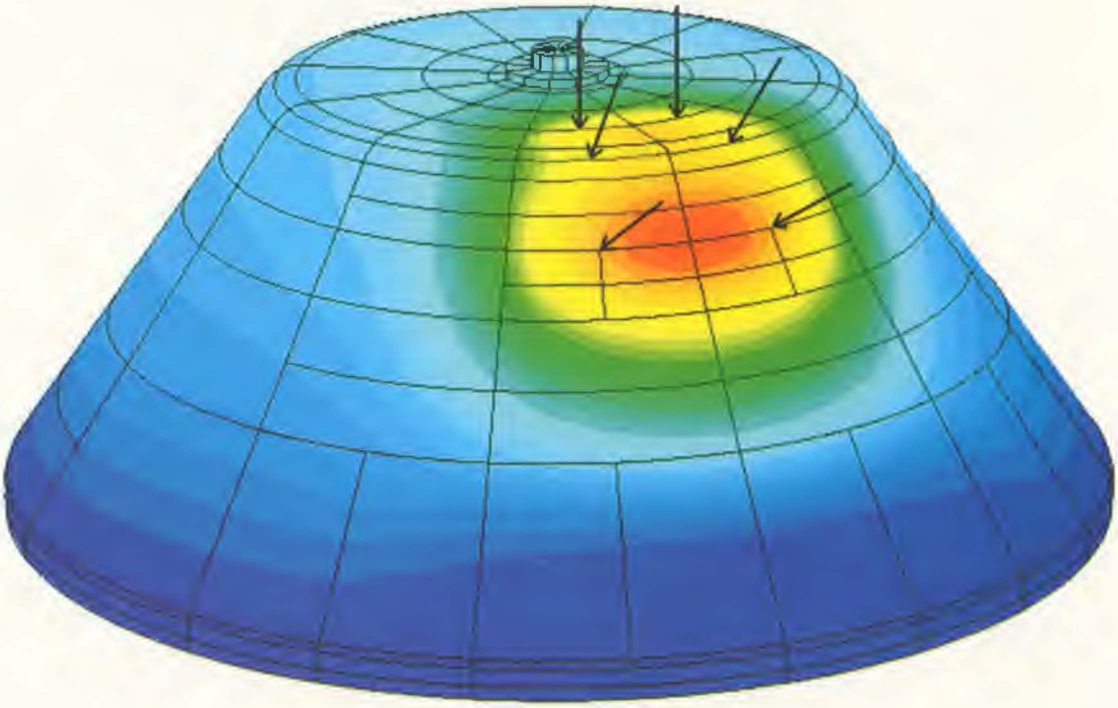
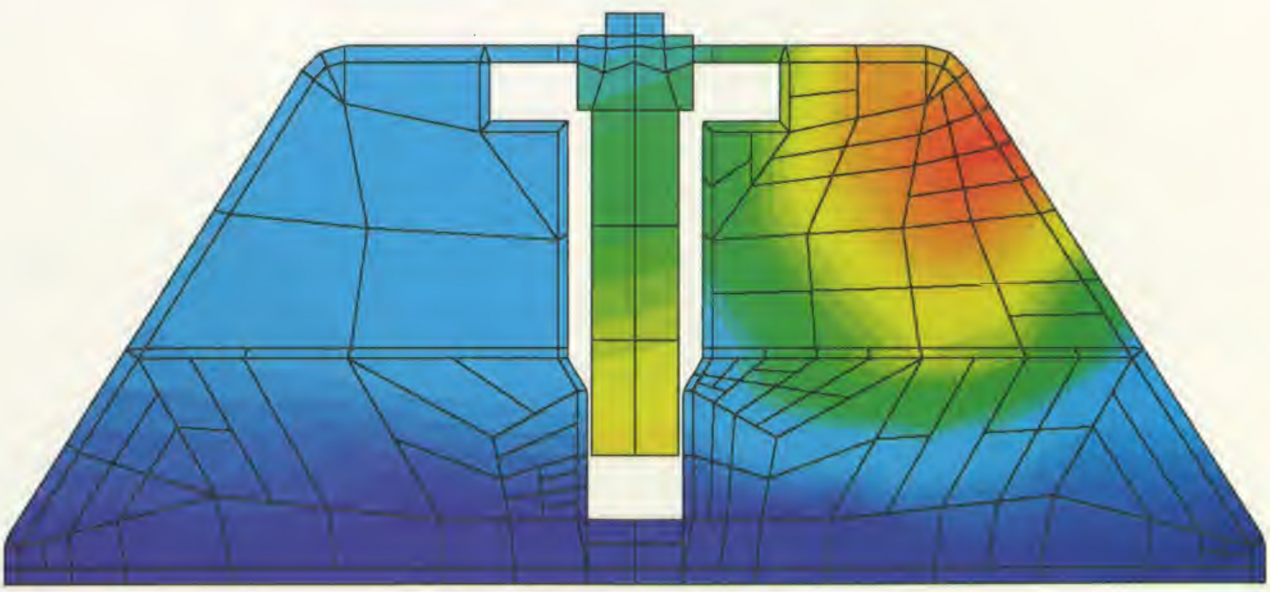
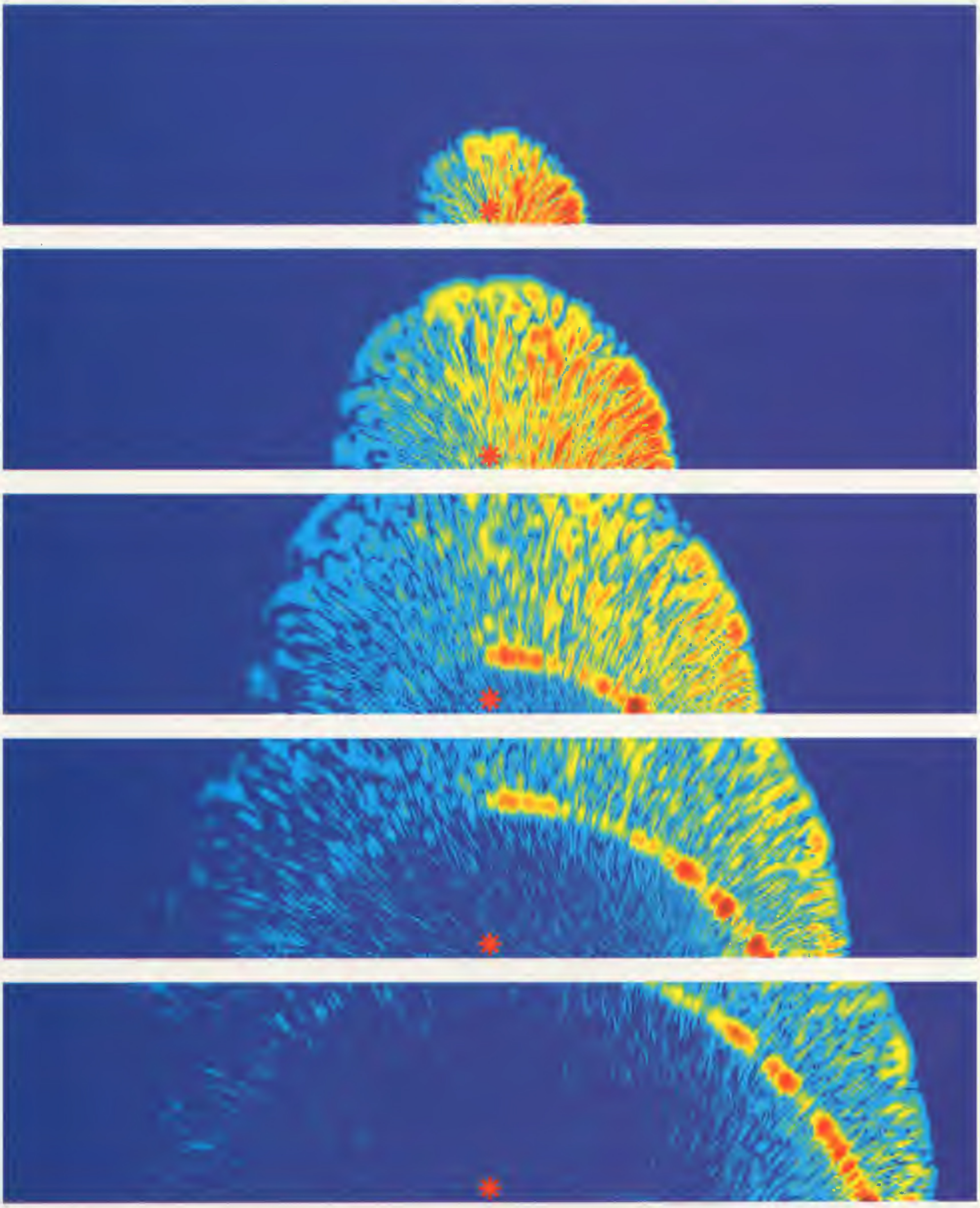
NATO SACLANT
UNDERSEA RESEARCH CENTRE



ANNUAL PROGRESS REPORT 1999





The image shows sediment scattering from a mine hunting SONAR. The position of the SONAR is indicated by the red star. The four panels show the scattered field 0.15, 0.30, 0.45 and 0.60 seconds after the SONAR has transmitted its ping. The forward scattered field is shown to the right of the SONAR position, while the backscattered field is shown to the left, (see pages 87 to 94).

See pages 53 to 57 for a description of the figures on the front cover

Annual Progress Report 1999

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Annexes

Plus ça change... 1959-1999

The year 1999 saw the 40th anniversary of the Centre and the 50th of NATO. The wisdom and vision of the "founding fathers" manifested by the creation of an undersea research centre for the NATO Alliance "... pooling the technical data and scientific personnel of NATO countries, in an effort to solve some of the problems that none of these countries had been able to solve independently" have allowed scientists, engineers, technicians and naval officers from national research organizations, universities, naval establishments and other distinguished and respected institutes to work at the Centre. All brought their wide national experience and knowledge, a deep understanding of the challenge, enthusiasm for scientific research and most importantly, a shared belief in its relevance. Several hundreds of NATO's best brains in underwater acoustics, oceanography, signal processing, mathematics, physics and ocean engineering have inspired each other to excel, supported by the expertise and ingenuity of technical support staff and the dedication of the small but effective administrative support department. They have made the Centre's relevance to NATO outstanding and unique, under the policy guidance of SACLANT, augmented by invaluable counsel from the Scientific Committee of National Representatives.

Although the Kosovo crisis prevented the Secretary General, SACLANT and the Military Committee from being present as planned, the Fortieth Anniversary of the Centre was appropriately marked by a number of events attended by staff, VADM Manlio Galliccia, RADM Giuseppe Celeste and RADM Dino Nascetti, (Chairman of the SACLANTCEN Scientific Committee of National Representatives), representing the host nation which makes an inestimable contribution to the success of the Centre and six former directors and deputy directors. Congratulatory messages were received from the Secretary General, Dr. Javier Solana; SACLANT, ADM Harold Gehman and the Chairman of the NATO Military Committee, ADM Guido Venturoni.

The continuing quest for adequate funding remained a dominant theme. Numerous briefings to NATO HQ committees resulted in an increasing awareness, that although the problem has not yet been resolved, the Centre's predicament is firmly on the agenda. There were some successes, such as funding for replacement of the 46-year old poor relation of the research fleet, the coastal research vessel Manning and for an autonomous underwater vehicle. The new vessel, provisionally named Leonardo, is scheduled to be in service in 2002, while the AUV will be delivered in 2000, inaugurating a new era in the Centre's programme of work. We continue to plan for further updates in our equipment and infrastructure, while making steady, recognized progress in improving efficiency, commensurate with the nature of scientific research.

The reader will find in this report how the Centre discharges its mission under the terms of its Charter. The raison d'être of the Centre as quoted earlier is, after forty years, mirrored in the recently approved new NATO research and technology strategy "... to ensure that the Alliance has at its disposal the best scientific and technical capability that member nations are prepared to make commonly available". In order to ensure that eminent scientists will continue to contribute to fulfilling NATO's requirements, it is of utmost importance that this strategy is translated into a stable funding regime. Only then can NATO, the most successful alliance in history, be guaranteed that the quality of our work as exemplified in this annual report, can continue.

Jan L. Spoelstra
Director

See photographs on pages 2 and 117

The celebrations to commemorate the fortieth anniversary of the Centre in May 1999 were attended by, back row, left to right: Dr Richard Nagelhout, (US), Deputy Director, 1991-1994; Dr John H. Foxwell, (UK), Director, 1990-1993; Dr David L. Bradley, (US), Director, 1993-1996; RADM (retd) Jan L. Spoelstra, (NL), Director since October 1996; Prof. Dr. Peter C. Wille, (GE), Director, 1987-1990; Ing Giancarlo Vettori, (IT), Deputy Director, 1994-1998; Dr William J. Jobst, (US), Deputy Director since October 1998; front row seated: Ms Heather Barrett, Secretary to SACLANTCEN Directors, 1959-1999 and Mr Melvin Arsove, (US), Deputy Scientific Director, 1959-1961.

RADM Dino Nascetti, Direttore, Arsenale Militare Marittimo and Chairman, SACLANTCEN Scientific Committee of National Representatives, presenting certificates commemorating 40 years of service, signed by the Secretary General, to Mrs MariaPia Vergassola and Mrs Gabriella Parmigiani.

A group photograph taken during the annual maintenance of the Centre laboratory on the island of Formica Grande. Standing left to right: Angelo Spairani, Sauro Giusti, Emilio De Cola. Seated left to right: Umberto Varlese, the Director, Mauro Lombardi, Mauro Pini, Umberto Fabiani.

Thrust 01 Rapid Environmental Assessment (REA)

1

Project 01-A: Rapid assessment of ocean parameters (Alliance days – 49, Manning days - 7)

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.

MILOC support, data fusion and transmission

In preparation for operational REA surveys, data transfer between ships was effected for the first time with spread spectrum radios. Two-dimensional sound velocity fields on the track between an acoustic source and a receiving array, continuously acquired on a tow ship, were accessible *via* the computer network of NRV *Alliance* by standard file transfer, the high bandwidth radio link between the ships being fully transparent. Spread spectrum technology is easy to install and to use. It does not suffer from multipath signal cancellations when ships are close together. After having gained positive experience in another sea trial, spread spectrum technology was proposed by the Centre and accepted by SACLANT for operational REA data communication between survey ships. It will be in place for Linked Seas 2000, planning for which commenced in January 1999. During the REA survey, SACLANTCEN personnel will embark on one of the survey ships and work on bottom assessment for mine warfare. In addition, the Centre will be engaged in ocean modelling and data fusion.

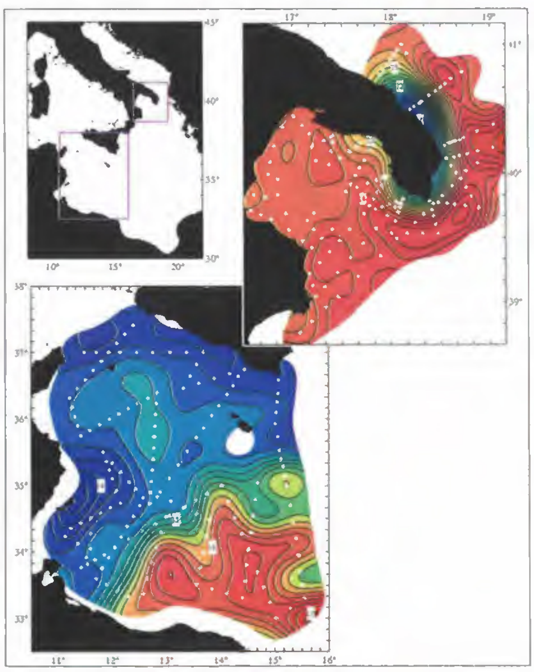


Figure 01-A.1. *Positions of CTD (conductivity, temperature, depth) stations (white circles) in the survey regions of IONIAN99 and temperature distribution (°C) at 10 m depth obtained by objective analysis. Note the cold water on the Tunisian Plateau and around the heel of the Italian boot. Objective analysis smooths fields and occasionally creates unrealistic extrapolations such as the discontinued Adriatic coastal current.*

Oceanographic field work

Of the three research cruises with NRV *Alliance*, only the IONIAN99 cruise in February was exclusively dedicated to oceanography, investigating the origin and generating mechanism of patches of exceptionally cold water observed at intermediate depth in the central Ionian Sea in 1998. Subsurface lenses of deviating temperature-salinity characteristics affect sonar performance because of the changes in the sound velocity profile. Volumes of cold, subsurface water that might be detected at any season, can only be generated in winter, when heat loss of the ocean increases surface water density to a level equal to or exceeding that of intermediate water.

Winter surface temperatures in the vicinity of the Ionian Sea observed by satellites are lowest in the outflow from the Adriatic Sea and on the Tunisian shelf. Both areas were visited during IONIAN99. Positions of conductivity, temperature, depth (CTD) profile measurements are given in Fig. 01-A.1 on surface temperature maps smoothed by objective analysis.

The most notable observation of the IONIAN99 cruise was the outflow of dense Adriatic Surface Water on the 100 m deep Italian shelf. In February the density of the coastal current can even exceed that of Adriatic Deep Water in the Strait of Otranto. The dense water is prevented from immediately gliding down the shelf slope only by Coriolis force. After streaming around the southern cape, it leaves the shelf and under entrainment of surrounding less dense water, proceeds to the depth of neutral buoyancy. Figure 01-A.2 shows profiles south of Capo S Maria di Leuca. Close to the coast, the water is homogeneously cold, fresh and dense. Further out, the surface water continuously approaches Ionian Surface Water conditions. At the bottom, water density decreases. At the second position from the south, the sea bottom is deeper than the density horizon of the modified coastal water, which in 160 m depth exists as a subsurface patch replacing the high salinity, Levantine Intermediate Water of the southernmost profile. When a subsurface patch spreads horizontally, it gains anticyclonic vorticity by which it is enabled to survive over a long period and travel through the Ionian Sea.

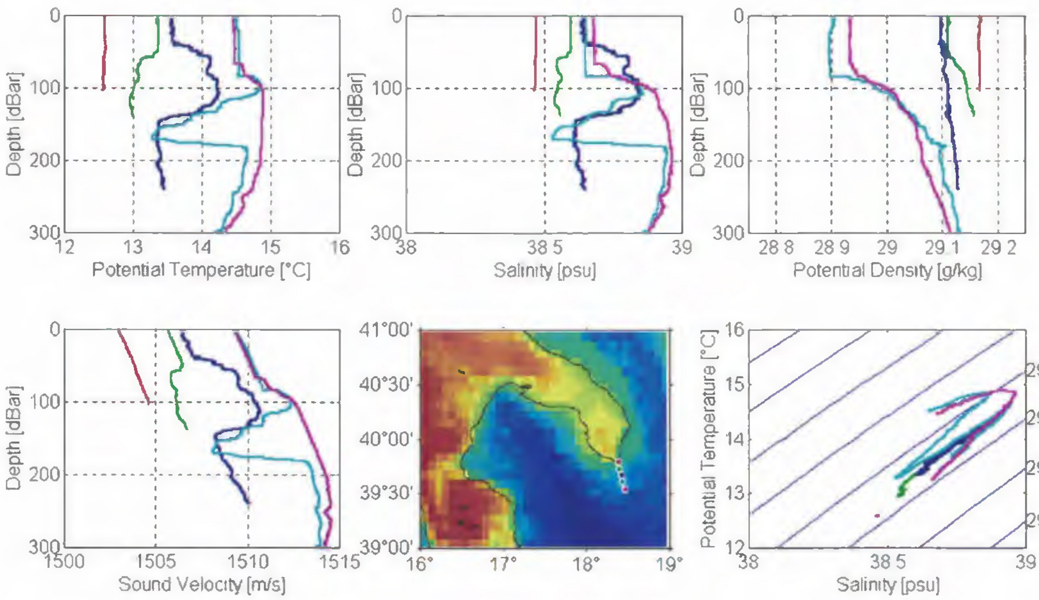


Figure 01-A.2. *Temperature, salinity, density anomaly and sound velocity profiles truncated at 300 m depth. The cold and least saline coastal water is denser than intermediate water further out. In the temperature-salinity diagram, it appears as a dot on the same isopycnal as the Eastern Mediterranean Deep Water.*

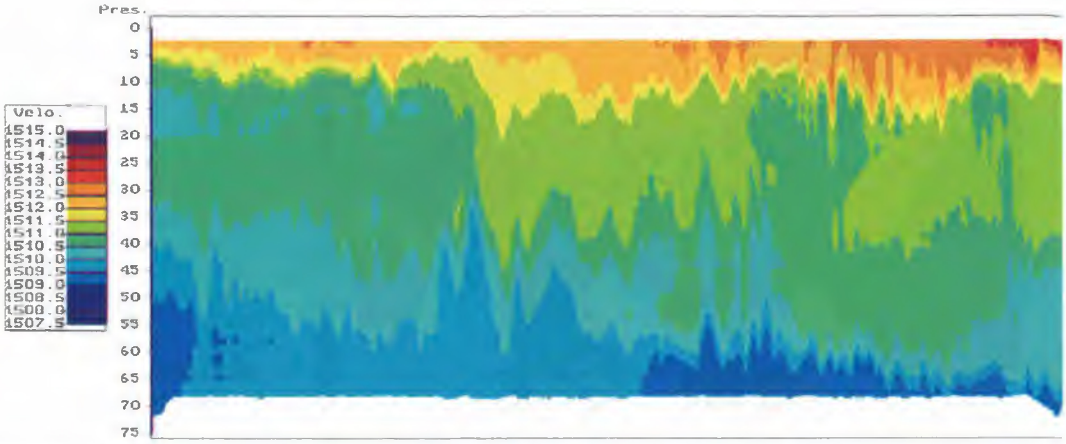


Figure 01-A.3. *Sample high resolution sound velocity field between the acoustic source and the receiving vertical hydrophone array. Spatial variability was measured with the towed CTD chain during all fixed range experiments.*

The data set obtained during IONIAN99 south of 35 ° N covers a "white spot" in winter climatology. The dense water produced on the very shallow Tunisian Plateau by cooling and evaporation flows as a bottom current towards the deeper Ionian Sea. It is identified far from its origin on the African continental slope before, by dilution with adjacent water, it is totally merged.

