume properties, on acoustic scattering. The vertical velocity and density gradients and their relative local fluctuation are an important cause of scattering in soft sediment at minehunting frequencies. Interface roughness, which was believed to be the dominant scattering mechanism in these sediments has been shown to be often dominated by volume scatter. The effect is, perhaps surprisingly, greater in the softer sediments in which mines tend to become buried. Acoustic measurements were supplemented with x-ray analyses of horizontal and vertical seabed cores with the finescale seabed topography being obtained from a recently developed, fully automatic two-dimensional stereo photogrammetry device. It is possible to envisage this device on an AUV to remotely assess one of the key input parameters to MCM sonar performance prediction models.

Since the development of the XBP and stand-alone High Frequency Reverberation (HFR) as REA techniques in 1996, surveys involving these instruments have been requested during various Military Oceanography (MILOC) Rapid Response Operations and Naval exercises (Fig.03-D.2). These systems have proven to be useful tools for acquiring information about seafloor properties that are important for mine burial modelling and mine hunting system performance prediction. As part of the SACLANTCEN contribution to Linked Seas 2000, REA measurements were taken in the MW area during the period of 10 - 20 April by a SACLANTCEN scientific team, aboard HMS *Roebuck*, with the assistance of her crew. Results of the survey, using XBPs and the HFR measurement system (100 kHz) were published as a CD-ROM with high frequency side-scan sonar images and a synthesis of the results of the MW environmental parameter measurement systems, in order to determine bottom type classifications required for general operational MCM applications. Figure 03-D.3 is a signal to reverberation (SR) map for a modern mine that the HFR system can provide rapidly prior to a MCM operation.

Figure 03-D.2 *the High Frequency Reverberation (HFR) measurement system, shown here mounted on a sled, consists of simple and relatively small components that can be mounted on various platforms, including MILOC ships, Autonomous Underwater Vehicles (AUV's) and expendable buoys. The system transmits and receives acoustic signals from a fully calibrated high frequency transducer (80-110 kHz) and simultaneously measures its exact orientation with respect to the seafloor using an echosounder and inclinometers. Also mounted on the sled shown here are the electronics package and a small video camera. A prototype device and analysis algorithms have been developed and used as part of the MILOC exercises Rapid Response '96, '97 and '98.*

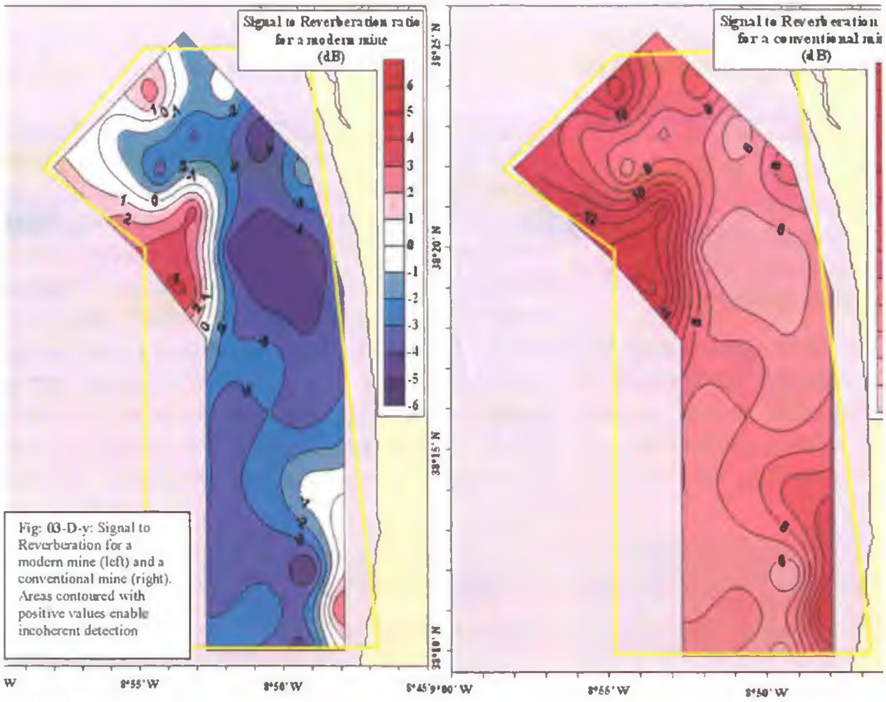


Figure 03-D.3 *Signal to reverberation for a modern mine (left) and a conventional mine (right). Areas contoured with positive values enable incoherent detection.*

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, Nick Pace is a Fellow of the Acoustical Society of America (1985) and of the Institute of Acoustics (1986).*

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 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. At present he is studying seafloor acoustic interaction and high-resolution characterization of seafloor sediment. He received the Thomson Sintra ASM award in 1993 and the Brittany Region Council Award in 1997.*

Project 03-E: Modelling of MCM related propagation, reverberation and target scattering (Manning days – 10)

3

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-D structural acoustic scattering models for seabed mines

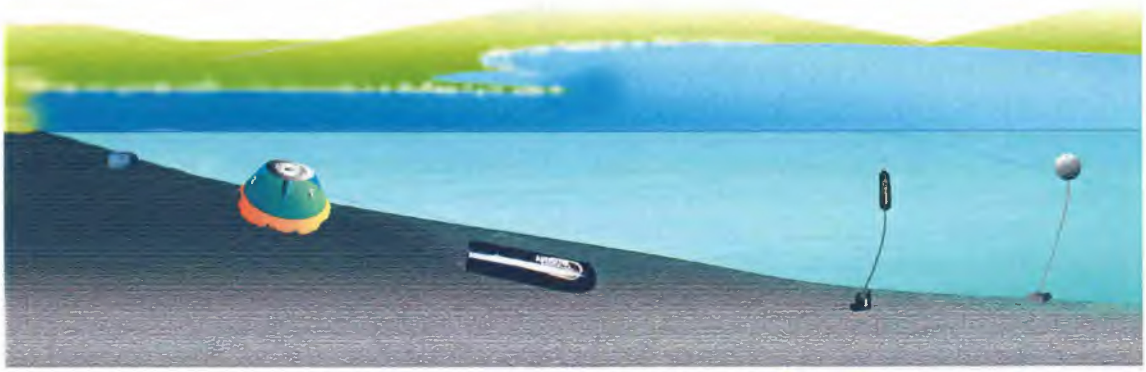
The objective of the project is the development of a 3-D, state-of-the-art, finite-element, structural acoustics code for modelling the scattering of acoustic waves from undersea structures. The primary application will be for predicting the scattering of sonar signals from mines in, on or moored above the seabed (Fig. 03-E.1). Projects in 2001 and beyond will extend the application to scattering from submarines and torpedoes.

A structural acoustics code models wave propagation in two types of media: solids and fluids. Solids (structures) are modelled as elastic media, or viscoelastic when damping is present. Fluids are modelled as acoustic media, or viscoacoustic when damping is present.

The development of the structural portion of the code which was completed in 2000 will constitute the subject of most of this report. Work also began on the acoustics portion; acoustic modelling will be described briefly at the beginning

milestone

Figure 03-E.1 *Computer models will be used to predict scattering of minehunting sonar beams from many types of mines in or near the seabed.*



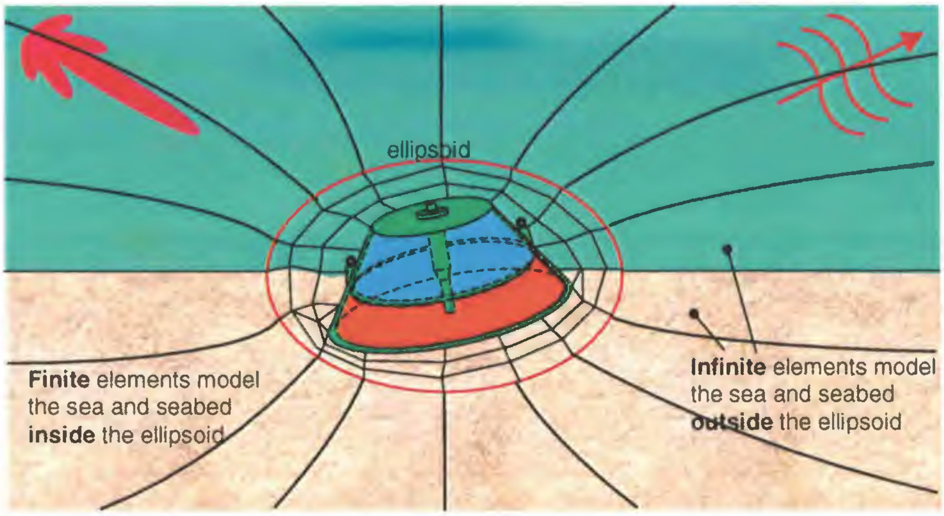


Figure 03-E.2 *Approach used for modelling the large expanses of sea and seabed surrounding a mine: a combination of finite and infinite elements.*

and progress on acoustic code development at the end.

Modelling methodology

Two types of technology are being employed.

- A patented[1] mathematical acoustics technique for modelling large expanses of sea and seabed, using computationally efficient "infinite elements"

The acoustic environment surrounding a mine is the sea and seabed, both of which are extremely large spaces compared to the dimensions of a mine — too large to be modelled by conventional FE methods. Many mathematical techniques for modelling such large spaces have evolved, but, prior to the early '90s, none had been numerically efficient. The patented "infinite element" technique is more than 400 times faster than competitive techniques to achieve the same solution, to the same degree of accuracy, in benchmark tests.

Figure 03-E.2 shows how finite and infinite elements will be used to model the sea and seabed, using a partially buried Manta mine for illustration. Finite elements will model a small volume of sea and seabed surrounding the mine, out to an ellipsoidal surface that closely circumscribes the mine. The remaining space "out to infinity" will be modelled by the infinite elements, each one modelling a sector of the space between the ellipsoid and infinity.

- A unique, commercial, state-of-the-art, FE technology for structures and fluids

The Centre is combining in-house R&D with three commercial FE software packages: ProPHLEX, PHLEXsolid and HyperMesh.

ProPHLEX

Developed by the R&D Division of Altair Engineering (formerly COMCO) in Austin, Texas, this package is a suite of software development tools for developing customized FE codes for any physical system describable by a system of linear or nonlinear second order partial differential equations. The numerous fields of application include elasticity, acoustics, fluid mechanics, heat conduction and quantum mechanics. The core mathematical technologies have been evolving from a close collaboration with the Texas Institute for Computational and Applied Mathematics (TICAM) at the Univ. of Texas, Austin, which for many years has been one of the foremost contributors to the foundations of FE technology.

A central feature of this software is "*hp*-adaptivity", which is a highly automated procedure for achieving near-optimal FE meshes, with consequent major reduction in use of computer resources. An integral part of this capability is automatic error estimation. Element-by-element *a posteriori* error estimates provide a rigorous mathematical basis for automatic adaptation of the FE mesh until a user-defined error is

[1] US Patents 5604891, 5604893, 5963459

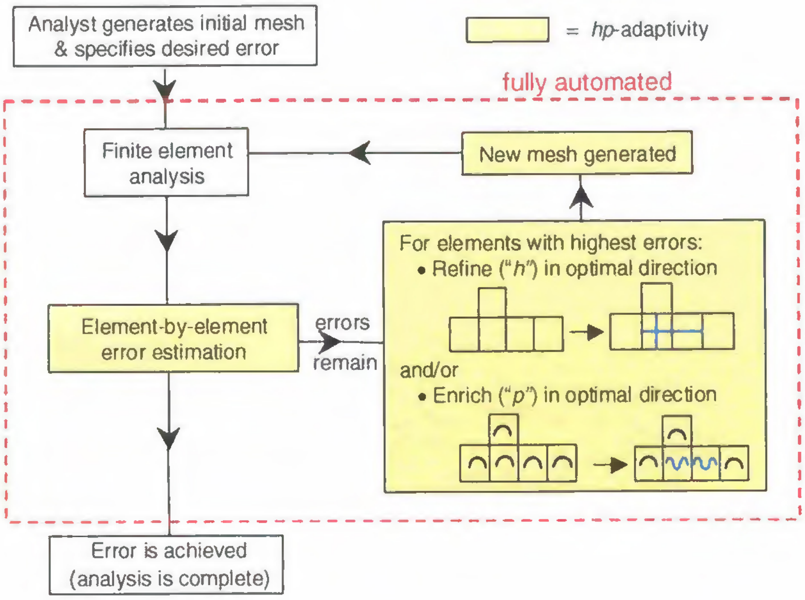


Figure 03-E.3 *Control of error using hp-adaptive FE technology.*

achieved. The estimates also provide a quantitative indication of the quality of the resulting FE solution.

The *hp*-adaptive procedure is illustrated in Fig. 03-E.3. The analyst constructs a first mesh with a few large elements — to define the geometry. The software performs an analysis with this mesh and then estimates the discretization error (the departure from the exact solution) in every finite element in the model. This element-by-element error estimate is then used to modify the mesh, by (1) making selected elements smaller or larger (so-called "*h*-refinement/unrefinement") and/or (2) increasing or decreasing the degree of the approximation polynomials within selected elements (so-called "*p*-enrichment/unenrichment"). A new analysis is performed using the new mesh. This cycle of analysis/error-estimation/mesh-adaptation is executed iteratively until an error is achieved that is less than that requested by the analyst (e.g., ±5% relative to the exact solution). The result is a model with near-optimal computational efficiency, i.e., one that achieves the user-specified error at the lowest possible cost in computer resources. (This, in turn, permits modelling to higher frequencies, as computational costs, by any method, increase exponentially with frequency).

PHLEXsolid

This package, which was created using the ProPHLEX development environment, is an *hp*-adaptive 3-D structural analysis code. Solution types include static, transient (wave propagation) and eigen (resonant modes) analyses. Capabilities include damping, anisotropic materials, thermal stresses and nonlinearities; the latter includes large deformations, hyperelasticity (e.g., rubber-like materials) and contacting surfaces.

The continuum mechanics in the code employs full 3-D physics for all modelling, eschewing the traditional 2-D and 1-D engineering approximations for, e.g., structural plates, shells and beams. This approach is motivated by the need to model accurately corners and material discontinuities where the deformation field is singular and/or strongly 3-D, especially the critical outer shell of the structure, which "launches" the scattered acoustic field. Thus, the code is capable of producing high fidelity models, i.e., models with high accuracy relative to the real world, even up to very high frequencies, which is an important feature when validating the code against experimental data measured at sea.

Most important, the Centre's capability for modelling transient wave propagation in damped elastic structures is now complete and ready for

milestone

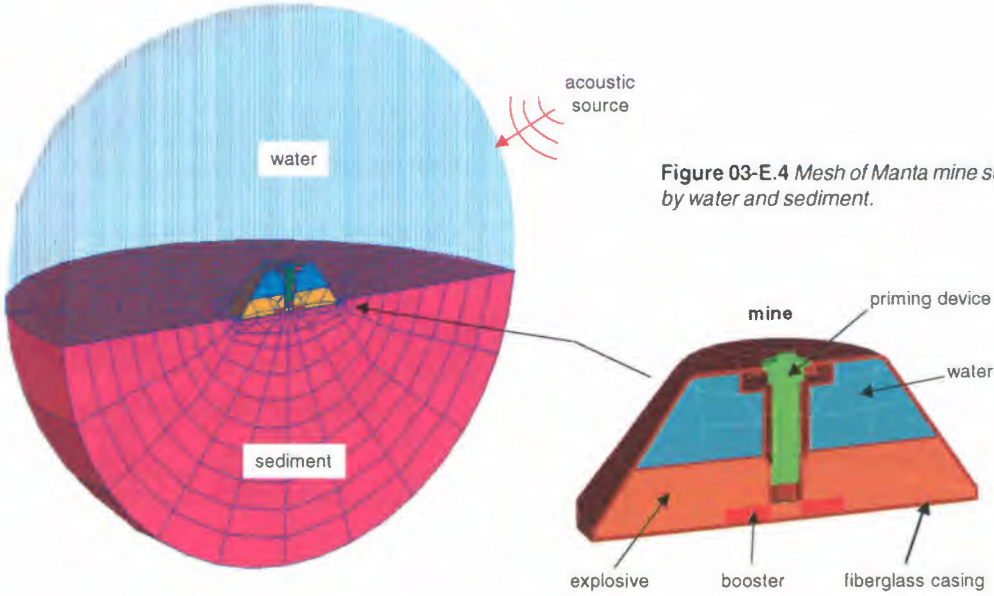


Figure 03-E.4 *Mesh of Manta mine surrounded by water and sediment.*

application.**HyperMesh**

This is a general FE pre- and postprocessing package developed by Altair, compatible with many popular FE analysis codes. As a preprocessor it generates the initial meshes and other input data for models that will be analyzed with the PHLEX codes. As a postprocessor it is currently being used to generate and display animated graphical plots of the transient solutions produced by the PHLEX codes, e.g., propagating contours of stress or displacement fields as well as the time-varying deformation (vibration) of the structure.

Demonstration problem: scattering from a Manta mine on the seabed

Figure 03-E.4 shows a mesh of a Manta mine partially buried in the sea bed, surrounded by a hemisphere of water above (shown translucent, so mesh lines are not visible) and a hemisphere of sediment below. The complete mesh of water and sediment is a sphere, half of which is shown to reveal mesh details on a vertical bisecting plane. This mesh was prepared using the HyperMesh package; the PHLEXsolid *hp*-adaptive algorithms automatically adapted the mesh during the solution process.

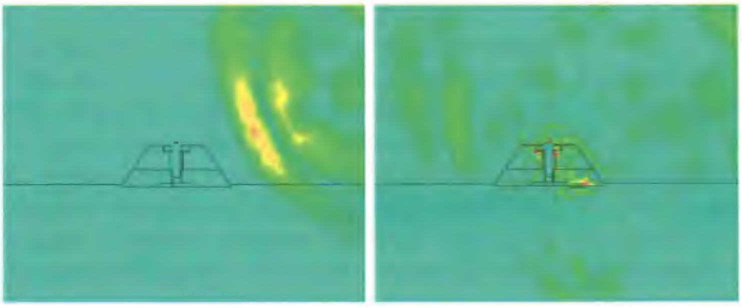
Although PHLEXsolid is a structural code (elastic media only), lacking acoustic finite and infinite elements, it is still possible to simulate acoustic propagation by the following two expedients (which are temporary only, until the acoustics portion of the code is developed):

- A fluid medium, e.g., water, can be modelled as an elastic medium with a very low shear modulus, i.e., a gelatinous material. In particular, the bulk modulus and the mass density, which determine the speed of an acoustic (compressional) wave, may be given the actual values for sea water, which will therefore yield the correct acoustic wave speed. The shear modulus may be chosen low enough (ideally it would be zero) to make the shear wave speed very small, typically only a few percent of the compressional wave speed.

This approach can yield a realistic simulation, but it is obviously computationally very inefficient, as a scalar acoustic field is being modelled by a vector elastic field. The inefficiency is partly offset by the optimization aspects of the *hp*-adaptivity.

- The large water and sediment regions may be modelled albeit computationally inefficiently, with very large water and sediment meshes. However, as transient analyses involve only local disturbances, the wave may be allowed to propagate across the water/sediment mesh and the analysis terminated before the wave reflects from the opposite (artificial) boundary of that mesh.

The mine was modelled using realistic material properties for the fibreglass outer casing and internal partitions, explosive, booster, priming device and water. The sediment was modelled as an unconsolidated medium with properties similar to sand and gravel. An acoustic source was approximated by a vibrating pressure applied to a small patch on the outer surface of the water mesh. The pressure oscillated sinusoidally for one cycle at a frequency of 2000 Hz, then stopped and remained zero thereafter, resulting in a pulse-like wave propagating toward the mine.



(a) (b)

Figure 03-E.5 *Contours of magnitude of particle displacement at (a) before the wave strikes the mine and (b) after striking the mine.*

PHLEXsolid performed a transient analysis. The complete time history can be displayed on a computer monitor as a smooth animation of propagating contours. A sequence of snapshots taken from this animation is shown in Fig. 03-E.5. Zooming in on the animation (not shown here) reveals the vibration of the mine as the wave passes through it.

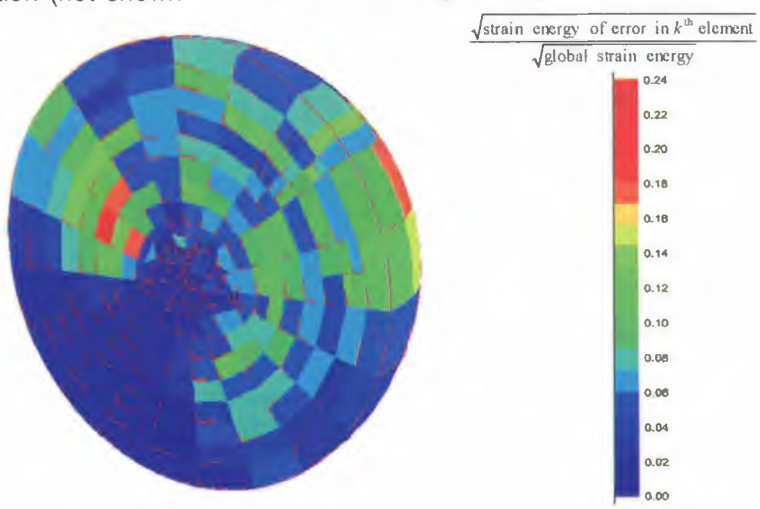
To illustrate the error estimation capability in PHLEXsolid, Fig. 03-E.6 shows the element-by-element estimated error in strain energy for the solution in Fig. 03-E.5. In the elements coloured green, for example, the relative error, i.e., the ratio of the strain energy of the error to the global strain energy, is about 1% (the square root of the ratio is shown as 0.10). The red elements have relative errors of about 5%. These errors can be increased or decreased using a variety of manual and automatic controls in the software. Error estimates such as these are important in providing confidence in the quality of the solution.

Progress towards an acoustic propagation code

Work began on the development of an *hp*-adaptive acoustic propagation code, using the ProPHLEX development environment. An initial version, which incorporates *hp*-adaptive acoustic elements, has been successfully tested with a simple transient propagation problem.

Current infinite element technology is for modelling a single fluid. As the mine hunting problem involves water and sediment (the latter often modelled as a heavy, viscous fluid), research has begun on developing a new type of acoustic infinite element for use when there are two infinite fluid regions in the model. Significant progress towards this goal was made during 2000.

Figure 03-E.6 *Element-by-element error estimates for solution shown in Fig. 03-E.5(b).*



During 2001, work will continue with ProPHLEX to create an *hp*-adaptive acoustic propagation code, with a graphical user's interface (GUI) and pre- and postprocessing capabilities similar to the current structural code. ProPHLEX will subsequently be used to combine the structural and acoustic technologies into a coupled structural acoustics code.

Acoustic infinite elements will be added to the code, which will obviate the use of large spheres of water and sediment, as in the above model. Only a small layer of acoustic elements surrounding the structure will be necessary as the infinite elements will model the water and sediment "to infinity" (Fig. 03-E.2). Acoustic sources will then be able to be located anywhere and the scattered wave will be able to propagate indefinitely outward.

Another important capability to be added will be steady-state (i.e., c.w. or frequency domain) analyses. As the core computational approach will be transient analyses for all modelling (for fundamental mathematical reasons), a shell will be built around the code that will synthesize a transient acoustic signal with the desired frequencies. At the end of the transient analysis the shell will analyze the separate frequencies in the scattered wave, computing, e.g., target strength at each frequency.

Low-frequency acoustic model for mine sweeping predictions

One of the important signals used by mines to assess the presence of a ship is a low-frequency (2-100 Hz) acoustic tone. The design of the low-frequency acoustic part of the sweeping system is crucial. However, difficulties have been experienced when exciting low-frequency acoustic signals (low source level), especially in shallow-water regions and during the construction of the ideal acoustic waveforms to be transmitted by the mine sweeping system. Numerical sound propagation models play a major role in assessing mine sweeping performance by predicting pressure levels radiated from a sound source (ship) to different receiver locations (mines). However, special properties are required in order to predict the sound levels accurately at low frequencies (2–100 Hz) and at short ranges from the acoustic source (<100 m).

A numerical study was carried out to select a model that provides accurate predictions of sound propagation within 100 m of the source and for frequencies as low as 2 Hz. Standard acoustic models available at SACLANTCEN were benchmarked on suitable test problems before selecting the SAFARI/OASES model as the most accurate and computationally efficient for solving "nearfield" acoustic problems. A parametric study determined the important environmental parameters affecting sound propagation close to the source. It was found that the effect of a changing sound-speed profile in the water and any realistic range dependence was negligible. Important parameters relate to the bottom type (Fig. 03-E.7, left panel) and the water depth (Fig. 03-E.7, right panel), and, of course, transmission losses are strongly frequency dependent. These simulation results were used in designing the experimental phase of this study.

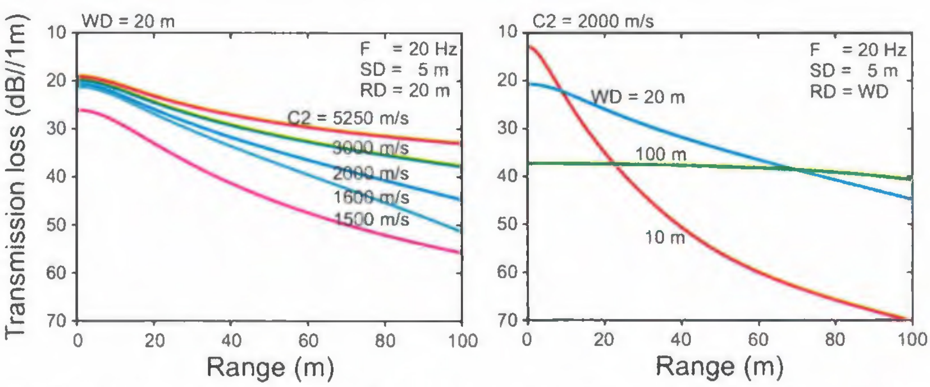


Figure 03-E.7 *OASES modelling results for the SWEEP-2K experiment. Transmission loss varies up to 20 dB dependent on the bottom reflectivity (left panel). Simple halfspace bottoms with increasing sound speed C2 from mud (1500 m/s) to rock (5250 m/s) were considered. The right panel shows that also the water depth WD is an important parameter for a mine on the bottom. All results shown here are for a frequency of 20 Hz and a source depth of 5 m.*

During the SWEEP-2K experiment in September/October, environmental and acoustic data were acquired for model validation purposes. Three shallow-water experimental sites (Fig. 03-E.8) were defined with water depths ranging from 15 to 100 m. The seabed characteristics vary from clay to gas-filled sands. Seismic profiling along pre-defined acoustic tracks was used to identify the deeper layering of the bottom. Acoustic tones at frequencies of 6, 10, 20 and 100 Hz were transmitted by a towed source at depths of 5 and 10 m to a maximum propagation range of 500 m. The transmitted signals were received on geo-phones located on the seabed and hydrophones in the water column at different depths. The data analysis and model-data comparison is in progress and results will be available by summer 2001.

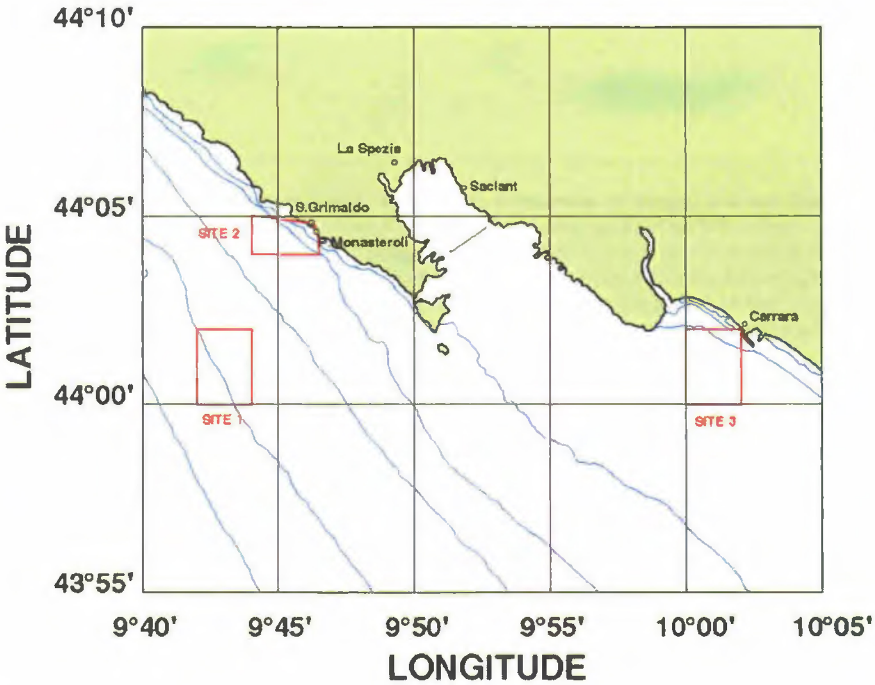


Figure 03-E.8 *Sites for the SWEEP-2K experiment. The water depth ranges from 15 to 100 m, and the bottom varies from clay (SITE 1) to gas-filled sand (SITE 3).*

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 University of California, Berkeley, in 1969. He worked more than 28 years at Bell Laboratories (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 FE 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 Laboratories' 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 FE homework problems; and a 200-page manual on computation structural acoustics. He joined SACLANTCEN in 1998.*

Carlo M. Ferla received the B.S. degree in information sciences in 1974 from the University of Pisa, Italy. Since 1978 he has been employed by the SACLANT Undersea Research Centre as a senior scientist in the Environmental Modelling Group. He is responsible for the design and development of models for signal and noise propagation in ocean waveguides, as well as their application to modelling data from experiments at sea and in simulating sonar system performance.

Project 03-F: Minehunting sonar performance model

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 and evaluation tool MCM EXPERT.

3

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) and this will require further investigation.

The input parameters required by the model include sonar, target and environmental parameters. 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.

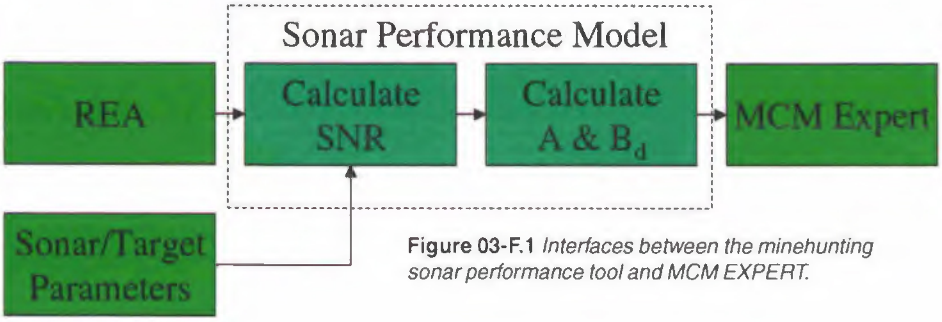


Figure 03-F.1 *Interfaces between the minehunting sonar performance tool and MCM EXPERT.*

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.

milestone

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 Bellhop).

problem

Reverberation modelling

milestone

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 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. Although additional work is needed to validate the reverberation model, tests done so far have yielded good results.

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 03-E) and seabed

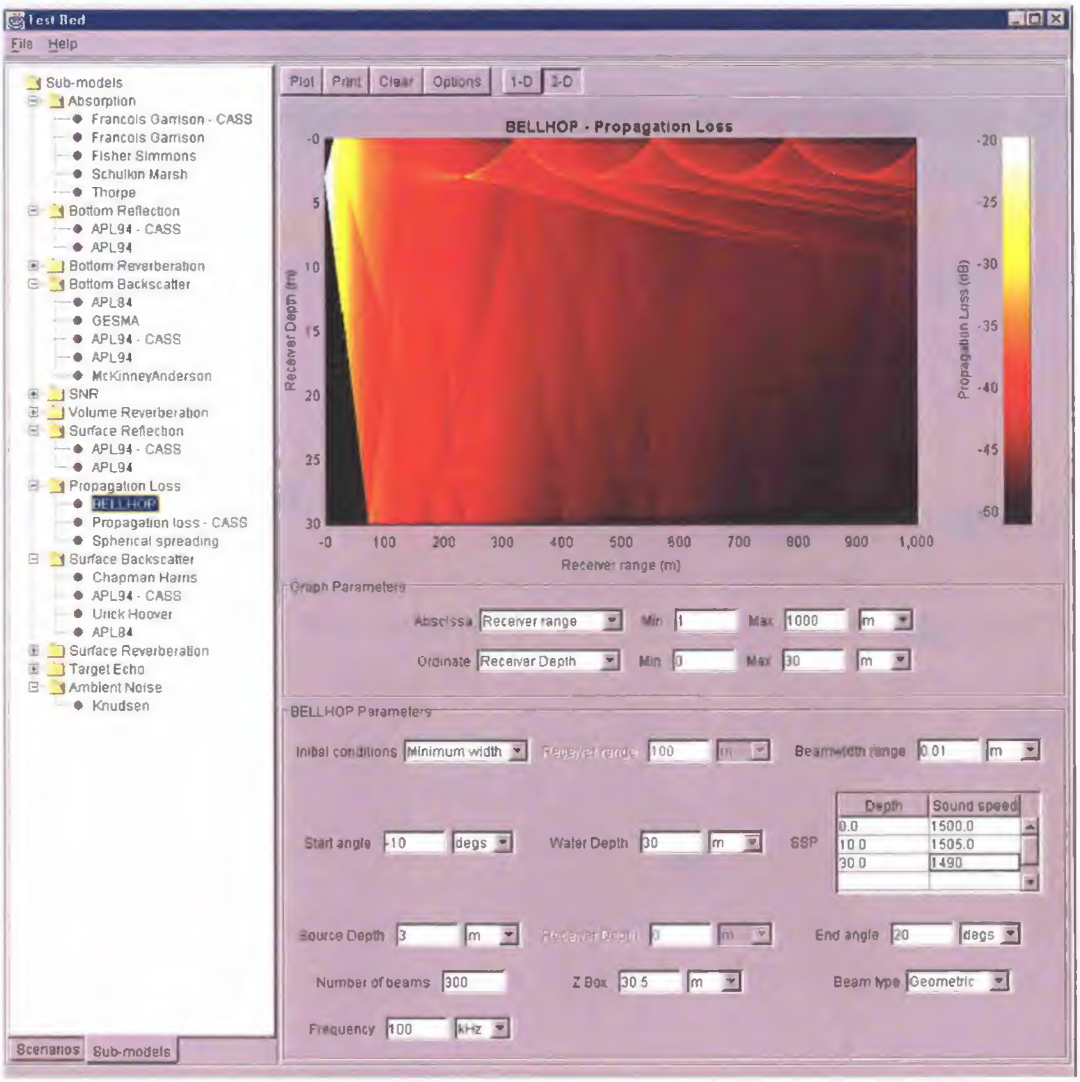


Figure 03-F.2 *Prototype software example showing propagation loss.*

scattering (Project 03-D). 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 03-E will provide a robust target strength model. It is also anticipated that Project 03-D (Project 03-H from January 2001) will be able to provide information on the statistics of bottom reverberation as well as mean scattering strength. This information can be used to calculate detection probability more accurately.

The synergy resulting from the incorporation of sub-models developed within other projects into the performance tool enhances the value of several facets of the Scientific Programme of Work, to the benefit of all NATO nations.

Progress

The project plan has been updated since the SPOW 2000 was produced. Most of the tasks given in the SPOW for 2000 have been completed, but owing to the need to produce a reverberation model, the report for the first phase of the project has been moved into 2001. Under the current project plan, the beta test version of the minehunting sonar performance tool is scheduled for mid-2002, with the project then entering a final validation phase with completion by the end of 2003.

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Project 03-G: Advanced minehunting sonar concepts for UUVs (Alliance days – 14, Manning days - 22)

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.

Figure 03-G.1 *TOPAS parametric transmitter (orange) and 16-element vertical array (white) mounted on the chariot of the Lanvéoc rail facility of GESMA, France. Also visible is the frame and motor allowing the sonar tilt to be varied.*

The main effort in 2000 was the processing of data from a joint experiment with GESMA designated "Buried Mine Classification", in Lanvéoc, Brest, at the GESMA rail facility, a 12 m underwater rail which can be positioned at seven different heights above the seafloor. The SACLANTCEN 6-11 kHz TOPAS parametric source and a vertical line array (16 elements spaced at $\lambda/2$ at 8 kHz) were mounted on the chariot (Fig. 03-G.1), which was displaced along the rail to form a synthetic aperture sonar (SAS). In addition, GESMA mounted a linear 14-20 kHz transmitter and a multi-element horizontal receive array on the chariot.

The narrow beamwidth of the parametric source in the horizontal plane (5°) reduces the ensonification time, hence the resolution gain of SAS processing. To remove this limitation, the transmission beam was electronically scanned along-track, during displacement along the rail. An effective sector of 30°, centred at broadside, was achieved in steps of 2°. The directivity of the transmitter was used to reject the SAS azimuth grating lobes.

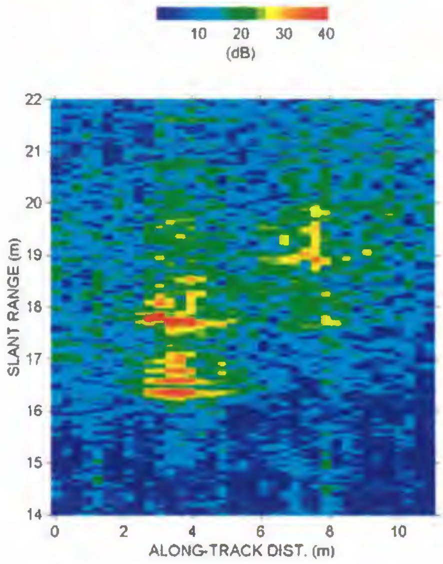

Figure 03-G.2 *Sidescan sonar image made with a single hydrophone. The direct echo of the buried cylinder is clearly visible at 4 m along-track, as well as the surface-bounced echo.*

The field of buried targets consisted of a 2 m concrete-filled cylinder, a buried sphere, a Rockan mine and a rock. The gain of the scanned parametric SAS processing over the conventional parametric sidescan is seen in Fig. 03-G.2. The classification of the other three targets is clearly more challenging, as there are other contacts in this somewhat cluttered area (Fig. 03-G.3). Classification techniques based on the echo structure, including structural acoustics, are being investigated to reduce the false alarm rate.

Echo analysis of buried objects, based on structural acoustics was demonstrated in previous work on a flush-buried sphere by using a free-field scattering model. The analysis has now been applied to data from half-buried and deeply buried spheres, acquired during the GOATS'98 experiment. Model-data comparison is shown in the 1-15 kHz bandwidth (Fig. 03-G.4), where the model, provided by the U.S. Coastal Systems Station based on the T-matrix solution, takes into account the water-sand interface and sediment transmission loss. Elastic scattering analysis, allows the study of the effects of burial, on the generation and dynamics of the elastic waves, which are known to characterize the response of the free-field target. The same families of waves are clearly identified notwithstanding the presence of the sand-water interface (Fig 03-G.5). Further, their energy, although attenuated by transmission through sediment, still allows the detection and identification of a number of modes.

Work on buried mine classification will continue, using the data from GOATS'98 and the Buried Mine Classification Joint Research Project. In addition, a new 8-16 kHz 2D sonar array (4x16 receive elements) procured from Florida Atlantic University (FAU), will be integrated in 2001 on the *Ocean Explorer* AUV for trials in 2002.

100 kHz multi-aspect synthetic aperture sonar

SAS is a key technology to enhance the area coverage of future minehunting operations. Its implementation on an Autonomous Underwater Vehicle, for large area, covert reconnaissance, is one of the recommendations of the MO 2015 study, which is being actively addressed by the Centre.

To assess the feasibility of SAS on an ocean-going platform (as opposed to more constrained experiments on an underwater rail), the

milestone

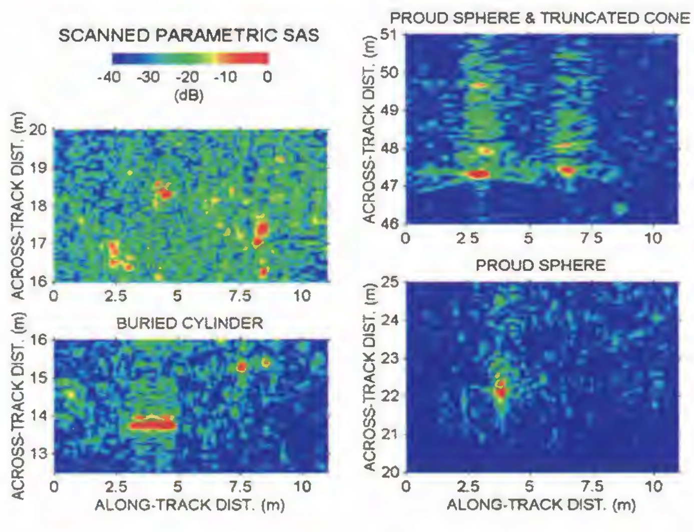

Figure 03-G.3 *Scanned parametric SAS image of the target field. The echoes forming the front and back faces of the cylinder are clearly visible as well as extended echoes. The proud sphere and truncated cone at 47 m across-track are the same as those imaged in Fig 9.*

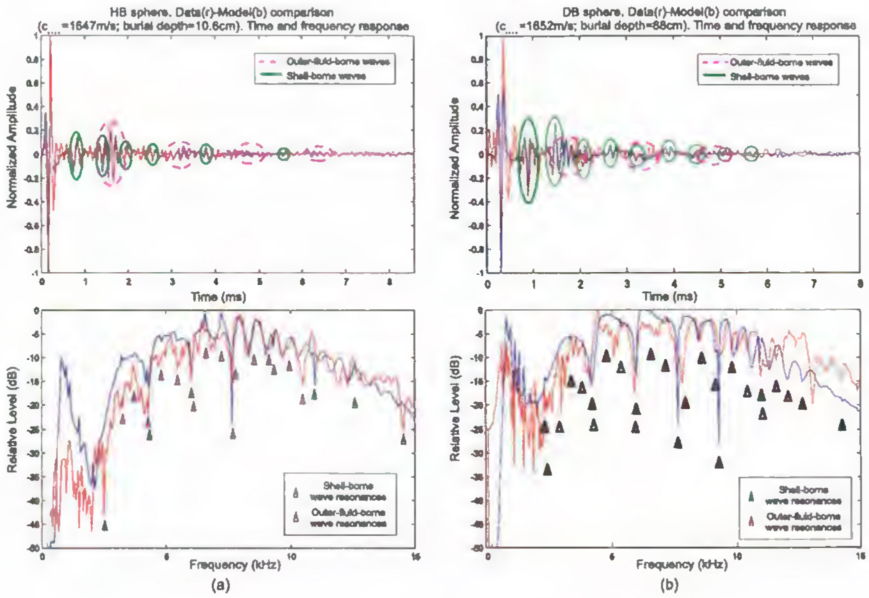

Figure 03-G.4 *GOATS98 data-model comparison of a half-buried air-filled steel sphere (a) and of an identical sphere buried 30cm-deep in the sandy bottom (b). The values of sand sound speed selected for the two cases should indicate the similar properties of sand as the burial depth varies. Main results of echo analysis are shown.*

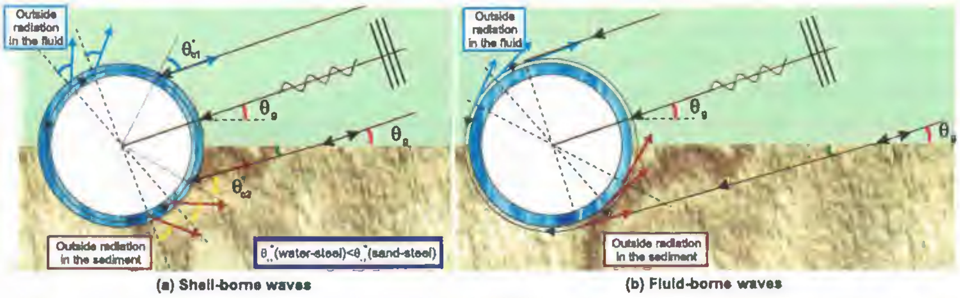

Figure 03-G.5 *Scheme of the travel paths of the two identified families of elastic waves revolving around the sphere in the shell (A) and in the outer media (B). The half-buried case is shown as an example.*

Figure 03-G.6 *MASAI towbody deployed from R/V Alliance off Punta Monasteroli. The sonar is the black beam below the towbody. It operates at 100 kHz with 256 transducers spaced at 7.5 mm, for a total length of 1.92 cm. In the narrowband mode (95-105 kHz) mode, the full aperture is used, whereas in the wideband mode (90-110 kHz) only the 128 central elements are used.*

SACLANTCEN 100 kHz sonar was installed on a passive towbody (Fig. 03-G.6) deployed from R/V *Alliance* (in June 1999 and June 2000), off Punta Monesteroli (near La Spezia). Data from this series of experiments (MASAI'00) were used to produce SAS images, demonstrating the possibility of obtaining gains in cross-range resolution of a factor Q>10 (Fig. 03-G.7), a major milestone in the 2000 SPOW.

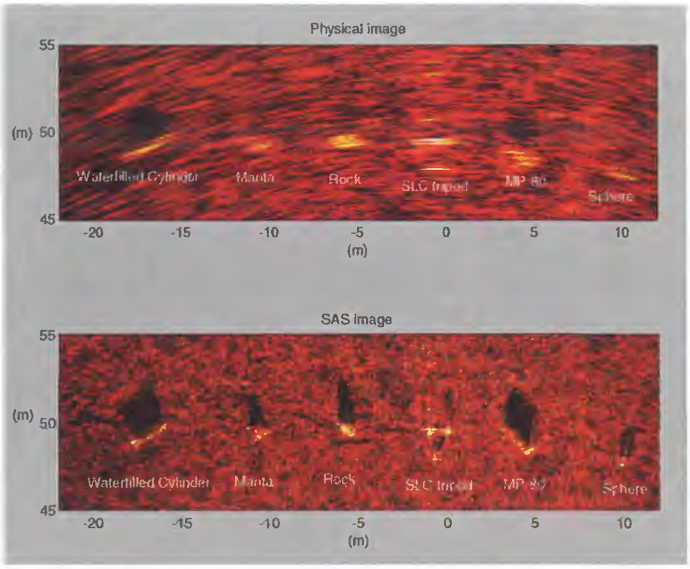

Figure 03-G.7 *Physical and SAS images of minefield on 50 m track. The SAS image is made in the wideband mode, by coherently summing the returns from 60 pings, whereas the physical image is that a single ping. The resolution achieved by the SAS is that of an equivalent physical array of length 10.57 m (Q=11).*

The quality of the SAS image demonstrates that a robust solution to the micronavigation problem, i.e. that of estimating the platform motion during the SAS integration time, with the required subwavelength precision, has been found. The micronavigation is performed using a data-driven technique known as the Displaced Phase Centre Antenna (DPCA), which correlates the seafloor backscatter at successive pings to estimate the sonar displacement. The theoretical study of DPCA micronavigation accuracy, initiated in 1998, has been improved and extended to study the influence of phase calibration errors of the physical array on DPCA accuracy.

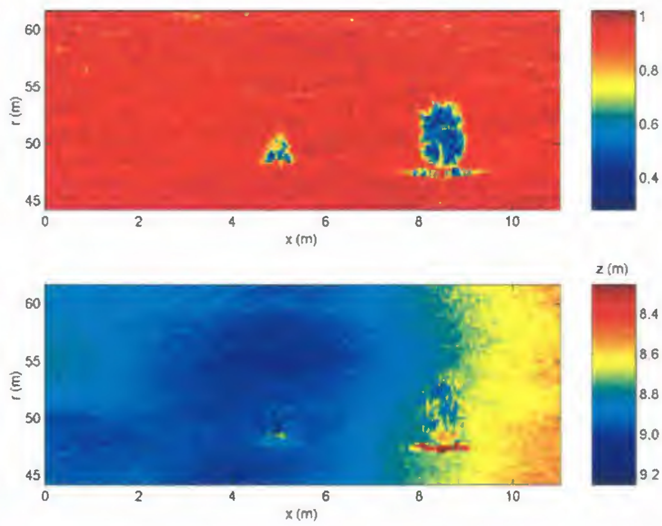

Figure 03-G.8 *Results of 120-180 kHz interferometric SAS with a baseline of 21.7 ?. For every column of the SAS image and for every 50 cm range window, the top and bottom SAS images are correlated. The correlation peak and lag gives the coherence map (top) and the delay gives directly the depth map (bottom), without the ambiguities inherent to the more conventional narrowband (phase-only) processing.*

Interferometric synthetic aperture sonar

High resolution, co-registered bathymetry and imaging is important for many survey applications, including future AUV-based MCM operations. A new approach to depth finding using interferometric sonar, based on direct time delay estimation, was proposed in 2000 and validated experimentally. The approach is particularly well suited to wideband signals and long interferometric baselines compared to the acoustic wavelength. The use of a long baseline increases the accuracy of the depth finding but exacerbates the ambiguity problem inherent with conventional interferometric processing. The data used was from a joint experiment between GESMA, France and DERA, UK carried out at the Lanvéoc rail facility. The sonar operates at 120-180 kHz with two receiving arrays (length 26.7 cm) of 32 elements and an interferometric baseline of 21 cm, an order of magnitude larger than existing systems. It was established that the combination of interferometry with SAS (known as InSAS) considerably improved the resolution and

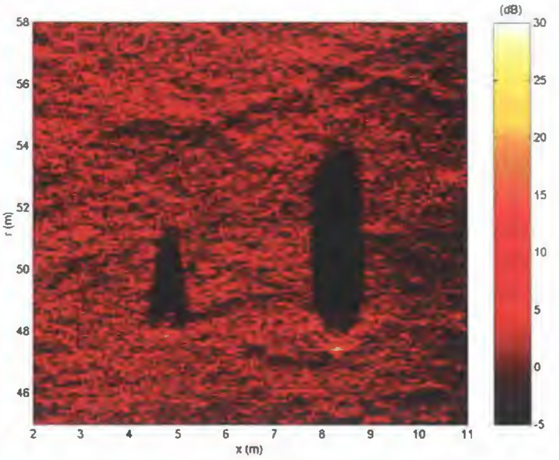

Figure 03-G.9 *SAS image (resolution in x: 10 cm, in r: 1.25 cm) for top array corresponding to Fig. 9 and integrated line-of-sight sways for top (red) and bottom (blue) arrays.*

accuracy of the bathymetry (Figs.03-G.8 and 03-G.9).

milestone

An experiment was performed in November 2000, jointly with DERA, UK and FFI, Norway with the objective of furthering the understanding of InSAS, another major milestone of the 2000 SPOW. In this experiment, DERA provided a 24 m underwater rail, a dynamic system allowing controlled sway, yaw and roll to be generated and a wideband interferometric sonar (Figs 03-G.10 and 03-G.11). The receive array was similar to the one described above, although the transmitter design was new. Three equidistant transmitters were used in order to investigate advanced SAS modes to increase the coverage rate. In addition to expertise in ocean engineering and logistic support for the trial, SACLANTCEN provided a strapdown inertial navigation system (INS), which is of the 0.1 n.mi/hr class (Fig. 03-G.12).

Aided inertial navigation

A significant gain in navigational accuracy will result from the combination, in an optimal Kalman filter, of a high grade INS and of DPCA micronavigation. This is being studied using the aided inertial navigation software, provided by FFI, called NavLab. The benefit of this gain for SAS is increased resolution at longer ranges. The benefit for an AUV equipped with SAS (alternatively a specifically designed navigation sonar optimized for DPCA micronavigation) will be increased range of autonomous navigation, between position updates (e.g. GPS fixes). The gain in performance over more conventional navigational aids, using a Doppler Velocity Log, will be evaluated in 2001.

problem

A major item of the 2000 SPOW was the issue of the specifications and international competitive bid, for a wideband high frequency transmitting and receiving sonar system to be integrated into the AUVs being procured from Florida Atlantic University. This work could not be undertaken due to the delay in the submission of the Capability Package.

Generic Oceanographic Array Technology Systems (GOATS)

The aim of the GOATS 2000 experiment was to assess the capability to detect, classify and identify modern mines in 9 m water depth by means of the *Ocean Explorer* AUV equipped with a commercially available side scan sonar (Edgetech DF-1000 dual frequency 100/ 390 kHz) and colour video camera. The AUV consistently detected all mines at ranges up to about 40 m and acquired side scan sonar images

Figure 03-G.10 *Mobile rail for InSAS'00 trial (DERA, U.K.).*

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of all targets at a variety of aspect angles (Fig. 03-G.13). In order to classify the targets, the images were processed off line with algorithms developed in a former SACLANTCEN project. The AUV performed a 3 track pattern to acquire aspects at 45° intervals. On each track, the analysis of local statistics allowed the rapid extraction of potential targets. The rectangular areas containing the potential target were automatically segmented into regions of three different types: shadow, echo and background. Spatial filtering was applied to remove artifacts in the shadow region. The shadow information was sent to a classifier trained on simulated target response. The classifier outputs for the three views were fused into a single result which infers the probability of the artifact being a particular target type (Fig. 03-G.14).

In a successive mission, the AUV executed a closely spaced search pattern centred on the geographical coordinates of objects classified as mine like for identification with the video camera (Fig. 03-G.15).

Figure 03-G.11 *Multi-axis motion system and 120-180 kHz interferometric sonar (DERA, U.K.)*

Figure 03-G.12 *High grade Inertial Navigation System procured by SACLANTCEN.*

Gyrometers (Honeywell GG1320)	
Range	±500 deg/s
Resolution	1.13 arcsec
Nonlinearity	10 ppm
Scale factor error	10 ppm
Random walk	0.003 deg/sqrt(hr)
Bias repeatability	0.003 deg/hr
Accelerometers (Honeywell QA3000)	
Range	±2g (high precision mode)
Resolution	0.2 μg
Nonlinearity	15 $\mu g/g^2$
Scale factor error	70 ppm
Random walk	8μg /sqrt(Hz)
Bias repeatability	30 μg
INS	
Size	< 260x370x200 mm
Latency	< 2ms
Sampling rate	Upto 1 kHz

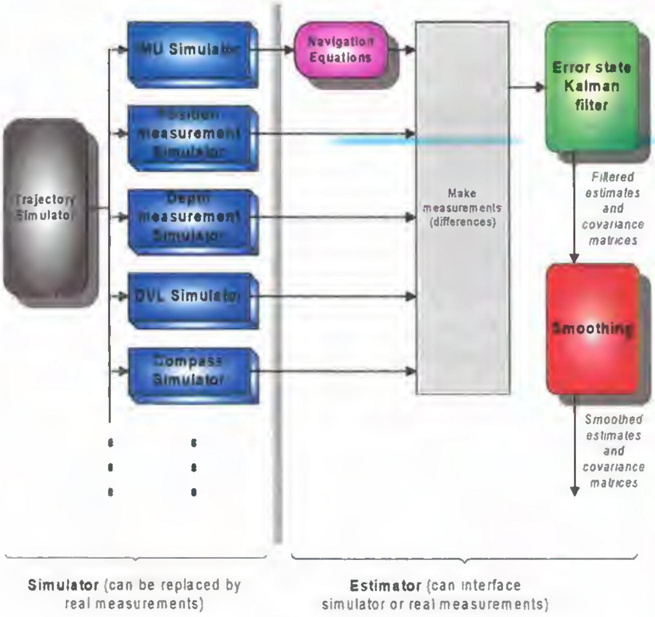

Figure 03-G.13 *Flowchart of the NavLab software (FFI, Norway) for the study of Aided Inertial Navigation.*

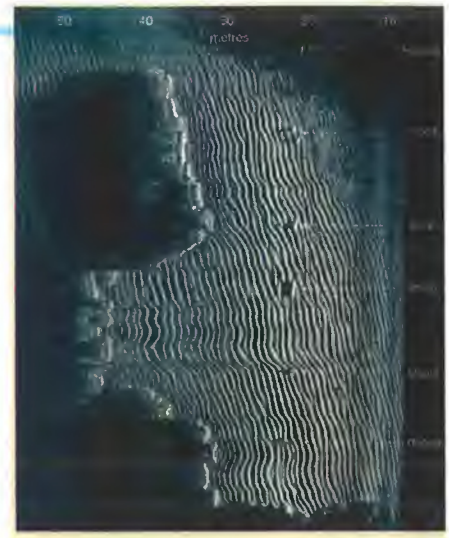

Figure 03-G.14 *Output of the multiple aspect classifier for the MP80 exercise mine.*

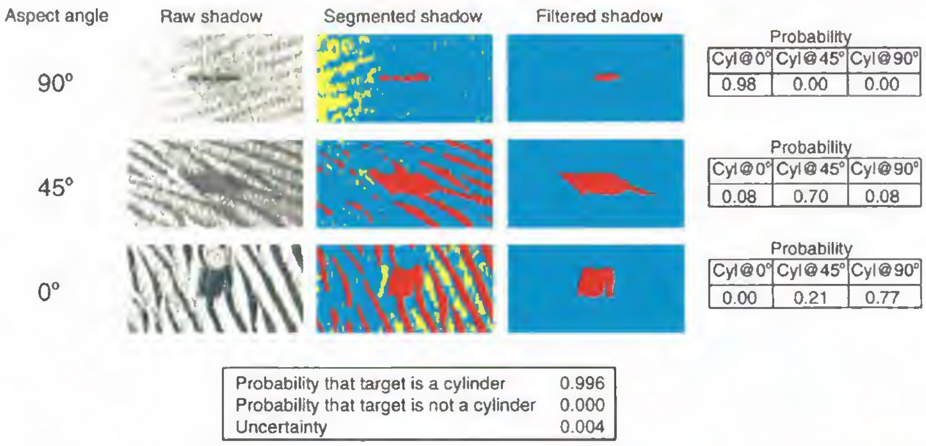

Figure 03-G.15 *Target field detected by the 390 kHz DF-1000 Side Scan Sonar mounted on the Ocean Explorer AUV.*

Figure 03-G.16 *MP80, Manta and Rockan mines identified by means of AUV video. The AUV coordinates are displayed on the upper left corner, the AUV depth and altitude on the upper right, mission time on the lower left, heading on the lower right.*

Thrust 03 publications and presentations

Acunto, S., Lyons, A.P., Pouliquen, E. Characteristics of the Mediterranean seagrass *Posidonia oceanica* contributing to high frequency acoustic scattering, SACLANTCEN SM-372.

Bellettini A., Pinto M. Experimental investigation of synthetic aperture sonar micronavigation. *In*: Zakharia, M.E., Chevret, P., Dubail, P., *editors*. Proceedings of the fifth European conference on underwater acoustics, ECUA 2000, 10-13 July, 2000, volume 2. Luxembourg, Office for Official Publications of the European Communities, 2000: pp. 445-450 [ISBN 92-828-9531-9].

Bellettini A., Pinto M. Experimental results of a 100 kHz multi-aspect synthetic aperture sonar, 5èmes Journées d'Etudes en Acoustique Sous-Marine, Brest 30 November – 1 December, 2000.

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Thrust 04 Tactical Active Sonar (from 2001 Littoral ASW)

Project 04-AB: Advanced shallow water tactical active and surveillance sonar (Alliance days – 18, Manning days - 5)

Operational relevance

To improve sonar performance in shallow water, reverberation-limited environments by exploiting the right/left ambiguity resolving capability of advanced towed arrays, broadband source/receiver technology and advanced processing techniques.

4

Upgraded ATAS system integration and improvements

One of the limitations of conventional towed array sonars is their inability to discriminate between echoes from port and starboard (and *vice versa*). Cardioid and twin array technologies exist, which overcome this limitation and effectively resolve the port/starboard ambiguity. In addition, broadband sonar is found to be attractive for reverberation/clutter reduction and classification. Broadband signals and processing have the potential to reduce reverberation and offer environmentally adaptable frequency selections. In addition, broadband sources and receivers improve the interoperability needed for multi-platform and multi-static operations.

problem

The newly procured low frequency broadband (two-octave) cardioid receive array and a pair of high power sound sources will provide a broadband transmission capability over the same two octaves. Effort has been concentrated on further understanding the performance of the cardioid array, leading to identification of deficiencies, which were initially discovered during analysis of the MERCURY'99 experimental data. The areas of concern are the array's mechanical characteristics and the signal quality of channel electronics.

problem

An engineering test conducted in August, confirmed that the fibre rod, which functions as a stabilizing mounting for the triplet housing, was inducing severe twisting and stress within the array (Fig. 04-AB.1). A scheme for removing this rod was developed and the triplet housings were attached to the internal, kevlar, strength members, with custom designed plates (Fig. 04-AB.2a and Fig. 04-AB.2b).

Testing during the ECHIDNA'00 sea trial, demonstrated that the design modification has improved the mechanical characteristics of the array. Calibration before removal of the rod indicated that severe stress induced excessive twisting. There were significant deviations between actual and assumed twist (via roll sensor readings), which affected right/left processing performance. Figure 04-AB.3 shows

Figure 04-AB.1 *Hydrophones with triplet housing attached to fibre rod .*

Figure 04-AB.2 *Design drawing of the modifications made to the triplet attachment using plates instead of the fibre rod .*

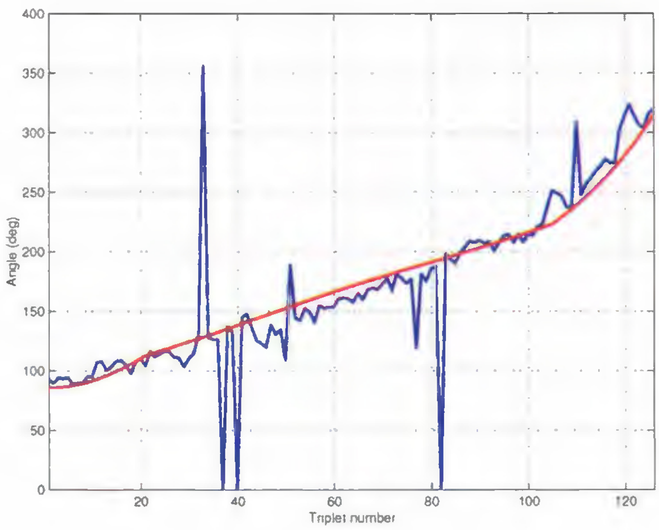

Figure 04-AB.3 *Array twist obtained through calibration measurement (blue) agrees well with the predicted array twist from only using roll sensors readings (red) .*

Figure 04-AB.4 *High frequency (HF) and low frequency (LF) high power sound sources.*

acoustic calibration of twisting after the rod was removed (with an appropriate bias correction). Twisting has been reduced and there is better agreement with predicted twisting from the five roll sensors. Work continues on improving amplitude and phase matching between acoustic channels.

problem

Figure 04-AB.4 shows the low (right) and high (left) frequency high power sound sources. The original concept was to procure a single-stave source with transducers of one size that would have frequency coverage over both octaves. This was eventually determined to be technically unfeasible and a compromise design of two separate staves was accepted. Each source is made up of three rings of ceramic material, with a centre air-filled resonating tube. Used together, these sources will cover a frequency range of two octaves. The HF source has been accepted from the manufacturer and successfully tested with maximum source levels over the cardioid array frequency range. The LF source has been delivered for acceptance testing. The integration of the two sources, the design and testing of an appropriate tow body and deployment/retrieval procedures will continue until the end of 2001.

The ECHIDNA'00 trial in November 2000, was designed to test and evaluate the various components of the LFAS system and to prepare for the multi-national CERBERUS'01 multistatic sea trial in August 2000. In addition to the source and array testing already described, measurements were conducted to evaluate the potential of spread sprectrum radio for ship-to-ship exchange of sonar contact data (a desirable component of the multistatic sea trial next year). Figure 04-AB.5 shows the data link availability and throughput achieved, during a link experiment with two nodes, in at-sea conditions. The measurements emulated the application of sharing of sonar "object" data (post-detection data including only targets and the most target-like false alarms). These results show that there is sufficient bandwidth and reliability over a range of 9 n.mi.

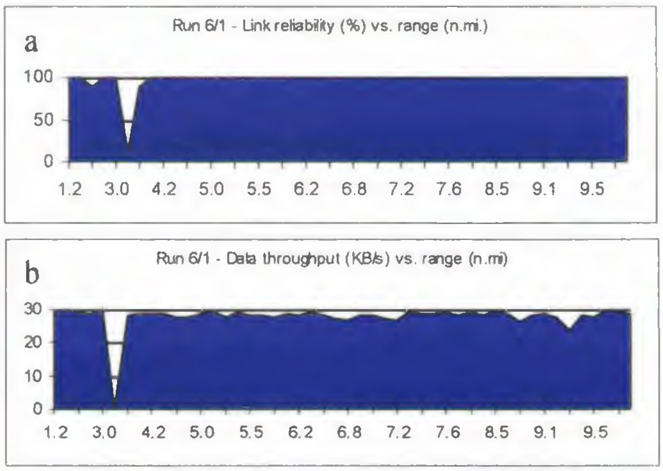

Figure 04-AB.5 *Ship-to-ship measurements show high reliability (a) with the sufficient data throughput for a variety of ranges.*

Advanced DUSS system acquisition

Deployable Underwater Surveillance Systems (DUSS) employ multiple, fixed, distributed, autonomous sonar receivers operating in conjunction with

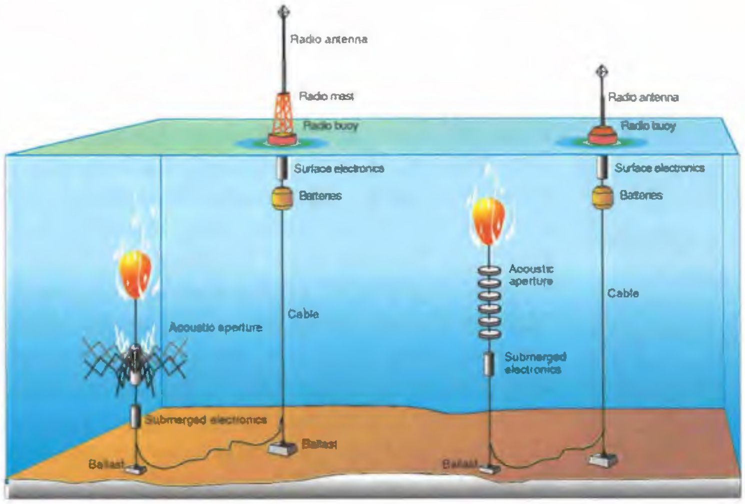

Figure 04-AB.6 *Depiction of Deployable Undersea Surveillance System (DUSS).*

one or more deployed or towed active sources. These systems exploit the advantages of multistatics in a "surveillance" mode at port exits, passages and choke points. Their main features are modular extension of surveillance areas and/or volumes and covert receivers with multiple, independent opportunities for target detection, with aspect or Doppler diversity. In addition, such systems may better overcome poor conditions of propagation and reverberation, by optimizing receiver location with respect to the target (Fig. 04-AB.6).

milestone

Upgraded DUSS source and receiver buoys were specified, a manufacturer selected and the procurement contract formalized. The detailed system design was initiated in the last months of 2000. The contractor will work closely with Centre engineering staff to ensure that the system delivered meets scientific requirements, based on extensive testing of prototypes. Delivery is expected in early 2002.

Measure of performance

Algorithms that are implemented for the detection of active sonar echoes in antisubmarine warfare are evaluated against some measure of performance. The classical ROC curve measures probability of detection against probability of false alarm per observation bin. For highly non-stationary data or after a cluster algorithm, the probability of false alarm per bin becomes less meaningful.

We have defined a new measure of performance that, within a ping of data, makes objects of connected pixels (data clustering) and determines the aiming point for each object, which is usually the data mass-centre and which defines the exact location of the object. An object within a certain distance from the submarine is considered a detection, otherwise it is counted as a false alarm. The number of false alarms is now per ping. This previously reported measure of performance has now been applied to the evaluation of cardioid beamforming and post-detection integration methods.

Cardioid beamforming

The object measure of performance was used to demonstrate the advantage of cardioid beamforming compared to conventional line array beamforming. The data were acquired during the BACCHUS '98 trial, an experiment configured with a reverberation ridge on one side of the array and a target on the ambiguous side, which would have been obscured by a conventional (non-cardioid) beamformer. The data were matched filtered using a 100 Hz bandwidth LFM and beamformed (narrowband), with conventional (one element of each triplet) and cardioid (triplets) algorithms. The data were then normalized using a split window mean normalizer with a window size to minimize the number of false alarms without losing the known target detections. The number of false alarms is determined by forming objects of the threshold crossings and counting them. A list of high-level clutter detections were identified, above a threshold.