The oceanographic component of the second sea trial ADVENT99 in May, supported the acoustic measurements by providing high resolution ocean stratification. An example of the sound velocity field on the main acoustic track is shown in Fig. 01-A.3.

During CORFU99, the third cruise of the project, oceanographic measurements contributed to mine warfare related rapid environmental assessment. Prior to and after the investigations in the vicinity of the island, CTD stations were taken in an area of 115 × 175 km, which in addition to the Greek shelf, contains deep water of the northern Ionian Sea and the Strait of Otranto. The data were used for initialization and verification of numerical ocean model runs (Fig. 01-A.4).

The SKERKI96 data set, which was collected in the Strait of Sardinia and eastward to Sicily, has been subjected to detailed investigation and prepared for publication. Skerki Bank is a barrier between the Sardinian channel and the Strait of Sicily, which impedes the flow of intermediate water. The choice of the area was motivated by the fact that knowledge of this region is essential for understanding the exchange between western and eastern Mediterranean. The high quality of data is ideal for use in numerical ocean models and model validation. A sample of the analysis is displayed in Fig. 01-A.5, showing the colour coded distribution of

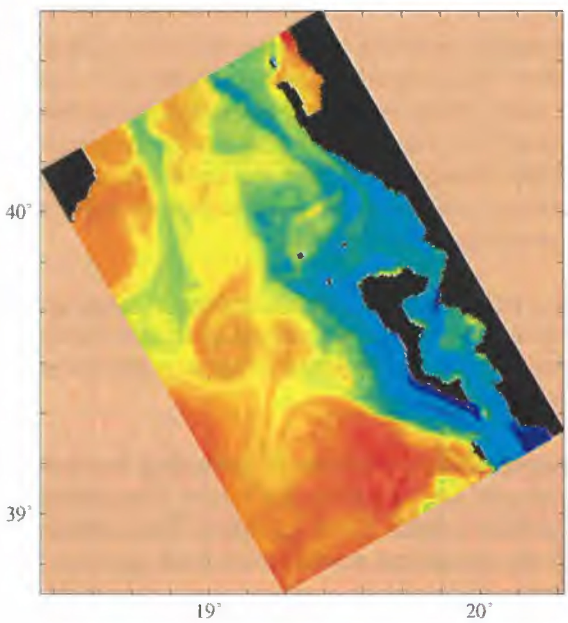


Figure 01-A.4. *Forecast of surface temperature for 11 September 1999, 12 days after model setup during CORFU99. The temperature ranges from 16 to 28 °C. Upwelling of cold water off the coasts of Albania and Corfu is a consequence of atmospheric forcing.*

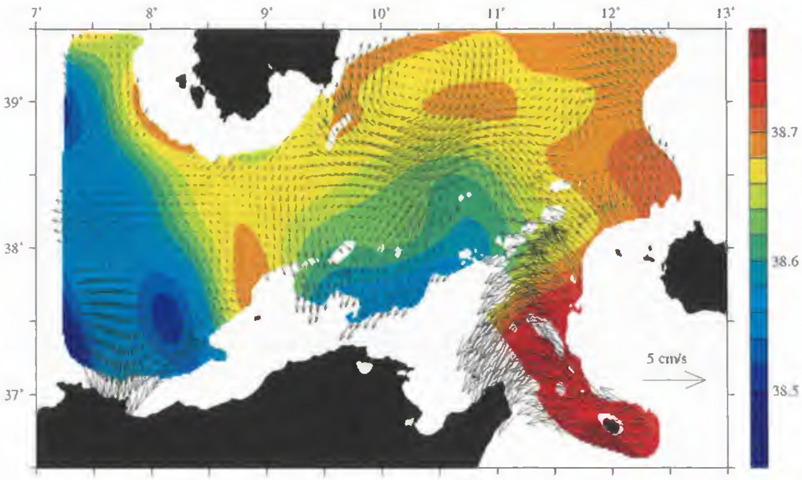


Figure 01-A.5. *Salinity (colour) at the salinity maximum and geostrophic currents (vectors) vertically averaged between 100 m and 700 m depth. Currents were calculated from horizontal pressure differences which are functions of the temperature and salinity distribution. Areas left white indicate that no maximum was found or that the statistical error of the analysis exceeds a certain threshold.*

salinity at the depth of its maximum and the currents at the same level. The salinity maximum is associated with Levantine Intermediate Water that is formed in the eastern Mediterranean in winter and mostly occupies the depth range from 200 to 500 m of the entire Mediterranean.

Numerical modelling

The Harvard Ocean Prediction System (HOPS) is the primary tool for ocean modelling at SACLANTCEN. Its forecast kernel is based on the system of hydrodynamic "primitive" equations with bottom following (sigma) coordinates. Packages for objective analysis, data assimilation and additional capabilities such as a coupled model for biological activity are components of the system. HOPS is applied operationally for rapid environmental assessment and used for oceanographic research in order to analyze an observed situation and to forecast its evolution. Figure 01-A.6 is a 10-day forecast of surface currents and salinity based on IONIAN99 data from the Tunisian shelf and the Sicilian Channel. The jet-like inflow of low salinity Atlantic Water through the Strait of Sicily from the west is clearly visible. During CORFU99, HOPS was applied to a shelf break and large coastal area containing islands. The HOPS prediction of surface temperatures in Fig. 01-A.4 shows upwelling areas off the Albanian and Corfu coast that are known from satellite images.

Numerical ocean models, which integrate forward in time the equations of ocean dynamics are the most intuitive tools for ocean prediction. They provide a complete physical view of the complexities of ocean evolution. On the other hand, numerical forecasts of the ocean require profound understanding of the dynamical laws controlling ocean processes. Consequential to the wide range of space-time scales arising from the turbulent nature of ocean dynamics, small scale oceanic processes cannot be resolved in coarse schemes, but have to be parameterized according to numerical mesh width.

A numerical and theoretical study of the influence of small scale variability on large scale currents has been carried out with oceanographers from the Universidad de le Islas Balears. It has been found that small scale eddies may reverse the direction of large scale currents when they interact with the underlying bottom topography.

An alternative approach to forecasting ocean evolution consists of extracting dynamical information from empirical data without imposing an explicit dynamical model. The extracted information about the past of the system is used to predict future evolution. The problem of ocean forecasting is thus reduced to finding the dynamical model which best explains the features of a given time series of observations.

Satellite imagery is appropriate to continuous monitoring of the space-time variability of the ocean. Although satellites provide only a limited view of the state of the ocean, the information may be sufficient for operational purposes. Promising attempts have been made to develop an ocean forecasting system using satellite imagery. The analysis of ocean dynamical tendencies in time series of satellite data and forecasting of future states of the ocean is based on genetic algorithms. Figure 01-A.7 shows the mean SST pattern observed in the Alboran Sea in November 1998 and the SST pattern forecast one month in advance by this approach.

Satellite remote sensing

Images of sea surface temperature provided by NOAA satellites have been processed for many years and used in many projects with great benefit. Since spring 1999, when a new antenna (1.5 Ø) was installed and a contract signed with NASA as an authorized SeaWiFS research station, SACLANTCEN is also receiving colour images of the sea surface that can be converted into quantitative information about transparency and chlorophyll. Raw data are preprocessed some hours after arrival and delivered to NASA. A key required for the conversion of preprocessed data into physical units is given to the Centre a few weeks later, in exceptional cases for real-time conversion. Ocean colour images processed at SACLANTCEN have been used in Project 06-C.

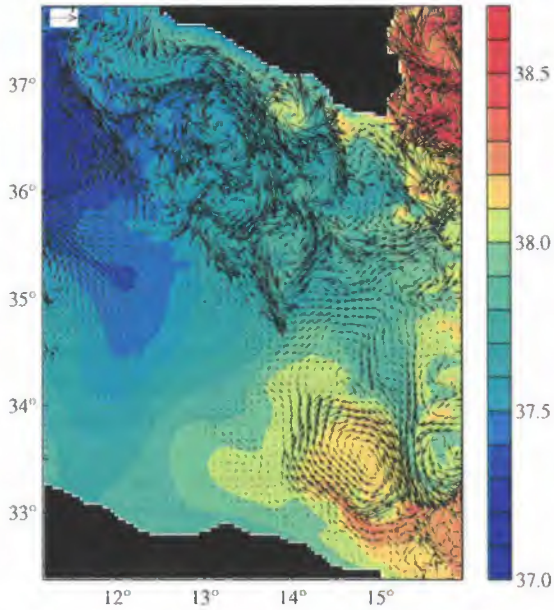


Figure 01-A.6. *Forecast of surface currents and salinity (colours) for 26 February 1999. The forecast is based on data collected from 10 to 16 February during IONIAN99. The scale arrow in the upper left corner corresponds to a speed of 20 cm/s. Note the highly variable currents in the Strait of Sicily and the quiet areas on the Tunisian shelf.*

Instruments for rapid oceanographic assessment

The prototype of a Shallow Water Expendable Environmental Profiler (SWEEP) was completed in 1998. The final design refinement prior to volume production was delayed in order to allow development of a Shallow-water Environmental Profiler in Trawl-safe, Real-time configuration (SEPTR). The SEPTR system combines the advantages of the trawl-safe bottom instrument platform and the SWEEP water column profiler developments. It is intended for extended duration deployments with real-time data return and control *via* two-way cellular or satellite communication in areas where water column instruments are at risk from fishing trawlers (Fig. 01-A.8).

The SEPTR design 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 profiler buoy and associated winch are designed for autonomous vertical profiling of CTD and optical properties of the water column down to 100 m. Features include DGPS navigation, two-way communication when surfaced, acceleration and magnetic field sensors. The bottom platform includes an extended duration battery package in the recoverable barnacle-shaped housing. For recovery, a messenger buoy is released by a command through the normal communication channel to the profiler or, acoustically, to the bottom mooring. If the platform becomes inverted, the system, which after release of the ballast is buoyant, can still be recovered by command to a backup acoustic transponder system in the bottom platform.

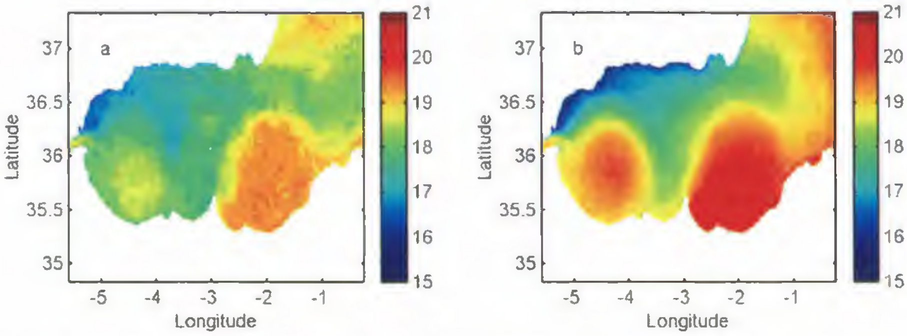


Figure 01-A.7. *a) Surface temperature of the Alboran Sea (western Mediterranean) obtained as an average of satellite observations in November 1998. b) Sea surface temperature one month later predicted from the time behaviour of orthogonal functions determined by a genetic algorithm.*

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, profile schedules and DGPS correctors to be sent to multiple profiler instruments. Complete profiles will also be stored on board the recoverable units. During sea trials in November 1999, critical subsystems were successfully tested.

The real-time data transmission capability of SEPTR is well-suited to provision of water property and ocean current data for assimilation into numerical ocean models. Two units will be operationally tested during the sea trial GOATS 2000, which in addition to bottom acoustics and mine warfare related tasks, encompasses an oceanographic observation and modelling programme.

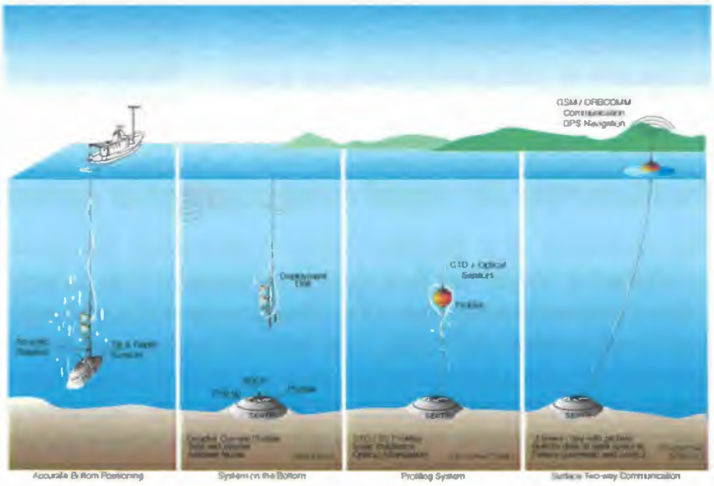


Figure 01-A.8. *The Environmental Profiler in Trawl-safe, Real-time configuration (SEPTR) is a high value multi-sensor platform for REA in accessible areas. After deployment, it does not interfere with fishing activity. At preprogrammed times, a float rises for measurements in the water column and data delivery.*

Comprehensive experiments and REA methodology validation

REA system components such as oceanographic and acoustic instruments, remotely sensed data, real-time ocean modelling, inverse acoustic methods, communications and data fusion are developed as the responsibility of the respective task leaders. When several components or the entire REA system is tested or a specific REA survey is requested, trials organization is transformed into a complex task, as during the ADVENT99 cruise in May 1999, which combined REA tasks with the acoustic REA Project 01-B and a multinational joint research programme. Figures 01-A.9, 01-A.10 and 01-A.3 illustrate data communications and high resolution oceanography.

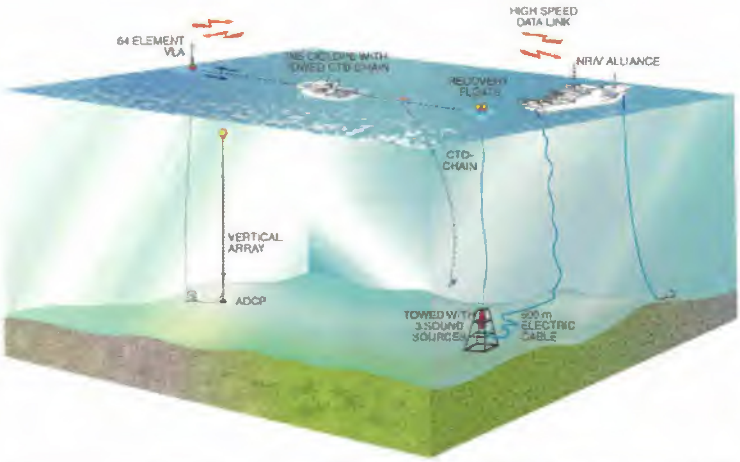


Figure 01-A.9. *Signals are transmitted and received over a fixed range. Environmental conditions on the acoustic range are measured at the same time.*

Following a Greek proposal for a limited REA experiment in their territorial waters in order to demonstrate skills acquired during Rapid Response, the mine warfare related CORFU99 sea trial was conducted in September 1999 with the Hydrographic Service of the Hellenic Navy and HNS *Pytheas* in conjunction with Project 03-D, which specializes in environmental characteristics for mine warfare. Figure 01-A.11, shows bottom mapping from a shallow water, multi-beam echo sounder, installed especially for this cruise.

Geophysical, oceanographic and acoustic results of the area assessment were processed on board, assembled into a data server structure and transferred to a CD-ROM, which was sent to the Hellenic Navy immediately after the cruise.

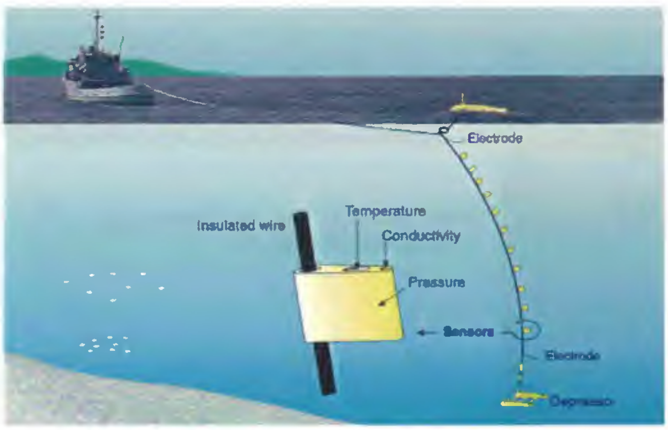


Figure 01-A.10. *CTD chain towed by the Italian navy tug Ciclope along the acoustic transmission track. The two-dimensional data of conductivity, temperature and depth were transmitted to NRV Alliance in real-time via spread-spectrum radio.*

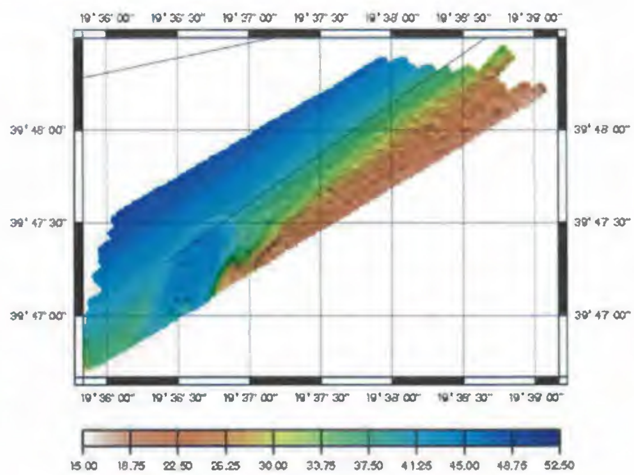


Figure 01-A.11. *Very high resolution bathymetry in a test area northwest of Corfu obtained from a Simrad EM-3000 echo sounder deployed from Alliance. The size of each box is 713 by 926 m. For structure enhancement, a hypothetical light source was applied.*

Grab sampling and the Greek vessel Pytheas during CORFU99

Project 01-A publications and presentations

Alvarez, A., Hernandez-Garcia, E., Tintore, J. On the effect of small scale oceanic variability on topography generated currents. *Geophysical Research Letters.*

Alvarez, A., Lopez, C., Riera, M., Hernandez-Garcia, E., Tintore, J. Forecasting the space-time variability of the Alboran Sea with genetic algorithms. *Geophysical Research Letters.*

Alvarez, A., Orfila, A., Tintore, J. An evolutionary algorithm to model chaotic time series. *Journal of Computational Physics.*

Berni, A., Mozzone, L. The application of spread-spectrum communications to REA tactical networks and deployable underwater surveillance systems, SACLANTCEN SM-367.

Nacini, E. Application of remote sensing in oceanography. Presented at Hydrographic Institute, Genova, February 1999.

Onken, R. Real-time modelling at SACLANTCEN using the Harvard Ocean Prediction System (HOPS). Presented at CNR/ENEA Colloquium, San Terenzo, 1 April 1999.

Onken, R., Sellschopp, J. Circulation and water masses between the Sicily Channel and the Strait of Sardinia. EGS, The Hague, 19-23 April 1999. *Geophysical Research Abstracts,* **1**, 1999:399.

Poulain, P.-M., Nacini, E., Pouliquen, S., Flament, P. Adriatic Sea, Sea surface temperature images from the NOAA advanced very high resolution radiometer, 9 May to 22 October, 1995. Ifremer, 1999.