Figures 04-AB.7 and 04-AB.8 show the results for line array and cardioid beamforming, respectively, for a single ping. The figures show the acoustic levels at the matched filter output, with location of post-detection objects (above a

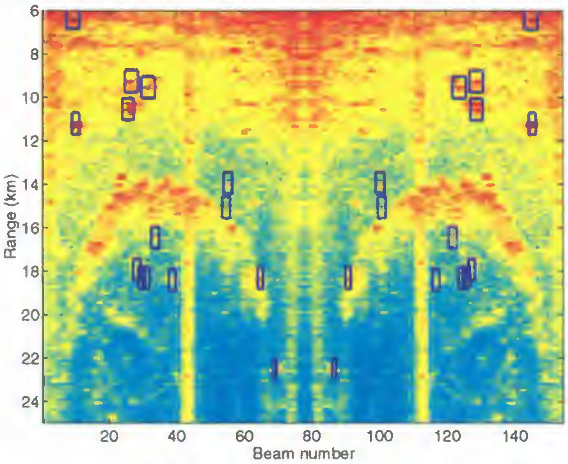

Figure 04-AB.7 *Single ping range-bearing image for conventional beamforming, showing the right/left ambiguity for both obscuring reverberation features and confusing clutter objects.*

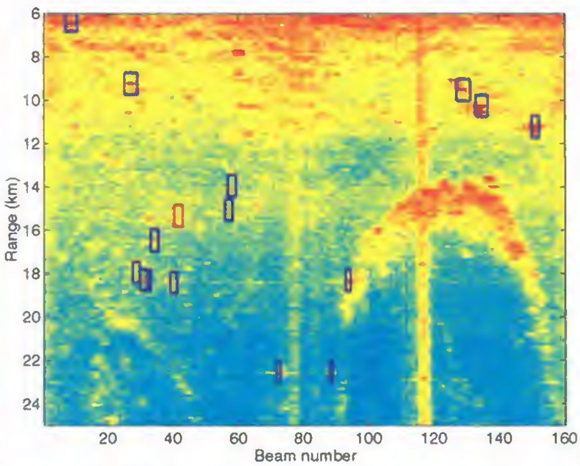

Figure 04-AB.8 *Single ping range-bearing image for cardioid beamforming, showing right/left discrimination and reverberation suppression on direction reverberation and overall reduction in clutter objects.*

threshold) indicated by the superimposed boxes. Clearly, the cardioid beamformer resolves the large reverberation ridge feature and a passive shipping noise line to the right side, while the conventional beamformer shows it on both sides. In the conventional processing, the ambiguous reverberation feature obscures a target echo making it impossible to detect. In the cardioid image, the target echo has been revealed, as shown in the red box. The blue boxes indicate locations of detected (false alarm) clutter objects.

The cardioid beamformer resolves most of this clutter to the right or left side. For example, the group of three clutter points in the upper left corner of the picture is divided into a group of two on the right and one on the left. Through the cardioid beamformer's ability to discriminate false alarms, there is a reduced total amount of detected clutter objects for the same threshold in this ping.

Figure 04-AB.9 shows the number of false alarm objects as a function of threshold for the data set (40 pings) of the previously shown ping. The green curves shows the number of false alarms for the conventional (line) array over all space (360°), taking into consideration that detected objects are counted twice as each object produces two false alarms, one for the left and one for the right. The blue curve shows the number of false alarms over all space (360°), for the cardioid array. The cardioid beamformer shows better performance against clutter, with about a 25% reduction of false alarms compared to the conventional beamformer.

The advantages of the cardioid beamformer are also demonstrated when considering target detection probability. For this data set, the target is obscured from the conventional array by the ambiguous return of the reverberation ridge, while the cardioid beamforming separates the reverberation ridge and the target to opposite sides of the array. This has the effect of revealing target detections which were previously obscured. For this data set, at a fixed level of 50 false alarms, the cardioid processing detects the target 90 % of the time, whereas the conventional beamformer detects only 15% of the time. It follows that cardioid processing improves probability of detection and decreases the false alarm rate (due to directional clutter), while providing a port/starboard localization advantage.

Post-detection integration study

The echo of a submarine may be dissipated in time by environmental multipath and/or the submarine itself. Methods referred to as post-detection integration, combine the energy of the submarine to improve detection probability.

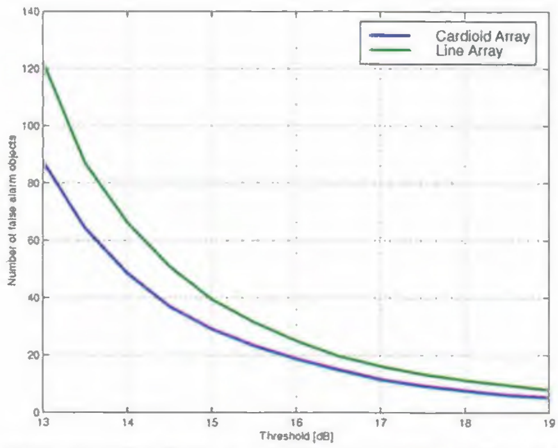

Figure 04-AB.9 *Reduction of PFA as a function of detection threshold is shown for cardioid processing (green) relative to conventional beamforming (blue).*

One way to collect the energy is by applying a sliding mean filter, which averages all the energy over a fixed range width. The time spread may, however, vary with different environmental conditions or different submarine aspects. Therefore, integrating with the same range extent may not be optimal all the time, under all conditions. Another approach, the Page test algorithm, adaptively determines the range extent by observing where the background statistics change (indication of start of echo) and where the original background statistics return (indication of end of echo).

In order to compare the moving average algorithm and the Page test, two active sonar data sets were used, with different centre frequencies for different environments.

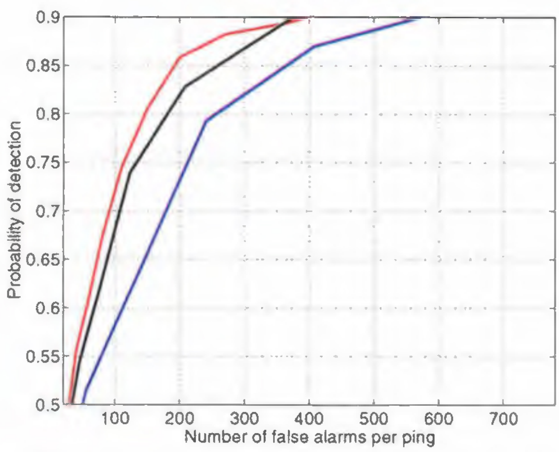

Figure 04-AB.10 *Post-detection integration schemes (red, black) improve ROC curve results over conventional post-detection processing on SHAREM data.*

The algorithms were applied to 160 pings of SHAREM data with a 100 Hz frequency band and 40 pings of BACCHUS'98 data with similar bandwidth. The SHAREM data were collected with a linear array, the BACCHUS data with a triplet (cardioid) array and processed for port/ starboard discrimination. Both data sets were acquired in the Mediterranean Sea, in shallow water areas.

Figures 04-AB.10 and 04-AB.11 show ROC curve (where false alarms objects are quantified on a per ping basis) results for the SHAREM and BACCHUS'98 data sets. There is almost an order of magnitude difference in the number of false alarms between the two data sets due to the different centre frequencies and environmental conditions. In both figures, the blue lines correspond to the case without post-detection integration. The black lines correspond to the moving average filter and the red line to the Page test. In both figures, both of the post integration approaches significantly improve the ROC curve performance. For the BACCHUS'98 data set, the submarine presented almost

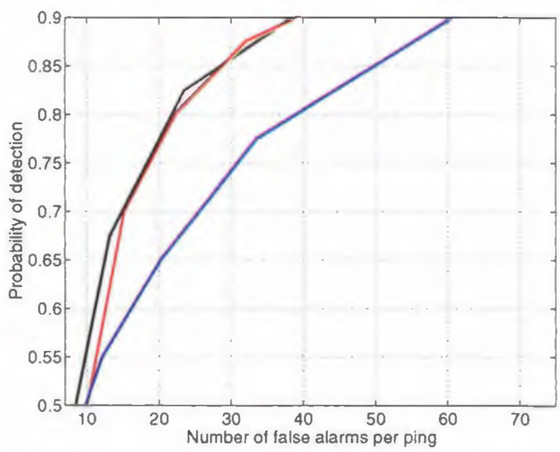

Figure 04-AB.11 *Post-detection integration schemes (red, black) improve ROC curve results over conventional post-detection processing on BACCHUS'98 data.*

constant aspect angle and the length of the time spreading was approximately equal to the length of the moving average filter. The Page test and the moving average filter gave equivalent results. For the SHAREM data set, the aspect angle of the submarine varied during the run and the Page test's adaptation to the change in echo spread gave slightly better performance, as shown in the ROC curve.

Broadband processing

New source and receiver technology, in conjunction with the development of processing algorithms is making possible the option of operating ATAS sonars over much broader frequency ranges (2 octaves or more) than has previously been possible. Broadband sonar operations can mitigate the reverberation problem (by reducing scattering patch sizes). They can also provide more flexibility by allowing for optimum frequency band selectivity and increasing the compatibility and interoperability between multiple or multistatic systems. Research has focused on evaluation and exploitation of the frequency variability of reverberation and submarine detection.

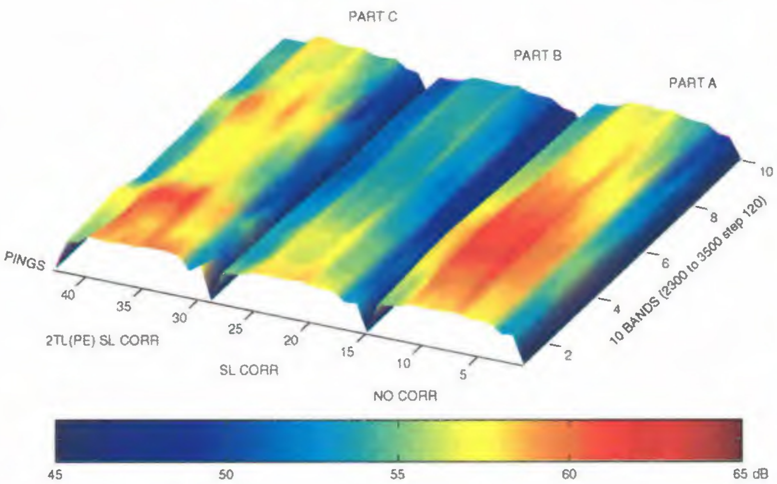

Figure 04-AB.12 *Frequency response of a reverberation patch for a sequence of 40 pings (a) no correction, (b) source level correction, (c) propagation loss correction.*

The frequency response of reverberation has been evaluated with SWAC4 reverberation data from a 200 m seamount. The replica of the transmitted signal was divided into ten equal width sub-bands, each of which is matched filtered individually, with the reverberation in the received data. The results are corrected for array gain, calibration settings, transmitted power spectrum and propagation loss and compared to determine the frequency dependence of reverberation. Figure 04-AB.12 demonstrates the three stages of this analysis: part A corresponds to the levels of the matched filter output, part B to the source level correction and part C to the final adjustment based on the predicted (through modelling) two-way propagation loss. The comparison between A and B reveals that the original bias towards low frequencies is attributed to the source's power spectrum. The correction for the propagation loss introduced small sub-band variations without creating any prominent frequency trend. These results are consistent with those obtained for the submarine target case of the same experiment (reported previously[1]) and lead to the conclusion that, for the particular experimental set up and environmental conditions, the available bandwidth does not demonstrate significant target echo or reverberation variability as a function of frequency.

Preliminary results from analysis of several pings of the MERCURY'99 sea trial, during which a significantly larger bandwidth was achieved, show an interesting frequency dependence for submarine target echoes. Results are presented from an active run where source and target are moving on parallel courses, approximately broadside to each other. The transmitted waveforms were LFM signals. Four different pulse lengths were used: 1, 1.5, 3 and 6 s, transmitted in sequence.

The first analysis was to evaluate the frequency of the system with (ten) constant bandwidth sub-bands for each signal. The received signal is matched filtered with each sub-band to determine if an optimum performing frequency band exists. The best performing frequency band was selected as a baseline and the effect of increasing and decreasing bandwidth evaluated.

Figure 04-AB.13 shows four consecutive pings of the run described above. For each ping (each of different pulse length), the matched filter output (in range) is plotted against ten 240 Hz sub-bands in increasing frequency order. The target range is in the upper part of the picture. It is clear in this case that, counter to the SWAC data, there is a clear frequency performance trend, which is maximized at the low end of the spectrum – taking into account that here, the

[1] SACLANTCEN SR-320

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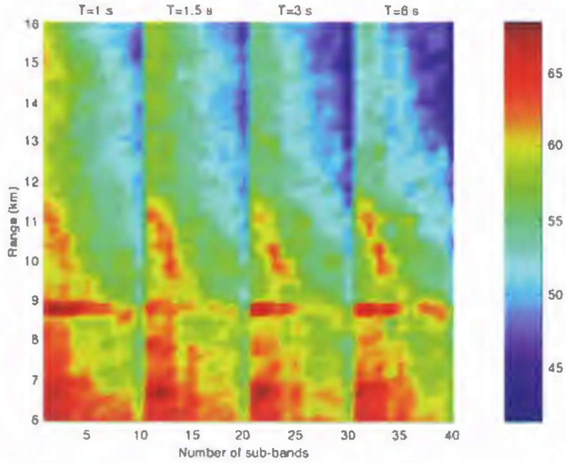
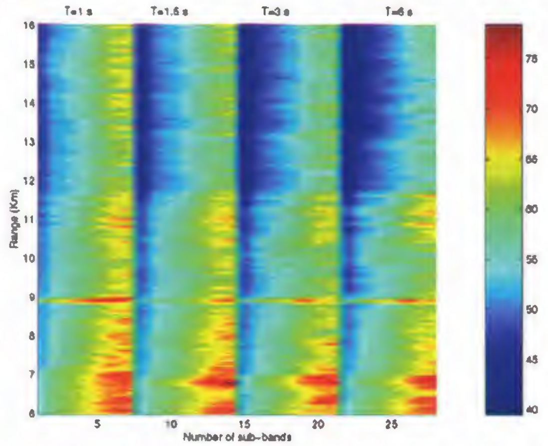


*Frequency range: 1-3.4 kHz. Ten 240 Hz subbands (with increasing frequency order) for each LFM (1 s, 1.5 s, 3 s, 6 s)

Figure 04-AB.13 *Acoustic levels versus range, frequency sub-band and waveform duration from the MERCURY'99 data set.*



* Frequency range: 1-3.4 KHz. Seven subbands with different spectra as shown:

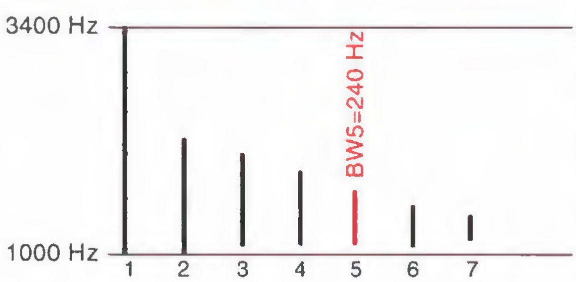


Figure 04-AB.14 *Acoustic levels versus range, sub-band bandwidth and waveform duration from the MERCURY'99 data set.*

source spectrum is not biased towards low frequencies. In particular, the lowest frequency regime yielded the optimum matched filter output. In terms of the acoustic background, it is observed that within each ping, ambient noise decreases with increasing frequency, while the comparison of adjacent pings shows that the noise level is inversely proportional to the pulse duration, as expected.

Next, the optimization of the bandwidth was addressed. A new set of seven frequency bands

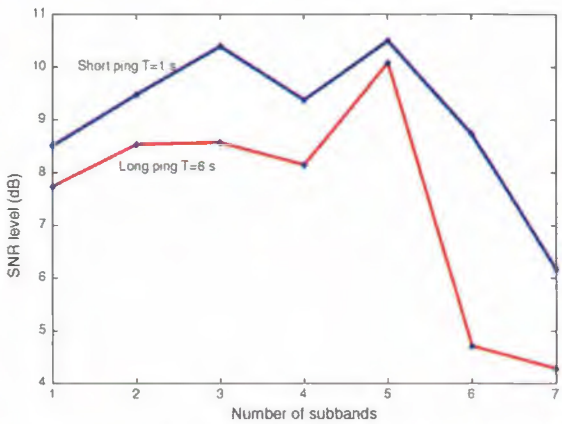


Figure 04-AB.15 *Signal-to-noise ratios versus sub-band bandwidth for 1 and 6 second waveforms.*

was selected (Fig. 04-AB.14), which are either supersets or subsets of the frequency band with optimum performance found previously. Figure 04-AB.14 shows the detection outputs based on this new set of frequency bands, with varying bandwidth. The very wide sub-bands demonstrate the least promising performance for all pings. A sub-band of 240 Hz around the low frequency end seems to yield the best detection performance. In all cases the background reverberation decreases with increasing bandwidth, as expected. Figure 04-AB.15 shows the signal-to-noise ratio of the two extreme pings, T=1 and T=6 s. For the environmental conditions in which the experiment was conducted, the geometry of the run and the type of signals utilized, the sub-band that maximizes the detection performance is the fifth. A more conservative choice would include three signal possibilities, namely the third, the fourth and the fifth. For this limited analysis of a small number of pings, the detection performance should be based on the lower half of the available spectrum using sub-bands with bandwidth of the order of 240 Hz. Further verification of these performance results is planned using a larger data set.

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Project 04-C: Low frequency shallow water reverberation and propagation: adaptation to large bandwidths (Alliance days – 21, Manning days - 3)

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. One of the goals of this project is to develop experimental techniques for measuring bottom scattering in shallow water, which in conjunction with advances in modelling will improve performance prediction of frequency dependent sonar systems.

4

Introduction

Low frequency (1 – 4 kHz) active sonar systems in shallow water must contend with seafloor reverberation, which confounds the detection and classification of small submarines. In order to predict system performance, models and databases of the seafloor are required. However, current NATO models are too simple to properly predict the dependence of sonar performance on frequency or bottom region. One of the most important obstacles to the development of improved models and databases is simply the lack of data. "It is a capital mistake to theorize before one has data"[1].

An important objective of Project 04-C has been to develop new techniques for measuring seafloor scattering and then conduct measurements in various environments to begin to have enough data "to theorize" (i.e., to develop an improved NATO model).

In conjunction with seafloor scattering measurements, seafloor reflection measurements were also conducted. The reflection data are used to extract high resolution geoacoustic models. This novel approach provides data for propagation predictions and key data for interpreting seafloor scattering measurements.

milestone

The highly successful *Boundary2000* experiment conducted on the Malta Plateau in April-May 2000 was the first of three Joint Research Project experiments with the United States. Although the cardioid array was not available for reverberation measurements, high quality seafloor reflection and monostatic and bi-static seafloor scattering experiments were conducted. In addition REA reverberation measurements (using SUS) were carried out at the same locations, as the vertical array benchmark method. These data will allow validation and refinement of the REA reverberation technique. In related research areas, the focused field reverberation data analyses were completed, showing that gain against seafloor reverberation is possible using a focused acoustic field, but substantial horizontal resolution is required. The transition of the seafloor reflection and scattering measurements to AUVs was not funded, but remains an attractive possibility.

[1] Sir Arthur Conan Doyle (1859-1930). Scandal in Bohemia.

Refinements in the processing techniques developed this year have led to some of the highest quality (in terms of angular resolution and frequency coverage) seafloor reflection data available anywhere. New bi-static reverberation measurements are shown and discussed. The data indicate a surprising phenomenon that gives rise to sonar clutter in this area.

Geoacoustic measurement results

Two shallow water, geologically complex regions were selected, the Malta Plateau south of Sicily (Fig. 04-C.1) and an area north of Elba. Environmental measurements of the Malta Plateau are important because it is the experimental area for sonar system development (Project 04-A). One of the important bathymetric features is the Ragusa Ridge (east of Site 10). Swath bathymetry data acquired in 1998 (Project 04-C) and 1999 (Project 01-B) were merged to create a detailed map of this feature.

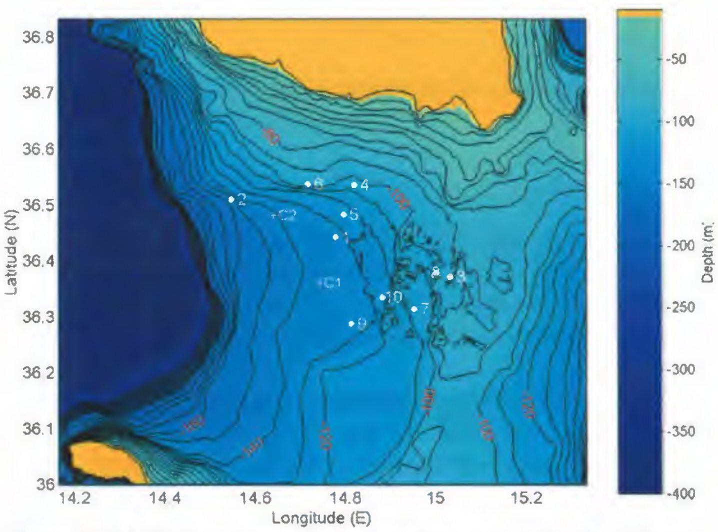

Figure 04-C.1 *Site locations and bathymetry in metres on the Malta Plateau for the Boundary2000 Experiment. C1 and C2 indicate locations of REA reverberation measurements.*

Nearly the entire western area of the Malta Plateau is covered with silty-clay sediment, although a few areas in the northern region (e.g., near Site 6) exhibit rock outcrops. One of the properties of silty-clay is that it has a sound speed less than that of water, even though its density is greater than that of water, giving rise to an effect, at a certain angle, when the reflection coefficient is zero and there is complete transmission of sound into the seafloor.

In practice, not all the energy is completely transmitted, because of sediment attenuation (including absorption and scattering). Figure 04-C.2, shows measurements at Site 4, for the silty clay layer. The angle of near complete acoustic transmission into the sediment is apparent at 15°. One of the remarkable aspects of this kind of sediment is the nearly complete acoustic transparency. Even up to 5 kHz (not shown), the data indicate that 99% of the energy is transmitted into the seafloor above 10° grazing angle. At the angle of intromission, ~99.95% is transmitted. The implication is that sediments *below* the first layer, will largely control the acoustic reflectivity and scattering characteristics, i.e., will strongly influence sonar performance.

A simple geoacoustic inversion method has been developed for extracting the sound speed and density from this sediment type by measuring the angle of intromission and the normal incident reflection coefficient. By reading these quantities off Fig. 04-C.2, 15° and 19 dB respectively, the technique yields a sediment sound speed and density of 1480 m/s and 1.32 g/cc. Model-to-data comparisons using those inputs (and a fitted effective attenuation of 0.07 dB/m/kHz) are shown in Fig. 04-C.3. The fit is very good, indicating that these properties are correct. In addition, the inversion results are in excellent agreement with core data analyzed after the inversion of 1484 m/s and 1.346 g/cc.

The slight frequency dependence and the fluctuations around the model results indicate the presence of fine-scale layering, volume inhomogeneities, and/or surface roughness. The effective attenuation value is useful in defining the absolute upper bound for intrinsic attenuation, which for this sediment type is

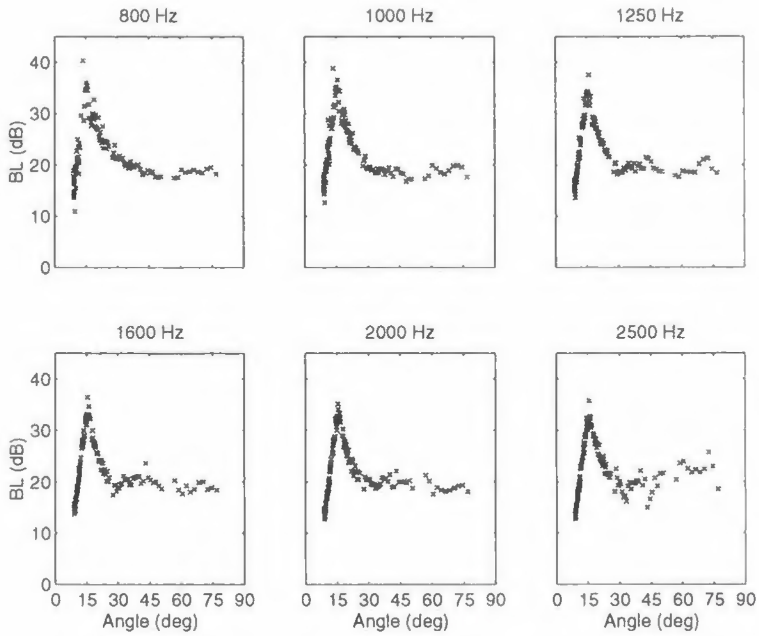

Figure 04-C.2 *Seafloor reflection loss from first layer of Site 4.*

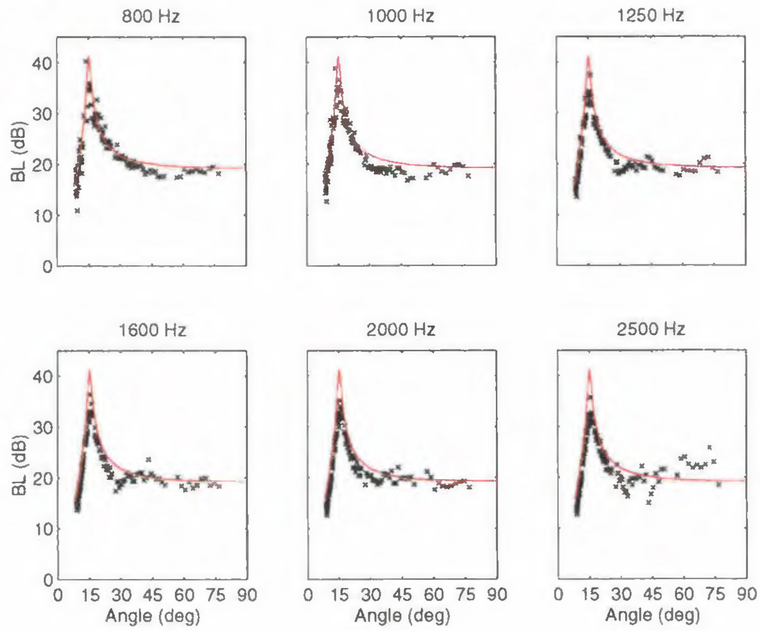

Figure 04-C.3 *Measured seafloor reflection loss (x) from the first layer of Site 4 with the model results from the geoacoustic inversion (red line).*

expected to be one order of magnitude smaller than 0.07 dB/m/kHz.

Another remarkable aspect of these data is the similarity to sites at the same water depth north of Elba, 500 n.mi distant. Figure 04-C.4 shows 2000 Hz measurements in the Malta Plateau (red) and in the North Elba area (blue and green). The implication is that the surficial sediments in both areas are almost identical. This is surprising, given the notorious geoacoustic variability that characterizes shallow water sediments and the distinct riverine environments feeding both regions. The layer properties also appear consistent across the entire western Malta Plateau region.

Although the properties of the first layer are so remarkably uniform, the reflection and scattering from the entire sediment column is very definitely not uniform. This is so because the first layer thickness is variable across the region and also

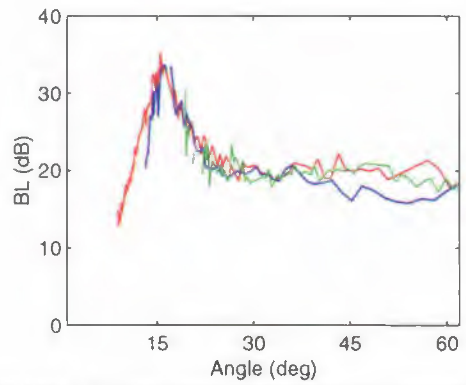

Figure 04-C.4 *Comparison of measured reflection coefficient at 2000 Hz for the first layer in the Malta Plateau (site 4: red) and north of Elba (site 5: blue, Site 4: green) at 102 m water depth.*

because the underlying strata are variable. Figure 04-C.5 shows the seafloor reflection loss at 3 sites on the Malta Plateau and 3 sites north of Elba.

These data provide new insight into variability in shallow water. For purposes of predicting propagation and reverberation, the important factor in the plots is the position of the "knee" where the reflection loss changes from a low value at low angles to a high value. Generally, with increasing frequency this knee occurs at decreasing angles, which indicates that propagation will be better (lower loss) at lower frequencies. A notable exception is the Malta Plateau at 130 m, where there the best propagation is in the middle band 800-1000 Hz.

These data have yielded significant information about the seabed in this region that will form the basis for model development and validation.

Seafloor scattering results

milestone

For the first time, direct path bi-static seafloor scattering strength experiments were conducted (Fig. 04-C.6). The source is a vertical dipole that helps reduce the effects of multi-paths. The receiver is the DUSS buoy developed under Project 04-B (Fig. 04-C.7). The star-shaped planar array configuration is designed to isolate scattering from a particular direction. The easily changeable inter-element spacing permits probing of the seafloor at various frequencies with a constant beamwidth. Figure 04-C.8 shows deployment of the system during *Boundary2000*. The ballast at the bottom of the array aids stability. For low (less than 0.2 kn) drift rates, the pitch and roll of the system was quite stable, usually less than 1°.

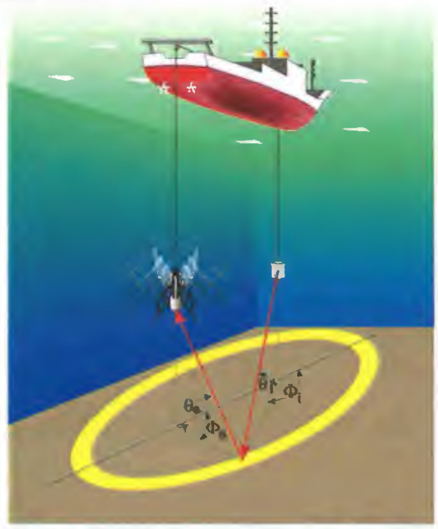

Figure 04-C.6 *Showing bi-static seafloor scattering measurement geometry. The objective was to measure the dependence of the seafloor scattering strength on the four angles shown.*

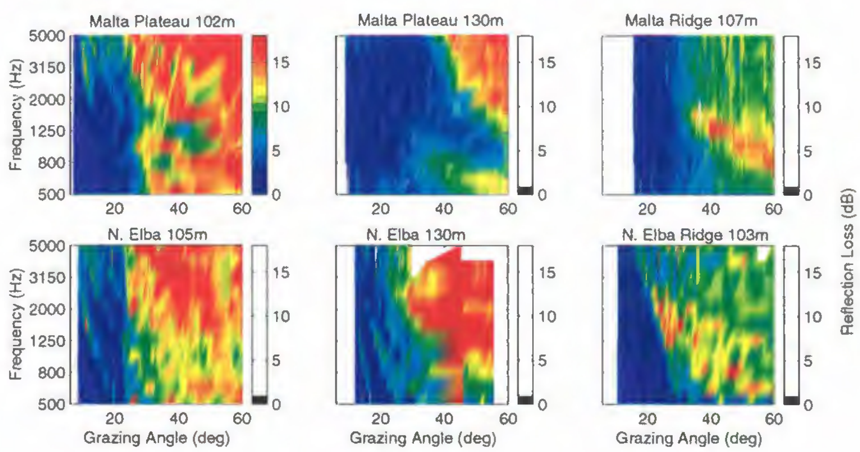

Figure 04-C.5 *Comparison of measured total reflection coefficient in the Malta Plateau (Site 4, 1, and 7) and north of Elba at similar water depths. One crucial factor controlling propagation is the position of the "knee" where the reflection loss changes from a low value at low angles to a high value. The position and frequency dependency of the knee is highly variable, although some similarities exist between the two study areas.*

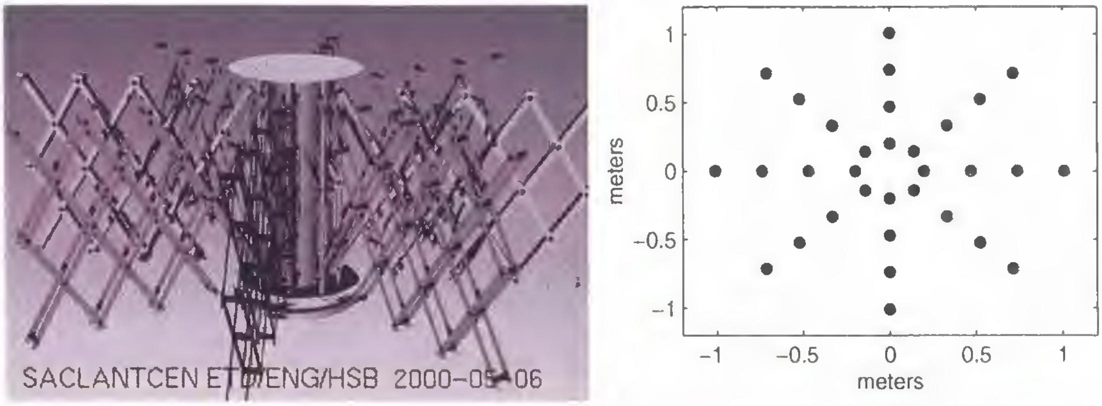

Figure 04-C.7 *Showing the DUSS structure. The folding frame allows the inter-element spacing to be easily changed. Three tiers of 32 hydrophones each, arranged in a star pattern (seen to right) provide the spatial resolution required for conducting these measurements. When the arms are fully extended the total array aperture is about 4 m.*

Figure 04-C.9 shows measured reverberation from the DUSS array at 1800 Hz. The x-axis is time relative to the source broadcast at 1 s; note the direct blast on the array shortly (50 ms) thereafter. The high energy returns on all beams (red stripes) are due to multipath from seafloor and surface reflections. Following the multipaths, there is randomly distributed reverberation. The data were acquired at a low sea state and it is believed that reverberation is mainly from the seafloor. At certain times and azimuths (e.g., Site 7 at 1.75 s and 160° azimuth) there are distinct sharp arrivals. These clutter events can give rise to false targets for low-frequency active sonar. At Site 7 and Site 3, these clutter events are caused by rock outcrops on the Ragusa ridge such as those in Fig. 04-C.10.

Figure 04-C.8 *Deployment of the DUSS array in its retracted position.*

The remarkable sharp clutter features in the flat basin area at Site 2 (e.g., at 1.75 s and 60° in azimuth in Fig. 04-C.9), are actually higher than

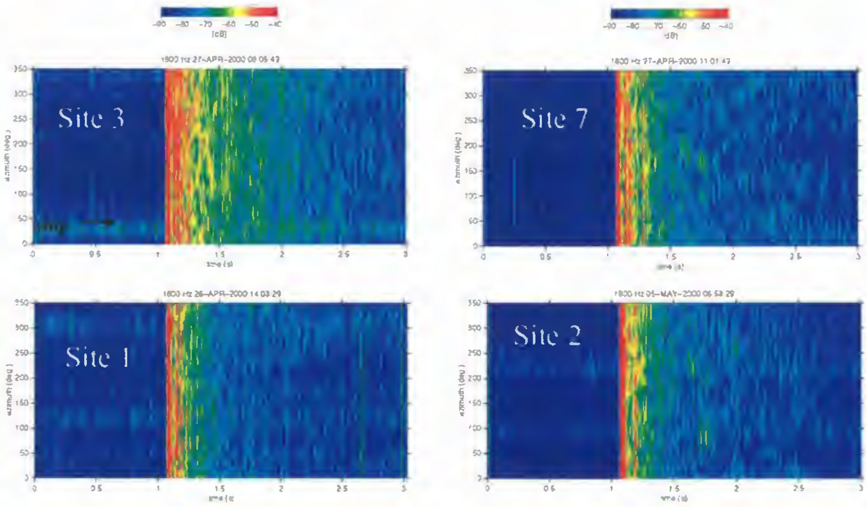

Figure 04-C.9 *Measured azimuthal dependence of 1800 Hz reverberation at various sites. Sites 3 and 7 are on the Ragusa Ridge and Sites 1 and 2 are in the basin. The source initiation is at 0 s. One of the salient features is the clutter observed at the various sites, even in the flat basin area.*

the clutter events observed on the ridge. The bathymetry at Site 2 shows that the seafloor is extremely smooth. Seismic reflection data show that the layering structure is also quite smooth. What could be causing these strong clutter returns? This question led us on a high resolution exploration around Site 2 in the direction and range of the strongest returns. However, for several days we were unable to observe anything in the sub-bottom profiler or sidescan records that could explain the clutter. Finally, literally in the last few hours of the experiment, our survey yielded data to verify our hypothesis: the clutter returns are caused by gas-charged sediments. The size of these features were surprising small

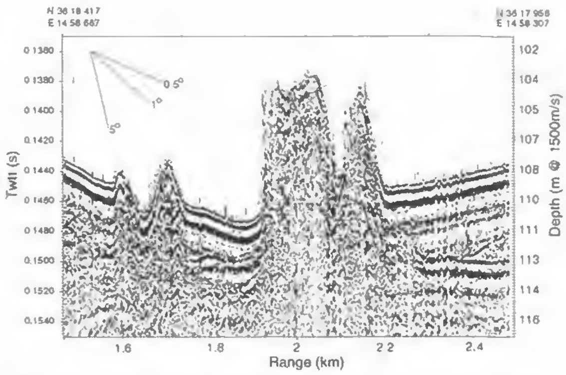

Figure 04-C.10 *Seismic reflection data on the Ragusa Ridge from a Uniboom source. The sharp features, for example at 2 km ranges are rocky outcrops that rise as high as 6 m above the seabed..*

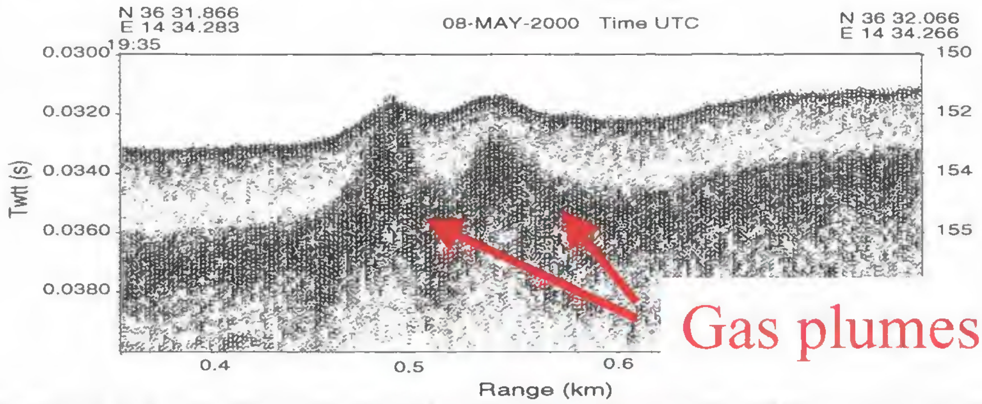

Figure 04-C.11 *Seismic reflection data from a chirp sonar. There are two gas-charged plumes at 0.5 and 0.55 km. The gas-charged sediment has an extremely low velocity and density, which makes it highly reflective to low-frequency sonar..*

(of order only a few tens of metres in lateral extent) which explained why they were so difficult to find, even though we knew from the reverberation data where to look.

Figure 04-C.11 shows two of the gas plumes as observed on the chirp sonar; one of the plumes appears to break the surface. The high reflectivity of these features (as strong or even stronger than the rock outcrops on the ridge) is due to the low density and velocity of the gas-charged sediments. Sidescan data taken at the same time appears to confirm that the rising gas does perforate the sediment surface. The dark spots of Fig. 04-C.12 mark the position of the gas plumes. Four dark spots, corresponding to the presence of gas-charged sediments are visible in the side-scan data; the sub-bottom profiler record shows only the two plumes along the centre-line of the track. The development and application of new measurement techniques has lead to new understanding about the seafloor, its spatial variability and the properties that control propagation, reverberation and clutter. The measurements conducted this year will be employed to develop and improve REA techniques and sonar performance models.

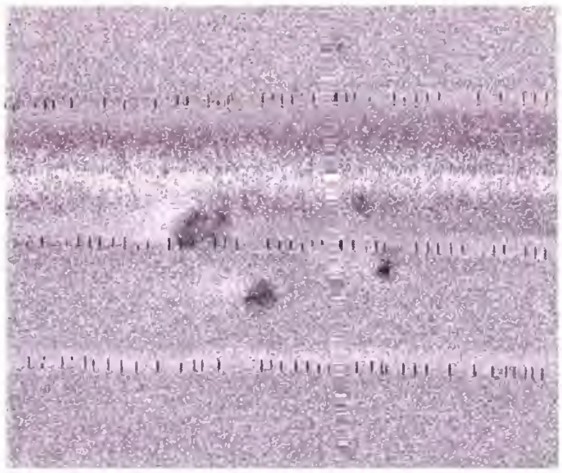

Figure 04-C.12 *Sidescan data showing the surface expression (dark smudges) of the gas pockets. This image was collected on the same tow-body as the chirp data of Fig. 04-C.11; the two gas plumes observed in Fig. 04-C.11 are the two closest to the centre line of the track (horizontal white stripe). The distance between the two plumes along the centre-line is about 50 m.*

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.*

B. Edward McDonald *received his Ph.D. in physics in 1970 at Princeton, after which he joined the Naval Research Laboratory (NRL) Plasma Physics Division. From 1970 to 1980 he carried out numerical investigations of ionospheric plasma processes related to high altitude nuclear weapons effects and to naturally occurring plasma turbulence affecting satellite communication. From 1980 to 1990 he worked for the Naval Ocean R & D Activity/ Naval Oceanic - Atmospheric Research Laboratory developing theory and numerical solution techniques for fluid dynamics and nonlinear acoustics. He joined the NRL Acoustics Division in 1990, where he developed theory and computer models for prediction and interpretation of ocean experiments. In 1997 he joined SACLANTCEN where he carries out theoretical and numerical investigations related to acoustic oceanography, acoustic modelling and fluid dynamic processes affecting ocean acoustics. McDonald has published papers in the fields of solar physics, fluid dynamics, plasma physics, numerical analysis, oceanography and ocean acoustics. He has been a member of the Acoustic Oceanography Technical Committee and the Underwater Acoustics Technical Committee of the American Acoustical Society. He holds NRL publication awards, NRL Division and Directorate best product awards and is a Fellow of the Acoustical Society of America.*

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Project 04-D: Broadband modelling of ASW monostatic and multistatic propagation and reverberation

Operational relevance

Broadband propagation and reverberation models are required to determine the performance prediction and system concept assessments related to low-frequency active sonars. Accurate models are essential for significantly improving the effectiveness of acoustic ASW operations. 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.

4

Shallow water acoustic variability

Sound propagation in the ocean is often considered to be time invariant over a period of hours or even days. However, the ocean environment may change rapidly with time and it is then important to know how this time variability affects acoustic propagation as a function of frequency and propagation distance. In April/May 1999 SACLANTCEN conducted the Advent'99 experiment (Project 01-B) in the Strait of Sicily (Adventure Bank) to further understand the effect of a time-varying ocean environment on sound propagation in a shallow water region. This particular area is characterized as benign because of a weakly range-dependent bathymetry, sandy-like bottom properties and only weak water column fluctuations caused by internal waves. Such an environment is ideal for conducting time variability studies and acoustic model-data comparisons.

Broadband acoustic signals were transmitted over fixed paths for up to 18 h, during which time the ocean environment was densely sampled. The sound-speed profile as a function of range was measured every hour to the maximum propagation range of 10 km. The acoustic signals were received on a 64-element vertical array. Received signals show increasing ping-to-ping de-correlation over time with increasing transmission time, propagation range and acoustic frequency. The normalized linear Bartlett processor is used as a measure of the

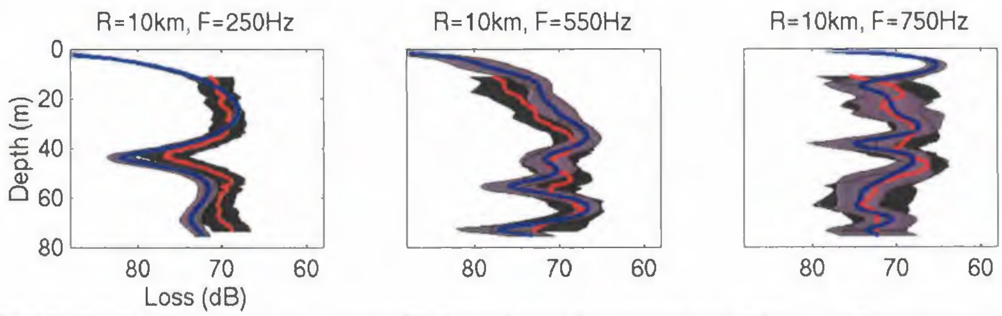

Figure 04-D.1 *Modelled (blue curve) and measured (red curve) mean transmission loss over 18 h of transmission for centre frequencies of 250, 550 and 750 Hz. The modelled (gray shaded area) and measured (black shaded area) standard deviation of TL over the same period is also shown. Fully range-dependent sound-speed structures and bathymetry were included in the modelling.*

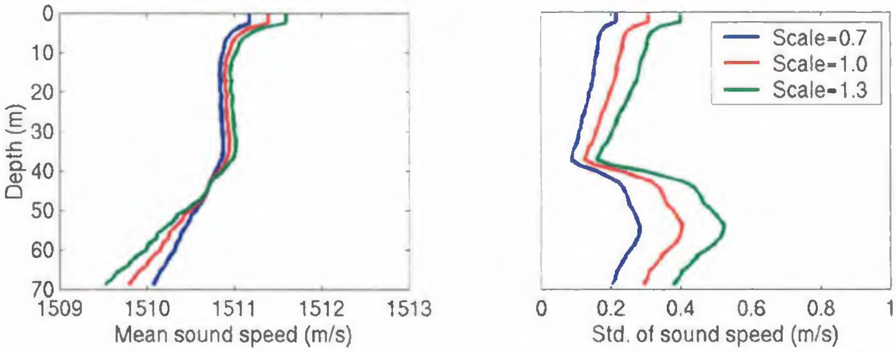

Figure 04-D.2 *Changes to measured sound-speed structures for sensitivity study. The depth gradient of the mean sound-speed profile in range (left panel) and the standard deviation of the sound-speed profiles in range (right panel) have been scaled by factors of 0.7, 1.0 and 1.3. The mean and standard deviation with a scaling of 1.0 represents the properties of the measured sound-speed structures.*

ping-to-ping correlation by adding the signals coherently across the vertical array for individual frequencies. The resulting measure of signal similarity has a value between 0 and 1 as a function of receiving time and acoustic frequency. A correlation of 0 means no similarity of signals received across the array between two transmissions and a correlation of 1 means two equal signals.

Dependent on the type of processing applied to the received signals, we can compute signal properties which are more or less sensitive to the ocean variability. Thus, time and frequency-averaged transmission loss is generally stable with time, whereas the directly recorded signal shapes are highly sensitive to fluctuations in the water column. Time and frequency-averaged transmission loss has been modelled with the SACLANTCEN coupled normal-mode model C-SNAP (Fig. 04-D.1). The propagation range is 10 km and the transmission loss is computed every hour over an 18 h period in the frequency band 200–800 Hz. The measured time and range-dependent sound-speed profiles and the range-dependent bathymetry are included in the modelling. The bottom properties were determined by geo-acoustic inversion of the measured data (Project 01-B). The mean transmission loss in Fig. 04-D.1 is shown for three selected centre frequencies (250, 550 and 750 Hz) averaged over a 10 Hz frequency band. There is good agreement between the modelling results and the data for the mean transmission loss and the standard deviation, reflecting the fact that accurately measured environmental input parameters to the acoustic propagation model were available.

The data used in the transmission loss modelling show very high correlation (Bartlett-processor output) over the entire 18 h of transmission at frequencies below 650 Hz. An abrupt decrease in the correlation, which persists up to 800 Hz appears at a frequency of 650 Hz. The correlation time of the acoustic signals is approximately one hour in this frequency band. The abrupt de-correlation of the acoustic signal is correctly modelled by using C-SNAP when the measured environmental parameters are used as input.

A sensitivity analysis of the acoustic signal correlation was performed in order to understand the influence of environmental parameters on this abrupt de-correlation of the acoustic signals as a function of frequency and time. The correlation was computed varying the geometry in the experiment (water depth, source-receiver position), bottom properties (layering, sound speed, attenuation) and the water column properties (decimation of sound speed in depth and range). It was found that the correlator is highly sensitive to the slope/gradient of the range-averaged sound-speed profile with depth and the standard deviation of the sound-speed profiles in range. Realizations of sound-speed profiles in range, depth and time were constructed by scaling the depth gradient of the measured range-averaged profile and standard deviation of the sound-speed, compared to the measured profiles. A scaling of 0.7 (smaller gradient and standard deviation), 1.0 (measured profiles) and 1.3 (larger gradient and standard deviation) was used in the realizations. Each of these modified sound-speed profiles (Fig. 04-D.2) was used as input to the propagation model for calculating the correlation of the acoustic signals as a function of frequency and transmission time (Fig. 04-D.3). These modified sound-speed structures shift the acoustic frequency and time of occurrence of significant de-correlation of the acoustic signals. The modified sound-speed structures (Scale=1.3) cause a higher degree of accumulated mode coupling along the propagation path, which results in stronger de-correlation of the acoustic signal at lower frequencies.

synthetic reference solutions representing the experimental data. Only the range-averaged, sound-speed profile of each experimental measurement and an averaged water depth is used to localize the source. The 18 source positions (18 sets of sound-speed structures) are well defined and the variation is small when the sound speed-structure with a low scaling (0.7) is used in generating the reference solution (Fig. 04-D.4 right panel, red signature). There is significantly more variation in the localized

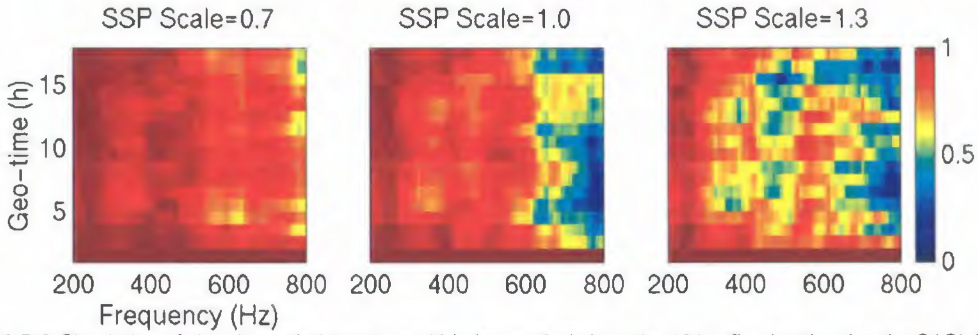

Figure 04-D.3 *Simulation of signal correlation over an 18 h time period along the 10 km fixed path using the SACLANTCEN normal-mode model C-SNAP. All measured sound-speed profiles (range- and time-dependent) and measured range-dependent bathymetry are included in the simulation. The measured sound-speed structures have been modified by scaling (0.7, 1.0, 1.3) the depth gradient of the mean profile in range and the standard deviation of the profiles in range. The correlation in frequency and time is clearly sensitive to these sound-speed modifications.*

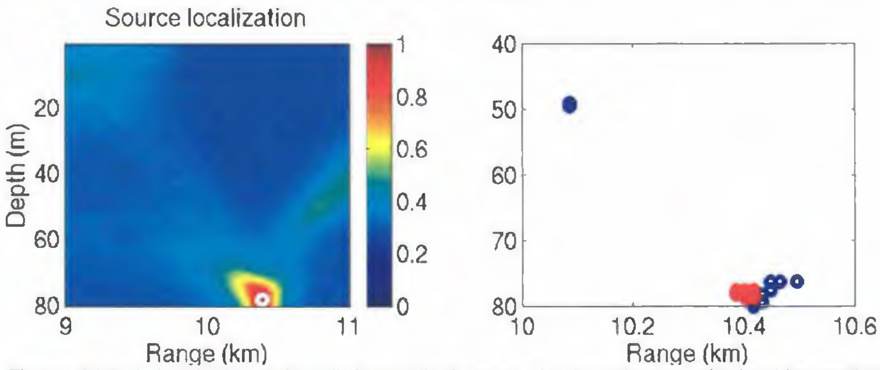

Figure 04-D.4 *Ambiguity surface (left panel) of source depth and range obtained by synthetic source localization where range-dependent sound-speed profiles and bathymetry were used as input to the propagation model generating the reference solution. Optimum source localization (right panel) using 18 sets of modified sound-speed structures in generating the reference solution. The red signatures indicate the source positions using the modified sound-speed structures with a scale of 0.7 and the blue signatures are the source positions using a scale of 1.3 in the modified sound-speed structures.*

The modified sound-speed structures do not significantly influence the modelling results of the time- and frequency-averaged transmission loss (Fig. 04-D.1). However, the modified sound-speed fields can cause noticeable effects if coherent processing is applied to the resulting acoustic signals. This is illustrated by performing source localization (Fig. 04-D.4) using the fully time- and range-dependent environment and the modified sound-speed structures to generate

source position if the high scaling (1.3) profiles are used (Fig. 04-D.4 right panel, blue signature). The source position is completely wrong in 2 out of 18 localization runs and these results are similar to the results obtained by using the experimental acoustic data in the source localization. Hence, oceanic variability must be accounted for in matched-field inversion schemes to provide stable and reliable localization results.

milestone

4

Bistatic reverberation model development

This year was marked by continued stand alone model development and participation in two experiments, during which, multi-static data sets were acquired. Participation in May 2000, in the Boundary 2000 experiment under Project 04-C, provided an opportunity to continue to develop the range-dependent BISTAR (BISTAtic Reverberation) model. The BISTAR model approach is tailored to provide reverberation predictions for the low-to-medium frequency regime (50–3500 Hz.) This model is evolving as the synthesis of the various reverberation model components which have been developed under this project during the past three years; including a range-independent monostatic component, reported in 1998 and a range-dependent monostatic and range-independent bistatic component, which are under development. During the Boundary 2000 cruise, the range-dependent, monostatic component of this model was refined and compared to available data.

During participation in the GOATS-2K experiment conducted under Project 01-B, a medium-frequency (2–15 kHz) bistatic reverberation data set was acquired, which will prove valuable for benchmarking enhancements to the MIT OASES code, to model bistatic volume inhomogeneity scattering, for smaller scattering geometries. For these geometries, the importance of high angle insonification and multipath determine the selection of OASES as the Green's function generator. During the GOATS-2K cruise, advanced signal processing algorithms were developed for imaging targets and scatterers in bistatic geometries.

(a) BISTAR

BISTAR is a collection of three codes for predicting reverberation, using normal modes to approximate the Green's function and the narrow-band approximation to synthesize the incident and scattered field. The range-independent monostatic code is a CMEX function operating under MATLAB. The functionality of this code has been subsumed under a second range-dependent monostatic version, which is a FORTRAN code based on the architecture of the C-SNAP SACLANTCEN coupled mode forward propagation code. This second code we refer to as BISTAR beta. The third code is a MATLAB "dot m" file that contains the bistatic equivalent of the range independent code.

During the Boundary 2000 experiment, BISTAR was used to compare reverberation predictions in various bands with data collected during the experiment. Since BISTAR has the propagation engine of C-SNAP, it is able to take as input the very detailed environmental information collected on the Malta Plateau site, during Boundary '98 and the MAPEX 2000 experiment conducted by Project 01-B, during the spring of 2000. This detailed environmental information included bathymetry acquired with the ATLAS and the EM-3000 multibeam echo sounders, sediment characterizations using the UNIBOOM seismic source and sediment acoustic parameter estimates, obtained by postprocessing analysis of other experiments, conducted during Boundaries '98 and 2000 and MAPEX 2000.

In Fig. 04-D.5, high resolution bathymetry collected over the Ragusa Ridge is shown superimposed on the background chart bathymetry of the Boundary 2000 experimental area. The Ragusa Ridge is responsible for a large feature in the reverberation that has been acquired by SACLANTCEN and others. The "petal patterns" shown in red in Fig. 04-D.5 are the ship tracks of the R/V *Alliance*, during monostatic reverberation experiments to aid in ambiguity removal. During one of the C2 petal legs, especially strong returns were seen from the Ragusa Ridge. One of the questions central to the thrust of Project 04-D is whether, given sufficiently good measurements of the acoustic and scatter parameters of the bottom, including sufficiently detailed measurements of the bathymetry and the sediment layering characteristics, predictions of reverberation level (RL) can be made which are "close" to the measured values in a meaningful sense.

BISTAR uses the high resolution, environmental information available, to make highly accurate estimates of the range dependent propagation from the source to the scatterers on the bottom,

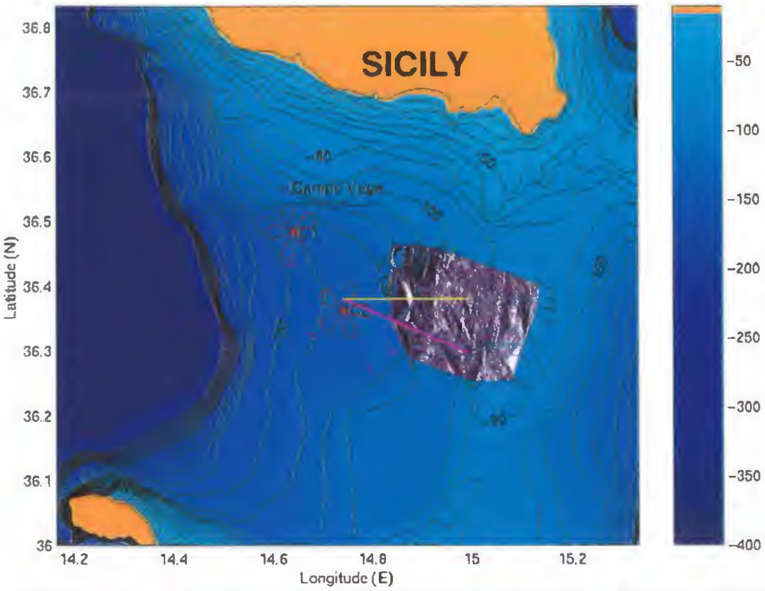

Figure 04-D.5 *High resolution bathymetry collected over the Ragusa ridge is superimposed on Malta Plateau chart bathymetry. The Alliance ship track for monostatic experiment C2 is shown at the centre of the chart in red. The beams for which model predictions and data are shown in subsequent figures are shown in*

the scattering process itself and the propagation from the scatterers back to the receiver. In Fig. 04-D.6, this process is schematically shown for the reverberation along the yellow trajectory in Fig. 04-D.5. The top panel shows the range dependent TL from the source to all points in the water column and the bottom. The lower panel shows RL prediction, which is a direct function of the propagation conditions shown in the upper panel, plus the angular distribution of incident energy at the scatterers, (in this case, rough bottom scattering is enabled) and the effects of bandwidth and dispersion. The resulting estimate shows that, even when the background scattering strength of the seafloor is assumed to be uniform, significant enhancements in RL are expected to occur when the incident acoustic energy interacts with strong range dependence in the bathymetry, in this case over the ridge. As the group speeds and modal dispersions for this range-dependent environment have been accurately estimated, the timing of these strong returns and their temporal extent are properly modelled.

In Fig. 04-D.7 a reverberation prediction for the magenta trajectory illustrated in Fig. 04-D.5 is compared to data acquired along the same azimuth. The results show that significant trends and characteristics in the reverberation are captured, including the temporal extent, if not the level of the RL enhancement associated with acoustic ensonification of the ridge and the decay of RL as a function of time. This data-model comparison is well constrained as bottom and water column properties for the experimental site were used in the model prediction. Knowledge of the scattering strength measured on the ridge and in the basin has not been incorporated, as this portion of the data has not yet been analyzed. As this and more refined information on sediment properties become available, updates in model-data comparisons can be made. Parallel efforts in testing the models, to accurately pre-

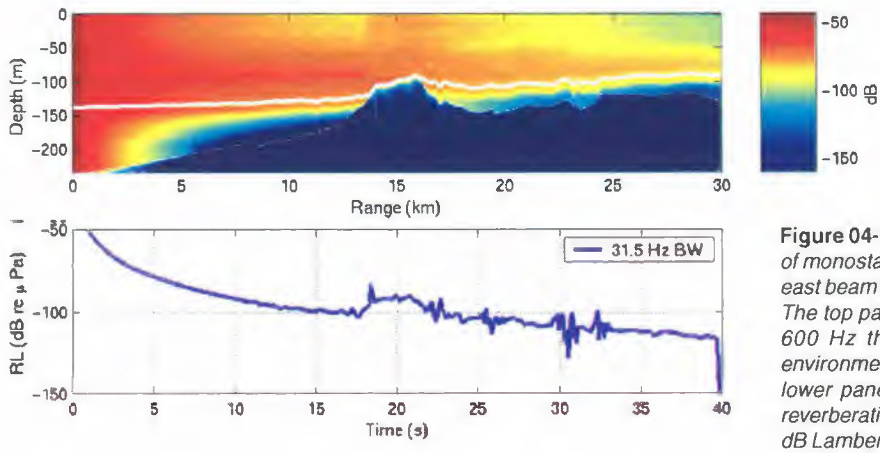

Figure 04-D.6 *BISTAR model prediction of monostatic reverberation for the west-east beam shown in yellow in Fig 04-D.5. The top panel shows the one way TL at 600 Hz through the high resolution environmental characterization and the lower panel shows the commensurate reverberation prediction assuming a –27 dB Lambert parameter.*

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milestone

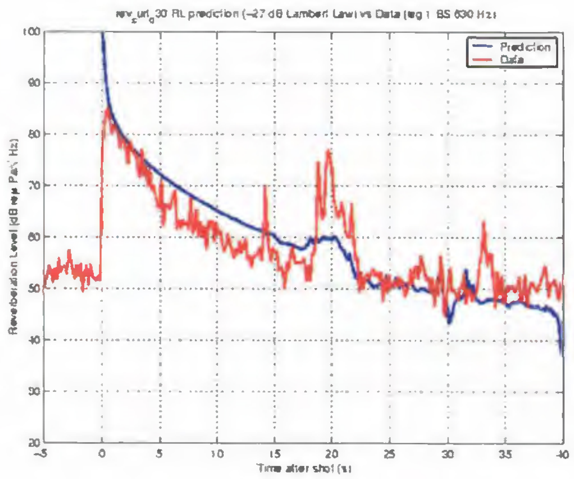

Figure 04-D.7 *Reverberation predictions and data at 630 Hz for the broadside beam for one of the legs of the "petal pattern" C2. This beam is shown in magenta in Fig 04-D.5. The results from the model were obtained with a Lambert's coefficient of –37 dB, which is about 15 dB too low for the rocky ridge itself and perhaps 3–5 dB too high for the soft muddy sediment leading up too it. These preliminary results were obtained using a sediment classification obtained for the area in question by Project 04-C.*

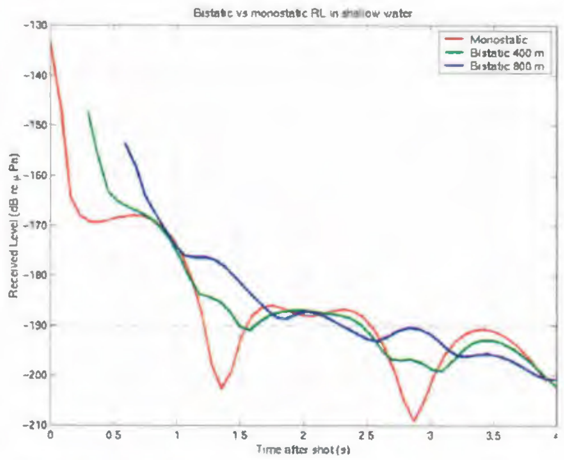

Figure 04-D.8 *Bistatic vs monostatic RL for a range independent, shallow water scattering scenario. The centre frequency is 75 Hz with 3.75 Hz bandwidth and the source receiver offset varies between 0 and 800 m. Results show that the interference pattern between the modes which causes the strong interference patterns in the monostatic RL is reduced for bistatic scenarios. This reduction is caused by the differences in the phase and group speeds of the various modes over the ensonified ellipse. Overall levels are seen to be about the same.*

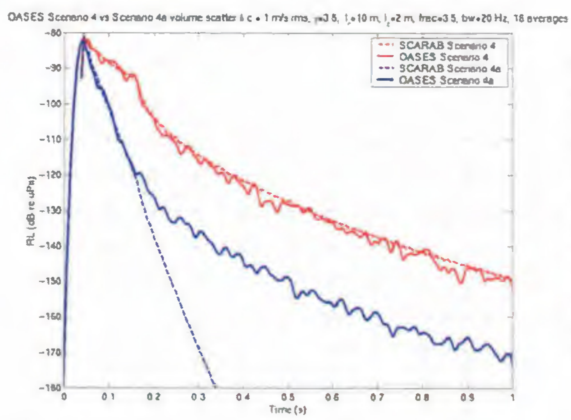

Figure 04-D.9 *Benchmark of OASES (solid) and SCARAB (dashed) predictions of scattered field intensity vs time from a 100 m thick sediment layer filled with sound speed and density inhomogeneities. Two cases are shown, the red curves represent scattering from a sediment layer with background attenuation of 0.01 dB/l and the blue curves for 0.5 dB/l. The SCARAB model agrees well with OASES for the low-loss scenario, but in the high-loss case, SCARAB under-predicts the late-time scattering intensity. The OASES code was developed under Project 04-D to serve as a computational benchmark for more efficient codes such as SCARAB and others that use approximations to predict the scattered intensity.*

dict the characteristics of measured data sets will be continued.

New research into coherent modelling of bistatic reverberation in range independent environments has resulted in the development of a MATLAB code, which serves as a prototype for the future extension of BISTAR to be able to treat true, three dimensional scattering. In Fig. 04-D.8, RL is shown as a function of bistatic offset for a source frequency of 75 Hz and a source bandwidth of 3.75 Hz in a 120 m deep downward refracting waveguide. These reverberation predictions show that as bistatic offset is increased, the amount of coherent, predictable structure in the RL is reduced; due to the differences in the illumination pattern of the monostatic and bistatic ensonification on the bottom. For bistatic scenarios, the differences between the phase and group velocities over the ensonified ellipse, cause a significant azimuthal variation in the structure of the bottom ensonification, resulting in less strong constructive and destructive interference in the total reverberation, which is summed over all azimuths. It is a goal of Project 04-D to further characterize bistatic reverberation time series, in order to quantify the controlling parameters, which distinguish this type of reverberation from its monostatic equivalent and to incorporate into FORTRAN the "m file" software, which has been used to facilitate the early evaluation of the bistatic extension shown here.

(b) OASES Scattering Implementation

A continuing effort in Project 04-D has been to increase the capabilities of the scattering module, which is being added to the OASES propagation code. The extension of the previous two-dimensional sediment volume inhomogeneity scattering implementation has been extended to 3D monostatic. The theoretical underpinnings of the full 3D bistatic extension have also been completed, with most of the required code changes. At the end of the current model development phase, a 3-D bistatic, spectral-integral-based, reverberation module to OASES will be available to complement BISTAR.

In Fig. 04-D.9, a benchmark result for the current 3D monostatic code is shown. The dashed curves are scattered intensity predictions from the SCARAB code (developed by C. Holland of SACLANTCEN and P. Neumann of Planning Systems Inc.) for sediment layer attenuations of 0.01 dB/l (red) and 0.5 dB/l (blue). Superimposed on these results are the new OASES predictions for the same scenario. For the lower-loss case, OASES and SCARAB are seen to agree. The good agreement between the two codes for this case is expected and indicates that the OASES code has been properly implemented. However, in the higher-loss case, the OASES results show that the SCARAB underpredicts the scattered intensity at late time because of certain approximations made in the code. Note that as SCARAB predicts the expected value of scattered intensity and OASES predicts the scattered field pressure for a particular realization of sediment volume inhomogeneity scatterers, the OASES results have been Monte-Carlo averaged over 16 scatterer realizations.

The value of the OASES implementation over previous implementations is in the quality of the Green's function, which is used to propagate energy from the source to the scatterers and back to the receivers. As these Green's functions are computed using a spectral integral over all wavenumbers, they are highly accurate for all source-scatterer-receiver geometries. For this reason we anticipate that the new OASES scattering module will serve as a reference or benchmark solution to more approximate techniques for estimating scattering from sediment volume inhomogeneities. The potential for this may be seen in Fig. 04-D.10, where the time-angle evolution of sediment inhomogeneity backscatter for the case illustrated in Fig. 04-D.9 is shown. The upper panel shows the SCARAB estimate of this quantity, the lower panel the OASES estimate. The results show that while SCARAB and OASES are in close agreement over angular regimes between 20 and 90° of grazing angle, there is a scattered branch associated with scattering from the forced evanescent wave, at the sediment-water interface, which SCARAB misses.