Sellschopp, J. Harvard University - SACLANTCEN efforts in the Mediterranean: A model case for data acquisition and assimilation into a real-time dynamic ocean prediction system. IOC Workshop Report No. 155, Paris, 83-85 (1999).

Sellschopp, J. Oceanographic measurements in the Sicilian Channel and its neighbourhood. Presented at CNR/ENEA Colloquium, San Terenzo, 1 April 1999.

Sellschopp, J. Rapid Environmental Assessment for naval operations, (i) SACLANTCEN SR-328, (ii) *Naval Forces,* **20**, 1999:110-115.

Sellschopp, J., Onken, R. Observations of small very cold lenses at intermediate depth in the Ionian Sea. EGS, The Hague, 19-23 April 1999. *Geophysical Research Abstracts,* **1**, 1999:399.

Sellschopp, J., Pace, N.G., Pehlivanoglou, K., Onken, R. Corfu 99 joint sea trial for rapid assessment of the environmental conditions for mine warfare, SACLANTCEN CD-31.

Sellschopp, J., Siderius, M., Nielsen, P. Flachwasser-Experiment zur akustischen Variabilität (Advent99, a shallow water experiment on acoustical variability). Presented at FWG-Kolloquium in Kiel, 23 June 1999.

Trangeled, A., Franchi, P., Berni, A. Data communication and data fusion architectures for Rapid Response 96-98, SACLANTCEN SR-296.

Tyce, R., de Strobel, F., Grandi, V., Gualdesi, L. Shallow water expendable and trawler safe environmental profilers. Oceans '99 MTS/IEEE Proceedings, 1229-1233.

Wagstaff, R.A., Hollett, R.D. Rapid assessment of undersea ambient noise. *Journal of the Acoustical Society of America,* **105**, 1999:1040:2aUWb2.

Warn-Varnas, A., Robinson, A., Sellschopp, J., Leslie, W., Hayley, P., Lozano, C., Piacsek, S. Strait of Sicily Water Masses. IUGG General Assembly, July 19 - 30, 1999, Birmingham, UK.

Zanasca, P., Poulain, P.-M., Sellschopp, J. Drifter track data in the Nordic Seas 1991 – 1995, SACLANTCEN CD-26.

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. He has held academic positions at both universities (1990-1997) and the Taiwan National Central University (1997-1999). He joined SACLANTCEN in May 1999.*

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.*

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 an engineering coordinator at SACLANTCEN since 1997.*

Project 01-B: Rapid environmental assessment of operational acoustic parameters (Alliance days – 25, Manning days - 12)

1

Operational relevance

Remote and rapid assessment of unknown littoral environments provides the necessary acoustic input parameters to enhance performance prediction of sonar platforms.

Seabed geoacoustic inversion techniques

Seabed geoacoustic inversion techniques have been developed and validated to rapidly and accurately predict the range dependent geoacoustic properties of littoral areas. These techniques will eliminate or reduce the need for seabed coring.

The strong dependence of shallow water sound propagation on sea-bed type has led to the development of inversion methods, which use measured acoustic transmissions to determine bottom properties such as sound speed, density and attenuation constant. Using acoustics for seabed characterization has several advantages over other methods (e.g. coring). The measurement equipment is easily and quickly deployed and because acoustic signals are used, the method is well suited to characterize the bottom properties which have the greatest influence on propagation. The inversion method is based on Matched Field Processing (MFP), the starting point for which, is to parameterize the environment with an assumed geoacoustic model consisting of several unknown parameters (Fig. 01-B.1). Computer simulation models the acoustic response to different seabed types and efficient search algorithms identify the environment which matches modelled and measured data.

To illustrate (and validate) the utility of MFP inversion, two sites were chosen which have very different bottom types. The first data set was collected during the EnVerse97 experiments on the Adventure Bank off Sicily, where the seabed is of sand over a rock sub-bottom. The second data set was taken from the PROSIM97 experiments near Elba, where the seabed

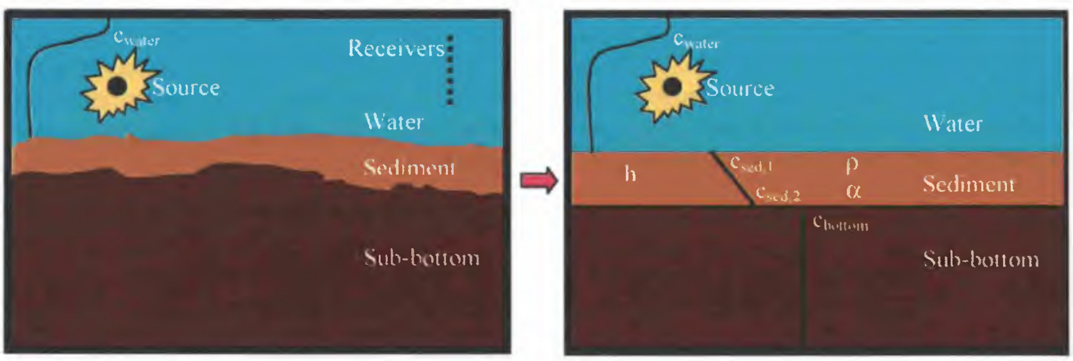


Figure 01.B.1 *Left panel is a representation of the true environment and the right panel is the geoacoustic model consisting of several seabed parameters. There is a sediment layer of thickness "h" over an infinite (homogeneous) sub-bottom. The sediment layer has a sound speed gradient denoted as "$c_{sed,1}$" and "$c_{sed,2}$" at the upper and lower points in the sediment, the sub-bottom has sound speed "c_{bottom}". Attenuation "α" and density "ρ" are also included in the geoacoustic model.*

consists of an acoustically slow clay layer over silt sub-bottom. At both sites, towed sources transmitted broadband signals from 200-800 Hz which were received on a vertical hydrophone array. The data sets were inverted using identical procedures and environmental parameterization (Fig. 01-B.1). Figure 01-B.2 shows the best fit between the computer simulated and measured data for the EnVerse97 site. The inverted values for the bottom are summarized in Table 01-B.1. The slow clay layer over silt (PROSIM97 site) and the faster sand bottom over rock (EnVerse97 site) were correctly identified from the inversions. The significance of this work is to illustrate correct seabed characterization without assuming prior environmental knowledge using an unbiased, automatic inversion procedure.

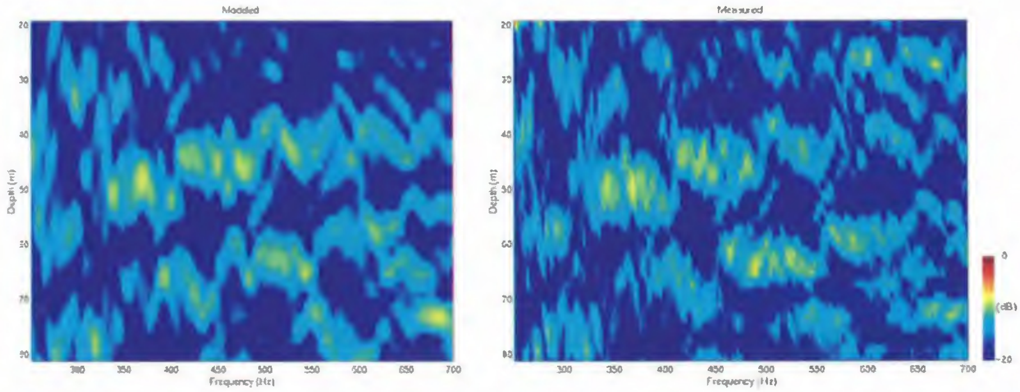


Figure 01-B.2 *Modelled (a) and measured (b) acoustic data taken along a 62 m vertical array from the EnVerse97 experiments. Measured and simulated pressure magnitudes are shown on a log scale as a function of depth, normalized at each frequency in the band between 200-800 Hz.*

The importance of correctly identifying the seabed type can be illustrated by example. For very different bottom types such as for the sites in Table 01-B.1, large differences in transmission loss (TL) are expected. But how do TL predicitions differ when the environmental properties are taken from an archive such as the Allied Environmental Support system (AESS) compared to sea-bed properties from MFP geoacoustic inversion? Broadband acoustic measurements with 2 km source-receiver separation were taken during the Advent99 experiments which took place at a shallow water site (80 m depth) in the Strait of Sicily. These data were used for geoacoustic inversion to characterize the seabed. The TL predictions as a function of range, using MFP inverted values for the seabed and the archived values are shown in Figure 01-B.3. Also shown are TL measurements (which were not used in the inversion) taken at 2, 5 and 10 km, which are in agreement with the predictions using MFP inverted seabed values. The differences in the TL predictions are large. Using the archived seabed properties would lead to over predicting the range of target detection by 15-20 km. In Fig. 01-B.4, measured TL at 10 km range is compared with predicted TL using the MFP inverted values for the seabed with those taken from the archive. The TL level and depth structure is matched well using the MFP inverted seabed properties, but not when archived values are applied.

Site	$c_{sed,1}$ (m/s)	$c_{sed,2}$ (m/s)	h (m)	(dB/)	(g/cm^3)	c_{bottom} (m/s)
PRO97	1464	1496	4.5	0.03	1.6	1549
ENV97	1545	1559	9.4	0.73	1.5	1739

Table 01-B.1 *Inversion results for EnVerse97 (ENV97) and PROSIM97 (PRO97) experimental data. Both data sets were collected on a vertical array using a towed source near mid-water depth in the frequency band 200-800 Hz. Using the same data type and inversion procedure, the two different bottom types were correctly identified. The PRO97 inverted sediment and sub-bottom are in agreement with the expected seabed type of clay over silt and the ENV97 inverted values are consistent with sand over rock.*

In Fig. 01-B.5, matched field beamforming is used to localize the acoustic source (located near 2 and 10 km from the receiver array). The figure shows good localization of the source in range and depth. Rather than using plane waves as with conventional beamforming, the matched-field beamformed image uses the computer model to generate wavefronts more appropriate for the environment. Here, the computer model uses the environment taken from the MFP inversion.

The research demonstrates that the geoacoustic inversion procedure can be successfully applied without prior knowledge of the seabed. The Advent99 data and analysis showed that data acquired at relatively short source-receiver range (2 km) give a stable prediction of seabed properties over many hours. These seabed properties were used to accurately predict TL measured on a different day with 10 km source-receiver range separation. The Advent99 data and analysis also show the value of using correct seabed properties for TL prediction and target localization in range and depth.

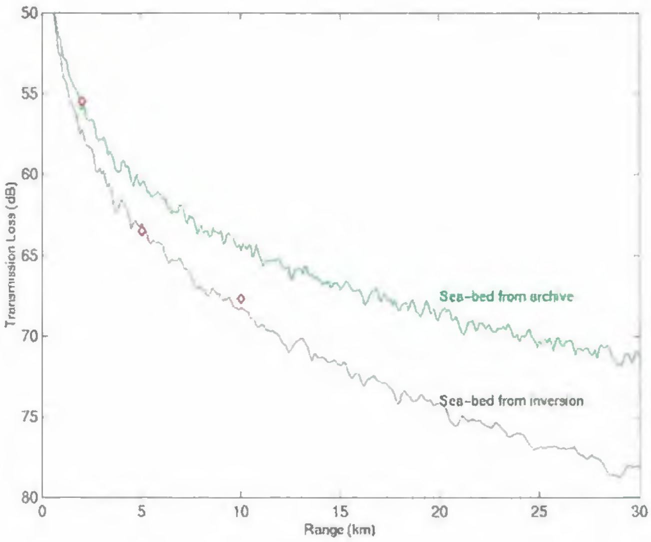


Figure 01-B.3 *Green curve shows predicted TL using archived seabed parameters, black curve uses seabed parameters determined by MFP geoacoustic inversion. The red diamonds show measured TL (The data shown as red diamonds was not used in the geoacoustic inversion). The TL is depth and frequency averaged using tones spaced at 100 Hz from 200-700 Hz.*

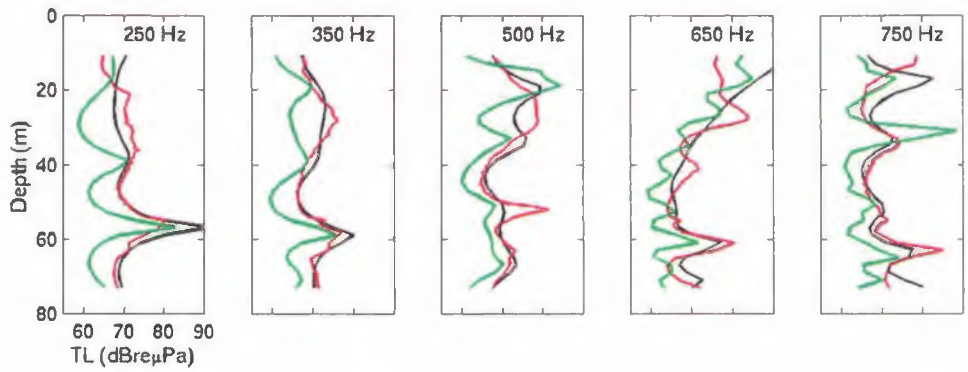


Figure 01-B.4 *Red curves show measured TL as a function of depth at 10 km source receiver separation at the indicated frequencies, (water depth 80m, source depth 76m). Black curve is the predicted TL using seabed properties taken from MFP inversion (MFP inversion data was collected at 2 km source receiver separation). Green curves were generated using archived seabed parameters.*

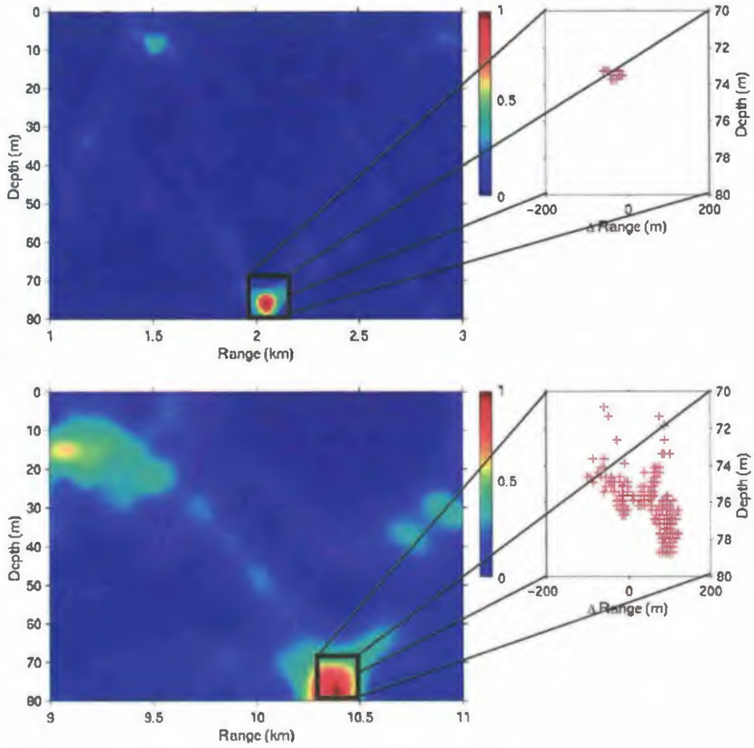


Figure 01-B.5 *Matched-field beamformed images of acoustic source at 2 km and 10 km range. To generate the image, model based processing was used with the inverted seabed parameters from data collected at 2 km. On the right are zoomed pictures of the source location for each multi-tone transmission (200-700 Hz in 100 Hz increments) taken at 4 min intervals over 6 h (2 km data) and 18 h (10 km data). Note the overall stability of the source position, with many data points in the same location. There is a larger spread of predicted source positions at 10 km due to time-variable ocean processes.*

Geoacoustic inversion using drifting sonobuoys

Drifting sonobuoys which feature large dynamic range signal conditioning and precise GPS positioning, were utilized in the rapid assessment of littoral environments to resolve the range-dependence of seabed properties. The buoys drift away from a stationary source, receiving pings at known positions. Single hydrophone, matched waveform, inversion techniques are applied to the received signals to invert for the geoacoustic parameters.

A field of eight prototype buoys was successfully tested on the western Sicilian shelf in EnVerse97. A follow-up geophysical survey in 1998 provided ground truth seabed data to support and validate the buoy field inversion. A unique feature of the survey is that the seabed was characterized at particularly high spatial resolution using Swath multibeam system, seismic boomer, *in situ* sound speed bottom probes (Forchetta) and a large number of water-sediment cores. Figure 01-B.6 shows several layers of a GIS map. Of particular interest is the thickness distribution of the sand cover, automatically reconstructed from a fine grid of digitized seismic profiles. The locations of water-sediment cores and bottom-penetrated acoustic probes are shown. CD-ROM versions with associated data such as seismic reflection or sediment sound speed profiles are available. The geometry of an EnVerse 97 acoustic run is overlaid, including the positions of a bottom-moored sound source and the tracks of the current-driven acoustic buoys. The zoomed regions illustrate the degree of detail achieved in producing this unique two dimensional, ground truth, geoacoustic model.

Satellite remote sensing and ambient noise estimation

Algorithms have been developed for extracting estimates of shipping density and wind speed from satellite remote sensors (Synthetic Aperture Radar). Shipping noise and wind speed are two environmental parameters which are required in directional ambient noise prediction models such as RANDI.

The physical processes contributing to ambient noise variability include the effects of surface wind and wave activity, rainfall, wave-wave interactions, monomolecular surface films, seismo-acoustic noise, marine organisms and anthropogenic noise. Here we demonstrate the methodologies for an ocean acoustic ambient noise prediction system from satellite derived information.

The surface processes which dominate ambient noise between 500 to 50,000 Hz can be measured from a number of satellites, including the special sensor microwave imager (SSM/I) on the defense meteorological satellite program (DMSP), an ideal sensor for wide-area, daily coverage of critical environmental parameters. SSM/I is passive microwave with a swath width of 1400 km and spatial resolution of 50 km. In Fig. 01-B.7 the surface wind speed is estimated by measuring sea surface microwave emissions which are related to wave structure and foam, which in turn are related to the surface winds. The wind retrieval method uses a linear combination of measured SSM/I brightness temperatures that vary with frequency and polarization. The SSM/I accuracy specification for wind speed retrieval is ±2 m/s over the range of 3-25 m/s. Rainfall rates can also be measured from SSM/I using attenuation-based and scattering-based inversion techniques. More recent inversion algorithms use regression analysis based on ground-based measurements of rainfall and brightness temperatures from the SSM/I channels.