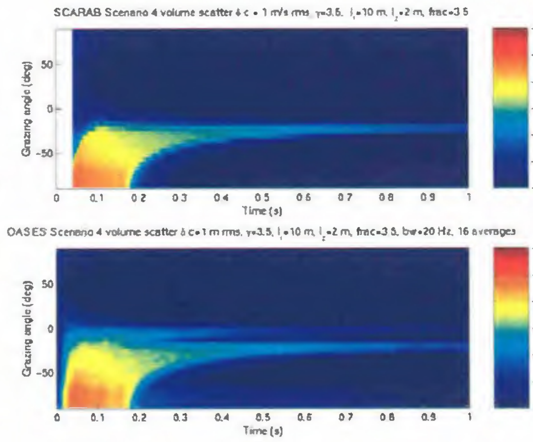

Figure 04-D.10 *Time-angle evolution of scattered field predicted by SCARAB (upper plot) and OASES (lower plot.) While there is good general agreement between the two codes for scattering from grazing angles greater than 20°, the benchmark OASES result shows that there is an additional scattering branch at very low grazing angles, which is not included in the SCARAB prediction. It is anticipated that the OASES scattering extension developed under Project 04-D, will prove to be highly valuable as a reference solution, for volume scattering in layered sediments.*

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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, Associate Editor of Acta Acustica and Editor of the Journal of Computational Acoustics. He is also the co-author of a 600-page textbook on Computational Ocean Acoustics published in 1993.*

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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.*

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.*

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Thrust 05 Command Support (CDS)

Project 05-C: Command and operational support

Operational relevance

Force Employment Studies are a major part of the Centre's Operational Research and Command Support programme. The studies make specific recommendations to operational commanders, NATO and the nations on the optimal use of undersea warfare resources. The studies vary in scope from advising an at-sea commander on the best use of sensors to achieve his mission, to advising senior NATO and national decision makers on the most cost effective way to proceed with future procurement and research and development. Another key part of this work is operational planning which supports NATO crisis response. This work aids operational commanders in determining which forces they must commit to accomplish a particular mission. In the past, studies have typically been quite specific in terms of the scenario, the geographical area, the NATO objectives and force composition and the threat. These specific studies are no longer appropriate given the transformation of NATO's defence posture. The present approach is to produce computer based decision aids which have the flexibility to cope with any situation that could arise. Because of the flexibility of these decision aids, they can also be used to support higher level force requirements.

Implications of New Technologies for Maritime Operations in 2015

The aim of this study, initiated by SACLANT and sponsored as a Long Term Scientific Study by the NATO Research and Technology Board, is to help NATO and the Nations with long-term defence planning and new systems requirements, in the context of a transformed security environment and diminishing defence budgets.

Phase I of the study, which was completed in 1995, provided a detailed evaluation of potential security challenges, ranking critical shortfalls in maritime force capabilities and assessing the most promising and affordable systems for development up to 2005. Phase II, which started in 1997 and completed this year, comprised two Advanced Concept Studies (ACS), one on Antisubmarine Warfare (led by France) and the other on Mine Warfare (led by Germany). The aim of the two ACS's was to recommend the most promising direction for Allied research and development leading to affordable system packages in the 2005-2015 time frame, which reduce the most significant shortfalls in ASW and MW.

The studies culminated this year with two Multi-National Exercises (MNE), one for ASW and the other for MW. Each MNE comprised two panels, a Military Worth Panel and an R&D Panel, which undertook the final evaluation of the system concepts and decided on an R&D road map.

Contributions to the ASW ACS and MW ACS

Support to MO2015 activities in ASW and MW throughout Phases 1 and 2. This was in conjunction with representatives from Belgium, Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Portugal, Spain, Turkey, United Kingdom and the United States.

Contributions to the ASW ACS in 2000 comprised:

- Performance evaluation of baseline ASW systems and a selection of the new system concepts, in preparation for the MNE
- Presentation of results to the panels at the MNE
- Co-authoring of relevant chapters / annexes of the final report

Contributions to the MW ACS in 2000 include the following:

- Preparation for the MNE by providing expert input on UUV-based mine-hunting and mine jamming concepts
- Participating in the panels at the MNE

After completion of the study, recommendations were reviewed for implementation in the context of the Centre's Charter and Scientific Programme of Work. As a result four concepts, with SACLANTCEN as the lead agency, were submitted to the Concept Development and Experimentation (CDE) Database administered by SACLANT. These concepts were favourably reviewed by the Bi-Strategic Command CDE Working Group; two of the concepts were recommended for further supporting funding.

milestone MO2015 study results published and Centre's initial review completed (September).

NATO Defence Requirements Review

The Centre is currently supporting both NATO's Strategic Commanders (SCs) in their assessment of ASW force requirements for the 2001 DRR, due for completion in early 2001. The ASW studies are examining the capability of a variety of NATO ASW assets to conduct ASW operations in various locations defined by the Bi-SC planning situations.

milestone NATO ASW sonar performance estimates generated and forwarded to the Strategic Commands (December).

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 at Northwood, UK and the Independent Maritime Analysis Team 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.

Exercise planning and analysis

One of the most significant activities during 2000 under the exercise support activity of Project 05-C has been the planning and analysis of 'Percentage Clearance (PC 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 is under continuous development. A number of minehunting performance parameters have been evaluated, including the capability for environmental assessment, contact errors (Fig. 05-C.1) 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 MCMFORMED. During 2000, PC Trials were carried out during Exercises DAMSEL FAIR (MCMFORMED) and BLUE GAME (MCMFORNORTH). The minehunters participating in the DAMSEL FAIR PC Trials were

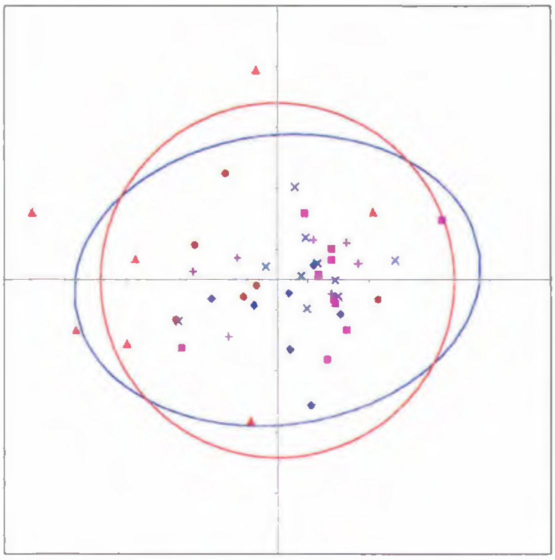

Figure 05-C.1 *Minehunting contact error analysis.*

de-briefed on their results within 14 days of the last ship completing operations. ORD personnel also travelled to Naples to debrief COMNAVSOUTH. COMNAVSOUTH requested all CNOs in the Southern Region to incorporate PC Trials into national MW exercises. Consequently, ORD supported the TURKISH MINEX-2000 by analyzing the effectiveness of MCMFORMED units in a PC Trials scenario.

In addition to preparing the formal reports, ORD has debriefed the results of PC Trials to the NATO Minewarfare Conference, the Minewarfare Working Group, the MCM EXPERT User's Group and to NATO MW Officers visiting the Centre. The results obtained always generate considerable significant interest and discussion and have already been used as a basis for changes to NATO's MW tactical publications.

Specific exercises supported by ORD during 2000 are:

DOGFISH 2000

ORD made a significant contribution to the analysis by carrying out all the necessary reconstruction, contact validation and missed opportunity analysis. The EXCEL-based analysis system developed by ORD and used for the analysis of DOGFISH 99 was again used successfully.

milestone ASW analysis completed (May).

LINKED SEAS 2000

ORD provided support to CINCSOUTHLANT for the use of the Electronic Minefield Referee (EMIR) system (see below). The necessary EMIR data files were generated and a copy of the EMIR client application produced for all maritime units participating in the exercise.

EMIR support provided (April). *milestone*

DAMSEL FAIR 2000

ORD provided support for the PC Trials including a detailed brief at the exercise pre-sail conference (PSC). The analysis was carried out at SACLANTCEN over a five-day period and the results briefed to COMMCMFORMED and participating units at their next port call in Istanbul, Turkey.

Analysis completed and COMNAVSOUTH debriefed (July). *milestone*

BLUE GAME 2000

In addition to the PC Trials, ORD provided support for the planning of the exercise and fitted all participating fast patrol boats with EMIR. Members of ORD provided a brief at the exercise pre-sail conference (PSC) and attended the analysis conference.

EMIR support and exercise analysis completed (June). *milestone*

TURKISH MINEX-2000

ORD provided support for the PC Trials including a detailed brief at the exercise pre-sail conference (PSC). The analysis was carried out at SACLANTCEN and at COMTURSARSOUTH over a five-day period and the results briefed to COMMCMFORMED at the post –exercise discussion (PXD). For these trials, a signal format was developed in conjunction with COMNAVSOUTH staff that successfully allowed the analysis to be carried out without reference to written records.

Analysis completed (November). *milestone*

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Exercise support tools

Maritime Electronic Log (MEL)

MEL was developed for Exercise DOGFISH 1999, to replace the paper versions of FORMEX's 110 and 114 with an accurate electronic log. It was successfully employed during DOGFISH 2000 on board 6 submarines and 3 surface ships. MEL features a GIS interface and an interface with commercial NMEA 0183 compliant GPS systems.

milestone See DOGFISH 2000.

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, which automatically feeds positional data to EMIR. EMIR was used during exercises BLUE GAME and LINKED SEAS and during the UK's Joint Maritime Courses (JMC). An improved version of the planner program is under development, which will include a track analysis module.

milestone See BLUE GAME 2000 and LINKED SEAS 2000 above.

Tactical Decision Aid for Planning ASW Barrier Operations in the Strait of Gibraltar (STROG TDA)

The objective of this task is to develop a prototype Tactical Decision Aid which permits the optimal allocation of available units to antisubmarine barriers in the Strait of Gibraltar. The project was initiated in January 1999. A document containing the user requirements was submitted to the Spanish Navy and approved. A prototype of the man-machine interface was designed and delivered to the Spanish Navy.

A genetic algorithm has been developed to optimally allocate available units to the barrier. The algorithm needs to be provided with the performance of every unit on every cell in the area. The solution can be a connected or disconnected barrier. The time to obtain a solution for an area containing 500 cells and 5 units is considered to meet user requirements. The algorithm designs the barrier taking into account the coastline and a preferred transit axis for the submarines.

A prototype TDA, which requires environmental support data to function, has been developed and is under internal review.

Beta version completed in July 2000. *milestone*

Mine Countermeasures Exclusive Planning and Evaluation Tool (MCM EXPERT)

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 incorporating algorithms developed by a NATO ad Hoc Working Group consisting of representatives from NATO agencies, NATO Commands and national research laboratories. As part of this working group, SACLANTCEN is responsible for the standard NATO method to calculate the threat posed by mines to a defined target vessel. The software is maintained by the NATO Integrated Software Support Centre (ISSC). During 2000, SACLANTCEN continued to support the MCM EXPERT User Group (MEUG) meetings. A paper examining the different definitions and representations of risk to follow-on shipping will form the basis of the new Standard NATO Agreement (STANAG).

Three working papers issued to MEUG (January 2000). *milestone*

Two MEUG meetings supported (April and December 2000).

Decision Aid for Risk Evaluation (DARE)

During 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.

No progress to report.

Search and Screening Working Group (Maritime Tactical Working Group)

The Centre has been a regular participant in the proceedings of the group, assuming responsibility for developing an area search tactical planning aid in 2000.

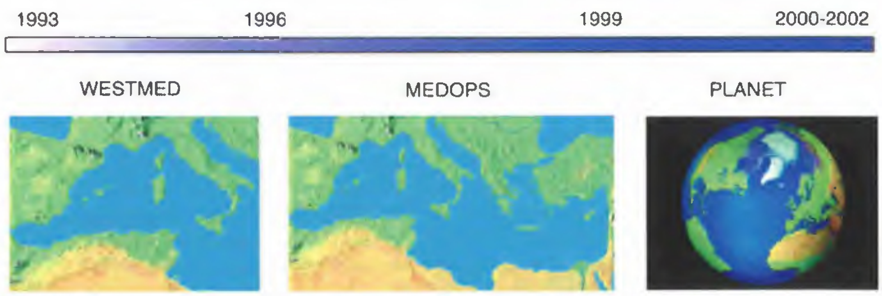
Planning support for underwater warfare operations

The objective is to provide decision support aids to NATO Commands and Nations for planning underwater warfare operations for future crisis operations, the location and timing of which are unpredictable. Activities have concentrated on providing operational planning tools for ASW operations. Mediterranean Operational Planning Software (MEDOPS) evolved from WESTMED, which was limited to the western Mediterranean Sea. Both projects were sponsored by Commander Naval Forces Southern Europe (COMNAVSOUTH).

PLANET (Planning Expert Tool), sponsored by SACLANT, will increase the geographical coverage of the ASW planning tool. Figure 05-C.2 shows the relationship and progression of these planning tools.

PLANET is a decision aid which combines high quality sonar modelling with sophisticated search algorithms. Mission planners can quickly determine the most efficient force deployment with software running on a standard PC. Intuitive interfaces and extensive on-line help allow the configuration of complex operations without specialist training or computer knowledge.

PLANET provides easy access to generic sets of ASW platforms, reflecting NATO ASW capability. These assets can be assigned to any mission and stored in a database for subsequent use. High-resolution vector maps are provided to allow the user to select the proper mission area (Fig. 05-C.3). Purpose - built, high - speed zooming tools ensure that accurate scenario definition is possible. Results are provided in report and graphical format. Acoustic sensor performance predictions at high and low frequencies have been made using appropriate propagation and reverberation models. Temporal and spatial resolution are based on the expected



- COMNAVSOUTH
- ASW
- SONAR PERFORMANCE
- EFFECTIVENESS OF OPERATIONS
- SEARCH PLANNING
- SAFEST ROUTE

- COMNAVSOUTH
- ASW
- NON-ACOUSTICS
- ADVANCED SAFEST ROUTE
- MORE SENSORS
- MCCIS PROTOTYPE

- SACLANT
- PLANET V1, V2, V3
- OTHER GEOGRAPHICAL AREAS
- OTHER WARFARE AREAS

Figure 05-C.2 *Evolution of operational and defence planning decision aids at SACLANTCEN.*

variability and the subsequent availability of data to NATO. Fast, high order interpolation and graphic algorithms have been developed to ensure that the maps have a high degree of smoothness.

A Steering Group, consisting of Command and National representatives, has been established to guide this project and the follow-on work on PLANET.

The major accomplishments of 2000 are:

- Steering group meeting in May 2000 (principle activity: requirements specification for PLANET 1.0).
- Design and production of PLANET 1.0 beta.
- Steering group meeting in November 2000 (Review of PLANET 1.0 beta version).
- Completed production of acoustic data sets for two major areas.
- MEDOPS Version 1.1 tested by STANAVFORMED.

milestone

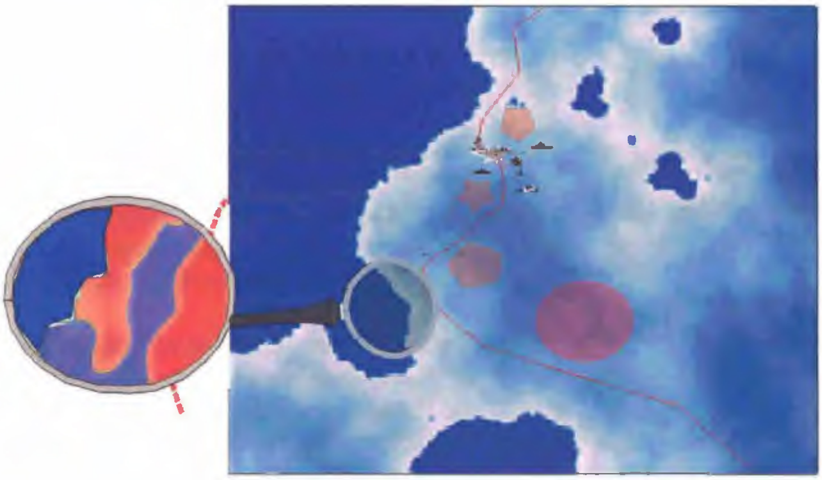


Figure 05-C.3 *Example of a direct support operation providing maximum protection to the High Value Unit. High risk/no go areas shown in red. Underlying area and data (partly shown under magnifying glass).*

Project 05-C publications and presentations

Redmayne, J.C.J. DAMSEL FAIR 2000 Minehunting task analysis, SACLANTCEN SR-339

Commander South Norway. Exercise Blue Game 2000 Analysis Report.

***Ken Pye** holds a B.Sc from Sheffield University England and an M.Sc in Operational research from Strathclyde University, Scotland. His career in operational research spans some 30 years. In the 1970's he worked on weapon systems development and conducted studies at the then SHAPE Technical Centre, the Netherlands. In 1981 he joined the NATO E-3A Component at Geilenkirchen, as Chief of the Plans and Analysis Office in the Software Support Centre. In the 1990's he was the Operational Research Scientist Scientific Advisor to the Former CINCHAN and then to CINCEASTLANT/ COMNAVNORTHWEST. He joined the Centre in 1998 as Head of the Operations Research Department.*

Thrust 06 Exploratory Research (EXR)

Project 06-B: Focused acoustic field (FAF) studies (Alliance days – 27, Manning days - 18)

Basic studies and potential applications of the focussed acoustic field (FAF) technique

Operational relevance

To experimentally demonstrate the feasibility of phase conjugation in shallow water, the use of phase conjugation techniques to mitigate multipath in acoustic data communication and to enhance echo-to-reverberation-ratio in active sonar.

Focused acoustic field

A phase conjugate "mirror" time reverses the incident signal, returning it precisely to its original source location. This phenomenon occurs independently of the complexity of the medium. The time reversal process can be accomplished by a retransmission procedure, whereby a signal received at an array is time reversed and retransmitted. A full water column source array excited by the phase conjugated (time-reversed) signal received at the array position, will focus at the position of the radiating target. The medium fluctuations are embedded in the received signal, so that if retransmission occurs on a time scale less than the dominant fluctuations, the variability of the medium will be eliminated by back propagation.

Here, we briefly review the physics of a TRM and then present the results from a series of experiments in which a TRM was implemented, including demonstrations of applications to active sonar and underwater acoustic communication.

A probe source (PS) indicated by one of the rectangles on the vertical receive array (VRA), transmits a pulse which is received at the source-receive array (SRA). The dispersed signal and complete multipath structure is time reversed and retransmitted by the SRA. The resulting signal multipath structure collapses to a spatial and temporal focus (original PS pulse length), at the original PS position, which is co-located in range with the VRA (Fig. 06-B.1).

The size of the focal region depends on the wavelength and the effective aperture of the SRA that increases due to the wave-guide nature of acoustic propagation in the ocean, over the free space. Analysis using image methods, including attenuation effects of the ocean bottom, indicates that the diffraction limit on the size of the focal region was reached experimentally.

PC or TRM is relevant to the recent trends in acoustic signal processing which have

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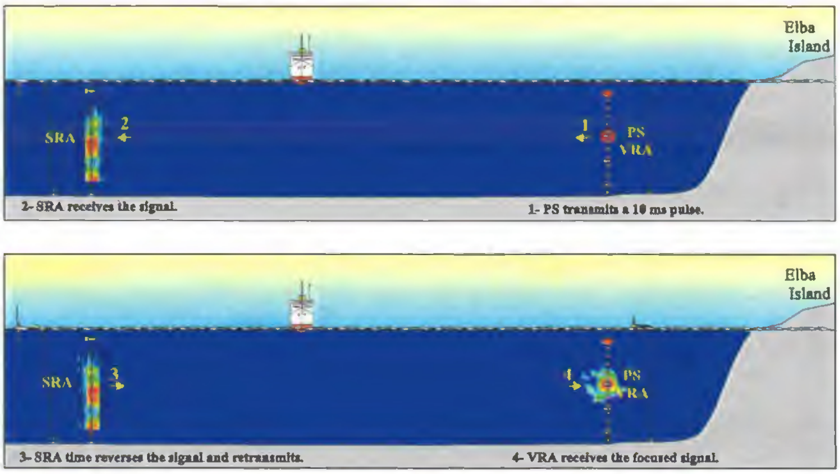


Figure 06-B.1 *Experimental configuration of generic time reversal mirror.*

emphasized utilizing knowledge of the environment, e.g., matched field processing (MFP). However, MFP requires accurate knowledge of the environment along the propagation path. Phase conjugation is an environmentally self-adaptive process applicable to localization and communication in a complex ocean environment. The fact that a TRM refocuses energy spatially and temporally with the aid of a probe, suggests that ocean self-equalization with respect to communication processing is possible, as described below.

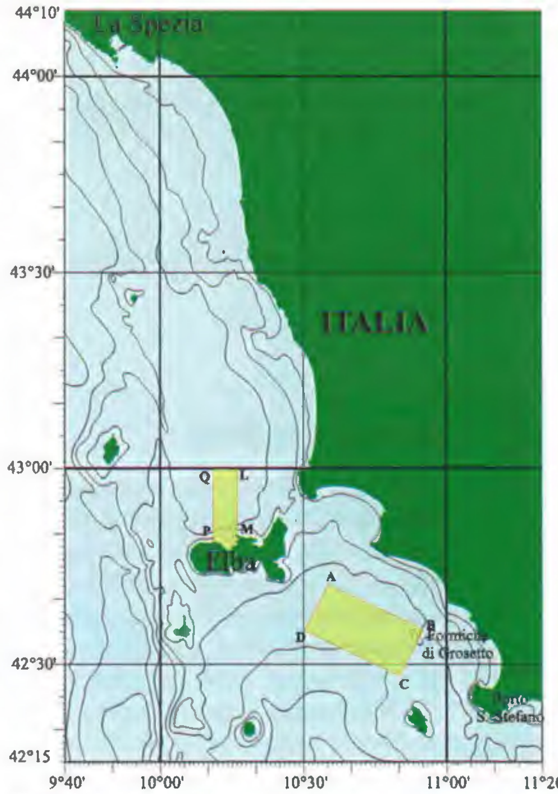


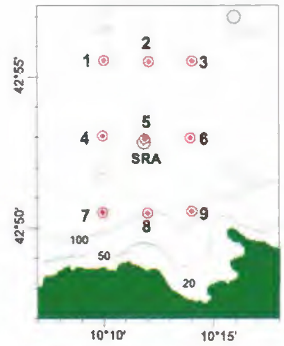
Figure 06-B.2 *Ocean acoustic time reversal mirror experiments off the west cost of Italy.*

FAF experiments

The 1996 and 1997 experiments using a 450 Hz SRA hardwired to the Island of Formiche di Grosseto, were the first to implement and demonstrate the TRM process in the ocean (Fig. 06-B.2). At 450 Hz, focal distances out to 30 km and multi-day stability of the focal region were demonstrated. A new process to shift the focal range was derived and experimentally confirmed.

The third experiment conducted in 1999 used a 3500 Hz array. The SRA was moored and tethered to a remote, self-contained buoy system with electronic and computer systems to function as a node on a local area network (LAN). However, the probe source was not fixed to the VRA so that field measurements were often not acquired at the precise focal position. Focal ranges out to about 15 km were demonstrated (the maximum LAN range at that time). Data acquired in the Formiche di Grosseto and Elba areas with different bottom types revealed markedly different dispersion characteristics. The data indicate that for the 450 Hz and 3500 Hz experiments, the diffraction limit on the focal size was achieved. A short communication sequence indicated communication utility, although the quantity of data was insufficient to perform statistical bit error analysis. An up-slope experiment with the SRA in 100 m, PS in 30 m

Spatial and time Variability of Sound Speed during 7,8 and 9 June



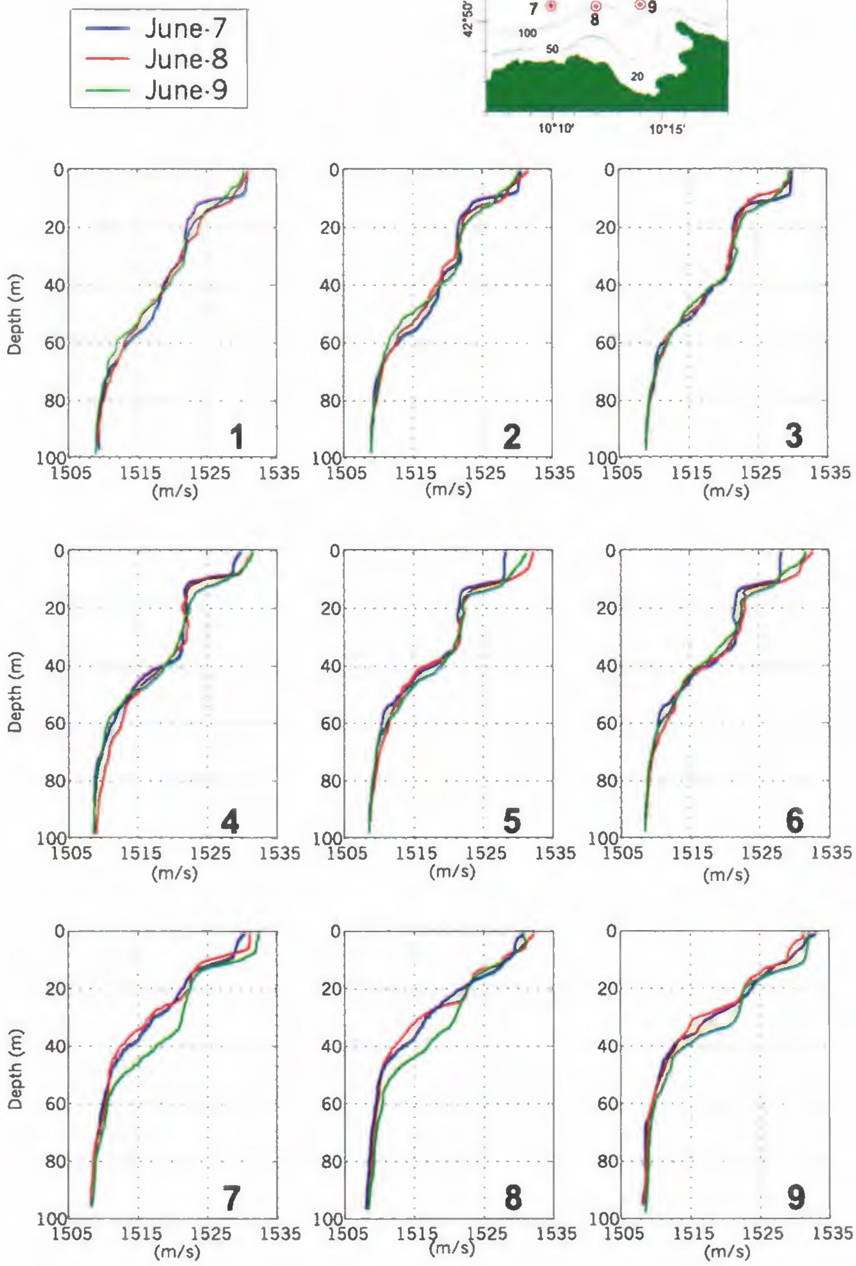


Figure 06-B.3 *Sound speed profiles on three consecutive days at nine different positions north of Elba derived from CTDs.*

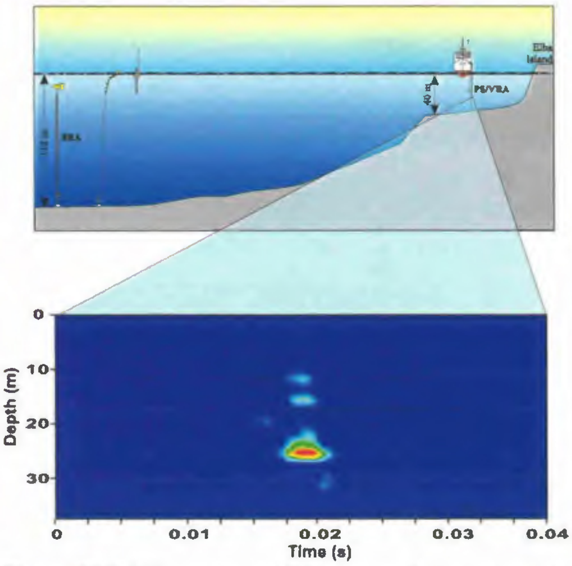


Figure 06-B.4 *Geometry and data example for the range dependent TRM experiment.*

of water at a range of 10 km, demonstrated a remarkable focusing ability with 3 dB at a range of 1 m.

The goals of the fourth experiment between May 19 and June 13, 2000 using a 3500 Hz SRA. included:

1. The acquisition of sufficient data to characterize the error rate of the self-equalization undersea process as applicable to undersea acoustic communication.
2. To perform TRM measurements to provide data to begin to support applications of acoustic fields to active sonar concepts. In particular, echo to reverberation enhancement and forward scatter barrier.
3. To measure stability and fluctuation properties of the focused field out to significant ranges in both flat and sloping regions.

Ocean acoustic environment

The ocean environment was variable throughout the experiment. An example of the spatial-temporal variability is shown in Fig. 06-B.3 for 9 CTD sites north of Elba on three consecutive days. Preliminary analysis demonstrated that spatial dependence in the profiles had a significant effect on the properties of the focal region. Additional data from oceanographic moorings will provide valuable supporting information. *Hydrosweep* bathymetry, seismic profiling, expendable bottom penetrometer (XBP) measurements and cores were taken during the experiment, in conjunction with acoustic transmission loss (TL) runs.

Size of the focal region in up-slope environment

The size of the focal region in a range-independent wave-guide is analyzed using an image approach. Here we extend the analysis to a range-dependent upslope wave-guide, where extremely sharp focal regions are obtained as shown in Fig. 06-B.4.

Figure 06-B.5 shows measured focal sizes at 3500 Hz for three different environments: the Formiche, flat Elba and sloping Elba areas, which are in good agreement with the superimposed theoretical predictions, based on the image approach. From the perspective of adiabatic mode propagation, modes are compressed with up-slope propagation, resulting in higher resolution for the time-reversal process.

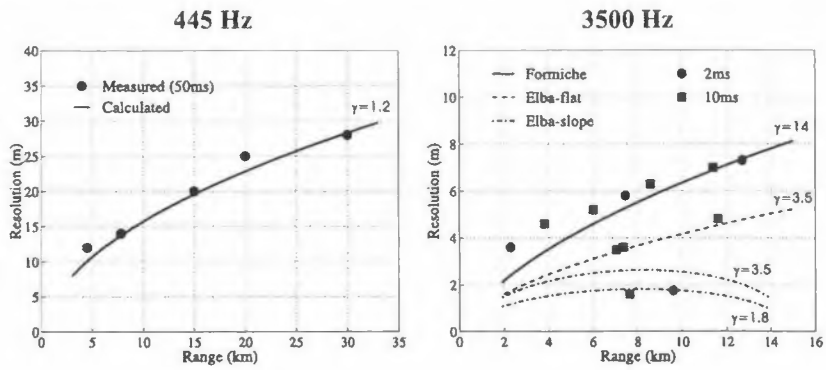
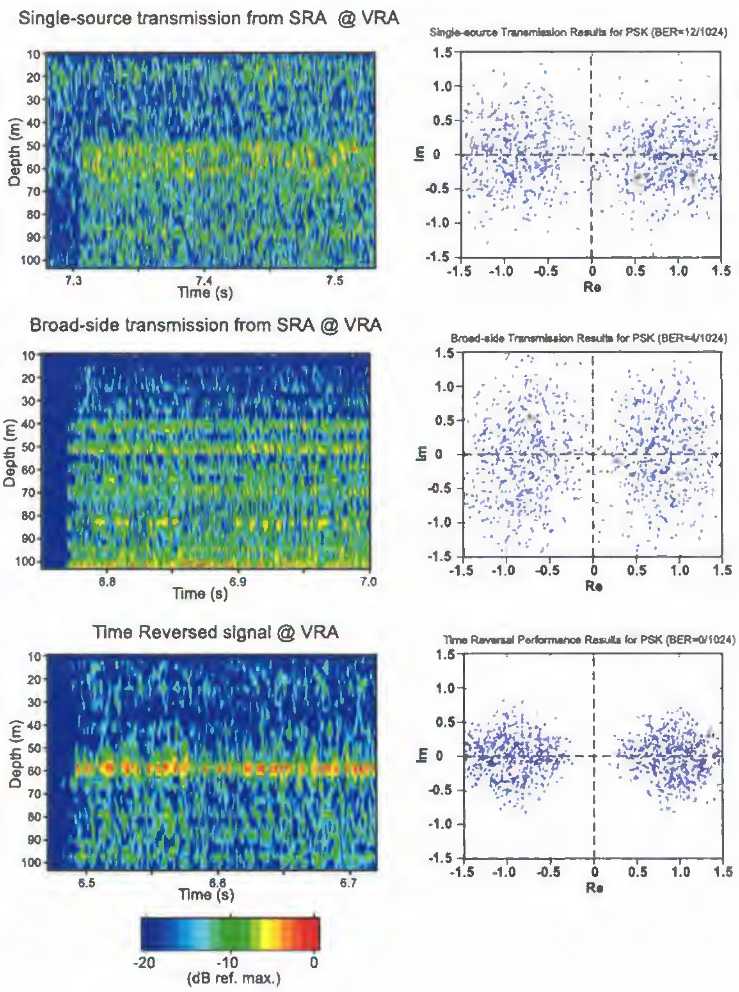


Figure 06-B.5 *Comparison between the measured vertical focal sizes and the calculated resolution based on the image aperture method, with appropriate bottom attenuation for 3500 Hz in three different environments.*

Self-equalization underwater communications

The communication experiments were performed in the fixed-fixed configuration with the SRA and VRA operated remotely. A 2 ms CW probe source signal was received at the SRA; time reversed thereby creating the basic symbol for the communication sequence. This TR bit is copied onto a random sequence (plus and minus ones) to produce a 10 s, 5000 bit coded communication sequence for acoustic transmission to the VRA at a range of 8 km. The communication terminology for this coding is Binary Phase Shift Keying (BPSK). One-way broadside and single source, control communication experiments were also performed. A subset of the BPSK focused results as received at the VRA is shown in Fig. 06-B.6, with broadside and single source control examples. Decoding was done by the synchronized correlator receiver or matched filter. The scatter plots on the right are an indication of the robustness of the communication 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-reversed process. Data were also taken for other types of coding: BPSK, QPSK, 8-PSK and 8-QAM in order to explore the potential for higher bit rate communications.

The communication experiments were also conducted in the upslope range-dependent environment shown in Fig. 06-B.4, where the SRA was operated remotely and the PS/VRA was 9.8 km distant at a depth of 40 m. Figure 06-B.7 demonstrates again that performance of two-way time reversal communication is better than one-way single source and broadside communications.