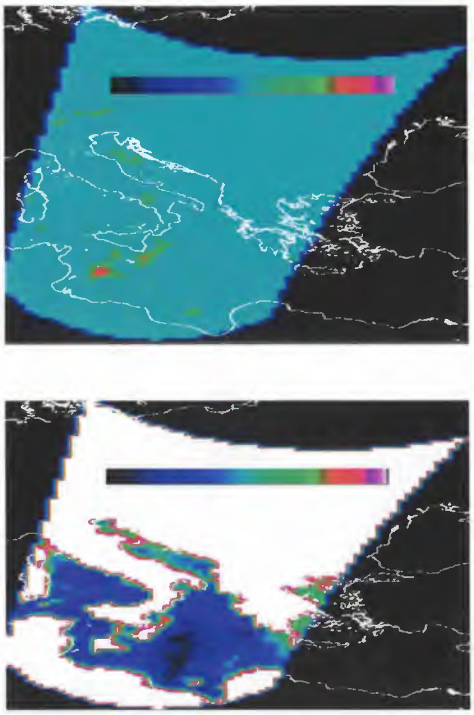
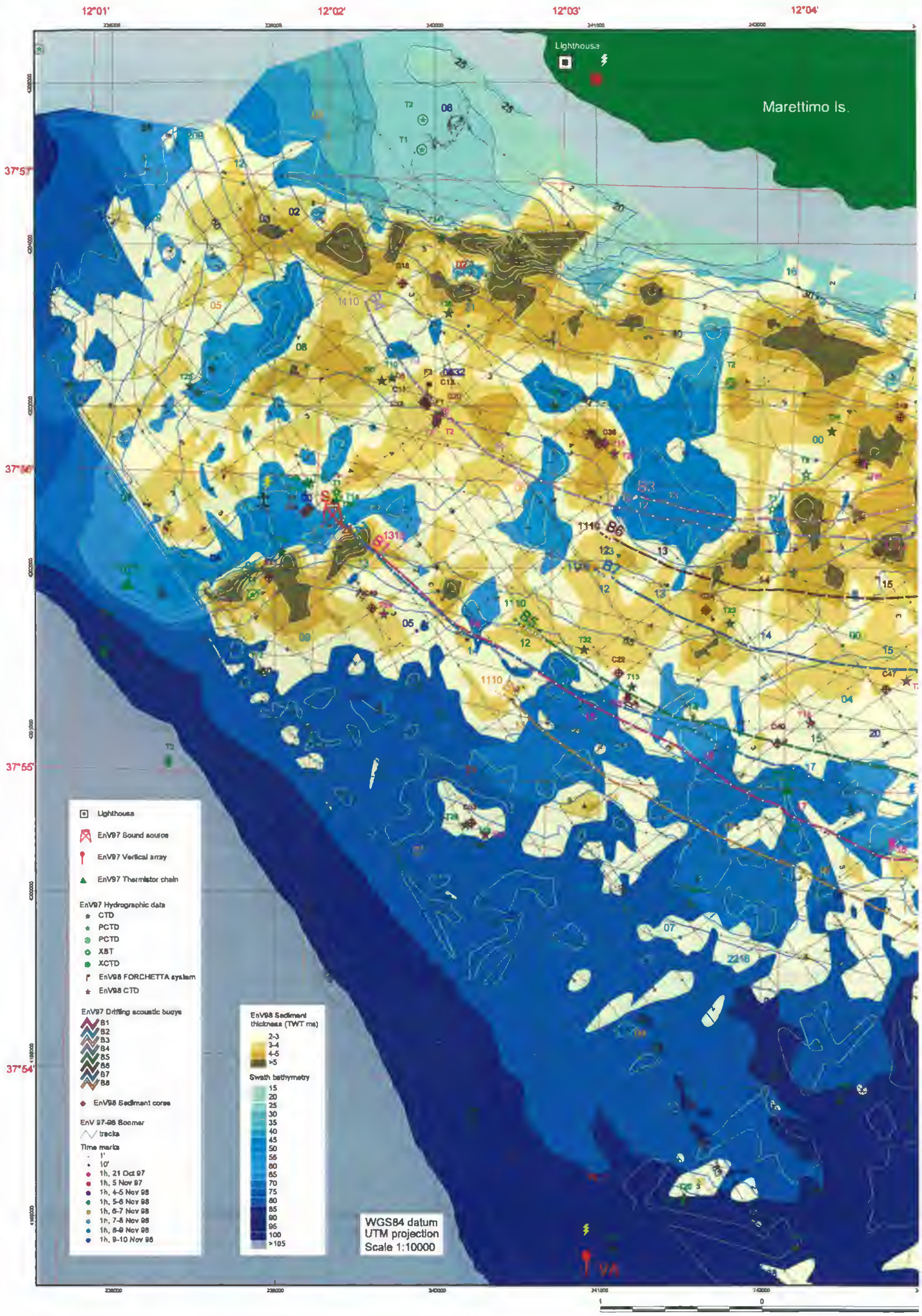


Figure 01-B.7 *Wind speed (m/s) and rainfall (mm/hr) and estimated noise levels.*

For resolving the spatial variability of the wind field in the coastal regions at spatial resolutions of 5 km and below, we utilize the ERS-2 synthetic aperture radar (SAR), an active microwave, all-weather sensor. The oceanic wind vector is retrieved by inverting a scatterometer model function which relies on the "Bragg resonant" reflections from the slopes of wind-generated gravity-capillary short waves. In Fig. 01-B.8 the CMOD4 scatterometer model function is used to convert between the SAR image intensity or the normalized radar cross-section and the wind speed. Because SAR responds only to the line-of-sight component of the wind vector, the true wind direction must be measured independently or derived from image processing techniques. Here we use the two-dimensional image spectra of the wind-wave field as a means of deriving the wind direction. An empirical model is used to convert wind speeds to wind-induced source levels at the acoustic frequency of 300 Hz.

In the frequency band between 20 to 500 Hz, the noise spectrum is dominated by shipping. To model ship-generated noise, shipping density must be determined as a function of range and azimuth from the receiver. Figure 01-B.9 shows the processing steps involved in

Figure 01-B.6 (pages 18 and 19) *GIS Map with overlays showing the area and thickness of the sand cover, acoustic tracks geometry and positions of cores and bottom-penetrating acoustic probes*


12°01'
12°02'
12°03'
12°04'
37°57'
37°56'
37°55'
37°54'
Lighthouse
Marettimo Is.
Lighthouse
EnV97 Sound source
EnV97 Vertical array
EnV97 Thermistor chain
EnV97 Hydrographic data
CTD
PCTD
PCTD
XBT
XCTD
EnV98 FORCHETTA system
EnV98 CTD
EnV97 Drifting acoustic buoys
B1
B2
B3
B4
B5
B6
B7
B8
EnV98 Sediment cores
EnV 97-98 Boomer
tracks
Time marks
EnV98 Sediment thickness (TWT ms)
2-3
3-4
4-5
>5
Swath bathymetry
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
>105
WGS84 datum
UTM projection
Scale 1:10000
VA


12°05'
12°06'
12°07'
12°08'
EnVerse 97-98
Advanced Drifting
Acoustic Buoy Field
Geoacoustic Inversion Experiments
Geophysical Survey
1
2
3
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5 Kilometers

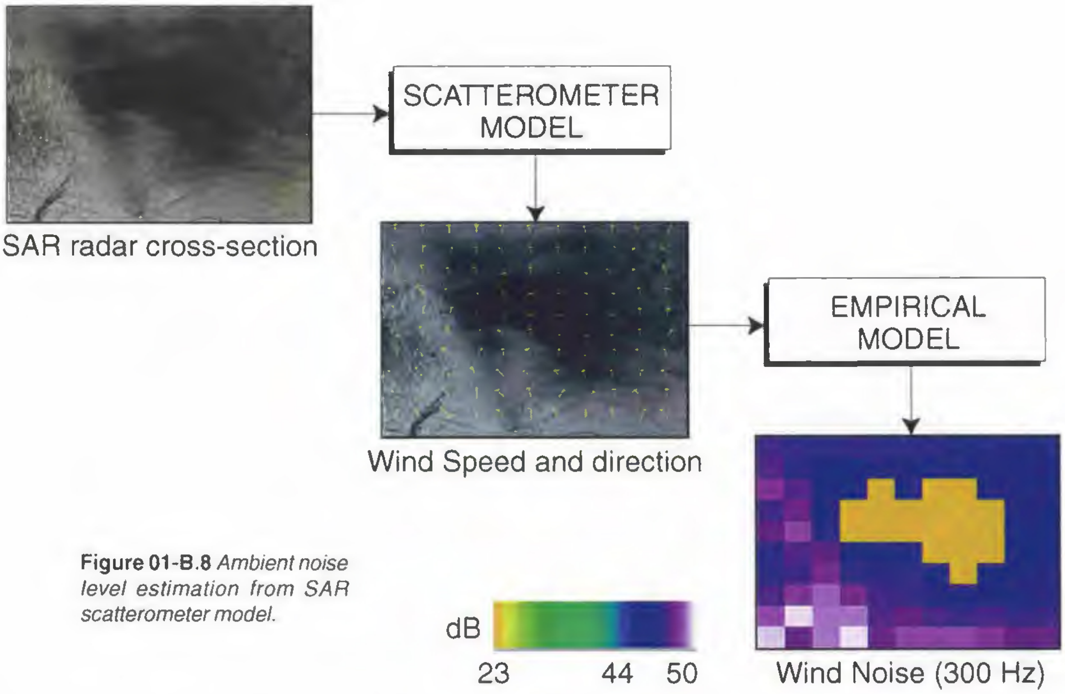

Figure 01-B.8 *Ambient noise level estimation from SAR scatterometer model.*

deriving shipping information. Artificial neural network architectures for hard target detection in spaceborne SAR imagery, produce a return which is a function of radar frequency, incident angle, sea state, wind speed and look direction. In automatic detection a 2-D SAR image is classified using four 1-D profiles. For each profile, the network outputs a decision that the detected profile belongs to a predefined shape. The individual opinions are fused to derive the final classification results. The second and third steps are measurements of the ship heading and speed which are critical to directional ambient noise calculations. For ship heading estimation, we rely on the visibility of the wake patterns, which depends on the choice of radar parameters and environmental conditions. Detecting ship wakes in a SAR image automatically involves several steps which include de-speckling, edge detection,

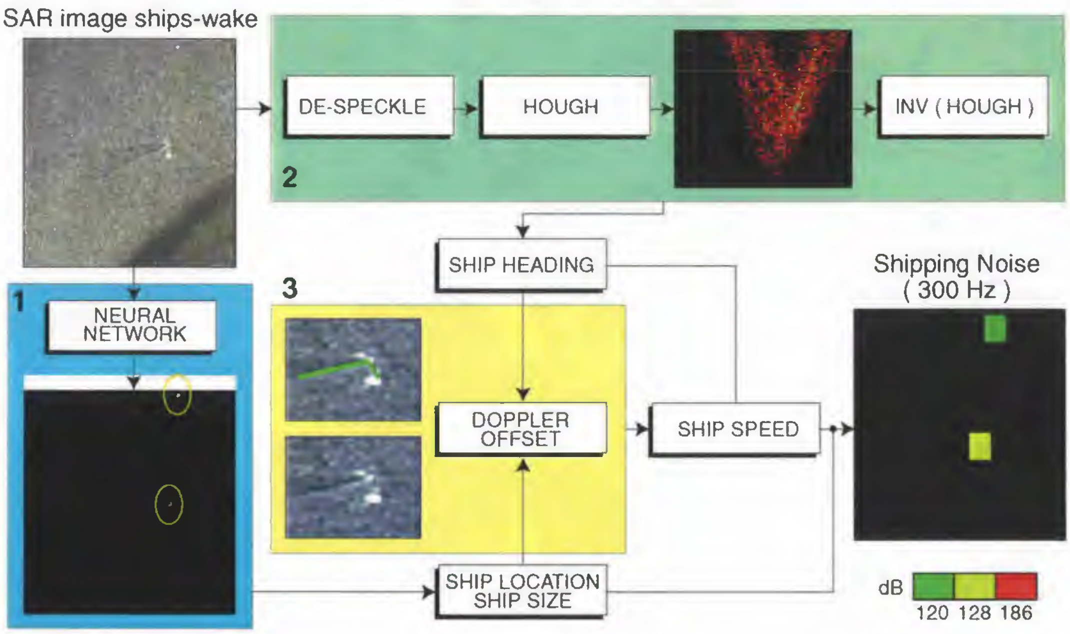

Figure 01-B.9 *Ambient noise level estimation from SAR-derived ship distributions.*

transformation of the edge-detected image to the Hough parameter space, local maxima selection, inverse Hough transform and line detection. The Hough transform algorithm is a robust method for automatic detection of lineaments in imagery. For estimating ship speeds we rely on the Doppler-offset or the displacement of the wake from the hard target in the image. In the final step, source levels associated with different ship types and sizes are estimated using empirical data.

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Shallow water expendable environmental profiler (SWEEP) and Shallow-water environmental profiler in trawl-safe, real-time configuration (SEPTR) REA buoy development

The SEPTR provides additional support to environmental modelling and rapid environmental assessment, permitting real time reporting of ADCP, tide/wave gauge and directional acoustic data, in addition to SWEEP water column profiler data, over a three month period. Dual development of SEPTR and SWEEP is made practical by designing common electronic and sensor systems. Sensor modules for the first SWEEP prototype were built and tested with hardware and software for acoustic ambient noise measurements. Submerged field tests of the SWEEP prototype and an early SEPTR prototype were conducted. Hardware and software development were commercially subcontracted. Development of a multi-element acoustic subsystem for SEPTR acoustic noise directionality and sound propagation experiments was initiated for use on SWEEP in single element form. Figure 01-B.10 shows the SWEEP prototype buoy on the bottom, prior to automatic ballast release. Divers were used to observe and film buoy dynamics.

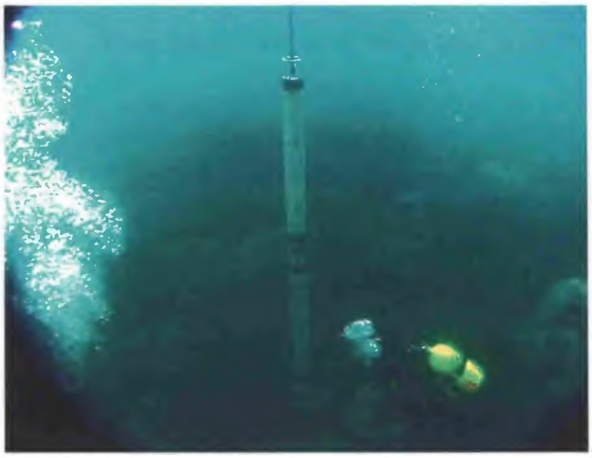


Figure 01-B.10 *SWEEP prototype prior to automatic anchor release.*

Water column environmental sensors were incorporated in a shallow water environmental profiler in a trawl-safe and real time configuration. The sensor system intended for long duration deployments, with real time data return, can be controlled *via* cellular phone or satellite transmission. An expendable, non-trawl safe version is under development.

Development tests included:

Orbcomm Low Earth Orbit Satellite communicator
GSM cellular phone communicator and antenna
DGPS navigation performance testing using GSM correctors
CTD calibration
Battery system
Accelerometer sensor
Acoustic subsystem
Pressure case overpressure and motor seals
Motor and winch performance
Submerged field

Standard SWEEP and trawler safe SEPTR profilers are being developed. By the fourth quarter 2000 the pre-production SWEEP prototype should be complete and commercial production undertaken of a series of SWEEP buoys for rapid environmental assessment demonstrations in 2001 and 2002. By September 2000, two SEPTR units will be complete and field trials undertaken as part of environmental modelling programmes.

Autonomous underwater vehicle (AUV) for rapid environmental assessment

The Centre specified and procured, through international competitive bidding, an AUV to conduct experiments in support of REA and MCM studies. The AUV selected is a modified Ocean Explorer (OEX), manufactured by Florida Atlantic University (Fig. 01-B.11). OEX is a modular vehicle which features a PC-104 Pentium, executing the supervisory control structure, interfaced to a distributed communication and control network, based on the open LONTalk network protocol. The modular design results in a field reconfigurable vehicle which is well suited to experimental work

The aft section contains the propulsion unit, control surface motors, navigation sensors, computer, RF and acoustic communication systems and the nickel metal hydride (Ni-MH) battery packs. The navigation relies on a standard suite of sensors (tri-axial flux gate compass, precision rate gyros and accelerometers and a Doppler Velocity Logger), which provide relative and geodetic positional information. The modular design facilitates the inclusion of a variety of geodetic navigational instruments including a DGPS, long baseline (LBL) and ultra-short base line (USBL) acoustic tracking systems.

The payload section which contains the sensors is attached to the aft portion by a bayonet mechanism. Elements in the payload are simply additional nodes on the LONTalk network and are integrated with the tail section with a power conductor and a control line.

The nose section contains a video camera, strobe, emergency drop weight and the vehicle recovery line device. OEX can be tracked acoustically *via* USBL and communicate *via* the acoustic modem. Launching and recovery can be achieved in seas up to sea state 4 without diver intervention.

The REA payload section includes a Sea Scan PC (SSPC) side scan sonar system, developed by Marine Sonic Technology Ltd. The system transmits broad band pulses (5-7 cycles in length) at 150 and 600 kHz and receives the scattered signals with very low noise pre-amplification circuitry. The SSPC software allows automatic sonar data acquisition. Any item in the sonar imagery can be correlated with geographical position. The software provides complete playback of sonar images acquired. The geo-referenced sonar data files, rectified for orientation and track curvature, may be imported into a GIS platform such as ArcView.

AUV Parameter	Vehicle Specification
Shape	Gertler Series 58 Model 5154E
Diameter	0.533 m
Length	2.66 m - 3.91 m
Weight	550 kg
Speed	1 m/s - 2.4 m/s
Depth	300 m
Materials	Fibreglass, aluminium, plastics
Payload	$0.2 m^3$ - $0.3 m^3$
Actuation	4 independent stepped motors
Propulsion	Direct Drive DC motor
Battery capacity	Ni-MH, 3000 watt-hrs, 500 cycles
Operating system	QNX (PC-104)
Dynamic characteristics at cruise speed	Yaw : 1.02° RMS @ 3 Hz Roll : 0.50° RMS @ 3 Hz Pitch : 0.36° RMS @ 3 Hz Turning radius <10 m
Endurance	50 km @ 3 kn

Table 01-B.2 *Specifications of the Ocean Explorer AUV*

Two views of the AUV

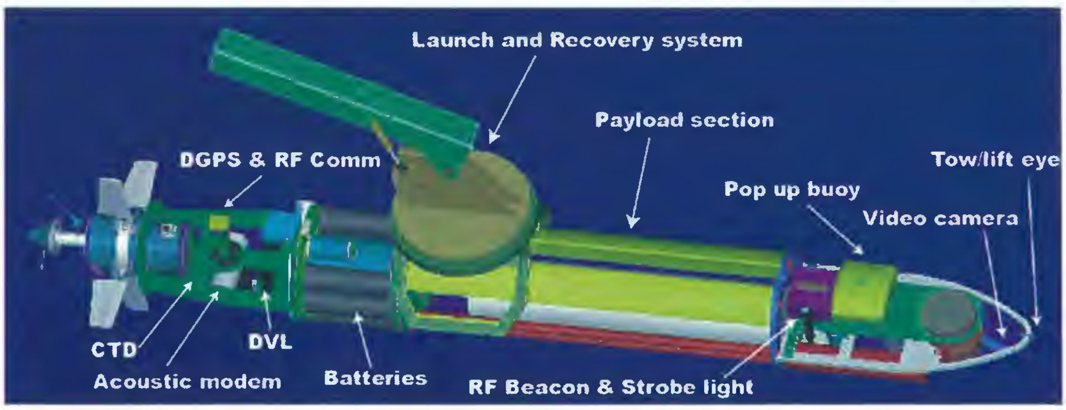


Figure 01-B.11 *Detail Of the Ocean Explorer AUV.*

Project 01-B publications and presentations

Askari, F., Malaret, E. Rapid Environmental Assessment using the World-Wide-Web Image Processing Environment (WIPE). The Ocean Observing System for Climate. St Raphael, France 18-22 October 1999.

Askari, F., Zerr, B., Harrison, C. H. Emerging satellite remote sensing technologies for undersea environmental monitoring. The Ocean Observing System for Climate. St Raphael, France, 18-22 October, 1999.

Harrison, C.H., Harrison, J.A., Curtis, D.I., Woollings, M.J. Time domain waveform generation for sonar validation: Synthetic Acoustic Environment (SAE).

Harrison, C.H., Siderius, M. Correlations between search parameters in geoacoustic inversion: study and experiment.

Harrison, C.H., Robins, A.J. Reverberation stimulation for sonar systems assessment. International Conference in Cambridge, U.K., 15-17 December 1999. Proceedings of the Institute of Acoustics, **21**, (9) 1999 pp 57-66.

Hermand, J.-P., Nascetti, P., Cinelli, F. Inverse acoustical determination of photosynthetic oxygen productivity of Posidonia seagrass, SACLANTCEN SM-366.

Nielsen, P.L., Siderius, M., Jensen, F.B. Acoustic time-variability measurements in the Strait of Sicily. European Conference on Underwater Acoustics, July 10-13, 2000, Lyons, France.

Siderius, M., Nielsen, P.L. Ocean variability effects on inversion of seabed properties in shallow water. European Conference on Underwater Acoustics, July 10-13, 2000, Lyons, France.

Siderius, M., Snellen, M., Simons, D. & Onken, R. An environmental assessment in the Strait of Sicily: measurement and analysis techniques for determining bottom and oceanographic properties. *IEEE Journal of Oceanic Engineering.*

Siderius, M., Yang, T.C., Al-Kurd, A. Temporal coherence and fluctuaution of acoustic signals in shallow water. European Conference on Underwater Acoustics, July 10-13, 2000, Lyons, France.

William Roderick received the B.S. degree in electrical engineering from the University of Rhode Island and the M.S. and Ph.D. degrees from the University of Birmingham, Birmingham, England. He currently serves as Head of the SACLANTCEN Acoustics Department. His previous appointment with SACLANTCEN was Head of the Environmental Research Division. Prior to his arrival at SACLANTCEN he served as Director for Science and Technology for the Naval Undersea Warfare Center, Newport, Rhode Island. He received NUWC's award for Excellence in Science for his research in underwater acoustics and signal processing and has a patent in underwater acoustic expendable sensors.