Echo to reverberation enhancement

The main goal was to demonstrate that (bottom) reverberation is minimized from the range where there is a time reversed, (TR) produced focus in the water column, (Fig. 06-B.8). The R/V *Alliance* deployed the probe source at 60 m depth and foci were produced at various ranges. At the same time, reverberation from the outgoing time-reversed SRA signal was recorded by the SRA. We see a decrease in the TR reverberation (notch) at the time

Figure 06-B.6 *Range-independent: Time reversal communication compared to one-way transmission control examples: single source and broadside. Bit error is denoted by BER.*

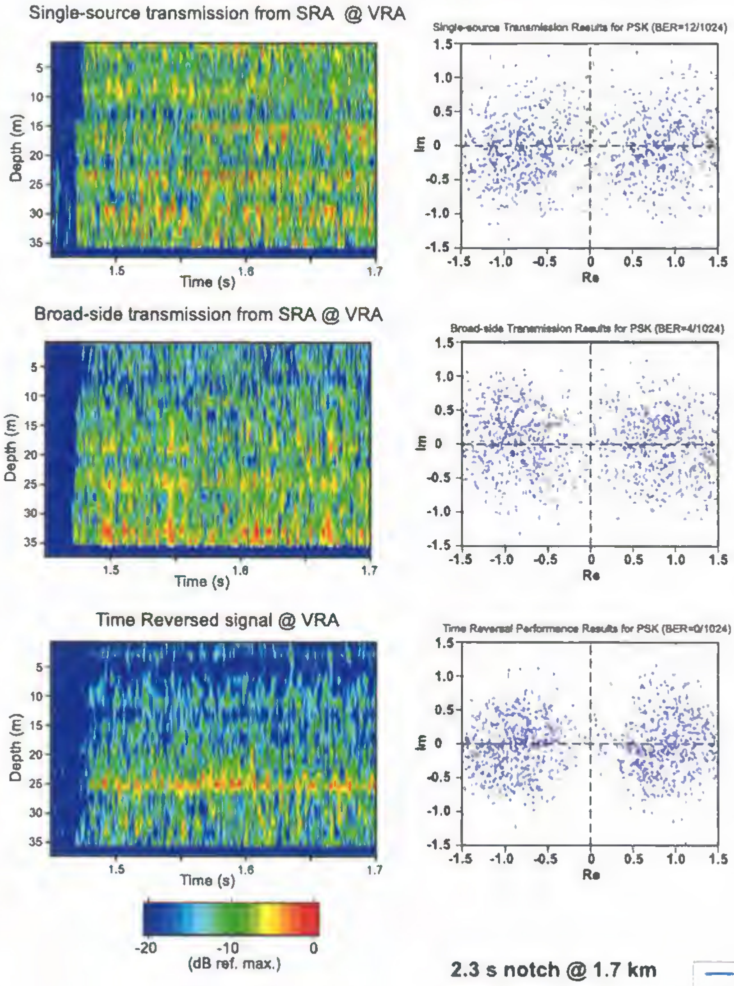


Figure 06-B.7 *Same as Fig. 06-B-6 except in upslope range dependent environment as shown in Fig. 06-B-4. The two-way time-reversal communication shows better performance than one-way single source and broadside communications.*

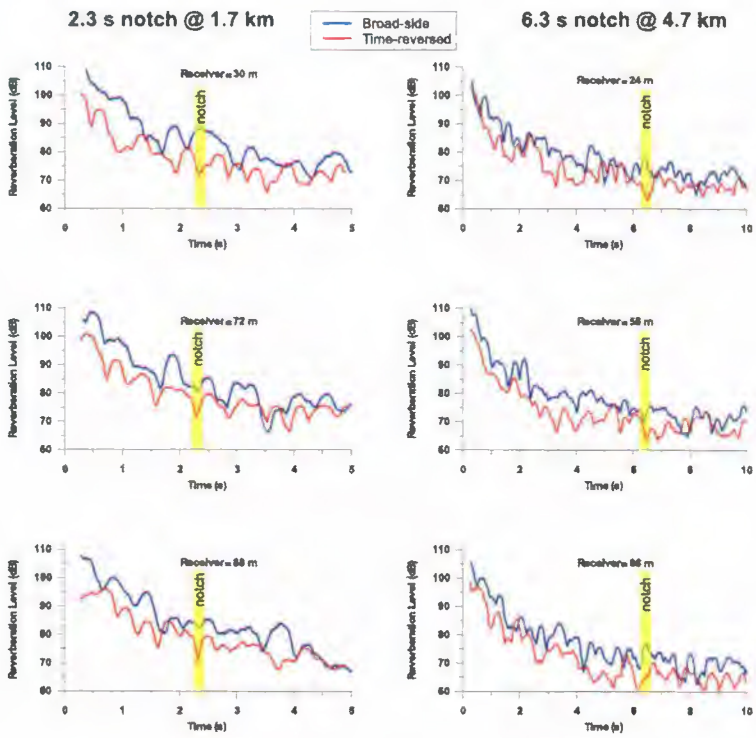


Figure 06-B.8 *Examples of echo-to-reverberation enhancement compared to reverberation from a broadside transmission. The position of the notch indicates the range at which the SRA was focusing.*

which corresponds to the TR focus at 1.7 km and 4.7 km range. Single source, monostatic reverberation measurements for CW tones and LFM chirps were also taken. Finally, a set of towed probe source runs was made in conjunction with the SRA to determine a path of minimum bottom reverberation return related to the moving focal range.

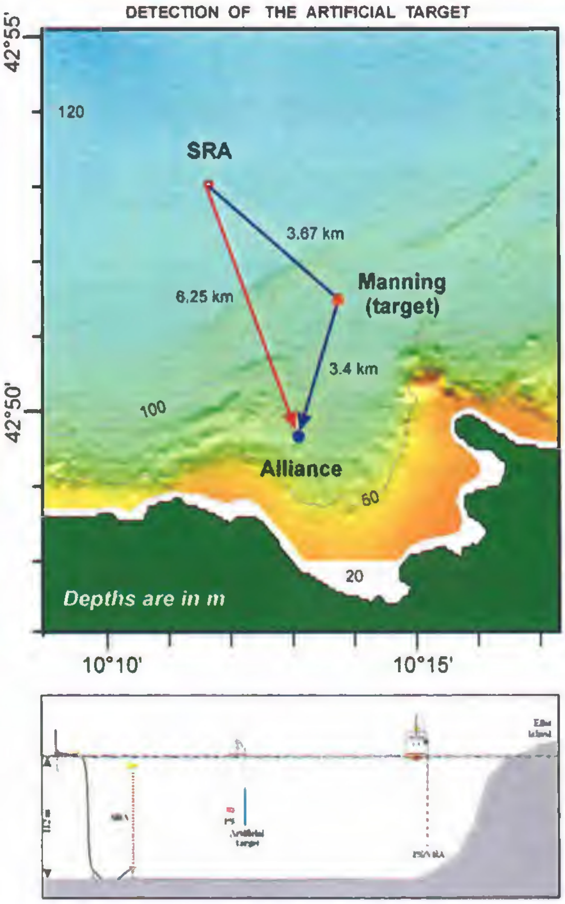


Figure 06-B.9 *Bistatic scattering, time reversal geometry. Manning had an artificial "fire hose" target and a probe source*

TR experiments including a target

An artificial target was deployed from the R/V *Manning* together with a probe source. It consisted of a 30 m air-filled hose folded 7 times. Figure 06-B-9 shows the geometry of one of the experiments and Fig. 06-B.10 shows bistatic results in which the *Manning* provided the probe source signal which was time reversed at the SRA, echoed off the target at the *Manning* with the echo shown being the VRA reception at the *Alliance*. The broadside control results do not show a target detection.

Forward scatter barrier

The classic difficulty in constructing an acoustic trip line barrier is that the forward scattered field from the target must be extracted from the (usually) much more intense direct blasting arriving beam, i.e., "looking into the sunlight effect." We investigated the forward scatter barrier concept using a 6 -element transponder at 65 m depth drifting along the *Alliance*, which traversed the trip line between two moored vertical arrays separated by 5 km as shown in Fig. 06-B.11.

Figure 06-B.12 shows a schematic of the experiment. A 10 ms CW pulse from the PS at the bottom of VRA is received and time-reversed at the SRA. The transmitted signal is then refocused at the PS location of the VRA. This time-reversed signal is also captured by the transponder simulating the forward scatter target

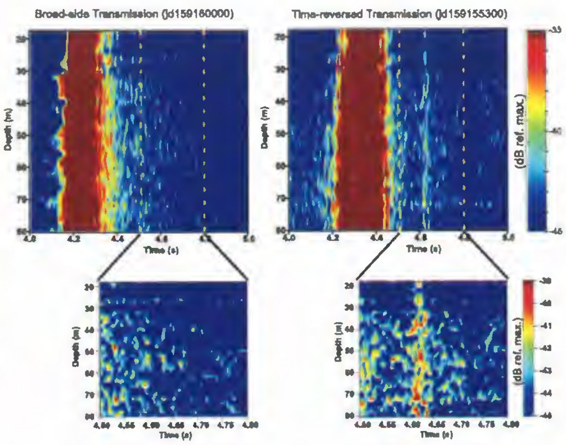


Figure 06-B.10 *Example of data obtained using the bistatic configuration as shown in Fig. 06.B-9.*

and is retransmitted to the VRA with various amplitudes simulating different target strengths. With an appropriate time delay, the main blast and the transponder signal arrived at the VRA simultaneously. For comparison, one-way broadside transmissions were also made. An example of data is shown in Fig. 06-B.13.

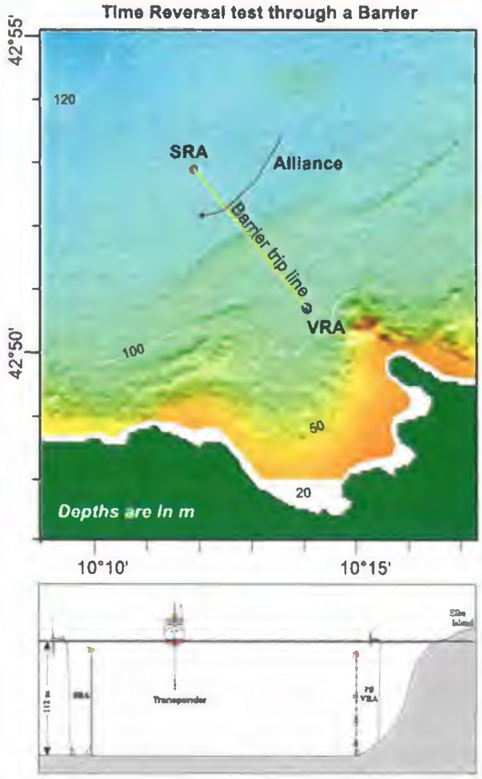


Figure 06-B-11 *The geometry of the TR barrier trip line experimental test utilizing forward scattering*

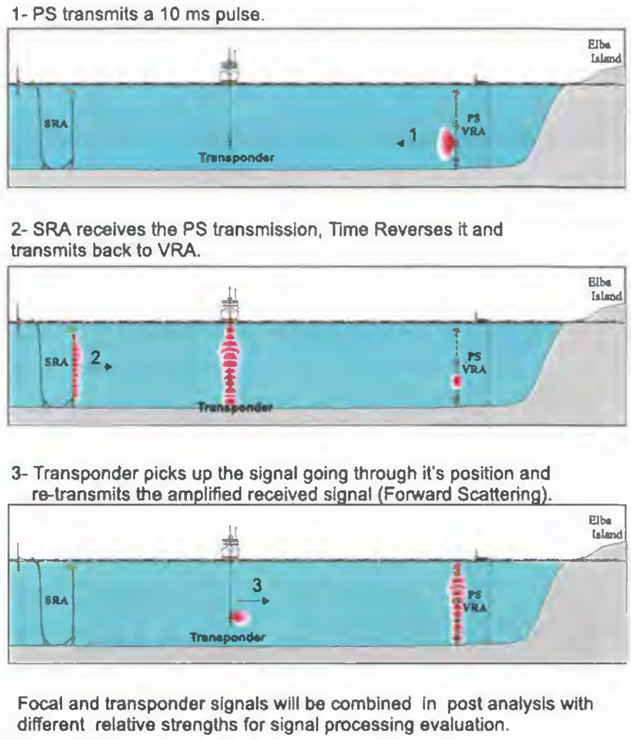


Figure 06-B.12 *Schematic explanation of the experimental procedure for performing the Forward Scatter Barrier test.*

Conclusions

We have implemented acoustic Time Reversal Mirrors in the ocean, which perform as well as they would in an ideal laboratory setting. In particular, the measured focus size was shown to be at the diffraction limit, even for the complex ocean environments in which the experiments were performed. Furthermore, we have demonstrated the potential utility of the time reversal physics when applied to sonar and acoustic communications.

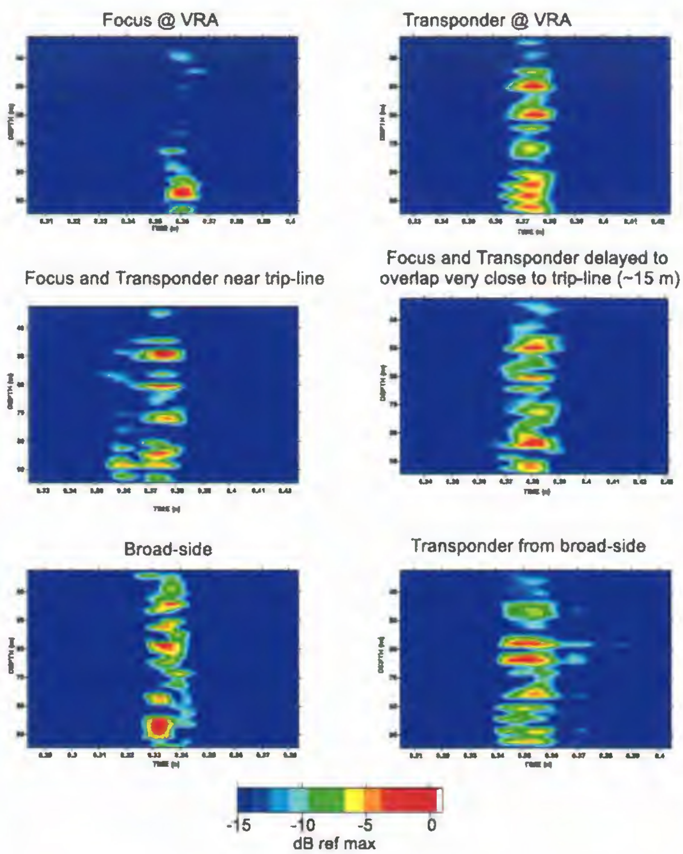


Figure 06-B.13 *The two bottom panels are the broadside control data. The existence of the forward scattered field (acoustic field from the transponder) in a non-focal region on the VRA is the trip line "alarm".*

Publications

Akal, T., Edelmann, G., Kim, S., Hodgkiss, W.S., Kuperman, W.A. Song, H.C. Low frequency and high frequency ocean acoustic phase conjugation experiments. *In:* Zakharia, M.E., Chevret, P., Dubail, P., editors. Proceedings of the fifth European conference on underwater acoustics, ECUA 2000, 10-13 July, 2000, volume 2. Luxembourg, Office for Official Publications of the European Communities, 2000: pp. 989-994 [ISBN 92-828-9531-9].

Edelmann, G., Akal, T., Hodgkiss, W.S., Kim, S., Kuperman, W.A., Song, H.C. An initial demonstration of time-reversal self-equalization for underwater acoustic communication. *Submitted to: IEEE Journal of Oceanic Engineering.*

Edelmann, G., Akal, T., Hodgkiss, W.S., Kim, S., Kuperman, W.A., Song, H.C. Self-equalization communications using a time-reversal mirror. *Journal of the Acoustical Society of America,* **108**, 2000:2607:4aUW9.

Edelmann, G., Akal, T., Hodgkiss, W.S., Kim, S., Kuperman, W.A., Song, H.C., Guerrini, P. Underwater acoustic communication using time-reversal self-equalization, SACLANTCEN SR-341.

FAF 2000. Focused Acoustic Field Experiment, SACLANTCEN CD-38

Kim, S., Edelmann, G., Hodgkiss, W.S., Kuperman, W.A., Song, H.C., Akal, T. Spatial resolution of time reversal arrays in shallow water. *Journal of the Acoustical Society of America,* **108**, 2000:2606:4aUW4.

Kuperman, W.A., Akal, T., Hodgkiss, W.S., Kim, S., Edelmann, G., Song, H.C. Forward-scatter barrier with a time-reversal mirror. *Journal of the Acoustical Society of America,* **108**, 2000:2607:4aUW7.

Kuperman, W.A., Hodgkiss, W.S., Akal, T., Kim, S., Edelmann, G., Song, H.C. Robust diagnosis for the focal stability in time-reversal acoustics. *Journal of the Acoustical Society of America,* **108**, 2000: 2606:4aUW3.

Kuperman, W.A., Hodgkiss, W.S., Akal, T., Kim, S., Edelmann, G., Song, H.C. Time-reversal acoustics. Acoustics 2000 – Australia.

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Project 06-C: Sound, oceanography and living marine resources (SOLMR) (Alliance days – 21)

Operational relevance

To support NATO Navies' peacetime operations by providing tools to determine areas of low environmental impact

- *Integrated oceanographic-biological database*
- *On scene mitigation procedures*
- *Long term acoustic monitoring buoys*

To formulate an Acoustic Risk Mitigation Policy designed to limit the exposure of human divers and marine mammals to low-frequency sound.

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Two sea trials were conducted in the Ligurian Sea as part of the *SIRENA* programme, which is designed to acquire environmental information and to evaluate techniques and methods for effective acoustic risk mitigation such as the low power, active acoustic, whale detection sonar and acoustic tags to measure the received acoustic level on a cetacean during sonar operations, which were used during *SIRENA '00.*

The selection of a trial area may be influenced by knowledge of the cetacean species present. During both *SIRENA* trials, the large *Physeter macrocephalus* (sperm whale) and *Balaenoptera physalus* (fin whale) were found predominately in the deeper areas of the Ligurian Sea, where the doming effect caused by the counter-clockwise current causes upwelling of the cold nutrient-rich deep water. *Ziphius cavirostris* (Cuvier's beaked whale) were found only in a submarine canyon, in the northeastern section of the basin. Figures 06-C.1a and 06-C.1b show satellite measured sea surface temperature for the *SIRENA* operation area (upper layer), the depth contour of the 13.8° C isotherm (middle layer), which is an indicator of upwelling with sightings of the deep diving sperm and Cuvier's beaked whales superimposed. The bathymetry of the Ligurian Sea is shown on the lower layer, for *SIRENA '99* and *SIRENA '00* respectively. Data from both cruises indicate an apparent correlation of the sperm whale locations with cooler surface and subsurface temperatures. In *SIRENA '99,* the water was warmer and no sperm whales were sighted. Figures 06-C.2a and 06-C.2b compare the satellite ocean colour (upper layer) of the operational area with the maximum subsurface chlorophyll value (middle layer) with fin whale sightings superimposed. The lower layer shows the depth at which the maximum chlorophyll value was measured. During both trials, the fin whales were located in the centre of the basin, correlated with the higher chlorophyll levels, indicative of higher biomass productivity. The Cuvier's beaked whale sightings in 1999 and 2000 were in the submarine canyon off Genoa, validating the suggestion that Ziphius prefer regions of steep bathymetry as shown in Fig. 06-C.3a. Oceanographic measurements in this region indicate that there exists a frontal zone which may induce higher biomass productivity. The locations observed for Cuvier's beaked whales during the SIRENA trials, correlate well

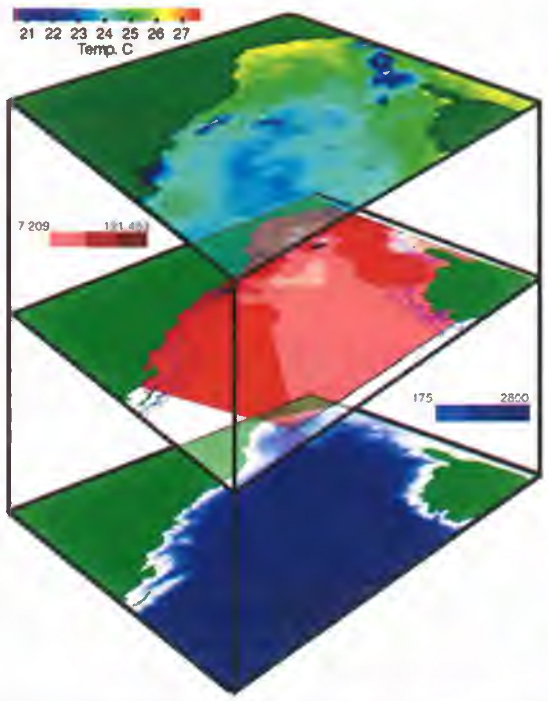
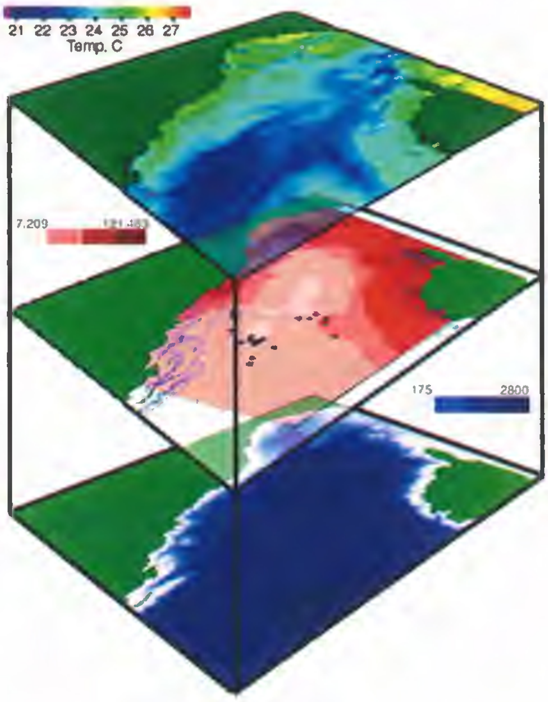


Figure 06-C.1a *SIRENA '99 sea surface temperature (°C) (upper layer), depth (m) of 13.8°C isotherm with sperm and Cuvier's beaked whale visual sightings (middle layer) and basin bathymetry (lower layer).*

Figure 06-C.1b *SIRENA '00 sea surface temperature (°C) (upper layer), depth (m) of 13.8°C isotherm with sperm and Cuvier's beaked whale visual sightings (middle layer) and basin bathymetry (lower layer).*



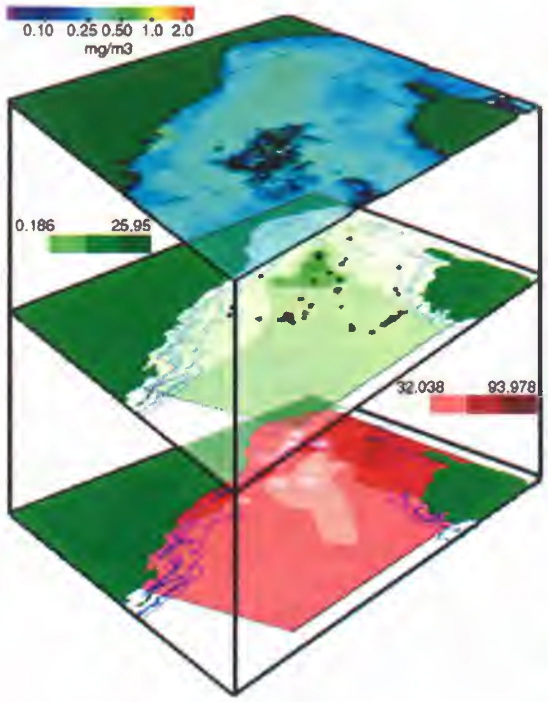
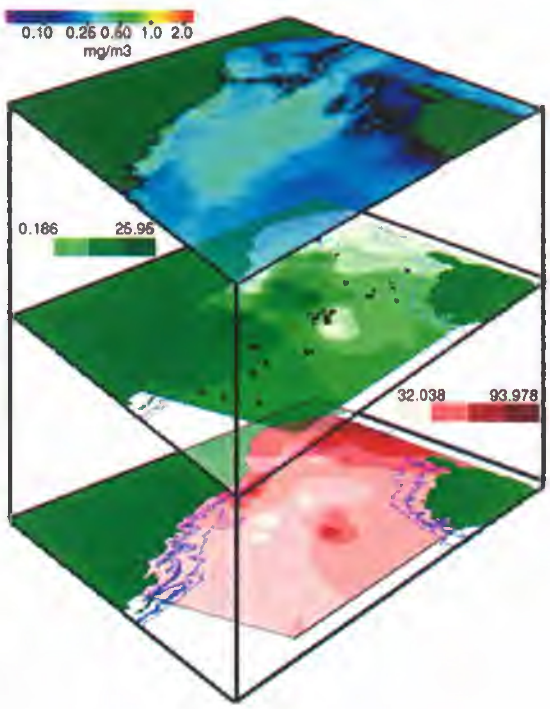


Figure 06-C.2a *SIRENA '99 SeaWIFS ocean colour (mg/ m³) (upper layer), chlorophyll maximum values (mg/ m³) with fin whale visual sightings (middle layer) and depth of chlorophyll maximum (m) (lower layer).*

Figure 06-C.2b *SIRENA '00 SeaWIFS ocean colour (mg/ m³) (upper layer), chlorophyll maximum values (mg/ m³) with fin whale visual sightings (middle layer) and depth of chlorophyll maximum (m) (lower layer).*



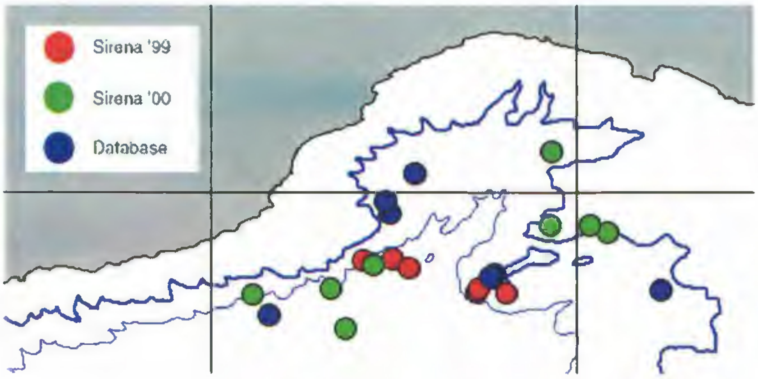


Figure 06-C.3a *Visual sightings of Cuvier's beaked whales during SIRENA '99 and SIRENA '00, with historical data.*

finding sonars, (Fig. 06-C.4). Active whale detection sonar was tested during *SIRENA '00*, locating dolphins in the correct position for measurement, a distance 400-800 m at broadside and swimming forward to aft, thus presenting a beam aspect to the sonar. Figure 06-C.5 shows the match-filter beamformed output at true received level *versus* range. A strong echo from one of the dolphins is seen at 650 m. The acoustic returns suggest a group size

with the historical stranding and sighting data collected for this species in the Mediterranean Sea shown in Fig. 06-C.3b.

On scene, one proposed solution to the marine mammal acoustic risk mitigation problem is the

of approximately 8 animals spread over 6-7 beams, identified by visual observers as striped dolphin, *Stenella coeruleoalba*. Whistles recorded passively in the same beams with the sonar echoes are consistent with this species.

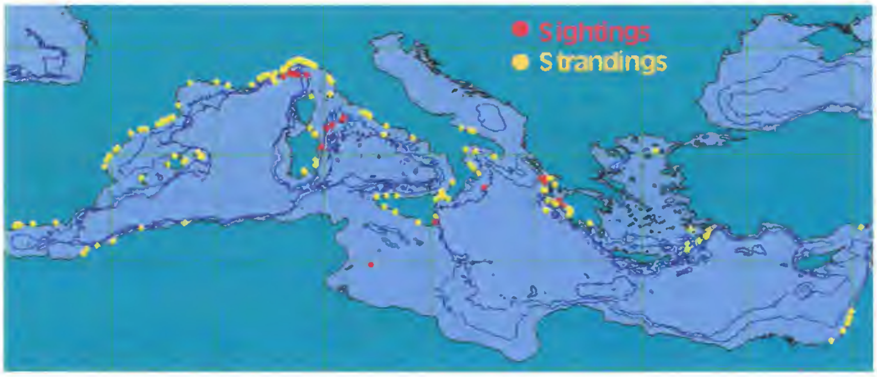


Figure 06-c.3b *Historical sighting and stranding locations of Cuvier's beaked whales in the Mediterranean Sea.*

use of active sonar, which can detect a non-vocalizing animal under the surface. The two-way travel time of a sonar-emitted pulse reflected from an object in the water column, provides a highly accurate range estimate to the object. It is advantageous to use existing equipment for a "through the sensor" risk mitigation tool by using it in low-power mode. The starting point for this idea is the adaptation of a mid-frequency, 1-10 kHz, towed array sonar system, commonly used as research sonars with modified processing, signal lengths and output power.

Source Levels of 160-180 dB re 1 µPa @1 m are comparable to the estimated source levels that marine mammals are known to use and are lower than typical commercial navigation and fish

Figure 06-C.6 shows received echoes from this group of striped dolphins normalized to target strength in dB re 1 m *versus* frequency. No data is available at 1 kHz, due to beam spreading of noise attributable to the short aperture at this frequency. The mean target strength is –20.3 dB re 1µPa @ 1 m with a standard deviation of 4.7 dB. The data spread can be attributed to a mixture of aspect angles and possibly different numbers of animals. Also, the transmission loss used in this calculation is an average value, local deviations of 5 dB are certainly possible. The *in situ* target strength is consistent with reported measurements[1,2].

[1] Au, W.L. Acoustic backscatter from a dolphin. *Journal of the Acoustical Society of America*, **95**, 1994:288(A).
[2] Love, R.H. Dorsal aspect target strength of individual fish. *Journal of the Acoustical Society of America*, **49**, 1971:816.

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Little or nothing is known about underwater motion and correlation of the acoustic activity of sperm whales with their diving behaviour, knowledge essential to determine behavioural characteristics of foraging sperm whales, in order to be able to assess the impact of anthropogenic noise. During *SIRENA 2000*, a sperm whale was tagged with a recording device, to gather multi-sensor data for better understanding of animal behaviour during deep diving. Approximately 4 ½ hours of acoustic and non-acoustic sensor data were recorded[3]. The animal was simultaneously tracked with a passive sonar system deployed from the *Alliance*. During the period, the animal carried out three deep dives with multiple foraging activities at a depth of about 900 m, providing novel insight into the diving behaviour of a sperm whale.

Figure 06-C.7 shows the decomposition of a sperm whale click into two distinct spectral components, a low frequency component below 1000 Hz and high frequency components above 4000 Hz. The low frequency component is extended in time and the high frequency components are very short pulses, characteristics highly suited to wavelet-based spectrum analysis as the spectral composition of clicks varies between animals.

Figure 06-C.8 shows the reconstruction of the underwater tracks of the tagged sperm whale, based on geometric multi-path ranging using the following components:

- Depth of the tracked sperm whale from the tag data,
- The acoustic array depth determined by the depth sensor)
- Path difference between direct arrival and surface reflected path estimated with passive sonar
- Bearing estimation using ships navigation system

The resulting sperm whale range and bearing were low-pass filtered. The reconstruction of the underwater tracks (Fig. 06-C.8) indicates that the sperm whale is moving in an unpredictable way. The tracks resemble random walks rather than well-determined traces. The tracks are similar in structure to the larger scale surface motion of foraging sperm whale groups, indicating a scaling property typical of random processes. The random walk concept is consistent with the assumption that sperm whales do not simply sweep through the ocean, but their motion may be controlled by random opportunities (search and hunt strategy).

To support acoustic risk mitigation, it is essential to learn how ocean dynamics affect the distribution and behaviour of whales and the organisms forming the food web upon which the whales feed. Multiyear, integrated data from the *SIRENA* trials allow correlation of mammal locations with oceanographic, biological and hydrographic parameters. Deep CTD measurements in these habitats suggest a high salinity, low dissolved oxygen layer at the depth where the sperm whale forages. Tag data has indicated that sperm whales in the Ligurian Sea dive to depths consistent with this low oxygen layer, suggesting that this layer may provide a preferential habitat to their prey species, pelagic squid. This suggests that the water mass structure of the deeper layers cannot be neglected. This information can be provided by oceanographic circulation models that provide physical parameters such as currents, upwelling centers and water mass properties. For on-scene risk mitigation, the active whale finding sonar shows promise of being able to detect a cetacean near to an acoustic source, prior to its operations.

The data collected during *SIRENA* sea trials have supported the SOLMAR project by seeking to establish a paradigm for monitoring and conservation of marine species, by:

- determining regions of high and low cetacean density through oceanographic, biological and historical means and using this information as a basis for selecting regions for the conduct of acoustic trials where the likelihood of cetacean presence is low.
- employing visual and acoustic monitoring techniques during acoustic trials to establish a marine mammal free zone,
- by establishing an acoustic methodology to determine the baseline behaviour of a cetacean prior to exposing it to acoustic transmissions.

Bondaryk, J.E. The detection and localization of marine

[3] Using Digital Tag (DTAG) developed and deployed by Peter Tyack and Mark Johnson of Woods Hole Oceanographic Institution.