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.*

1

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.*

Jean-Pierre Hermand *holds the Ingénieur Civil and Ph.D. degrees in electrical, electronics and telecommunication engineering from the University of Brussels (ULB), Belgium. From 1981 to 1984 he conducted research in the Department of Acoustics and Optics on sound intensimetry, ultrasonic tissue characterization for medical diagnosis and holographic interferometry. Since joining SACLANTCEN in 1985 he has been engaged in various research projects on underwater acoustics and geomagnetics. From 1991 to 1993 he was a consultant to the Naval Undersea Warfare Center (NUWC) on broad-band environmentally-adaptive signal processing for active sonar application. Since 1991 he has lectured on image processing at the International School of Optical Technologies (AILUN), Italy. Since 1993, as Principal Scientist, he has lead research and development activities for inversion of oceanographic, sediment geoacoustic and plant oxygen synthesis parameters in shallow and very shallow waters.*

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.*

***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.*

***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-A: Detection and classification of buried mines (Manning days 13)

3

Operational relevance

A mine may become buried in marine sediment as a result of impact in soft muddy bottoms, scouring and ridge migration in hard sandy bottoms or the mine may be designed to be self burying. As the major mine influences, (magnetic, low frequency acoustic, pressure) and their explosive potential are unaffected by burial, buried mine countermeasures are a widely recognized NATO capability shortfall, identified in the NATO study MO 2015, to which this project has contributed.

Mine sweeping is the only active measure against all types of buried mines, but arming delays, ship counts and pressure sensors reduce its effectiveness.

Conventional mine hunting sonar is ineffective against mines which are completely buried in sediment, in which sound absorption is very high because at the usual minimum operating frequency of 80 kHz, sediment sound absorption reduces the level of the target echo to well below that of the seabed.

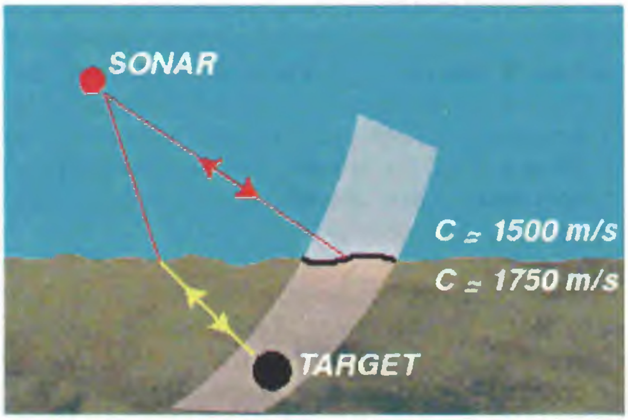


Figure 03-A.1 *Geometry of a buried mine sonar.*

Buried mine sonar must therefore be designed to minimize sediment sound absorption and the loss of resolution which affects sonar performance in reverberation limited conditions (Fig. 03-A.1). In hard bottoms, in which sediment sound velocity is greater than in the water column, penetration of sound into the sediment is limited to high grazing angles by the critical angle of total reflection. The operating range is therefore limited to approximately twice the height of the sonar above the seafloor, a significant limitation, especially in the very shallow waters where mine burial is most probable. The concept does become feasible however, if the sonar is deployed by means of autonomous underwater vehicles.

GOATS

To experimentally quantify the detection performance of such a sonar system, a parametric source was deployed, generating sound in the 2-15 kHz band and a receiver consisting of a segment of towed array 12 m in length, deployed statically 7.5 m above the seafloor (Fig. 03-A.2). The source was mounted on a 24 m underwater rail and placed in the middle of the water column, in 20 m of water. Thin-walled spherical shells 1 m in diameter S1, S2 and S3, were buried at depths of 0 m, 0.5 m and 1 m respectively from the centre of the spheres.

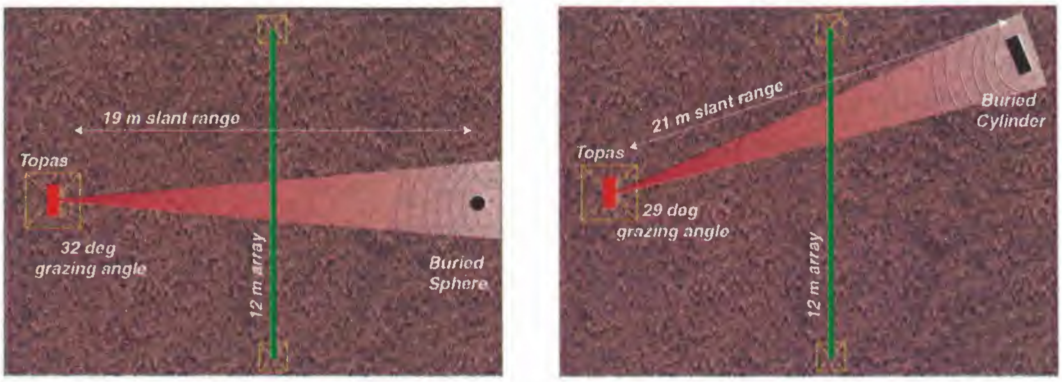


Figure 03-A.2 *Experimental configuration.*

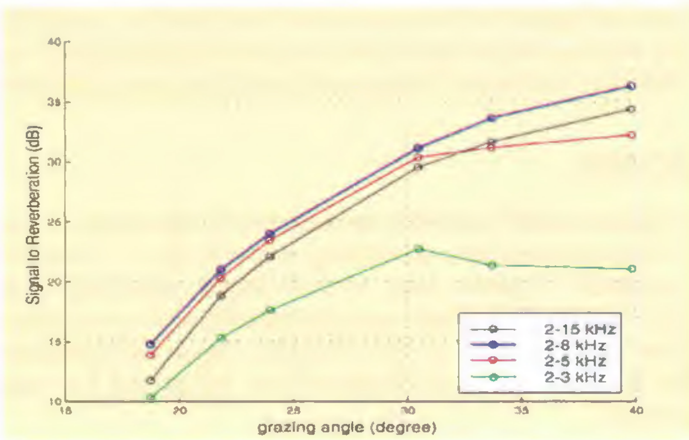
The data were processed in various frequency bands and the signal-to-reverberation ratio for S2 computed as a function of the incident grazing angle (Fig. 03-A.3). There is significant signal excess at the higher incident grazing angles and detection becomes more difficult as the angle is reduced.

It is apparent that detection is better in the 2-8 kHz band than in the 2-15 kHz band, which highlights another characteristic of sonar detection of buried objects, namely that increasing bandwidth does not necessarily improve detection performance in reverberation. This is because the reduction of the seafloor reverberation level is offset by the increased attenuation of the subbottom echo at the higher end of the frequency band. The opposite situation is obtained in the 2-5 kHz band, where the increase in the level of the subbottom echo fails to compensate for that of seafloor reverberation, due to the loss in bandwidth and angular resolution of the receiver array.

As a preliminary assessment of the feasibility of buried mine classification, high resolution images of a buried 1 m air-filled spherical shell and a buried water-filled cylinder, 2 m in length and 0.5 m in diameter, were formed with the 12 m towed array (Fig. 03-A.4). The array was focused at short range (~7.5 m) to produce images which reveal interesting target features. Sound is scattered specularly by the front face of the sphere and by the front and back faces of the cylinder. In addition, in the case of the spherical shell, a second highlight is visible which corresponds to a resonant effect created by waves travelling within the metallic shell.

Future work will focus on reproducing similar detection performance, with more compact sonar designs suited to AUV operations and on classification.

Figure 03-A.3 *Signal to reverberation ratio (dB) as a function of grazing angle and frequency for a buried sphere (TS=-16 dB).*



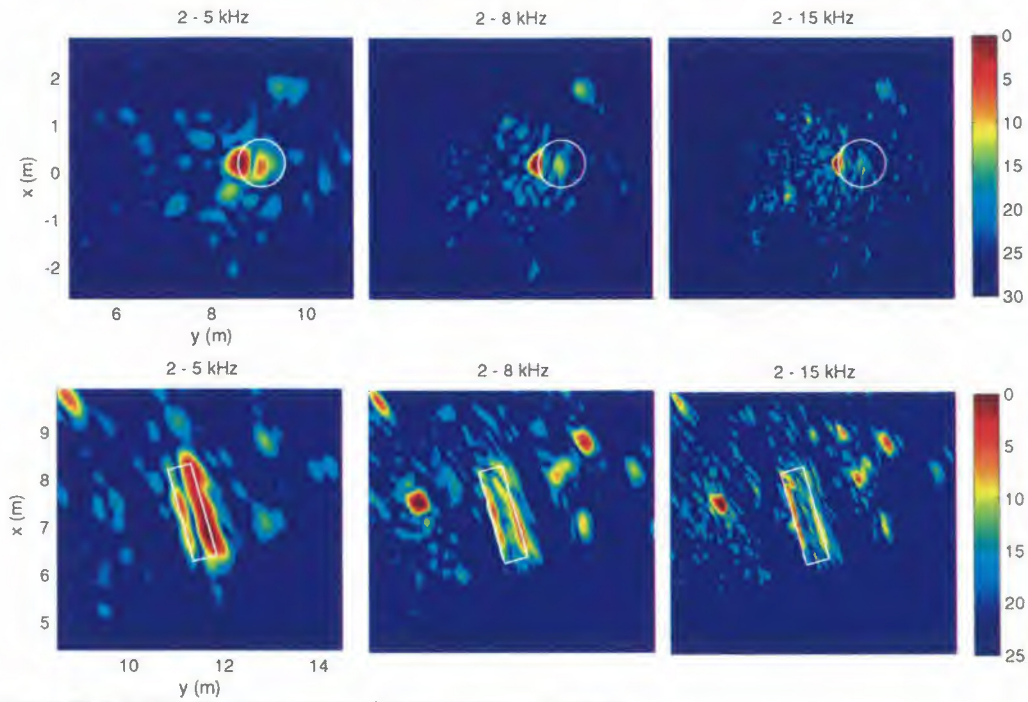


Figure 03-A.4 *High resolution images of buried sphere and cylinder.*

Results from (terminated Project 031-2) on temporal classification contributing to Projects 03-A and 03-B

In order to validate mine classification techniques exploiting the aspect dependence of the acoustic signature, the TASCOE (TArget Scattering in COntrolled Environment) experiment was conducted at Marciana Marina (Elba). The acoustic devices are installed on a tower mounted on a 24 m linear rail (Fig. 03-A.5). At the top of the tower, a frame which may be horizontally and vertically positioned supports a high frequency (325 kHz) interferometric sonar and a low frequency sonar with high fractional bandwidth (2-16 kHz). The high frequency sonar images the acoustic shadow of the objects at several aspects (coarse sampling). The low frequency sonar acquires the aspect dependence of echoes with an extremely fine sampling in azimuth. The interferometric capability of the high frequency sonar is used to compute the fine scale bathymetry of the experimental site.

Figure 03-A.6 shows the improvement of shadow based mine classification when combining three views at intervals of 45 °. An exercise mine and a rock were acquired at low frequency with an aspect resolution of 1 °. The difference between the two targets, clearly seen in the frequency domain using spectrum variation when circumnavigating the object, is also visible in the spatial domain when tomographic reconstruction is applied (Fig. 03-A.7). Another way to represent the aspect variations of the target signature is to reconstruct a temporal signal from the aspect varying spectrum. When the reconstruction is carried out in the audio frequency band, a rock and a geometrical object produce different sounds (see Fig. 03-A.8).

When the object is classified as man-made and considered as a potential mine, additional geometrical and elastic properties can be estimated from the multi-aspect resonance scattering analysis, as demonstrated in previous work on water-filled steel cylinders. The same methodology is applied to an exercise mine with a fibre-glass shell which is shown to generate both diffraction (Fig. 03-A.9a) and elastic features (Fig. 03-A.9b). The feasibility of classification schemes based on resonance scattering analysis, developed and tested on free-field and proud targets was demonstrated on buried targets, from analysis of

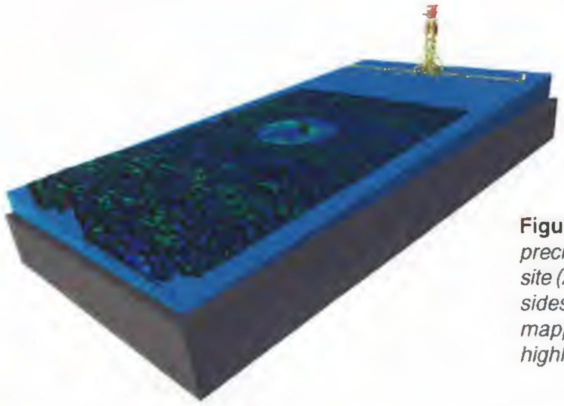


Figure 03-A.5 *TASCOE experimental configuration. The precise digital terrain model (DTM) of the experimental site (20 m x 30 m) is reconstructed from the interferometric sidescan sonar data. The georeferenced sonar image is mapped on the DTM. The targets are placed in the highlighted area at the centre of the site.*

air-filled, steel, thin walled spheres buried in sandy sediment.The existence of the same families of elastic waves and comparable amplitude levels, particularly of the shell-borne resonance modes (relative to the specular echo), between the free-field and buried cases are shown in Fig. 03-A.10.

The results from the analysis of TASCOE experimental data demonstrate the potential of a mine classification approach combining multiple aspects of the acoustic signature in conjunction with high and low frequency bands. The manoeuverability of small autonomous underwater vehicles will allow these techniques to be applied when conventional mine hunting sonar is of limited use.

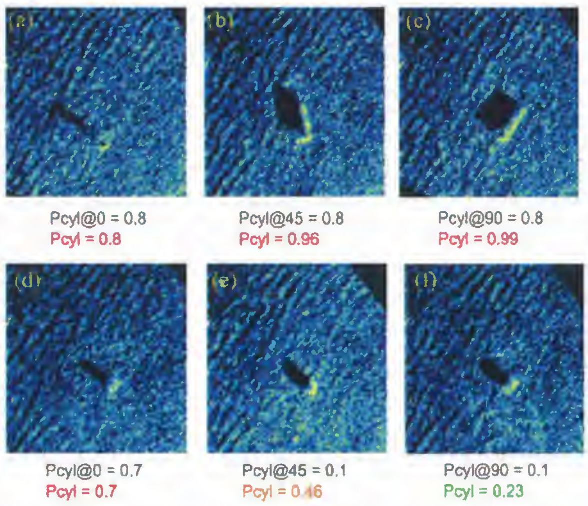


Figure 03-A.6 *Multiple aspect shadow classification. As shown in the first view, a rock (d) and an exercise mine (a) can have similar shadow. Fusing information from additional views by evidential reasoning allows discrimination between the two objects.*

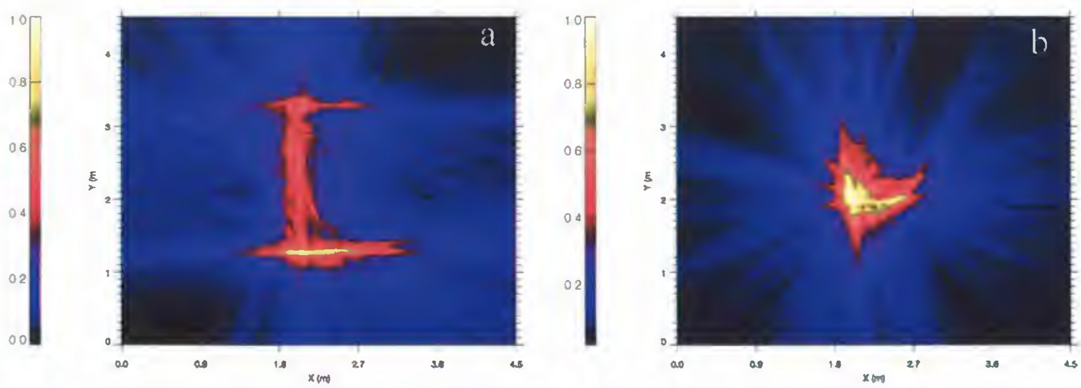


Figure 03-A.7 *Partial (from an aspect variation of 180 degrees) tomographic reconstruction of an exercise mine (a) and a rock (b) using low frequency acoustic wave (8 kHz Ricker pulse).*

3

Deployment of cylinder and rock off the Cinqueterre

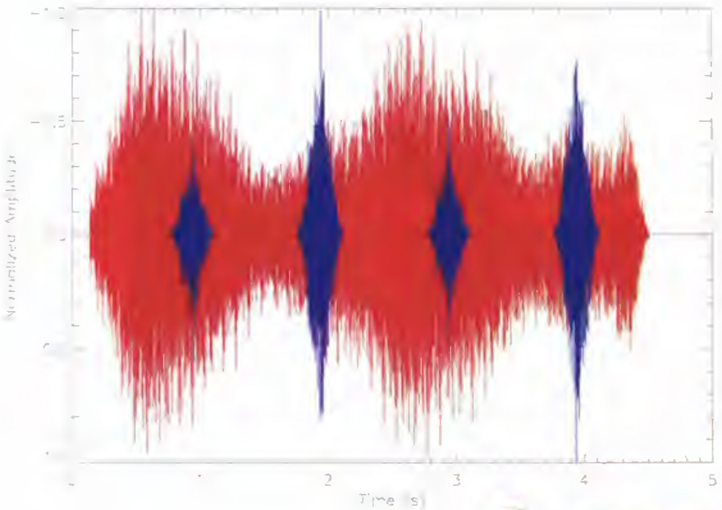


Figure 03-A.8 *Reconstruction of time series in the audio band from the aspect varying spectrum of a rock (red) and a cylinder (blue). The input data are generated by 2D time domain finite difference (TDFD) modelling tools.*

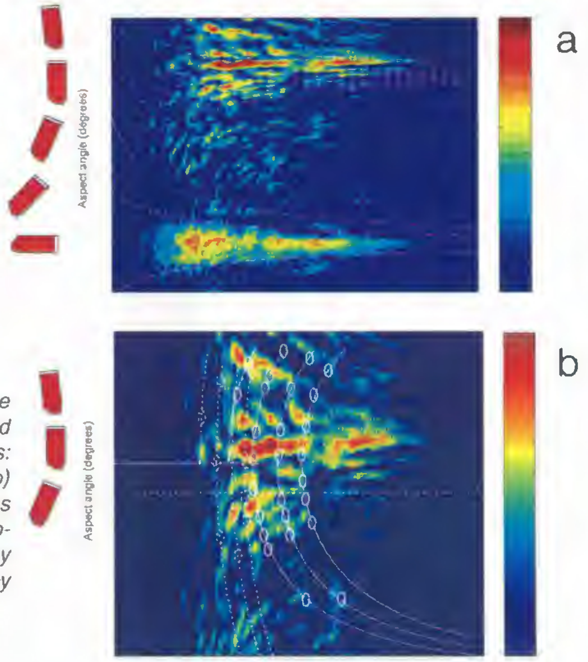


Figure 03-A.9 *Rigid and elastic feature identification of a cylindrical exercise mine proud on a sandy bottom. (a) Diffraction feature analysis: axial (dashed) and radial (solid) mode loci. (b) Elastic feature preliminary analysis: the curves corresponding to shear (dashed) and S_0 Lamb-type (solid) wave modes are obtained by connecting the detected energy peaks (shown by circles).*

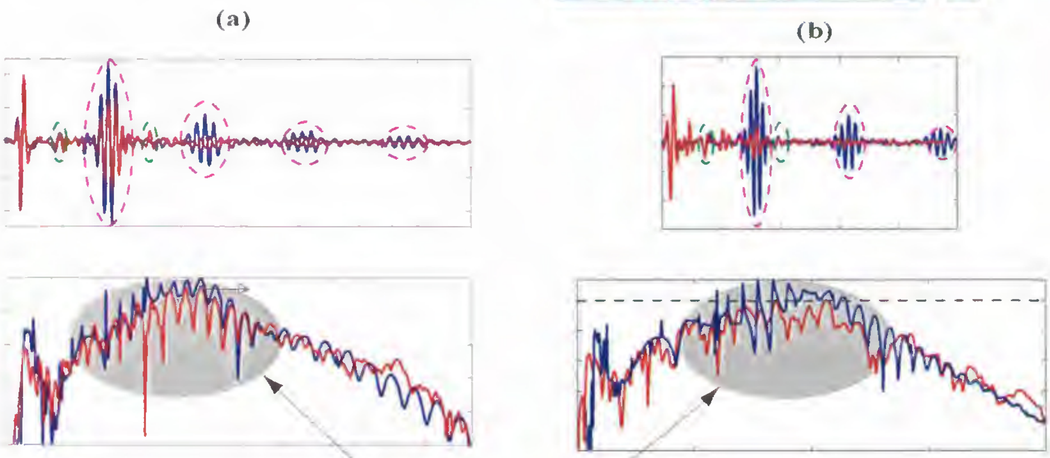


Figure. 03-A.10 *GOATS 98 data-model comparison of time and frequency response of 1 m∅ air-filled sphere in free space (a) and flush buried (b). The model assumes the sphere in the free field even when buried. Main results of elastic wave analysis are included.*

Project 03-A publications and presentations

Maguer, A., Bovio, E., Fox, W.L.J., Schmidt, H. *In situ* estimation of sediment sound speed and critical angle. *Journal of the Acoustical Society of America* (submitted).