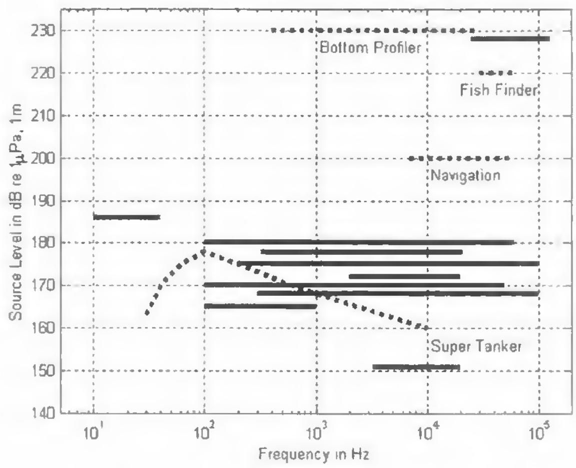

Figure 06-C.4 *Source level versus frequency for whales common to Ligurian Sea and man-made sonars.*

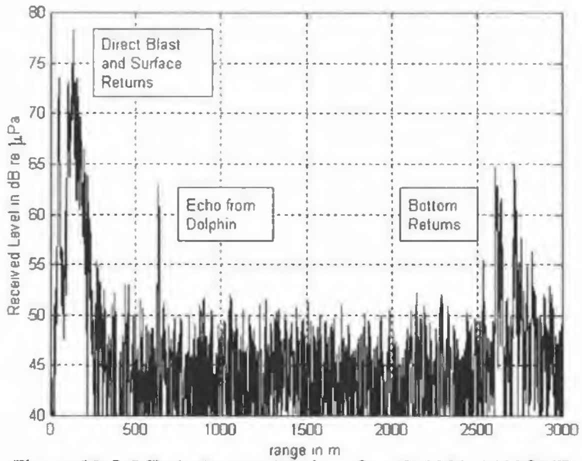

Figure 06-C.5 *Typical sonar data from Sept 3, 2000, 1400GMT. Post match-filter received level versus frequency at $f_c = 8kHz$. Strong echo from dolphin appears at 650m.*

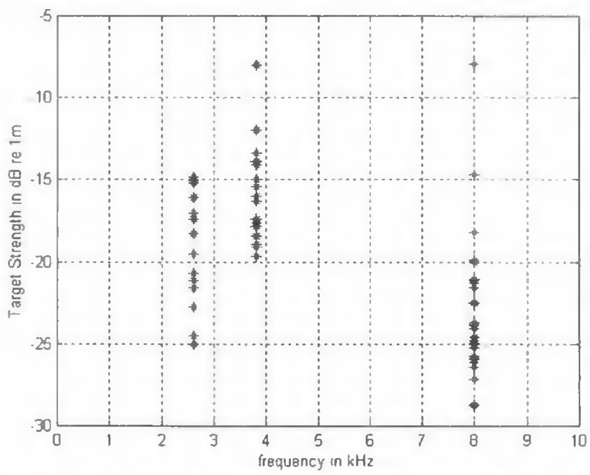

Figure 06-C.6 *Target Strength vs. frequency for striped dolphin, Stennela coeruleoalba. Aspect and number of animals is variable and unknown.*

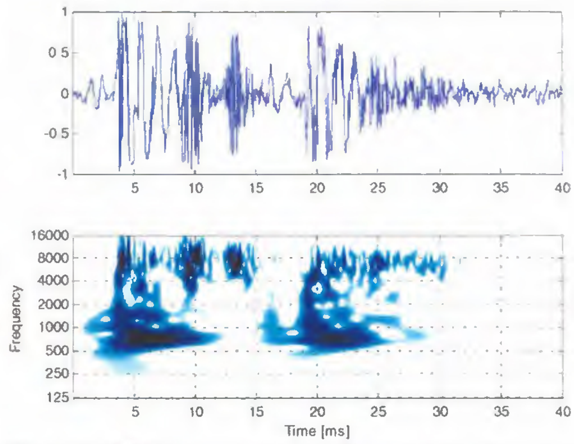

Figure 06-C.7 *Time series and wavelet spectrum of a sperm whale click with surface reflection received by passive sonar system.*

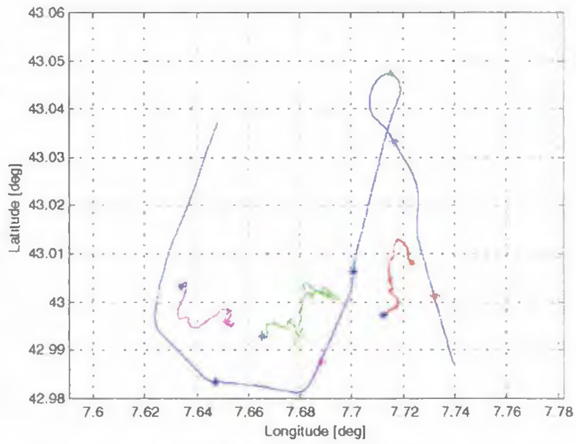

Figure 06-C.8 *Reconstruction of underwater track of the tagged sperm whale. The blue line is the track of NRV Alliance, the red line corresponds to the first dive, the green line to the second and the magenta line to the third dive. The coloured stars indicate the position at the beginning and the blue stars indicate the position of the end of the regular clicks of each dive.*

6

Project 06-C publications and presentations

mammals with dual-use acoustic technology. Secondo Convegno sulle Scienze del Mare, Genova, 22-25 November 2000.

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

D'Amico, A. Bioacoustics - an overview of current technology. Secondo Convegno sulle Scienze del Mare, Genova, 22-25 November 2000.

D'Amico, A. Italy, progress report on cetacean research, January 1999 to December 1999, with statistical data for the calendar year 1999. International Whaling Commission Annual Report.

D'Amico, A., Bergamasco, A., Zanasca, P., Carniel, S., Nacini, E., Portunato, N., Teloni, V., Mori, C., Barbanti, R. Correlation of oceanographic, biological and physical parameters with marine mammal presence in the Ligurian sea, (i) SACLANTCEN SM-378, (ii) *submitted to: IEEE Journal of Oceanic Engineering.*

Podesta, M., Williams, A., D'Amico, A., Fossati, C., Manghi, M., Di Natale, A., Gobey, C., Panigada, S., Quero, M., Portunato, N., Bontempi, P. Cetacean visual sightings in SIRENA 99 – a sound, oceanography and living marine resources project research cruises. Presented at 14[th] Annual Conference, European Cetacean Society, Cork, 2-5 April, 2000.

Schweizer Fernsehen DRS. NETZ Natur. Das Meer, das uns am nächsten liegt. Director and commentator Dr Andreas Moser. 21 September 2000 (duration 60 minutes, of which 20 minutes devoted exclusively to SACLANTCEN).

SIRENA 00, SACLANTCEN CD-41.

Teloni, V., Zimmer, W.M.X., Fossati, C., Manghi, M., Pavan, G., Priano, M. Variability of temporal and spectral click characteristics of sperm whales (Physeter macrocephalus). Presented at 14[th] Annual Conference, European Cetacean Society, Cork, 2-5 April, 2000.

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), (i) SACLANTCEN SM-380, (ii) *submitted to: IEEE Journal of Oceanic Engineering.*

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.*

__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.

__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.

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Farewell speech by Dr William Jobst, Deputy Director 1998 - 2001

Sea stories and thanks

There are many differences between the SACLANT Undersea Research Centre and the laboratory I left, but the most significant, at least for this time, is that Centre speeches are always given before lunch, while in the US, speeches are always given after guests have been fed. Maybe this keeps the Centre speeches short, but I find this custom of talking, then eating, to be inconsistent with everything I've learned to know and love about Italian culture. If I could change one "tradition", subjecting you to speeches before lunch would be it.

"Sea stories" are those incidents that give character to an organization, and I must relate two of them, one rather old that gives some of my personal background, and one very recent.

In 1980 I left a small research group in Miami, FL, to head the Acoustic Projects group at the US Naval Oceanographic Office, a laboratory best known for worldwide ocean surveys and extensive data archives. The group had just moved from Washington, DC to Mississippi, and most senior personnel decided to stay behind. Other than a few remaining "old hands", our group of 50 plus people was composed of new graduates with little experience in acoustics. Our job was to establish a worldwide low frequency, passive acoustic forecasting capability, complete with the best databases we could provide. Bathymetry and ocean sound speed were fairly well along thanks to the efforts of others, but we had to develop instrumentation, processing algorithms and data base storage for bottom loss/transmission loss, bottom environmental properties, and ambient noise, almost from scratch.

I toured several US and European laboratories. Although there were many promising technologies, the technologies were generally not developed nor documented to a level that would make transition to our inexperienced scientific team easy. Then I visited SACLANT Centre. Robert Seynaeve showed me his HP computers that had *just come off two months on ALLIANCE. We copied those computers part number-for-part number and line-of-code for line-of-code. We cemented a relationship with Tuncay Akal and copied his software for bottom loss/transmission loss as well as his geophysical methods for understanding transmission loss variability. Ole Hastrup, now retired from the Centre, had ambient noise instrumentation and software, and we again copied most of his work. For acoustic models we turned to Finn Jensen. His work with the parabolic equation was the cornerstone of our modeling program.*

The techniques that the Centre had developed were applied worldwide, and today, there are very few military acoustic systems that the Centre's research has not affected. The Centre's 1980 technology has been greatly improved of course, but it is still a major part of the core of the passive acoustic forecasting systems in day-to-day use on every ASW surface ship, surveillance system, aircraft and submarine in the US navy, and in most other NATO navies as well.

I thought you should hear that sea story about the past successes of our scientists. (Besides, it's the only way I could reveal Finn's true age.)

1980 was a long time ago. My favorite recent sea story involves our efforts to convince the Senior Resource Board that our funding needs were genuine and thoughts of commercialized "customer funding" should be forgotten. In a preliminary visit, a small delegation headed by a very skeptical individual with a Masters degree in economics was given a laboratory tour.

In the Engineering Department, he met Luigi Troiano, Bruno Miaschi and Marc Pinto. After a demonstration of the cardioid array and synthetic aperture sonar, our visitor commented in a tone of amazement "You're not like other NATO groups that do studies, this is real hardware."

The tour moved on to Walter Zimmer's multiscreen ASW show. After the impressive demonstration, our visitor asked about Walter's credentials. I replied that Walter was one of the Centre's technicians, our expert in real time systems software, and he had a PhD in Physics; but that wasn't unusual here since many of our technicians had PhDs. Our visitor was obviously impressed.

Our final stop was Dave Burnett's office where Dave's whiteboard was covered with multicolored finite element theory. Our visitor skipped Dave's demo to look at the whiteboard and at Dave's bookshelf. After realizing that Dave had written most of the books, our visitor turned to me and said, "You really didn't set this up, did you? This is all real." My answer was that we were the best undersea military scientific group in the world.

On the way upstairs our visitor asked if we had openings for someone with a Masters degree in economics. He was considering joining us. (Jan, while reading this, I realized that if we had hired our visitor, our financial problems might have been solved!)

There are many more "sea stories" that I could tell, but I'd like use the remaining time to give a few of you special thanks.

First, I couldn't ask for a better or more understanding secretary than June Waller. Together with Karin and Simonetta, they have come to realize my almost complete helplessness and reliance upon others.

The Engineering Department under Oddbjorn Bergem is filled with unsung heroes. My thanks to all of you for keeping the peace with the scientific staff (at least most of the time) and delivering equipment that worked (at least most of the time). In the future I hope you will continue to develop your sense of ownership and apply the principal of continuous improvement to those systems that form the core of our Centre's science program.

There is another member of the Engineering Department who must be mentioned. Federico de Strobel, your interest in 2000 year-old charts will be carried with me forever. Don't let Oddbjorn Bergem force you into throwing away everything. And remember, the Scripps library is a terrible place to store your treasures; it's on the San Andreas fault. Call me at NRL if you need a stable library.

Shortly after my arrival, Umberto Varlese informed me that within NATO, the Deputy Director was only responsible for the technical need, not for complying with financial or contractual regulations. Umberto, my thanks to you for simplifying my life. With Roberto Albini, Luigi Parise and your very competent staffs, you have kept us out of trouble despite more auditors than I could ever have imagined.

The Department Heads, also known as Thrust Area Managers, form an extremely bright and diverse group. Over the past year we've struggled with our concept of customers, our understanding of what our customer wanted, the research program to provide it, and how to manage with both scientific disciplines and thrust areas. The solution to the management dilemma (Organization by Scientific Disciplines and/or Thrust Areas) remains with you and Ken Pye, but the most recent multiyear rolling plan provides a long term view of what the Centre must do and the resources needed to do it. Despite widely different opinions, you've kept the atmosphere cordial. Nick Pace and Bill Roderick, Oddbjorn Bergem, Stephane Jespers, Jurgen Sellschopp, and Ken Pye, a special thanks to you for your patience and tolerance. Regardless of the organization, keep working together, and you will be successful.

The scientific staff is too numerous to mention, but I've enjoyed working with all of you. There is one person, however, that I'd like to single out. She arrived at the Centre with two children in tow and two scientific programs that were neither funded nor staffed adequately. She will tell you that they are still neither funded nor staffed adequately, but somehow she has managed to make the Marine Mammals project an outstanding success. My special thanks to Angela D'Amico. When things were going poorly in the front office, I would go to her office, listen to her problems, and then feel so much better about my own. Thanks for the counsel, Angela.

Our military staff has been the crutch that the Director and I have come to lean on whenever there is work to be done. Oreste Molino, Bjorn Egenberg and of course John Staveley have been the sparkplugs that keep us going. Despite all the visitors, we've never missed a viewgraph. Perhaps more important, their counsel on the direction that our scientific program should take has proven to be absolutely correct. John Staveley, I'll especially miss your wit, and I particularly appreciate the way you've changed my computer to spell "programme" in the manner of a true cricket fan.

In my previous work, the first order of business every morning was a briefing on the status of shipboard equipment. I was amazed to learn that the Centre front office "didn't worry about the ship". With Chris Gobey I visited ALLIANCE in drydock one *cold rainy evening and learned why. The Captain, first officer, engineering officer and Denholm staff were all down in the drydock, under the ship helping change a shaft seal. The ALLIANCE was their home and they wanted it to work right! Aside from an occasional visit to talk sailing, I don't think I've visited Chris' office on business more than twice. Thanks for making my job easier, Chris.*

The Naval Advisor, CDR Brian Williams, our business manager, David Bennett, and my outstanding boss and Director, Jan Spoelstra have kept up the fight; getting across the message that we're working on NATO requirements and doing a great job. I believe Jan has entertained more visitors, fed more people and earned more trans-Atlantic frequent flyer miles than any previous Director. And it works. We are making headway in our SPOW budget, Capabilities Packages are in process, and that's far different from where we started. We have a new ship under contract. And we have a full table of food.

There are many of you whom I haven't mentioned: Cesarina who kept me awake after all those late NATO evenings, the Caribineri who kept a watchful eye on the Centre and probably fixed my 1963 Porsche speeding tickets, and many others. I thank all of you for the opportunity to serve as Deputy Director of the best undersea laboratory in the world. Susan and I are truly proud to have been a part of it.

Ken Pye, your new Deputy Director, says it's time to eat.

W. Jobst
Deputy Director, SACLANT Undersea Research Centre
26 January 2001

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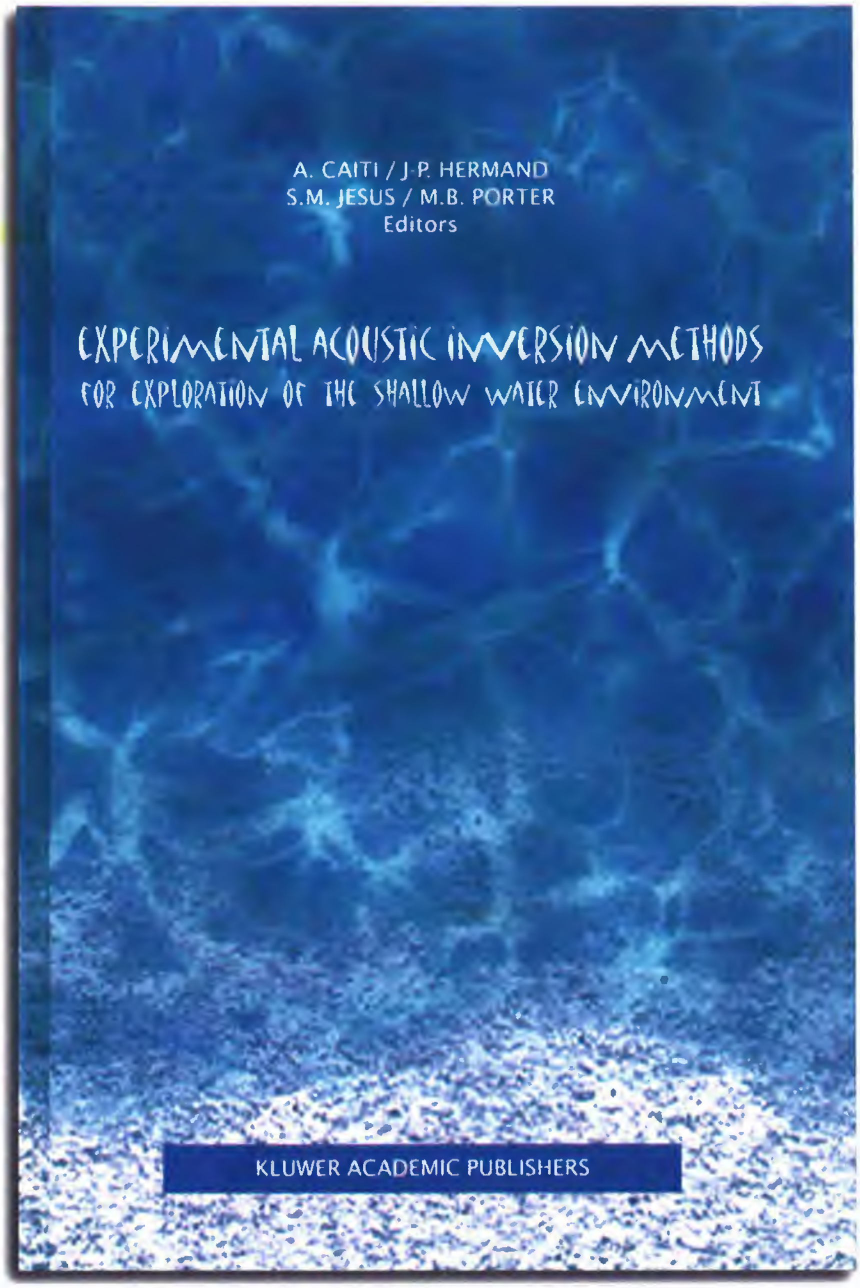
Annual Bibliography of SACLANTCEN



SM-371

Bini-Verona, F., Nielsen, P.L., Jensen, F.B.
PROSIM Broadband Normal-Mode Model. A user's guide.

PROSIM is a layered normal-mode model approach for adiabatic broadband range-dependent sound propagation. The kernel of this model is based on a recently developed range-independent model called ORCA, which includes a very efficient eigenvalue solver and frequency interpolation technique. This implementation of range-dependency involved special handling of the range segments and the frequency interpolation to minimize hardware requirements and still keep the efficiency of the model. The computation speed of PROSIM is a function of the number of layers describing the environment in depth and the influence of the maximum efficiency and bandwidth considered; nevertheless the calculation of broadband transfer functions up to 10 kHz in shallow water acoustic waveguides involving hundreds of modes and thousands of frequency components is performed in a few minutes on a state-of-the-art workstation.

SM-371

Nielsen, P.L., Jensen, F.B.
Mode and PE predictions of propagation in range-dependent environments: SWAM'99 workshop results.

Three numerical acoustic models, a coupled normal-mode model (C-SNAP), an adiabatic normal-mode model (PROSIM) and a parabolic equation model (RAM), are applied to test cases defined for the SWAM'99 (Shallow- Water Acoustic Modeling) workshop, Naval Postgraduate School, Monterey (CA), 1999. The test cases consist of three shallow-water (flat bottom) scenarios with range-dependent sound-speed profiles imitating internal wave fields and a shelf-break case, with range-dependent sound-speed profiles and bathymetry. The bottom properties in all cases are range independent and modelled as a homogeneous fluid halfspace. The results from the modelling are presented as transmission loss for selected acoustic frequencies and source-receiver geometries and as received time series. The results are compared in order to evaluate the effect of applying different propagation models to the same range-dependent underwater environment. It should be emphasized that the propagation analysis is not an attempt to benchmark the selected propagation models, but to demonstrate the performance of practical, range-dependent models based on different approximations, in particular underwater scenarios.

SM-372

Acunto, S., Lyons, A.P., Pouliquen, E.
Characteristics of the Mediterranean seagrass *Posidonia oceanica* contributing to high frequency acoustic scattering.

Posidonia oceanica meadows are the most important ecosystem for the life cycle of coastal Mediterranean benthos with a fundamental role in the primary production of the neritic system and a decisive influence on other vegetation and animal communities. Posidonia oceanica meadows are undergoing a slow but progressive regression, the most common cause of which is enhanced turbidity and the consequent reduction of water transparency. The first step towards the preservation of coastal environments is to define their extent and condition. Echographic surveys allow general maps to be obtained, but accurate seafloor characterization requires knowledge of the characteristics of seabed vegetation which affect acoustics propagation.

A preliminary study quantified the gas within the leaves of Posidonia oceanica as a function of the plant life cycle. An order of magnitude of the volume of the different elements considered and their relative importance expressed as percentages is given. The values obtained were considered with reference to the seasonal changes of the phenological variables from which they depend and also to the main structural variable: the density of leaves.

A future step based on the present work will be the development of a model of acoustic scattering by Posidonia oceanica derived from a model developed for gassy sediments. The final result would enhance the capability of rapidly acquire information on the extention of meadows, plant density and height. From an operational point of view it could improve the performance of mine-hunting sonars.

SM-373

Weber, R.
On the spatial variability of the impulse response of an underwater acoustic channel.

In many applications like adaptive equalization, beam-forming, matched field processing or focalization the performance is limited due to changes in the impulse response caused by variations in source-receiver range or in bathymetry. As one wishes to quantify the degree of degradation and possibly compensate them it is important to understand the effects of parameter variations on the impulse response.

This report focuses on examining the similarities of simulated impulse responses belonging to scenarios in which environmental parameters are changed one at a time. As a measure of similarity the classical correlation coefficient and the maximum magnitude of the cross correlation function between the complex equivalent lowpass representation of the signals are introduced and their properties are discussed. The results of the correlation analysis demonstrate the properties of the two correlators and show the limits of their applicability. Furthermore, they give evidence that some parameter perturbations are more critical for impulse response variations than others.

SM-374

Alvarez, A., Harrison, C., Siderius, M.
Predicting underwater ambient noise with an evolutionary signal processing method.

In this report we employ recent developments in non-linear physics and time series prediction to study the physical characteristics of measured underwater ambient sounds. Specifically, we examine the predictability of samples of ocean ambient noise recorded in the Strait of Sicily, Italy. An approach based on genetic algorithms has been employed. Results indicate that, while showing complex time variability, the recorded signals are highly predictable.

SM-375

Alvarez, A., Orfila, A., Sellschopp, J.
A satellite based ocean forecasting system to support naval operations in crisis situations.

We employ a nonlinear ocean forecasting technique based on a combination of genetic algorithms and empirical orthogonal function (EOF) analysis. The method is used to forecast the space-time variability of the sea surface temperature (SST) of the ocean area around the Island of Elba. The genetic algorithm identifies the equations that best describe the behaviour of *the different temporal amplitude functions in the EOF decomposition and therefore, enables global forecasting of future time-variability.*

SM-376

LePage, K.D., Schmidt, H.
Spectral integral representations of monostatic backscattering from three dimensional distributions of sediment volume inhomogeneities.

A theory is developed for generating short time, monostatic reverberation realizations caused by three dimensionally distributed volume inhomogeneities in stratified media. A spectral integral approach to treating the propagation to an from the scatterers, combined with a two dimensional spectral representation of the azimuthally averaged scatterer realizations and a novel numerical implementation, combine to yield an efficient, high fidelity reverberation realization generator for predicting monostatic backscatter from realistic sediments.

SM-378

D'Amico, A., Bergamasco, A., Zanasca, P., Carniel, S., Nacini, E., Portunato, N., Teloni, V., Mori, C., Barbanti, R.
Correlation of oceanographic, biological and physical parameters with marine mammal presence in the Ligurian sea.

Spectral integral representations of monostatic backscattering from three dimensional distributions of sediment volume inhomogeneities.

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

Bondaryk, J.E., D'Amico, A.
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 1μPa, 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 behavior 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 NATO research vessel 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 behavior. While it was tagged, the whale carried out 3 deep dives to a depth of about 900m 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 subtle changes in the behavior of diving whales. This is not only important for basic research, but also enables studies of the responses of these animals to controlled exposures of manmade noise and to infer the biological significance of behavioral disruption.

SR-322

Di Iorio, D., Bergem, O., Pace, N.
Atmospheric and sea surface wave effects on current and temperature/salinity variations in a shallow water environment.

A shallow water experiment (d = 10 m) was carried out to measure the contribution of wind, precipitation and sea surface wave effects on current, pressure and temperature/salinity variations. It is found that during heavy rainfall (precipitation exceeding 5 mm), there is a corresponding salinity decrease of approximately 1 psu at 5.8 m depth. Analysis of wind data shows that the cross-shore winds exhibit 24 h periodicity associated with land/sea breezes as a result of land cooling and heating. The 24 h periodicity of cross-shore winds is reflected in temperature and salinity variations leading to the conclusion that advection by wind is the primary cause of low frequency variations. Sea surface wave data show predominantly Mediterranean swell (mean period 4 s and significant wave heights less than 1 m). During the passage of a storm, significant wave heights exceeded 3 m and so the theory of Stokes finite amplitude waves in conjunction with linear theory is used to model particle motion, pressure, temperature/salinity and sound speed variations. Observations and models are compared for six different days and conditions: a local storm event, a calm period, during the peak of a major *storm, the post-storm stage, during swell-dominated seas and finally when the sea was calm again. The velocity field shows current oscillations characteristic of a wave boundary layer. The temperature/salinity and hence sound speed variations show that when the orbital particle motions are strong, there is a low frequency spectral power law of $f^{-5/3}$ to the left of the surface wave peak and a high frequency spectral power attenuation of approximately $f^{-3.5}$ to the right.*

SR-332

Siderius, M., Nielsen, P.L., Sellschopp, J., Snellen, M., Simons, D.

Optimized sound propagation modelling in a time varying ocean environment.

In May 1999 SACLANTCEN and TNO-FEL, conducted an experiment on the Adventure Bank off the southwest coast of Sicily, Italy, in order to assess the effects of a time-varying ocean on acoustic propagation in a shallow-water area. A favourable area for acoustic propagation was identified which had slight internal wave activity and a weakly range-dependent bathymetry with sand-like bottom properties. Oceanographic and acoustic measurements were performed continuously over a three day period. Broad-band (0.2—3.8~kHz) acoustic signals from a bottom-moored source were transmitted over fixed paths every minute for up to 18 h. The signals were received on a moored vertical array at ranges of 2, 5 and 10 km. During the acoustic transmissions extensive measurements of the environmental parameters (e.g. sound speed, current, sea-surface wave height etc.) were made to correlate the time-varying environmental and acoustic data. In particular, a Conductivity-Temperature-Depth chain was towed along the acoustic track resulting in time- and range-dependent sound-speed sections. modelled acoustic data show time variability which agrees with the measurements. Further, these results illustrate severe problems when modelling shallow water acoustic propagation at ranges beyond a few kilometres in the frequency band considered.

SR-333

McDonald, B.E., Sperry, B., Baggeroer, A.B.

Theoretical and numerical issues in travel time tomography.

Results from perturbation theory for changes in ocean acoustic modal group speeds due to small environmental changes are investigated with regard to their applicability to inversion schemes for large scale trends in the ocean's thermal structure. In regions where adiabatic mode theory is applicable, the inverse problem for each vertical eigenmode consists of an integral equation whose kernel involves the eigenfunction and its frequency derivative. We give a proof for the so called 'third term problem' which requires equivalence between two dissimilar integrals relating the perturbations in the water column, the resulting perturbations in the acoustic eigenmode under consideration and the frequency derivative of the eigenmode. We give numerical examples for the inversion kernel for four types of sound speed profiles and then explore numerically the parameter range (amplitude and scale size) in which perturbation theory is accurate.

SR-334

Lyons, A.P., Fox, W.L.J., Hasiotis, T., Pouliquen, E.

Characterization of the two-dimensional roughness of shallow-water sandy seafloors.

Surface roughness is a fundamental seafloor property affecting a variety of physical phenomena including sediment transport and the interaction of acoustic energy with the seafloor. Characterization of seafloor surface roughness and its dynamics is therefore essential for understanding and quantifying the influence of sediment microtopography. Field measurements have been taken recently with an end-to-end digital photogrammetry system providing quantitative, two-dimensional seafloor surface roughness measurements on spatial scales of approximately a millimeter to a meter. Results of these measurements have shown that sediment surfaces in shallow water are often anisotropic and/or exhibit non-Gaussian height distributions, both of which have the potential to strongly affect high-frequency seafloor acoustic scatter. For these kinds of surfaces, simple roughness parameters such as rms height or the slope and offset of a power law representation of the power spectra will not give a sufficiently complete description. Two-dimensional statistical models are needed to capture the anisotropic nature of sediments with oriented features, while for seafloors with peaked forms, it is the phase information in the frequency domain that is required, as this controls the shape characteristics of a surface. Characterization of seafloor roughness based on these ideas will be presented using results from the digital photogrammetry system.

SR-336

J. Sellschopp

REA fusion centre operations

A capability for data fusion in rapid environmental assessment (REA) operations has been developed and practiced. The concept and the steps for its realization are described in enough detail to be used as a guide to similar exercises in the future. Examples are taken from Linked Seas 2000 data fusion, the most recent, most advanced and most complex data fusion activity for military oceanography. All functions of a data fusion centre are described, from data collection over data base organization, administration, maintenance, conversion, visualization and search to placement on one or more networks. Platform independent Internet technology is used with standard software for servers and clients. An html-version of this report is included on the SACLANTCEN CD-40 with active links to the respective examples.

SR-337

Haralabus, G., Capriulo, E.

SWAC 4: Broadband data analysis using sub-band processing - part II

The frequency dependence of reverberation is examined using the processing method as for the frequency analysis of target detection during the same experiment.

In this experiment, reverberation is induced by abrupt changes in the bottom bathymetry (a 200 m sea mount). For the analysis of the received signal a sub-band matched filter scheme is devised, according to which, a replica of the transmitted pulse (2300 Hz-3500 Hz LFM signal) is segmented into ten 120 Hz sub-bands, each of which is processed independently through a matched filter detector. Following the necessary corrections for array gain and calibration, transmitted power spectrum and propagation loss, the matched filter data are compared to reveal the frequency dependence of reverberation. Due to insufficient in situ measurements, the propagation loss estimate is based on model calculations – a challenging task for the range dependent seafloor at the experimental site.

After examining a large number of pings it is concluded that the reverberation energy calculated at the correlator output is *comparable for all ten sub-bands. This leads to the conclusion that for the particular environment and experimental geometry, the frequency spectrum is not sufficiently wide to allow significant frequency variability which may indicate an optimum operational frequency.*

SR-338

Askari, F., Zerr, B.
An automatic approach for ship detection in spaceborne synthetic aperture radar imagery: an assessment of RADARSAT imagery.

This report describes a methodology for automated ship and wake detection in space-based synthetic aperture radar (SAR) imagery. The methodology incorporates a multistage approach involving several algorithms which can be applied according to requirements, computational resources, and scene composition. We suggest that the localized K-distribution be used for scene segmentation and identification of regions containing probable targets. For a more detailed quantitative scene analysis and accountability for probabilities of occurrence of targets in conjunction with other oceanic features, a coupled neural-networks/Dempster-Shafer detection system is used. The mathematical morphology algorithm is better suited for SAR imagery with low signal-to-clutter ratios, as it incorporates neighbouring information and signal amplitudes for target detection. The methods are tested on several RADARSAT images with different imaging geometry and beam modes. On the basis of our findings, concerning the use of different RADARSAT imaging modes, we demonstrate conclusively that the STANDARD beam is far superior to SCANSAR-NARROW beam for automatic ship detection

SR-339

Redmayne, J.C.J.
DAMSEL FAIR 2000 Minehunting task analysis.

This document contains the analysis of specific minehunting tasks, more generally referred to as Percentage Clearance (PC) Trials, carried out by five minehunters of NATO's southern region MW force MCMFORMED during exercise DAMSEL FAIR 00. The complete sequence of activities necessary to execute a minehunting task is analyzed, including environmental assessment, planning, evaluation and remaining risk assessment and sources of error are identified. The minehunting performance actually achieved by the participating units is also determined. In line with other PC Trials' analyses, the identity of the participating units is not disclosed in this report.

SR-340

Holland, C., Preston, J., LePage, K., Gauss, R., Turgut, A., Harrison, C., Askari, F., Hutt, D.
Boundary 2000 experiment: A measurement approach to shallow water reverberation

The weakest link in performance prediction for naval systems operating in coastal regions is the environmental data that drive the models. In shallow water downward refracting environments, the seabed properties and morphology often are the controlling environmental factors. There are two important acoustic parameters for predicting acoustic interaction with the seabed: bottom reflection and bottom scattering strength. The Boundary2000 Experiment conducted measurements of seafloor reflection, scattering and propagation and reverberation in order to validate and refine Rapid Environmental Assessment (REA) methods and develop high-resolution scientific measurement techniques. This report contains an overview of the measurement techniques and initial results. One of the results was the discovery that sub-seafloor gas plumes on the Malta Plateau cause target-like clutter.

SR-341

Edelmann, G.F., Akal, T., Hodgkiss, W.S., Kim, S., Kuperman, W.A., Song, H.C.
Underwater acoustic communication using time-reversal self-equalization.

Although there has been some progress in overcoming the time-varying dispersion that can destroy coherent digital information, fast and reliable data rates have remained elusive. Time reversal was applied to the communications problem and shown to be an effective technique to counter the inter-symbol interference caused by multipath dispersion. A substantial advantage of time-reversal, self-equalization over one-way single source communication and to a lesser extent, one-way broadside (nearly single mode) communication, was demonstrated.

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C

Ship Management Office,

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

R/V Alliance

Maintaining what has now become accepted as a normal standard[1] of operational efficiency, the *Alliance* was at sea for 200 days.

Activity	*Days at sea*
Scientific Programme of Work	168
Italian Navy charter	6
Fincantieri charter Part funded by the European Union to test a novel composite propeller designed by a European consortium	14
MARIN charter A part European Union funded project (EUCLID CEPA 10.12) for validation of computational fluid dynamic models. The trial was supported by the Ministries of Defence of France, Italy, the Netherlands and the United Kingdom	12

R/V Leonardo

Following the successful bid for NATO funding to design and construct a replacement for the 47-year old *Manning,* (which, notwithstanding its age, spent 150 days at sea during the year under review), a significant proportion of SMO resources has been devoted to developing the design and specification for the vessel. An international competition concluded with the signing of a contract between the Centre and McTay Marine Ltd. Contract delivery date for the vessel *Leonardo* (the first Italian public flagged vessel) is scheduled for 30 April 2002.

Safety

As part of the systematic programme to improve the safety of scientific operations at sea, a two-day risk assessment and hazard identification course was conducted by Det Norske Veritas for *Alliance* personnel and Centre engineering coordinators. The course has already contributed to improved pre-experiment risk assessment techniques.

SMO continues to participate in and contribute to the Research Vessel Operators' Committee. The *Alliance* has operated under the strict, supervised terms of the International Safe Ship Management Code since 1996. ISSMC accreditation, an expensive and demanding procedure is an essential contribution to safety during the complex operations of the *Alliance*.

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

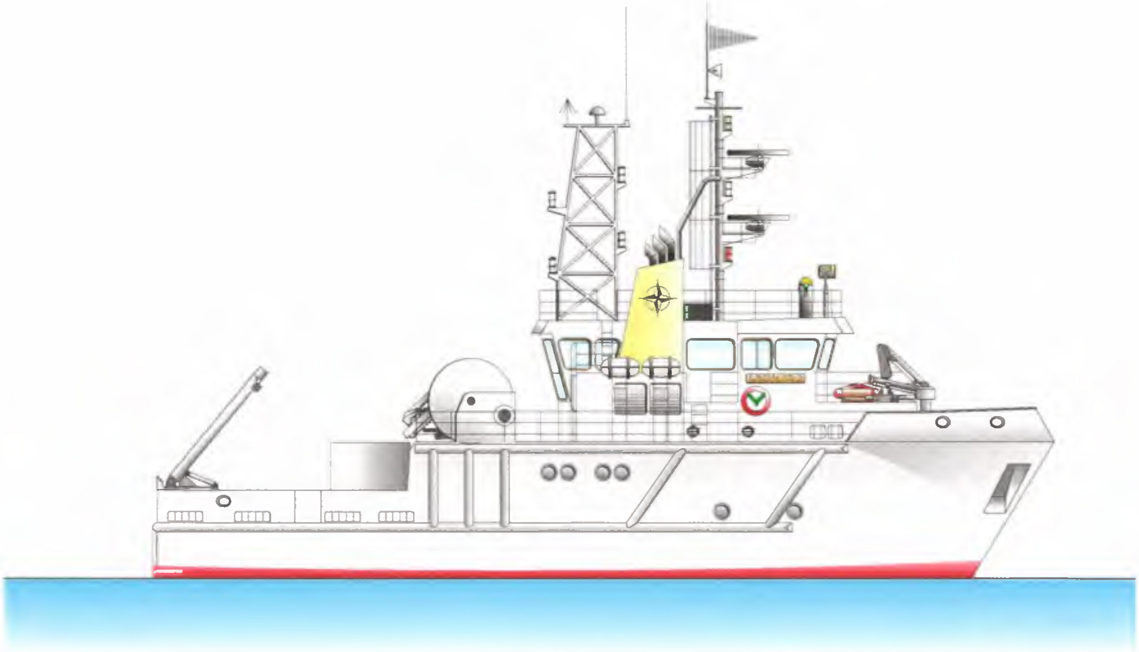

Fig. 1 *The Leonardo.*

Fig. 2 *From right to left: Umberto Varlese, Purchasing and Contracts Officer, Luigi Parise, Financial Controller, Jan L. Spoelstra, Director with Michael Brodie, Managing Director and Robert McBurney, Commercial Manager of the McTay Marine company.*

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.*

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Science and Technology Supporting Initiatives Office

Science and Technology supporting initiatives Office

STO promotes and co-ordinates collaborative initiatives in support of the Scientific Programme of Work with Italian and other national institutions.

Project	***Activity***	Return	Partner
01-A 06-C	Ocean modelling for support to GOATS 2000 experiment and the SOLMAR project (MOA)	4 man/months for modelling activity	ISDGM (CNR)
	Thesis work in support of the SOLMAR project for optical measurements and SEPTR development	one man/year	DIPSTER University of Genova
06-C	Ocean modelling, biological oceanographic data collection, and emergency management (LOI)	data analysis/collection and cruise participation (*Bestiaccia*)	ICRAM
	Support for CONISMA conference on marine bioacoustics	project visibility/2 invited speakers/1 session chair	CONISMA
	Cooperation within the framework of the SOLMAR project for oceanographic data collection and Magnaghi cruise participation	28 days of the *Magnaghi* (IN) ship, data collection/analysis participation to cruise	IIN, IOF (CNR)
03-C 01-A	Agreement for ocean engineering and AUV technology development (MOU)	Alliance chartering, ocean engineering developments	INFN
01-A 03-C	Agreement for bottom characterization and mapping, oceanographic data collection and modelling (MOA)	map conversion to hydrographic standards, support to cruises	IIN
ETD	CTD calibration	one man/year available to the Centre in support of SPOW activities	Idronaut S.r.l.

The office also coordinates the service of oceanographic instrumentation calibration provided to several navies and research institutions of NATO countries (Portugal, Spain and Italy).
In the spirit of the *Partnership for Peace* programme, the CTD calibration service has been offered also to the Slovenian *National Institute of Biology*.

ENEA:	Ente delle Nuove tecnologie, Energia ed Ambiente
ICRAM:	Istituto Centrale della Ricerca scientifica e tecnologica Applicata al Mare
CNR:	Consiglio Nazionale delle Ricerche
ISDGM:	Istituto per lo Studio della Dinamica delle Grandi Masse
IOF:	Istituto per lo studio della Oceanografia Fisica
INFN:	Istituto Nazionale Fisica Nucleare
CONISMA:	COnsorzio Nazionale Interuniversitario Scienze MArine
IIM:	Istituto Idrografico della Marina

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E

Organization and staff members with effect from 5th April 2001

1 DIRECTORATE

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

2 OFFICE OF THE DIRECTOR

Planner/Coordinator	D. Bennett (US)
Health & safety	R. Molteni (IT)

3 ASSIGNED MILITARY

Naval Advisor	Cdr B. Williams, USN (from July)
Security Officer	Cdr G. Piaggio, ITN
MILOC Survey Officer	D. Schaa (Civilian) (GE) (until July 2001)
ASW Programme Officer	Cdr B. Egenberg (NON) (until July 2001) LCdr P. Mathias-Jones (UKN) (from July 2001)
Mine Warfare Officer	LCdr O. Molino, ITN
Scientific Division Coordinator	LCdr J.R. Staveley (UKN)
Budget Officer	LCdr R. Reilly (USN) (until May 2001) LCdr R. Kusturin (USN) (from May 2001)
Naval Scientist	Capt. P. Golmayo (SPN) (until July 2001) LCdr J. Law (UKN) (from January 2001)
ADP Security Officer	Lt J.G. M.Shannon (USN) (until February 2001) Ens. W. Smiley (USN) (from February 2001)

9 FINANCE OFFICE

Controller:	L. Parise (IT)
Fiscal Officer:	M. Newman (US)
Internal Auditor:	G. Lambie (UK)

10 PERSONNEL & ADMINISTRATION OFFICE

Head of PAD	R. Albini (IT)
Logistics & Supply	
Information Services	

11 INFORMATION TECHNOLOGY OFFICE

Head of ITO	R. Seynaeve (BE) (until February 2001) M. Leonard (BE) (from May 2001)
Senior ADP Systems Spec	P. Colucci (IT)

12 SHIP MANAGEMENT OFFICE

Head of SMO	C. Gobey (UK)
Senior Engineer	A. Spairani (IT)
T-Boat Captain	A. Iacono (IT) (from September)

CHIEF SCIENTIFIC DIVISION

Deputy Director

4 ACOUSTICS DEPARTMENT

Head of ACD	W. Roderick (US) (until October 2000)
	N. Pace (UK) (from November 2000)
Senior Principal Scientist	F. Jensen (DA)
Senior Principal Scientist	N. Pace (UK) (until October 2000)
	R. Tyce (US) (from November 2000)
Principal Scientist	T. Akal (TU)
Principal Scientist	E. Bovio (IT) (from January 2001)
Principal Scientist	D. Burnett (US)
Principal Scientist	C. Harrison (UK)
Principal Scientist	J.P. Hermand (BE) (until August 2000)
Senior Scientist	M. Ferla (IT)
Senior Scientist	C. Holland (US) (until September 2001)
Senior Scientist	K. LePage (US)
Senior Scientist	E. Pouliquen (FR) (from October 2000)
Senior Scientist	R. Tyce (US) (until October 2001)
Scientist	A. Lyons (US) (until July 2000)
Scientist	P. Nielsen (DA) (from March 2001)
Scientist	E. Pouliquen (FR) (until September 2000)
Scientist	M. Prior (UK) (from January 2001)
Scientist	M. Siderius (US) (until July 2001)

5 ENGINEERING TECHNOLOGY DEPARTMENT

Head of ETD	O. Bergem (NO)
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)

6 OCEANOGRAPHY DEPARTMENT

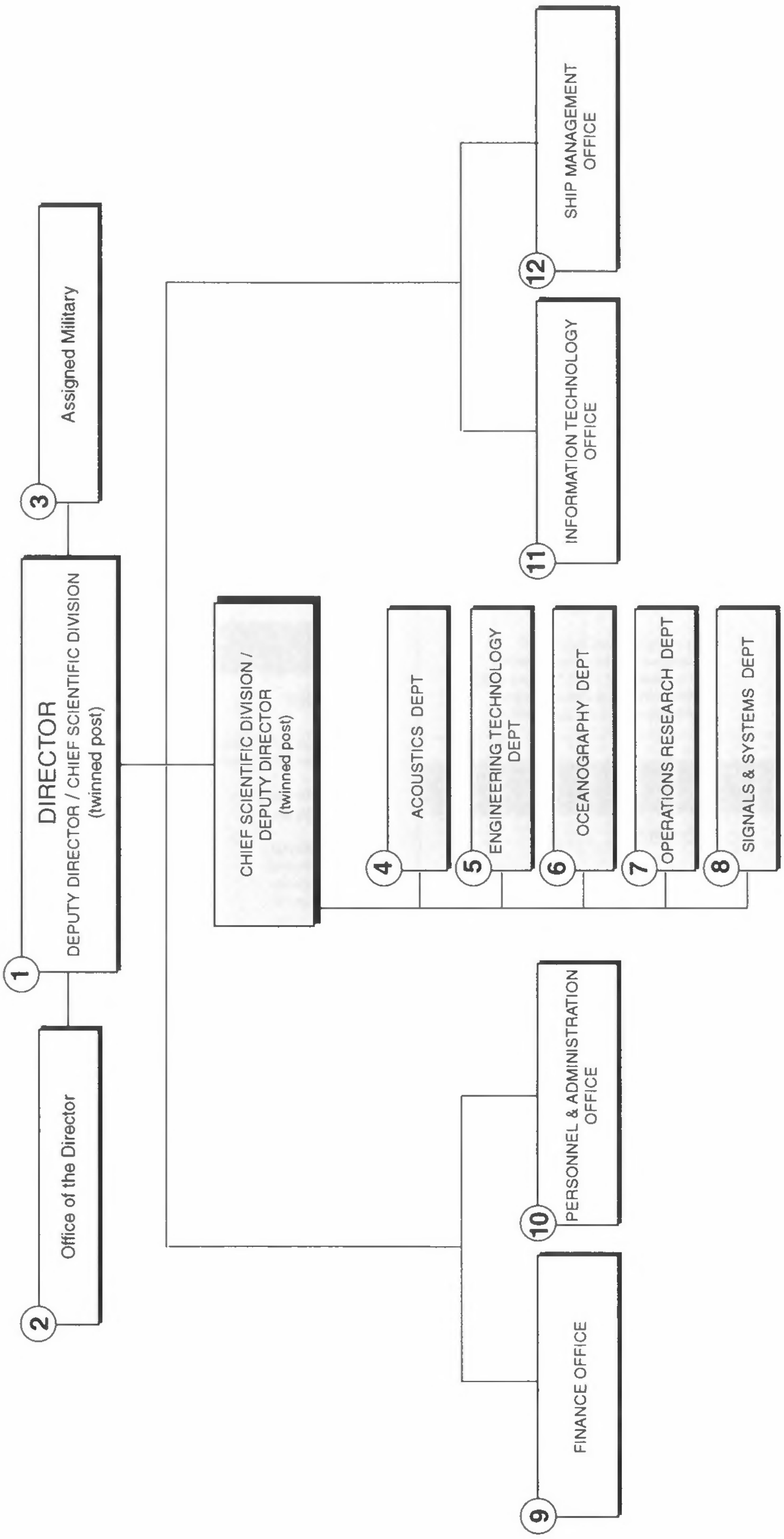
Head of OCD	J. Sellschopp (GE) (until September 2001)
Principal Scientist	F. Askari (US)
Principal Scientist	B. McDonald (US) (until September 2000)
Senior Scientist	R. Onken (GE)
Senior Scientist	R. Signell (US) (from January 2001)
Scientist	A. Alvarez (SP)
Scientist	D. Conley (US) (from October 2000)
Scientist	
Scientific Specialist)	F. Spina (IT)

7 OPERATIONAL RESEARCH DEPARTMENT

Head of ORD	K. Pye (UK) (until March 2001)
Principal Scientist	J. Redmayne (UK)
Principal Scientist	P. Simcock (UK)
Senior Scientist	E. Verhoeff (NL)
Senior Scientist	H. Yip (CA) (from January 2000)
Scientist	G. Arcieri (IT)

8 SYSTEMS AND SIGNALS DEPARTMENT

Head of SSD	J. Ziegenbein (GE) (until April 2000)
	S. Jespers (BE) (from May 2000)
Senior Principal Scientist	A. DÔAmico (US)
Senior Principal Scientist	M. Pinto (FR)
Principal Scientist	G. Field (UK)
Principal Scientist	D. Grimmett (US) (from July 2000)
Senior Scientist	G. Davies (UK)
Senior Scientist	D. Grimmett (US) (until July 2000)
Senior Scientist	D. Hughes (UK) (until December 2000)
Senior Scientist	M. Van Velzen (NL)
Senior Scientist	L. Wang (UK) (from May 2000)
Senior Scientist	B. Zerr (FR) (until January 2001)
Scientist	A. Bellettini (IT)
Scientist	J. Bondaryk (US) (until May 2001)
Scientist	S. Fioravanti (IT) (until March 2000)
Scientist	G. Haralabus (GR)
Scientist	R. Laterveer (NL)
Scientist	L. Mozzone (IT) (until April 2000)
Scientist	A. Tesei (IT)
Scientific Specialist	R. Hollett (UK) (from September 2000)
Scientific Specialist	W. Zimmer (GE)


1
DIRECTOR
DEPUTY DIRECTOR / CHIEF SCIENTIFIC DIVISION
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Office of the Director
3
Assigned Military
CHIEF SCIENTIFIC DIVISION /
DEPUTY DIRECTOR
(twinned post)
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ENGINEERING TECHNOLOGY
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OCEANOGRAPHY DEPT
7
OPERATIONS RESEARCH DEPT
8
SIGNALS & SYSTEMS DEPT
9
FINANCE OFFICE
10
PERSONNEL & ADMINISTRATION
OFFICE
11
INFORMATION TECHNOLOGY
OFFICE
12
SHIP MANAGEMENT
OFFICE

F

Visitors and meetings

February	RADM F.M.P. 't Hart, NLN,	*SACLANT ACOS, Strategy*
March	RADM Kenneth E. Barbor, USN	*Commander, Naval Meteorology and Oceanography Command*
	RADM Michel Verhulst	*(Chief of Naval Staff, BEN) and the Scientific Advisory Committee to the Belgian Navy*
	COL Judson Mason	*Chief of Staff TPO*
	James Grembi	*Assistant PEO for International Program PEO Mine Warfare, Washington*
	Wallace Ching	*Senior Scientist, PRESEARCH Incorporated*
	Group from BE-NL Minewarfare School, EGUERMIN	
	ITN Officers from SEGREDIFESA, Rome	
April	CAPT Dennis Ryan, USN	*Commanding Officer, ONR International Field Office*
	Dr Michael Pestorius	*Technical Director and Chief Scientist ONR IFO, London*
	CMDRE Massey, UKN	*SACLANT Deputy ACOS, Plans*
	Mr H.E. Nelson and Mr D.R. Griffin	*Naval Surface Warfare Center*
	ITN Officers	Hydrographic Institute of the Italian Navy, Genoa
	Dr Roger Gauss	*NRL Washington DC*
	Group of students from Pisa University attending Envrionmental Studies Course	
May	ADM Sir James Perowne, UKN	*Deputy SACLANT*
	76th SCNR Meeting	
	NATO International Staff Study Group	
	Dr Temel Oguz	*Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey*
	Prof. Ruhl Saatcilar	*Scientific and Technical Research Council of Turkey*
	Eng. Lt Hakki Celebioglu	*Turkish Naval Acoustic Research Group*
June	NATO Military Committee hosted by Deputy SACLANT hosted by Deputy SACLANT	
	NATO Senior Resource Board Deputation	
	Mr H. Perkins and Mr D. Payne	*Stennis Space Centre*
	Prof. E. Migneco	*Vice President of the Italian Institute of Nuclear Physics (INFN)*
	Dr Nadia Pinardi	*University of Bologna*
	Prof. Acheroy and Prof. Pemeel	*Royal Military Academy, Signal and Image Centre, Brussels SCNR Belgian National Representative*
	Dr Joachim Tintoré	*Coordinator SOFT project, Department of Physics (Oceanography), University of the Balears, Spain*
	Group from DERA, UK	

July	ADM Harold W. Gehman, USN	*Supreme Allied Commander, Atlantic*
	Mr Dick Arnold	*Director, Thomson Marconi, Paris*
	Dr Carl Andriani	*SPAWAR Science & Technology Office, ONR Arlington*
	Dr James Stevenson	*SPAWARSYSCEN, San Diego*
	Dr M. Richardson	*NRL Stennis Space Center*
	Dieter Brecht and Frank Ehlers	*FWG Kiel*
	Mr Gregory B. Jones	*Associate Director for UUV, ONR IFO*
September	Underwater Warfare Workshop	
	Mr André Flahaut	*Minister of Defence, Belgium and delegation*
	RADM J. P. Davies, USN	*Program Executive Officer, Submarines, NSSC*
October	Dr. Thomas Sams	*Danish Defence Research Establishment*
	77th SCNR Meeting	
	MCM Development Shop Window	
November	RADM Richard D. West, USN	*Oceanographer of the Navy, SNR and USN Representative to the NNAG*
	Dr M. J. Carron	*Chief Scientist, Naval Oceanographic Office, Stennis Space Center, US*
December	Mr John Ardis	*Programme Manager, Underwater Warfare Systems, MOD UK*

The 76th SCNR meeting in the refurbished Main Conference Room.

MCM Development Shop Window

ADMIRAL SIR JAMES PEROWNE KBE
United Kingdom Navy
Deputy Supreme Allied
Commander,Atlantic

VICE ADMIRAL FERDINANDO SANFELICE DI MONTEFORTE, Italian Navy
Deputy Chief of Staff, SHAPE

DR. PETER C. WILLE, Director, German Armed Forces Underwater Research Institute, Kiel, Germany

DR. DOUGLAS G. TODOROFF
Associate for Applications (MIW);
Ocean, Atmosphere, and Space
Department; Office of Naval Research

CAPTAIN H. SCHEERENS - Royal Netherlands Navy

Hosted by Admiral Sir James Perowne, Deputy SACLANT[1] and organized by SACLANTCEN, the two-day event consisted of a classified conference at the Villa Marigola in Lerici and an exhibition in a secure area adjacent to the Centre, made available by the Italian Navy.

The conference and exhibition were attended by some 200 flag rank officers and officials with financial planning and policy responsibilities. There were 20 exhibitors, from 9 NATO countries and the event was scheduled to allow participants in the NG3 and SCNR meetings at the Centre, to attend.

In his closing remarks Deputy SACLANT paraphrased the objectives of the MCM Development Shop Window to remind participants

- "that mine countermeasures remain a crucial operational enabler"
- "that nations and SACLANTCEN have a wide range of related programs in place (therefore the name Shop Window)"
- "that further research, development and investment are needed, with MO 2015 and CDE providing some of the tools and levers"
- "that SACLANTCEN continues to bring relevant, highly skilled R&T into play in the area"

The marked success of the Shop Window has prompted consideration of the event as a regular occurrence.

[1] The invitation from SACLANT to participate was issued on 15 July 2000. "Drawing on the achievements secured in the last 5 years and in the context of MO 2015 and the MW research directed by SACLANTCEN, MDSW aims to stimulate debate on the future of MW equipment research, development and acquisition strategies through the delivery of stimulating, forward-looking presentations and discussion".

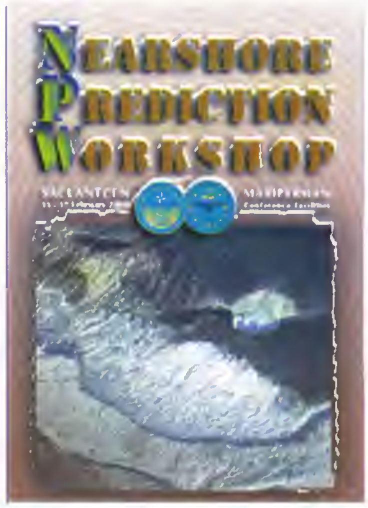
Underwater Warfare Workshop, 2000

The visit by Mr André Flahaut, Minister of Defence, Belgium.

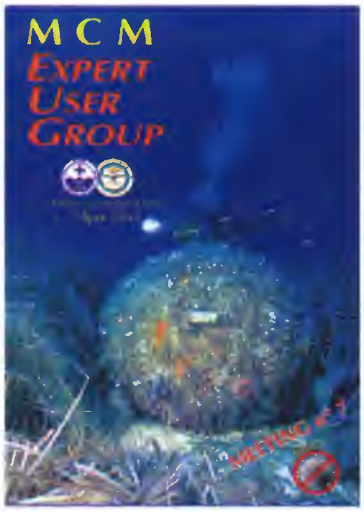
RADM Michel Verhulst, Chief of Naval Staff, BEN during a visit to the Centre accompanied by the Scientific Advisory Committee to the Belgian Navy


1st CERBERUS 2000
Planning Meeting
SACLANTCEN
11 - 12 January 2000


GOATS 2000
SACLANT Undersea Research Centre
SCNR Conference Room
January 17-18, 2000
PARTICIPANTS
CNRS FR Vaganay, Dr. Jerome
MIT US Schmidt, Prof. Henrik
ONR US Swean, Dr. Tom
FFI NO Hagen, Per Espen
Florida Atlantic University US Cuschieri, Dr. Joseph
Harvard University US Robinson, Prof. Allan
Herriot-Watt University UK Lane, Dr. David
SACLANTCEN Berni, Alessandro
Bovio, Ing. Edoardo
Grandi, Ing. Vittorio
Guerrini, Ing. Piero
Hollett, Dr. Reginald
Kantha, Prof. Lakshmi H.
LePage, Dr. Kevin
Pinto, Dr. Marc
Pouliquen, Dr. Eric
Sellschopp, Dr. Jürgen
Steiner, Per Arne
Spina, Ing. Francesco


NEARSHORE
PREDICTION
WORKSHOP
SACLANTCEN

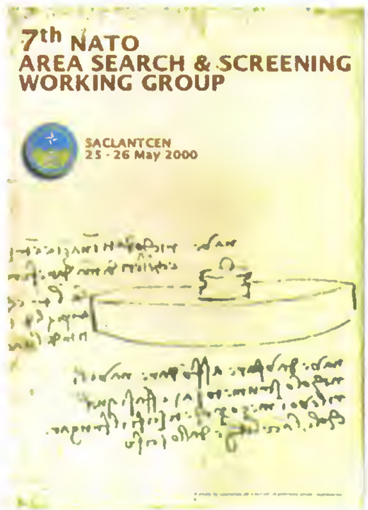

2nd CERBERUS 2000
PLANNING MEETING
1 - 2 March 2000
DERA
IWG
SACLANTCEN


MCM
EXPERT
USER
GROUP


MINE JAMMING
WORKSHOP
SACLANTCEN
COMFORDHAG
LA SPEZIA


76th
SCNR
MEETING
16-19 May


3rd OPERATIONAL PLANNING
SOFTWARE STEERING GROUP
MEETING
SACLANTCEN
22 - 24 May 2000


7th NATO
AREA SEARCH & SCREENING
WORKING GROUP
SACLANTCEN
25 - 26 May 2000


SIRENA 2000
SEA TRIAL
PLANNING
MEETING
whale


UNDERWATER
WARFARE
WORKSHOP
SACLANTCEN
12-14 Sep 2000


2000
csa
plenary
meeting
SACLANTCEN
LA SPEZIA ITALY

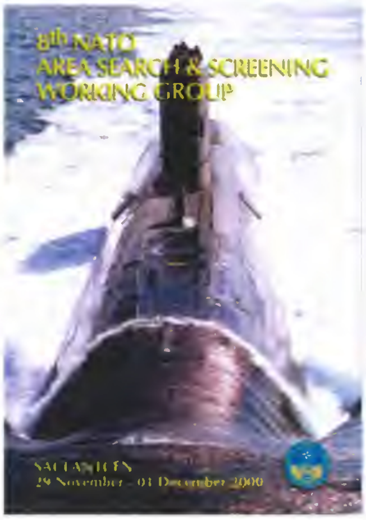

2000 AIS
PLANNING
MEETING
SACLANTCEN
La Spezia Italy
3-5 october 2000

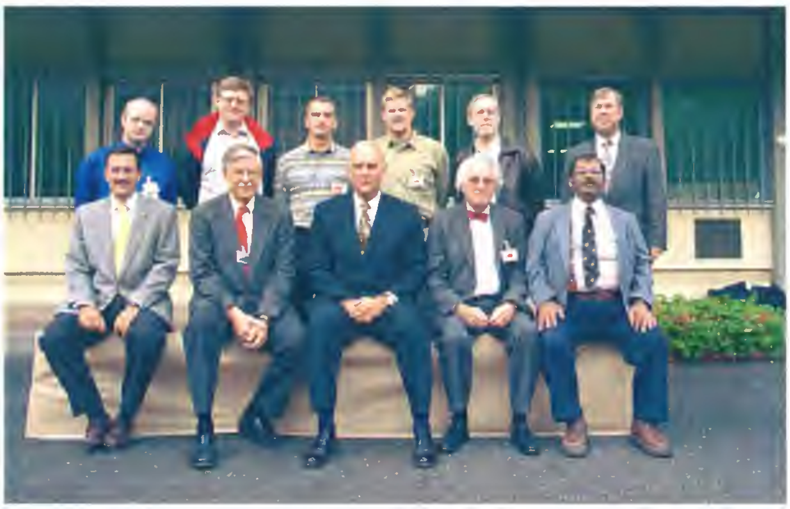

attendees
77th SCNP


NG 3
NATO NAVAL GROUP 3
MINES & MINE COUNTERMEASURES
SACLANTCEN La Spezia


MCM DEVELOPMENT
SHOP WINDOW
THE FUTURE OF MCM NATO
18-19 OCTOBER 2000
NATO SACLANT Undersea Research Centre
NATO SACLANT


OPERATIONAL PLANNING
SOFTWARE STEERING
GROUP MEETING
4th
SACLANTCEN
27-29 Nov 2000


8th NATO
AREA SEARCH & SCREENING
WORKING GROUP



Participants in the Nearshore Prediction Workshop 15-17 February 2000 presided over by Dr Lakshmi Kantha.

G

Scientific Committee of National Representatives and National Liaison Officers

BELGIUM *National Representative*	**CDR Claude L. Renard, BENA** Etat-Major de la Marine Section Systèmes d'Armes Lutte anti-sous-marine Brussels
CANADA *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, DENA** Defence Command Denmark, Vedbæk **Mr Bjarne Damsgaard** Danish Defence Research Establishment, Copenhagen
FRANCE *National Delegate*	**ICA Christian Bled** Service des Programmes Navals, Chef du Département Lutte Sous la Mer Paris
GERMANY *National Representative* *National Liaison Officer*	**Mr Siegfried Tympe** Bundesministerium der Verteidigung, Bonn **Dr Dirk Tielbuerger** Forschungsanstalt der Bundeswehr für Wasserschall-und Geophysik (FWG), Kiel
GREECE *National Representative* *National Liaison Officer*	**Captain Anastasios Sklavidis, HENA** Hellenic Navy Hydrographic Office, Holargos, Athens **Commander Dimitrios Paliatsos, HENA** Hellenic Navy General Staff A' Branch – Section A3-I, Holargos, Athens
ITALY *National Representative* *Alternative National Representative* *National Liaison Officer*	**Rear Admiral Dino Nascetti, ITNA** Direttore, Arsenale Militare Marittimo, La Spezia **Captain A. D'Andrea, ITNA** NAVARM, Ministero della Difesa Marina, Rome **Commander Fernando Cerrutti, ITNA** MARISTAT, Ministero della Difesa Marina, Rome
NETHERLANDS *National Representative* *National Liaison Officer*	**Mr Coenraad M. Ort** Head, Underwataer Acoustics Group, Physics and Electronics Laboratory, FEL-TNO, The Hague **Captain 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*	**Captain A. Felski, PLNA** Akademia Marynarki Wojennej Gdynia
PORTUGAL *National Representative*	**LCDR E. Ferreira Coelho, PONA** Instituto Hidrografico, Lisbon
SPAIN *National Representative* *National Liaison Officer*	**Captain Ticardo Gomez Enriquez, SPNA** JEFE Spanish MCM Flotilla, Cartagena **LCDR Juan A. Rico Palma, SPNA** Instituto Hidrografico de la Marina, Cadiz
TURKEY *National Representative* *National Liaison Officer*	**Eng. Captain Nazim Çubukçu, TUNA** Head of the Department of Navigation, Hydrography and Oceanography, Istanbul **Eng. LCDR H. Basaran, TUNA** Deniz Harp Okulu K.ligi, Istanbul
UNITED KINGDOM *National Representative* *National Liaison Officer*	**Dr. D. Wyn Williams** Operations Director, Sea Sysstems SectorDefence Evaluation and Research Agency, Portsdown West **Mr Jon Downing** Director of Equipment Capability (Underwater Battlespace), Ministry of Defence, London
UNITED STATES *National Representative* *Alternate National Representative* *National Liaison Officer*	**Dr Eric O. Hartwig** (Code 7000) Associate Director of Research, Naval Research Laboratory, Washington D.C. **Dr Steven E. Ramberg** (Code 32) Department Head, Ocean, Atmosphere and Space Department,Deputy Manager, Sensing and Systems Division, Program Manager, Littoral Warfare Advanced Development, Office of Naval Research, Arlington, VA **Commander 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 **Captain (Retd) Arcangelo Simi** Head, Naval Armaments Section
NAMILCOM *Representative*	**Col. Pat Nutz, USAF** Logistics, Armaments & Standardization Division, NATO Headquarters, Brussels

SACLANT *Representative*	**Rear Admiral Dieter George Leder, GENA** Assistant Chief of Staff, Strategy
Representative	**Rear Admiral Francisco Lima, PONA** Assistant Chief of Staff, Resources
Acting Representative	**Commodore Allan M. Massey, UKNA** Deputy Assistant Chief of Staff, Plans
Acting Representative	**Captain Eugene Alleman, BENA** Deputy Assistant Chief of Staff (Resources)
Liaison Officer	**Commander Gordon Stamp, UKNA**

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Personnel by category and nationality

Country (1)	*Scientific complement (Dec 2000)*	*Total scientist man years (1959-2000)*
Belgium	1	93.10
Canada	1	98.05
Denmark	2	140.00
France	3	157.00
Germany	2	129.04
Greece	1	30.00
Italy	5	238.11
Netherlands	4	126.00
Norway	1	101.00
Portugal	0	12.00
Spain	1	1.05
Turkey	1	37.00
UK	9	309.00
USA	11	369.08
Total	42	1843.07


R.V.
ALLIANCE

Visit of NATO Military Committee to SACLANTCEN on 15-16 June 2000

FRONT ROW LEFT TO RIGHT

- *Major General Bjørn Fredriksen, NOA, SACEUREP*
- *Lieutenant General Trond Moltzau, Norwegian Mil Rep to NATO*
- *Mr Arnór Sigurjónsson, Icelandic Mil Rep to NATO*
- *Lieutenant General Giuseppe Cucchi, Italian Mil Rep to NATO*
- *Major General Jaroslav Hudec, Czech Republic Mil Rep to NATO*
- *Lieutenant General Ioannis Mastrokostopoulos, Greek Mil Rep to NATO*
- *Brigadier General Henryk Tacik, Polish Mil Rep to NATO*
- *Admiral Guido Venturoni, Chairman Military Committee*
- *Vice Admiral José Poblaciones, Spanish Mil Rep to NATO*
- *Lieutenant General Laurits Tophøj, Danish Mil Rep to NATO*
- *Lieutenant General Emile Sabathe, French Mil Rep to NATO*
- *Vice Admiral Artur Sarmento, Portuguese Mil Rep to NATO*
- *Lieutenant General Willy Simons, Belgian Mil Rep to NATO*
- *Brigadier General Armin Hasenpusch, Deputy German Mil Rep to NATO*
- *Brigadier General Marion Callendar, Deputy US Mil Rep to NATO*
- *Colonel János Cserjési, Deputy Hungarian Mil Rep to NATO*

SECOND ROW LEFT TO RIGHT

- *Ing Federico de Strobel, ITCiv, Head of Science and Technology Office*
- *Ing Piero Guerrini, ITCiv, Head of Engineering Group*
- *Commodore Alan Massey, UKNA, DACOS Plans, SACLANT*
- *Lieutenant General Oktar Ataman, Turkish Mil Rep to NATO*
- *Rear Admiral Fernando Del Pozo, SPNA, DSACLANTREPEUR*
- *Vice Admiral Sir James Perowne, UKNA, DSACLANT*
- *Rear Admiral (ret.) Jan L. Spoelstra, NLCiv, Director*
- *Vice Admiral Egmond van Rijn, NLNA, SACLANTREPEUR*
- *Rear Admiral Alev Gümüşoğlu, TUNA, AD LA&R*
- *Dr William Jobst, USCiv, Deputy Director*
- *Captain (R/V Alliance) Lothar Holtschmidt*

BACK ROW LEFT TO RIGHT

- *Lieutenant Mark Cox, UKNA, ADC to DSACLANT*
- *Commander Oreste Molino, ITNA, MW Programme Officer*
- *Commander Bjørn Egenberg, NONA, ASW Programme Officer*
- *Mr Gary Appleton, USCiv, Assistant Director, RTA representative*
- *Lieutenant Colonel Lindsay Wilson, UKA, EA to SACLANTREPEUR*
- *Commander Harald Weis, GENA, HC-931 SACLANTREPEUR*
- *Colonel Pat Nutz, USAF, LA&R*
- *Dr Oddbjørn Bergem, NOCiv, Head of Engineering Technology Department*
- *Mr Christopher Gobey, UKCiv, Head of Ship Management Office*
- *Commander Brian Williams, USNA, Naval Advisor*

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