Maguer, A., Fox, W.L.J., Zerr, B., Tesei, A., Bovio, E., Fioravanti, S. Buried mine detection and classification (research summary 1996-1999), SACLANTCEN SR-315.

Tesei, A., Maguer, A., Fox, W.L.J., Schmidt, H. Measurements of acoustic scattering from partially and completely buried spherical shells, SACLANTCEN SM-362.

Tran Van Nhieu, M., Gensane, M., Fioravanti, S., Tesei, A., Maguer, A., Woodward, B. Detection of a buried water-filled cylindrical shell by the wavelet transform. Submitted to European Conference on Underwater Acoustics 2000, Lyons, July 2000.

Zerr, B., Tesei, A., Maguer, A., Fox, W.L.J., Fawcett, J.A. A classification technique combining aspect dependence and elastic properties of target scattering, SACLANTCEN SR-310.

Zerr, B., Tesei, A., Maguer, A., Houston, B., Sletner, P.A. Proud target classification based on multiple aspect broadband low frequency response, SACLANTCEN SR-324.

Zerr, B., Tesei, A., Maguer, A., Houston, B., Sletner, P.A. Classification of underwater elastic objects based on aspect dependence of their acoustic signature. Submitted to European Conference on Underwater Acoustics 2000, Lyons, July 2000.

Alain Maguer received the Ph. D. degree in acoustics and signal processing from the University of Lyons, France, in 1987. Between 1986 and 1991, he was with Thomson Marconi Sonars at Sophia Antipolis, France. In 1991, he joined SACLANTCEN wherein 1998, he lead two projects: Detection of Buried Mines and Temporal Classification. His research interests are sonar, statistical signal and array processing, synthetic aperture processing, time-scale and time-frequency analysis.

Warren L.J. Fox received the B.S.E.E. (cum laude), M.S.E.E. and Ph. D. degrees in electrical engineering from the University of Washington, Seattle, WA, in 1988, 1990 and 1994 respectively. He became a member of the professional staff at the Applied Physics Laboratory, University of Washington, in 1988 and earned his graduate degrees as an APL-UW Fellowship recipient. From 1996 to December 1998 he was in the Mine Countermeasures Group at SACLANTCEN.

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

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

Project 03-B Remote large area search in coastal waters (Alliance days – 13, Manning days - 3)

Operational relevance

Autonomous underwater vehicles (AUV) equipped with high resolution sonar and precision navigation sensors and systems will contribute significantly to the reduction of NATO MCM capability shortfalls identified in MO2015

In order to improve navigational accuracy, critical to successful AUV operations, data from traditional navigation sensors is combined with that of high resolution mine hunting sonar on the AUV. The traditional sensor package consisting of an inertial navigation system (INS), is converted into Aided INS (AINS) by the addition of Doppler velocity log and intermittent DGPS fixes, the data from which are fused by an extended Kalman filter. Although the recently acquired strapdown INS is one of the best available, the accuracy of positioning remains insufficient, in particular for synthetic aperture sonar, (SAS).

AINS performance analysis, using a navigation simulator/estimator provided by the Norwegian Defence Research Establishment (NDRE), demonstrated that the attitude error, shown in Fig. 03-B.1 (a) is negligible, due to very low sensor noise of the selected INS. The position error shown in Fig. 03-B.1 (b) is dominated by quadratic drift due to accelerometer bias. The SAS motion compensation technique is expected to significantly reduce this drift.

The proposed approach of data-driven motion compensation is the Displaced Phase Centre Antenna (DPCA) technique, which has been demonstrated to be precise to a fraction of the acoustic wavelength (1 cm for a 150 kHz sonar). The operationally significant feature of DPCA is that it is unaffected by seafloor topography.

The 100 kHz programmable sonar was integrated into a passive towfish which was successfully deployed from R/V *Alliance* in June during the MASAI'99 (Multi-Aspect Synthetic Aperture Imaging) experiment. This system (Fig. 03-B.2) is being used to experimentally

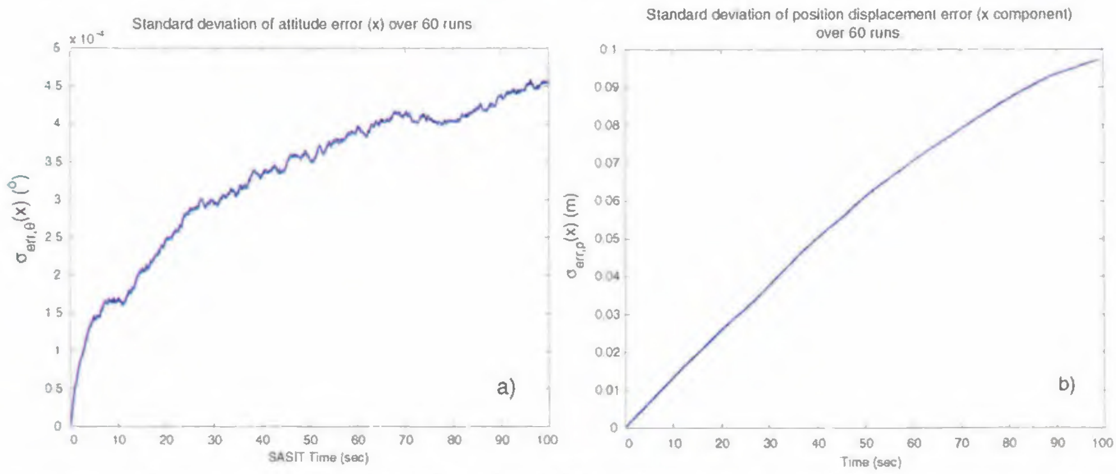


Figure 03-B.1 *Analysis of simulated AINS short-term residual error of attitude (a) and position displacement. Figure 03-B.1(b) shows only the x components, but analogous results have been obtained for the other two components.*

Figure 03-B.2 *The 100 kHz programmable sonar deployed from R/V Alliance in June 99 during the MASAI'99.*

validate a multi-aspect SAS concept (Fig. 03-B.3). In addition to the extremely high cross-range resolution provided by SAS, which allows shadow classification to be performed at increased ranges, better target recognition is expected to result from the acquisition of multiple high resolution looks. The benefits of multi-aspect processing are illustrated by images of a vessel sunk during WWII, obtained with the PS during MASAI'99 (Fig. 03-B.4). SAS processing is continuing. The challenge is that the motion compensation has to be performed by DPCA alone, due to the lack of INS in the MASAI'99 experiment. Preliminary DPCA estimates are shown in Fig. 03-B.5. The standard deviations are close to theoretical expectations but the attitude rates are offset for reasons that are as yet unexplained.

The AUV specified and procured in support of REA and MCM studies, is a modified *Ocean Explorer (OEX),* of modular structure, manufactured by Florida Atlantic University. The rear propulsion module houses the components common to all operations, including power, propulsion, navigation and control. One or more forward payload sections are dedicated to mission specific sensors A common nose cone section includes a video camera and a recovery line system. The MCM payload (Fig 03-B-6) will contain the recently procured INS and a wideband interferometric array for synthetic aperture sonar studies. The array will be specified and procured in 2000 and installed in the OEX in 2001.

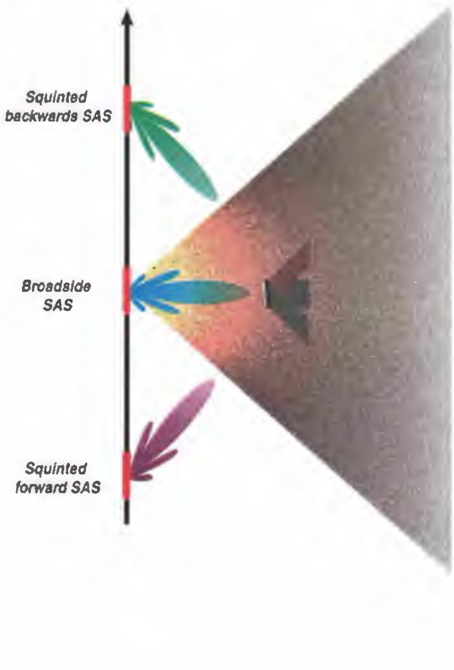


Figure 03-B.3 *Geometry of the multi-aspect synthetic aperture sonar.*

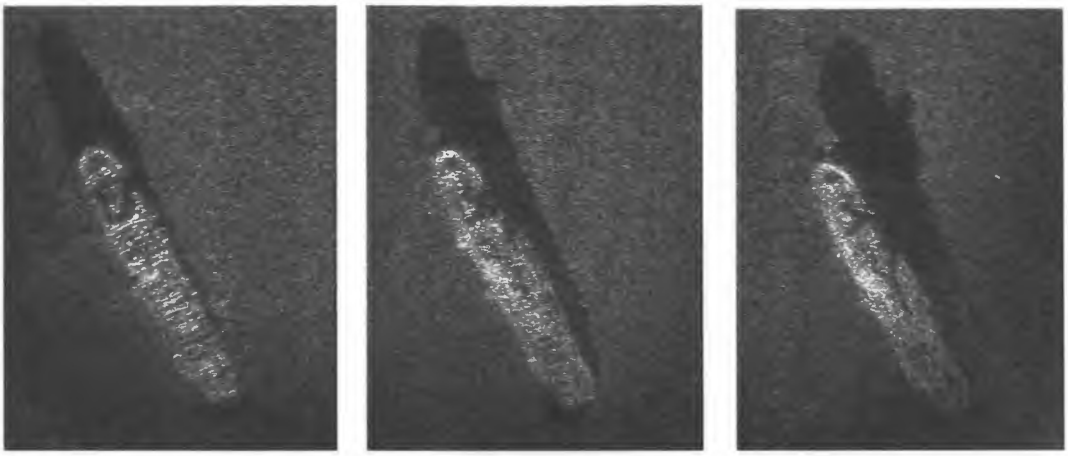


Figure 03-B.4 *Images of a vessel sunk during WWII obtained at multiple aspects with the 100 kHz programmable sonar during MASAI'99.*

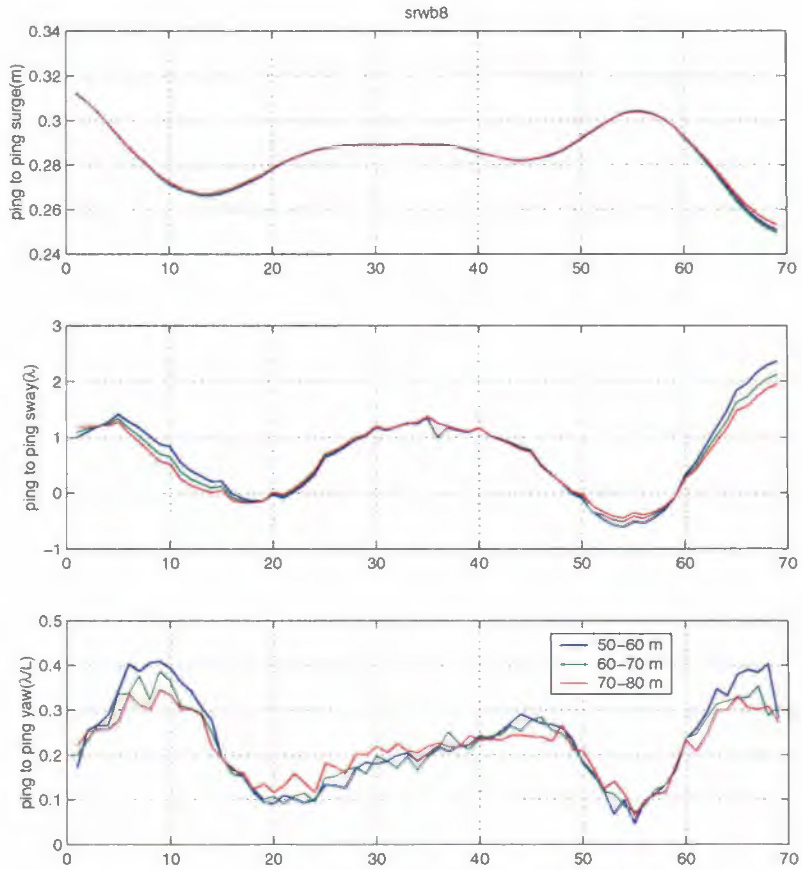


Figure 03-B.5 *DPCA micronavigation of MASAI'99 (carrier frequency 100 kHz, 20 kHz bandwidth, 128 channels spaced at l/2) for three different ranges giving three independent estimates of the motion in the slant-range plane. The yaw estimate is biased, possibly because of calibration errors of the physical array.*

The 100 kHz programmable sonar deployed from R/V Alliance in June 99 during the MASAI'99.

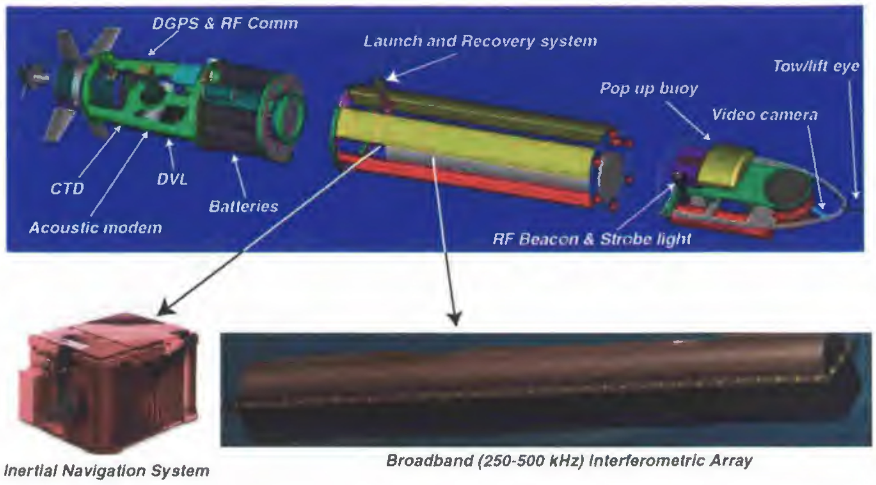


Figure 03-B.6 *The MCM autonomous underwater vehicle consists of a propulsion section which houses the common navigation components, a payload sections with the INS and the interferometric wide band sonar and a nose cone section with a video camera and a recovery line system.*

Project 03-B publications and presentations

Fioravanti, S., Bellettini, A., Pinto, M.A. Accuracy evaluation of synthetic aperture sonar micronavigation. *In:* Proceedings of the eleventh international symposium on unmanned, untethered submersible technology, 23-25 August 1999. Lee, NH, Autonomous Undersea Systems Institute, 1999: pp. 228-237. (99-8-01).

Pinto, M.A., Bellettini, A., Fioravanti, S., Chapman, S., Bugler, D.R., Hetet, A., Perrot, Y. Experimental investigations into high resolution sonar systems. OCEANS'99.

Tesei, A., Pinto, M. Application of aided inertial navigation system to synthetic aperture sonar micronavigation, SACLANTCEN SM-368.

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

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

Ing. **Edoardo Bovio** graduated in Electronic Engineering from the University of Genova, in 1976. He worked in communications and radar at the NATO Shape Technical Centre (NC3A) the Hague and in signal processing and vibration analysis for Hewlett Packard, Milano. In 1980 he joined SACLANTCEN where he led the initial work on low frequency active sonar. He is now involved with the design of mine detection and classification sonar for autonomous underwater vehicles.

Stefano Fioravanti received the Ph. D. degree in image and signal processing from the University of Genova, Italy, in 1994. Between 1990 and 1995, he was a research fellow in the Department of Biophysical and Electronic Engineering. He joined SACLANTCEN in 1995, where he is working on projects related to the detection of buried objects. His research interests are sonar, synthetic aperture processing, time-scale and time-frequency analysis.

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

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

Project 03-C: Mine-ship interaction

Operational relevance

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

3

Mine ship interaction

Research focused on mine jamming with a subsidiary task to develop planning algorithms for use in Target Sweeping Mode operation.

Mine sweeping

Many of the mines likely to pose a threat to NATO forces are *influence* mines, equipped with sensors to detect the presence of a suitable target vessel from the various influence fields (such as magnetic and acoustic) radiated by ships.

NATO nations have the ability to sweep these mines using equipment to generate the required influence fields. This equipment is towed through the water by surface or airborne assets to actuate mines by fooling their sensors and logic. Traditionally, influence sweeping has exploited particular weaknesses in mine design and has assumed a known mine threat. This is commonly termed minesweeping mode (MSM).

Mine jamming

Minefields are rendered safe by time consuming minesweeping or mine hunting operations. There are occasions when vessels are required to traverse a mined area before mine clearance operations can be completed. Project 03-C is studying techniques which will *jam* the mine's decision logic or algorithm allowing the target to proceed safely.

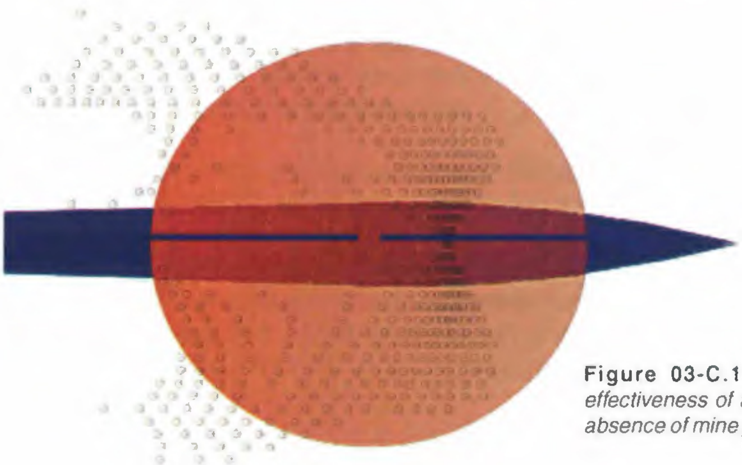


Figure 03-C.1 *Scatter plot illustrating the effectiveness of a particular mine algorithm in the absence of mine jamming.*

When time is unconstrained and the level of conflict is low, time can be spent on surveys and surveillance. As time becomes more constrained and as the conflict intensity increases, effort will be spent on rapid area assessment and covert surveillance. Subsequently the MCM operation includes remote mine hunting and minesweeping, followed by mine avoidance in support of an in-stride operation. Finally, when conflict intensity is high and time very limited, *mine jamming* becomes important.

Several *mine jamming* concepts were proposed during the pre study phase of this work[1] and computer models written to simulate these concepts.

Figure 03-C.1 illustrates the performance of one mine against a frigate with an outline of the ship and a damage circle. The mine actuations are represented by the grey symbols. It is clear that the mine presents a significant risk to the target. When a mine jammer protected this same target, the mine actuated in less than 0.05% of the engagements and no mine actuations presented a threat to the target. The trial data (Fig. 03-C.2) confirmed these findings.

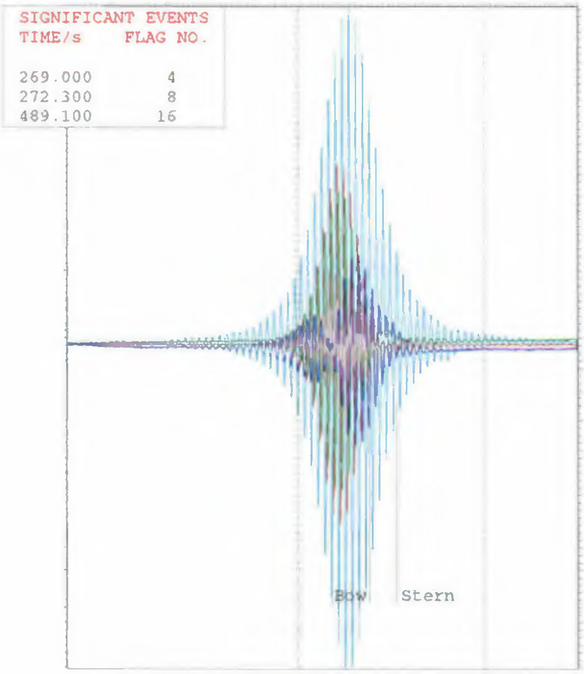


Figure 03-C.2 *Trial data showing the target ship protected by a jamming signal.*

The Joint Research Project partners met in September to discuss progress and the way ahead. A second trial was suggested for late 2001 at the Coastal Systems Station in Panama City.

Most of the mine jamming techniques considered are novel applications of existing equipment. Initial indications from the trial show that these techniques are promising and if successful, will augment the MCM armoury without significant additional cost to the NATO Nations.

Target sweeping mode planning

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 concept is termed target sweeping mode (TSM).

The objective of mine countermeasures (MCM) operations planning is to *minimize* the risk to subsequent target shipping, 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 performance, described 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.

[1] SACLANTCEN SR-271

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

During 1999, a technical solution was developed, which is an extension of the current NATO MCM planning and evaluation procedures implemented within 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. An example of the evaluation algorithm output is shown in Figure 03-C.3.

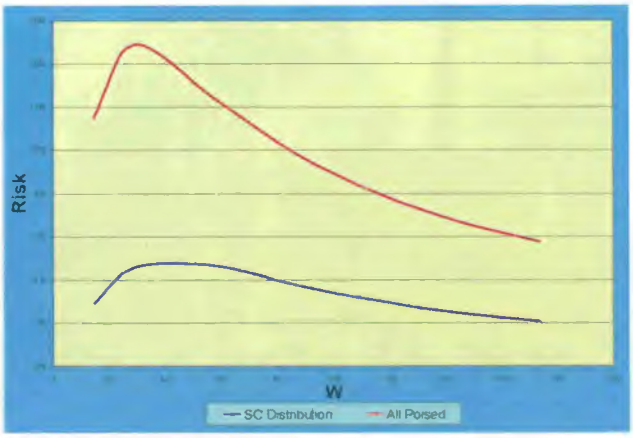


Figure 03-C.3 *TSM evaluation: the risk to the target plotted against the aggregate actuation width of the mine against the target.*

The algorithms have been implemented in EXCEL 97 VBA for development and testing. At a meeting with the project sponsor, Belgium, in November, the concepts were discussed and the algorithms and prototype user interface demonstrated for a standalone prototype TSM planning and evaluation software tool (Figure 03-C.4). It was agreed that the development of the software (Planning and Evaluation for TSM – PET) should be continued.

This task is scheduled to be completed at the end of May 2000 with delivery to the sponsor of the PET prototype software, source code, user guide, help files and a SACLANTCEN report describing the algorithms implemented.

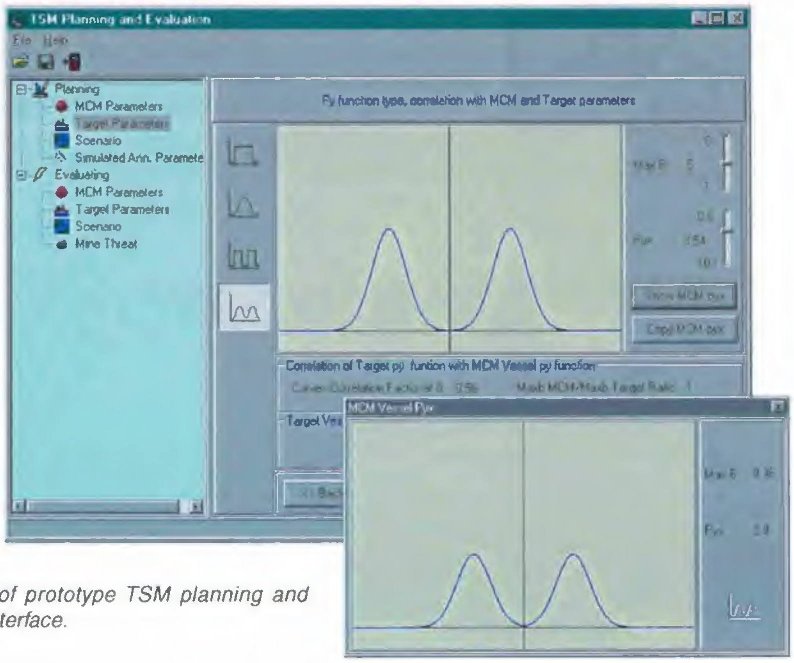


Figure 03-C.4 *Example of prototype TSM planning and evaluation software user interface.*

Mine jamming workshop held at Coastal Systems Station, Panama City, FL, October 1999.

***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 of MCM on sonar design and performance (Manning days - 36)

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.

Acoustic fluctuations due to water column effect

The effect of sea-surface waves on the travel time of acoustic signals in shallow water has been investigated theoretically and experimentally in the context of synthetic aperture sonar. Vertical and horizontal displacement of water, a function of depth and azimuth results from sea-surface waves. The horizontal displacement velocity produces a vector addition to the mean sound speed. Vertical displacement, in the presence of vertical gradients in temperature and salinity produces a scalar addition to the mean sound velocity. For one way transmission, scalar and vector effects will influence the signal. A backscattered signal will be affected only by the scalar effect if it can be assumed that the time scale associated with the variability is much longer than the two way travel time. Such effects have been modelled and verified against experiment. When this knowledge is applied to SAS in which displaced phase centre antenna (DPCA) techniques are used to micronavigate the synthetic aperture, the study has confirmed that fluctuations of the medium can be treated as an additional motion of the AUV and thus corrected for, provided the ping repetition period remains small compared to the temporal coherence time.

Physics of seabed acoustic scatter and penetration

Repeated experiments have demonstrated "anomalous" penetration of acoustic energy into the seabed below the critical angle. A major unanswered question is whether this energy can be exploited by MCM systems for detecting buried mines. An experiment (APEx99) was designed to address questions that recent SACLANTCEN investigations have failed to resolve:

- the arrival angle of acoustic energy
- the mechanism for subcritical penetration at higher frequencies
- the modelling technique which is most applicable to the interface scattering component.

The main experimental goal of APEx99 was to measure acoustic penetration into a sandy seafloor, above and below the critical grazing angle, over a wide frequency range and the

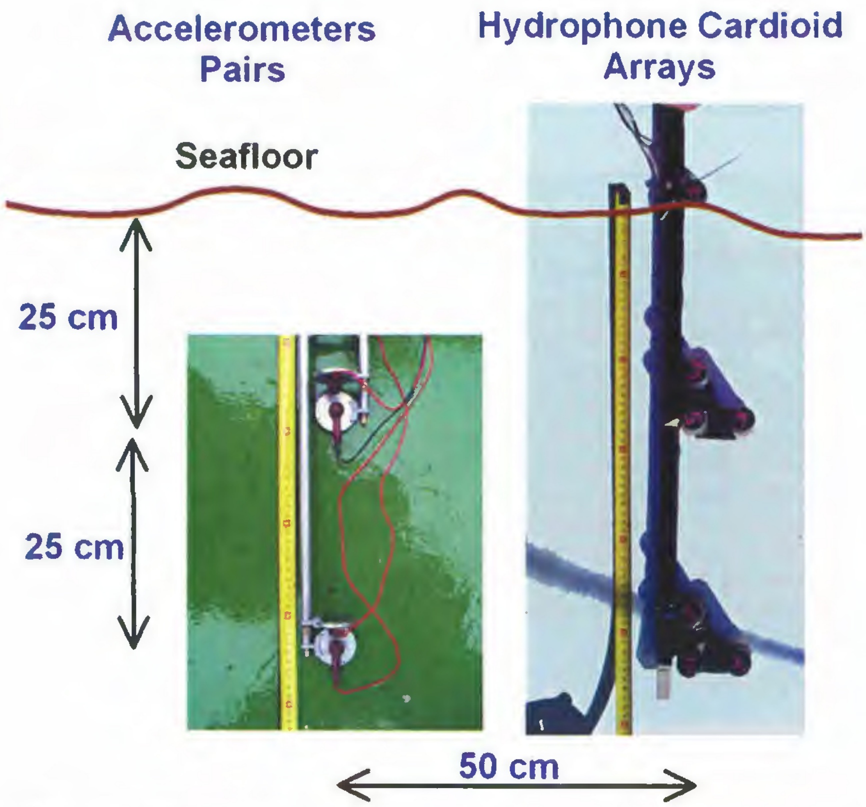


Figure 03-D.1 *Sensor hydrophone array.*

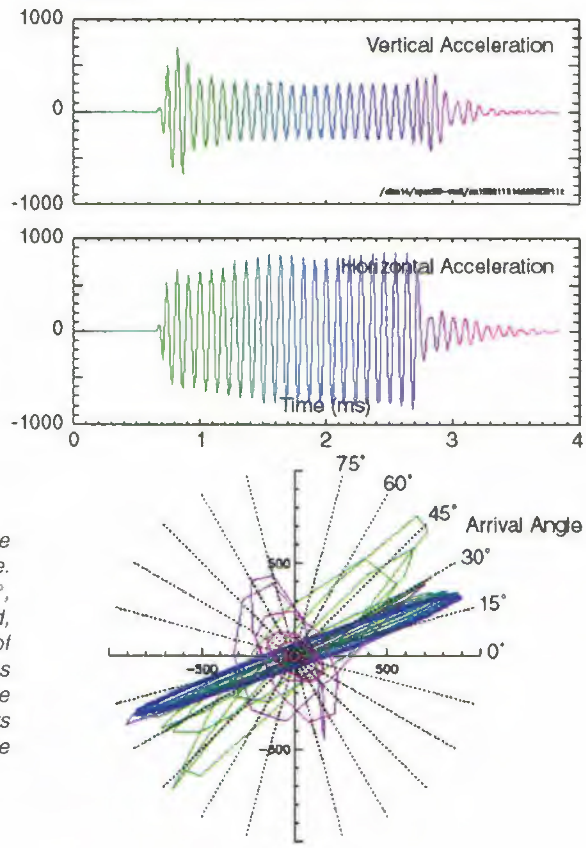


Figure 03-D.2 *Particle motion measured by the buried accelerometers for a 2 m, 11 kHz, CW pulse. The beam, which is incident on the seafloor at 37°, is largely just above critical angle and is refracted, after penetrating the seafloor, to 22°. The output of each accelerometer, displayed in the top two graphs are combined to give particle motion and thus the signal arrival direction. The colour coding allows spurious effects at the start and end of each pulse to be identified.*

angle of arrival. The latter is an important clue to the penetration mechanism (e.g., Biot slow wave or interface roughness scattering). Acoustic measurements in conjunction with ground truth measurements will allow discrimination between candidate mechanisms for penetration and a test of the robustness of the penetration prediction models, which have been developed.

The Apex99 experiment used a diver-buried vertical array of accelerometers in a sand seabed in conjunction with two small hydrophone arrays of 3 sensors each, closely positioned at the same depth (Fig. O3-D.1). Short acoustic pulses were transmitted from conventional sources mounted on a tower equipped with a pan and tilt mechanism. Different acoustic energy incidence angles on the seafloor were achieved by moving the tower, tilting the transmitter head and by raising the height of the telescopic tower. This configuration allowed the directionality of the incoming acoustic waves and transmitted pressure levels to be determined as a function of frequency (3-30 kHz) and angle (5°-35°). The buried directional sensors allowed the propagation direction of the penetrating acoustic waves to be accurately identified (Fig. 03-D.2). This technique is a considerable improvement on measurements made using pressure sensors, as the acoustic arrival angles are difficult to obtain with a sparse array. The use of linear as opposed to parametric sources will simplify the analysis of the penetration data. Accurate measurements of seafloor roughness were made daily with the new digital photogrammetry system and cores were analyzed for their physical properties.

High frequency volume scattering experiment (31 May - 18 June 1999)

This trial was the second milestone of the Defence Evaluation and Research Agency (DERA) Joint Research Project *Wideband acoustic interaction with the seabed* (April 1998 – April 2000). The emphases were on measuring high-frequency volume scattering from different seafloors (from silt to coarse sand) and extraction of statistical properties of backscatter as a function of ensonified area, grazing angle and frequency in relation to seabed properties. The DERA wideband research sonar (110-190 kHz) and the SACLANTCEN Simrad EM3000 (300 kHz) bathymetry/backscatter measurement system were deployed. Progress in this area will be of direct benefit to the interpretation and use of high-resolution sonar imagery.

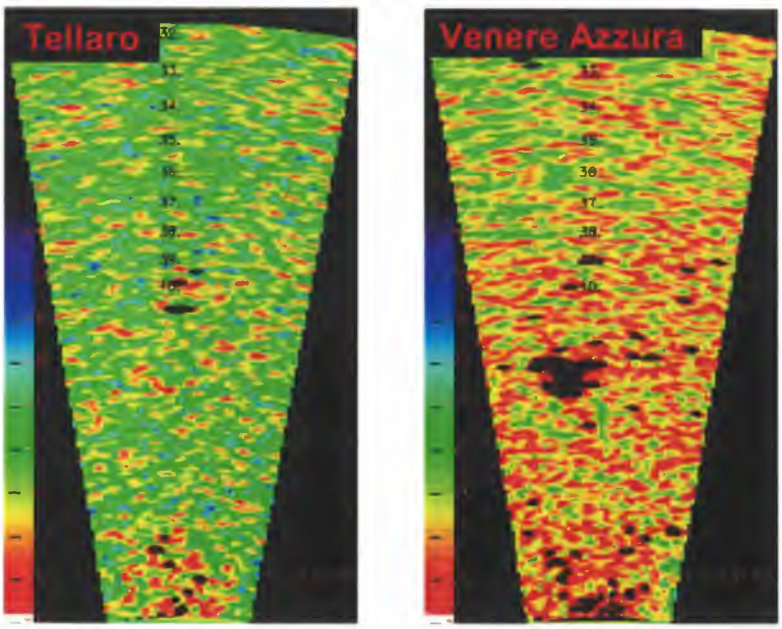
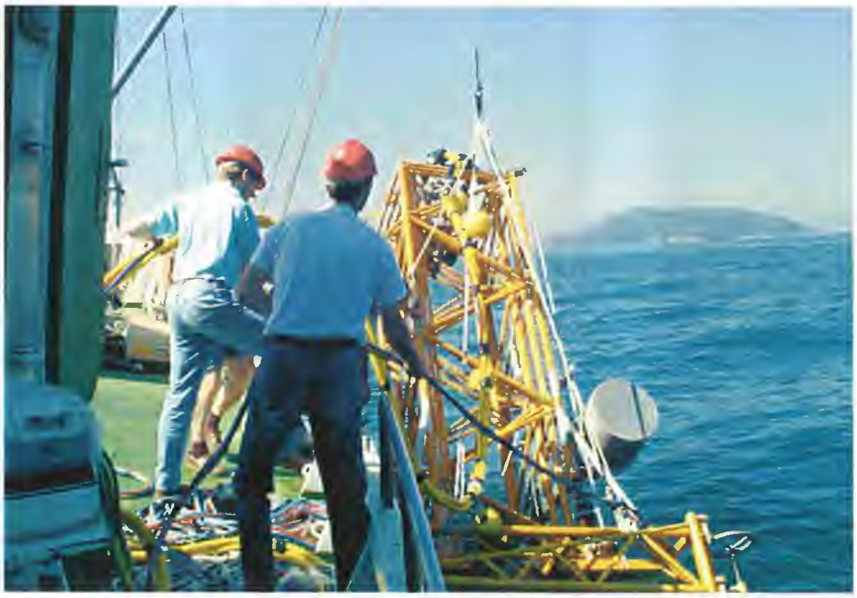


Figure 03-D.3 *Scattering strength versus range and azimuth at 140 kHz for a hard, rough bottom (left) and a soft, inhomogeneous bottom (right).*

Deploying the Tower



An example of acoustic scattering data obtained with the wideband system is shown in Fig. O3-D.3. The stronger returns from the soft bottom provide evidence of the importance of volume scattering even at frequencies above 100 kHz. Acoustic data was complemented by the EM3000 raw data at 300kHz over many beams with swath bathymetry and the sidescan sonar operating at the same frequency as the EM3000. Supporting environmental data including seabed roughness spectra derived from stereo photography, grab samples, sediment cores, conductivity, temperature depth (CTD) and video. The seafloor ground truth cores were analyzed using an x-ray computed tomography (CT) scan technique which provided important information on the internal three-dimensional structure of the sediment volume, such as density variations and the distribution of shell detritus and worm tubes (Fig. 03-D.4). These features have a significant impact on high-frequency volume scattering (Fig. 03-D.3) and their quantification is an important step in being able to model seafloor acoustic response which causes strong, high frequency volume scattering.

Positioning the core for the CAT scan at the Sant'Andrea hospital in La Spezia

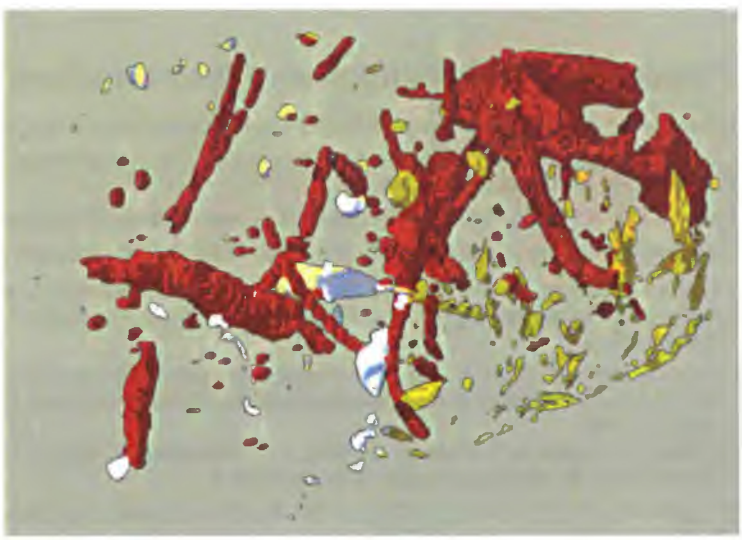


Figure 03-D.4 *3-D image of x-ray CT scan data showing shell detritus and animal burrows*

Fusion of acoustic data for sea-bed mapping

A procedure based on simultaneous operation of four acoustic sensors is under development to provide in a rapid, quasi-automatic and unsupervised manner, complementary information about an area of interest. A 300 kHz multibeam echosounder provides high resolution bathymetry and backscattering strength mapping. A sidescan sonar operating at the same frequency provides information about low grazing backscattering and textural imaging. Signals from a vertical echosounder are processed to discriminate between seabed types and complement information on bathymetry. A subbottom profiler provides vertical information on seabed substructure. The combination of these four sensors with the use of unsupervised segmentation algorithms produces high resolution mapping. Combining bathymetric, textural and discriminating information improves analysis and reduces ambiguity in the classification process. An interesting aspect of this procedure is its use of commercially available instruments. The procedure has been successfully tested at different, well known sites using video imaging, sediment grab samples and photography. Figure 03-D.5 shows an example of complementary data, unsupervised segmentation of 100kHz sidescan sonar with supervised segmentation based on angular dependence of backscatter coefficients from swath bathymetric sonar at 300kHz. The further development of segmentation and classification using fusion from several sensors will be conducted with the objective of producing the MCM ATP24 classification using an autonomous underwater vehicle as the sensor platform.

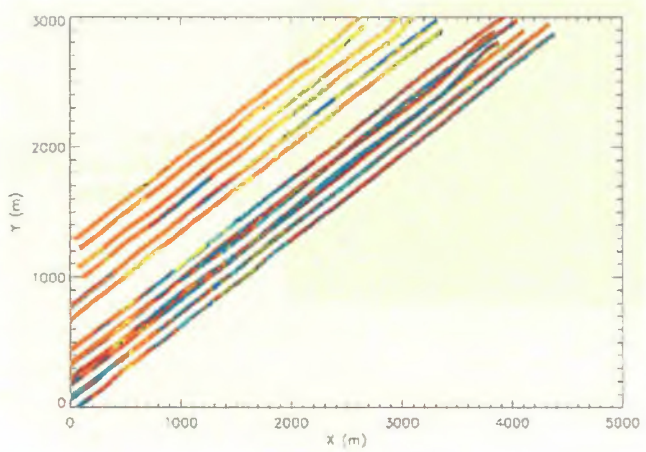


Figure 03-D.5 *Segmentation of the seabed off the northern coast of Corfu. Upper is unsupervised segmentation of 100kHz sidescan. The lower is supervised segmentation using the angular dependence of the backscatter coefficient derived from the combined bathymetry-backscatter mode of the 300kHz Simrad EM3000*

Project 03-D publications and presentations

Bergem, O., Pace, N.G. Surface wave influence on very shallow water propagation. Oceans99, Seattle.

Canepa, G., Pace, N.G. Seafloor segmentation from multibeam bathymetric sonar. European Conference on Underwater Acoustics, July 10-13, 2000, Lyons, France.

Lyons, A.P., Fox, W.L.J., Hasiotis, T., Pouliquen, E. Characterization of the two-dimensional roughness of shallow-water sandy seafloors. (i) SACLANTCEN SR-334 (ii) *IEEE Journal of Oceanic Engineering.*

Pace, N. G., Bergem, O. The influence of surface waves on very shallow water acoustic propagation. Stochastic volume and surface scattering: recent developments in underwater acoustics. Cambridge, Robinson College, 15-17 December, 1999.

Pace, N.G., Bergem, O., Pinto, M.A. Some aspects of shallow water fluctuations on SAS performance. Stochastic volume and surface scattering: recent developments in underwater acoustics. Cambridge, Robinson College, 15-17 December, 1999.

Pouliquen, E., Lyons, A. P., Pace, N. G., Orsi, T. H., Michelozzi, E. Muzi, L., Thomson, P. A. G. Evidence of the dominance of sediment volume scattering above 100 kHz.

Pouliquen, E., Zerr, B., Pace, N.G., Spina, F. Surface seabed survey using the combination high frequency sensors. Oceans99, Seattle.

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 and Lecturer in Physics since 1979. 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).

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Anthony P. Lyons received the B.S. degree in physics from Henderson State University, Arkadelphia, AR, in 1988 and the M.S. and Ph. D. degrees in oceanography from Texas A&M University, College Station, in 1991 and 1995, respectively. He joined SACLANTCEN in 1995 where he is involved in a variety of projects in the area of environmental acoustics. He is engaged in studies of high-frequency shallow-water propagation, acoustic interaction with the seafloor and high-resolution characterization of seafloor sediments. Dr Lyons is a member of the Acoustical Society of America.

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.

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.

Project 03-E: High fidelity, broadband structural acoustic scattering models for buried and partially buried mines

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.

Phase one of this project (1995-1998) focused on two-dimensional scattering from simple, highly idealized mine shapes (spheres and cylinders).

The objective of the current phase is to employ state-of-the-art finite element (FE) techniques to develop a more realistic and useful computer modelling capability for use in all research activities related to mine hunting sonar concept developments and performance predictions.

The following system requirements for the computer model have been established:

- **High fidelity**: Highest priority is the ability to model real (3-D) mines to sufficient structural detail (e.g., internal and external structural features, electronics, explosives, ballast, etc.) to provide high accuracy relative to real world conditions, thereby providing good agreement with experimental data measured at sea.
- **Broadband**: As different types of information are revealed across the frequency spectrum, it is necessary to be able to model from low to very high frequencies.
- **Computationally efficient**: The preceding requirements impose severe demands on the computational efficiency of the mathematics, numerical algorithms and computer hardware. Therefore state-of-the-art techniques are essential to providing a modelling tool which is affordable on in-house computers.
- **User-friendly**: The code is intended to be used by scientists who are not specialists in FE analysis, e.g., acousticians, signal processors, oceanographers. Therefore the code should be highly automated, in addition to having a good graphical user interface.

To meet all four requirements, two types of technology are being employed:

- a patented[1] mathematical acoustic technique using computationally efficient "infinite elements,"
- a unique, commercial FE technology which is considerably more advanced than that in conventional FE codes.

[1] US Patents 5604891, 5604893, 5963459

Mathematical acoustic technique

The acoustic environment surrounding a mine is the ocean 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 competing techniques in achieving the same solution, to the same degree of accuracy in benchmark tests and has been described as "one of those rare breakthroughs that caused the entire field of computational acoustics to re-evaluate itself and proceed in new directions"[2].

Figure 03-E.1 illustrates how finite and infinite elements will be applied, using a partially buried Manta mine. Finite elements will model the mine (e.g., casing, internal structure, mechanisms, explosive and ballast) and a small volume of adjacent water and seabed out to an ellipsoidal surface, which closely circumscribes the mine. For the remaining space "out to infinity", a single layer of the new infinite elements is sufficient to describe the full 3-D physics of any scattered field to any desired accuracy.

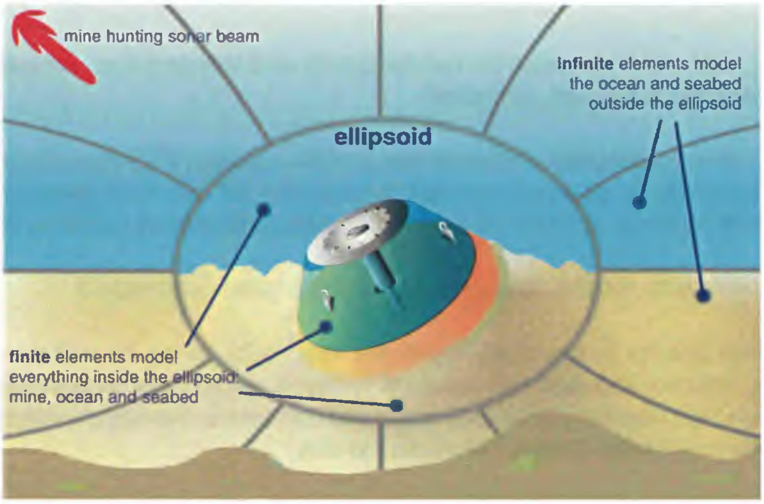

Figure 03-E.1 *Computer modelling approach for solving mine scattering problems by finite and infinite elements.*

Finite element technology

Although the infinite element technology is licensed to two commercial acoustic code developers and available in their current code releases, those codes lack other capabilities for meeting the above system requirements. Therefore, the Centre has acquired commercial FE software packages, which employ a *unique* state-of-the-art general FE technology, which is considerably more sophisticated than in other, more conventional commercial codes. Following installation and initial validation with vendor-supplied test problems, validation is continuing with Centre test problems.

The software employs full 3-D physics for all modelling, eschewing the traditional 2-D and 1-D engineering approximations such as plates, shells and beams. The additional computational costs, which normally accompany a richer physics are, nevertheless, dramatically reduced through the use of sophisticated error estimation and adaptive "meshing" algorithms. Thus, the software quantitatively estimates the discretization error

[2] J.T. Oden, Director, Texas Institute for Computational and Applied Mathematics.

throughout a model, i.e., the departure from the exact solution, which is used to automatically modify the "mesh" (computational grid) until a near-optimal mesh is created, which achieves a user-specified error at the lowest cost in computer resources. The result is a model with near-maximum computational efficiency. This, in turn, permits modelling to higher frequencies as computational costs increase exponentially with frequency.

Operationally, the analyst's task is limited to the creation of a first, coarse mesh of the mine,

Figure 03-E.2 *Half (180°) of the finite element model of the hard-plastic casing of a Manta mine.*

seabed and water, using a state-of-the-art mesh generator program. Then, upon specifying a desired error (e.g., ± 5% relative to the exact solution), the program takes over and follows the automated procedure until a solution with that error is found.

This process is illustrated by the following FE analysis of a Manta mine. Figure 03-E.2 shows a mesh for the hard-plastic casing of the mine; only 180° of the 360° rotationally

Figure 03-E.3 *Half (180°) of the finite element model of the casing and internal structural components of a Manta mine.*

symmetric structure is depicted, in order to reveal inner parts of the casing. Figure 03-E.3 shows the casing as well as the other internal structural components: the priming device (green), TNT charge (light yellow-brown), booster (orange) and water (blue), with appropriate material properties assigned to each different component. This model was then subjected to a purely structural load: a pressure exerted over a small area on the top and side surfaces, while the mine sits on a hard, flat ground. The analyst requested that the software produce a solution in which the maximum error (in strain energy) in any of the finite elements be less than 7%. Figures 03-E.4 and 03-E.5 show the resulting solution, the colour contours representing the magnitude of the computed displacement at every point on the surface, due to the deformation of the mine under the action of the applied pressure load. The view

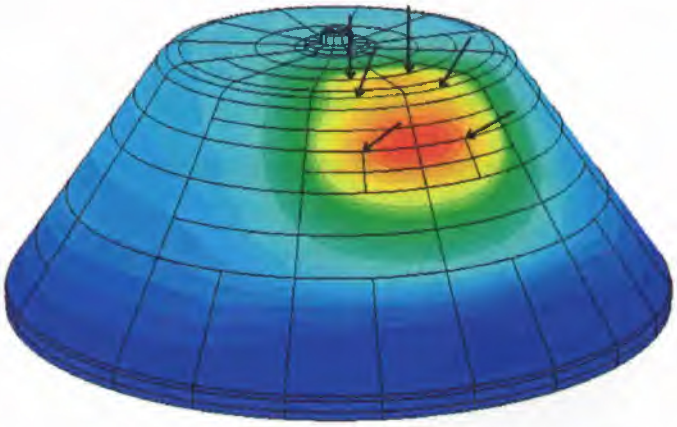

Figure 03-E.4 *Colour contours show displacement magnitude on the outside surface of the mine casing (red is maximum; blue is minimum).*

in Fig. 03-E.5 is of an interior vertical plane bisecting the mine; the plane contains the central axis and bisects the area of application of the pressure load. A comparison of the final mesh in Figs. 03-E.4 and 03-E.5 with the initial mesh in Figs. 03-E.2 and 03-E.3 reveals some of the mesh refinement that was performed automatically by the software to achieve the requested error.

Figures 03-E.2 to 03-E.5 illustrate a so-called static analysis, i.e., the equilibrium response of a structure to a load held constant in time. The software also performs dynamic analyses, i.e., the transient response to a time-varying load, with solutions displayed as animated sequences of pictures like Figs. 03-E.4 or 03-E.5, depicting the propagation of stress waves through the mine.

During the year 2000 we shall develop acoustic finite elements (for fluids), which employ the above error-adaptive technology. The code will perform in the same manner as the above structural code, except in fluids rather than elastic solids, i.e., generating animated solutions of acoustic wave propagation through fluids.

This acoustic technology will then be integrated with the structural technology to achieve the above-stated objective of this project: a structural acoustics scattering code, which will display animated sequences of pictures depicting the propagation of acoustic waves as they interact with the mine and seabed. The code will be directly applicable (without modification) to scattering from general targets, e.g., submarines. Indeed, the acoustic infinite elements were originally developed for ASW applications.

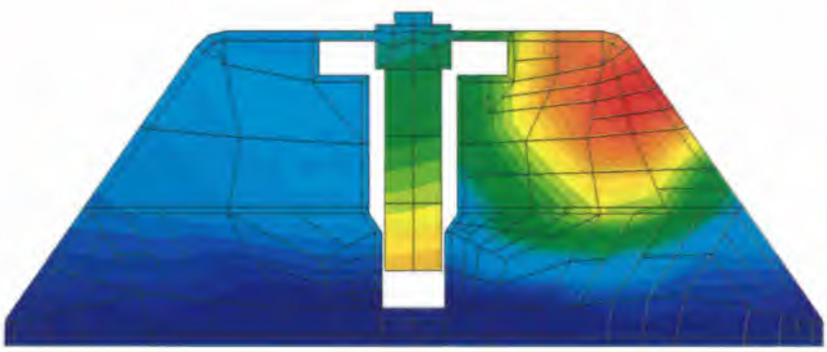

Figure 03-E.5 *Colour contours show displacement magnitude on a plane that bisects the mine.*

Project 03-E publications and presentations

Burnett, D.S. Modelling scattering from objects near boundaries using infinite elements. Acoustical Society of America conference, Berlin, March, 1999, invited paper. *Journal of the Acoustical Society of America,* **105**, 1999:1166:3aUWa4.

Burnett, D.S. Modelling scattering from objects near boundaries using infinite elements. 4th International Conference on Theoretical and Computational Acoustics, Trieste, May, 1999, invited paper.

Burnett, D.S. Numerical solution of the exterior radiation problem with infinite elements. Machine Acoustics '99, Wiesloch, Germany, Sept. 1999, invited plenary lecture.

Burnett, D.S. Development of high fidelity, broadband 3-D structural acoustic codes for scattering and radiation using acoustic infinite elements. Defence Evaluation and Research Agency, (DERA), Rosyth, Edinburgh, Oct. 1999, invited presentation.

Burnett, D.S. Acoustic infinite elements, University of Durham, Mathematics Department, October 1999, invited seminar.

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***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* Finite element analysis: from concepts to applications. *He joined SACLANTCEN in 1998.*

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.

The aim of Project 03-F is to provide NATO with a minehunting sonar performance prediction tool which is capable of interfacing to the NATO MCM planning tool, MCM EXPERT and environmental data supplied by Rapid Environmental Assessment (REA) and other sources. The tool will produce *p(y)* curves (probability of detection as a function of across track distance) and calculate A (characteristic detection width) and B_d (characteristic detection probability) values as required by MCM EXPERT. Figure 03-F.1 illustrates where the tool to be developed by Project 03-F fits with MCM EXPERT and REA data (or environmental data from other sources).

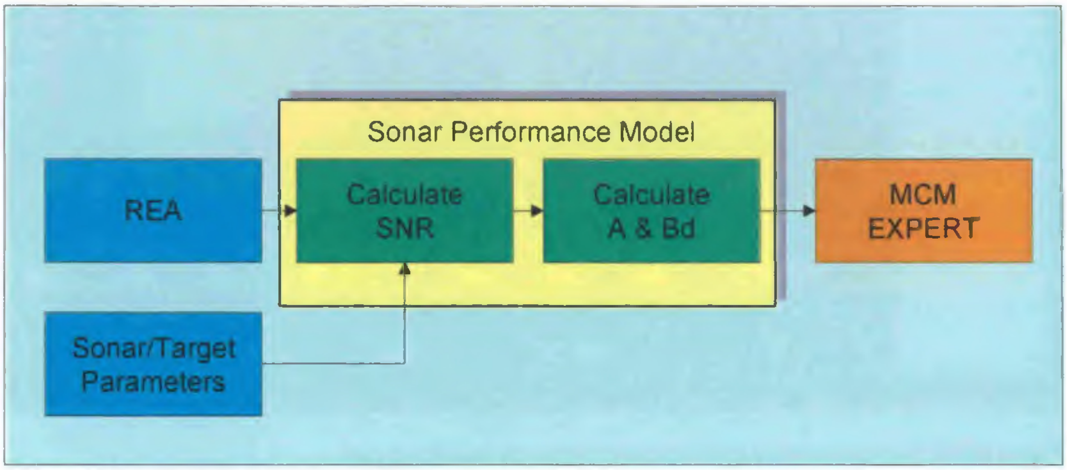


Figure 03-F.1 *Interfaces between the minehunting sonar performance model, environmental and target data and the NATO MCM planning and evaluation tool MCM EXPERT.*

This project aims to incorporate the best acoustic sub-models available from SACLANTCEN and other research centres. The research at the Centre on target modelling (Project 03-E) and seabed scattering (Project 03-D) is particularly relevant. The Centre's acoustic propagation expertise is being used to select a suitable propagation model, which includes multipaths, particularly important in shallow water environments.

A study is in progress to define the sub-models which will be used and to develop a preliminary design. Visits to government laboratories in the US, Germany, UK and Netherlands have been made, to establish which minehunting performance tools and sub-models exist and to ensure that the tool is state-of-the-art. The project will make use of existing tools and sub-models to avoid "re-inventing the wheel".

The preliminary design work has focused on adapting different acoustic sub-models and environmental descriptions, without having to re-write code. This is achieved by defining an "interface" for each major element in the model. "Adapter Classes" may be used to convert between incompatible interfaces. These are analogous to electrical adapters which provide a means of connecting incompatible electrical plugs and sockets. For example, if the environmental parameters describing the seabed do not match the parameters required by the bottom scattering sub-model, it may be possible to use an "Adapter Class" to provide a conversion.

Software prototyping is being used during the study to experiment with methods of allowing acoustic sub-models to be added without changing code in a "plug & play" style. Prototyping has also been used to develop aspects of the user interface. Figure 03-F.2 is an example from the prototype software, which is used to display the output of various acoustic sub-models showing seabed scattering strength in dB, from the McKinney and Anderson algorithm, as a function of grazing angle (abscissa axis) and bottom type (ordinate axis)..

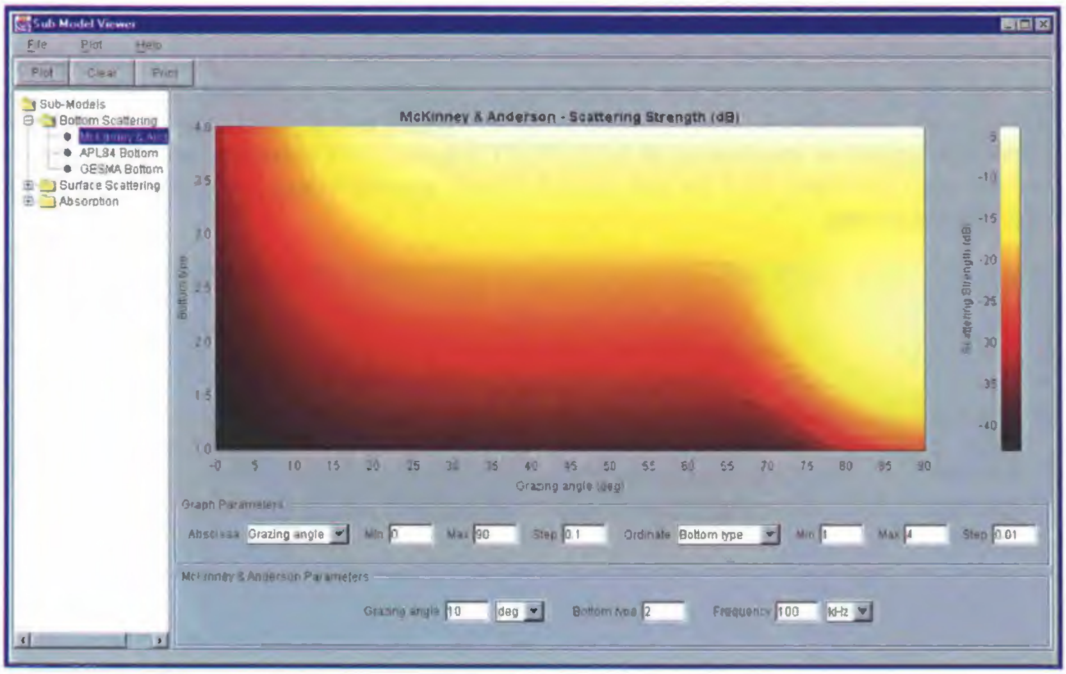


Figure 03-F.2 *Prototype software example showing bottom scattering strength*

Thrust 04 Tactical Active Sonar (TAS)

Project 04-A: Advanced active sonar (Alliance days – 31, Manning days - 2)

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

Background

Towed-array based active sonar (ATAS) systems have been the subject of evaluation and study at the Centre since 1981. The major challenge is to better discriminate between the threshold crossings caused by false targets and true target returns. The data contain more target information than can be extracted with available algorithms for signal/data processing and sonar information extraction. Future systems will have the potential to ensure exploitation of improved understanding of underwater acoustics, computer technology and the development of new algorithms.

The Active Towed Array Sonar (ATAS) was upgraded by implementing a broadband R/L directional cardioid towed array comprising two octaves, high capacity data acquisition and programmable real time processing system (CDAS). When the broadband, high power sound source is delivered in March 2000, the Centre will be well positioned to study advanced system concepts for signal/data processing and information extraction, which in the short to medium term could be exploited during the development and subsequent phases of national mid-life conversion and upgrade programmes.

Research has concentrated on

- investigating the potential of the cardioid array
- investigating the potential of broadband sonar signals
- defining a Measure-of-Performance (MOP) applicable to algorithms aiming at clutter reduction
- planning and executing the Joint Research Project (JRP) sea trial MERCURY 99 in conjunction with the Defence Evaluation and Research Agency (DERA).

Cardioid arrays

Conventional active towed-array sonar suffers from the problem of ambiguity. It is impossible to distinguish between returns from port and starboard. Although operational methods for overcoming this problem exist, they are time consuming, cannot be used for single ping applications and do not provide additional processing gain against reverberation.

France, Germany, the Netherlands and the United Kingdom are investigating equipment based solutions to the problem. One proposal is to use an array of triplet hydrophones. Such an array, also called a cardioid array, using state-of-the-art sensor/telemetry technology covering two octaves has been procured. The array comprises 126 hydrophone triplets implemented in a nested configuration.

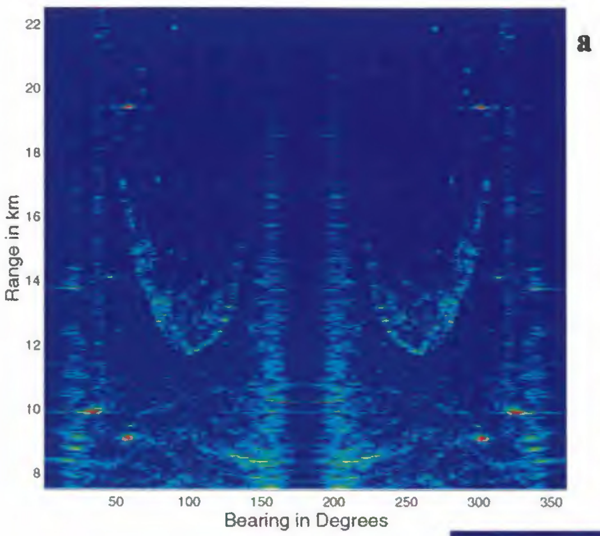
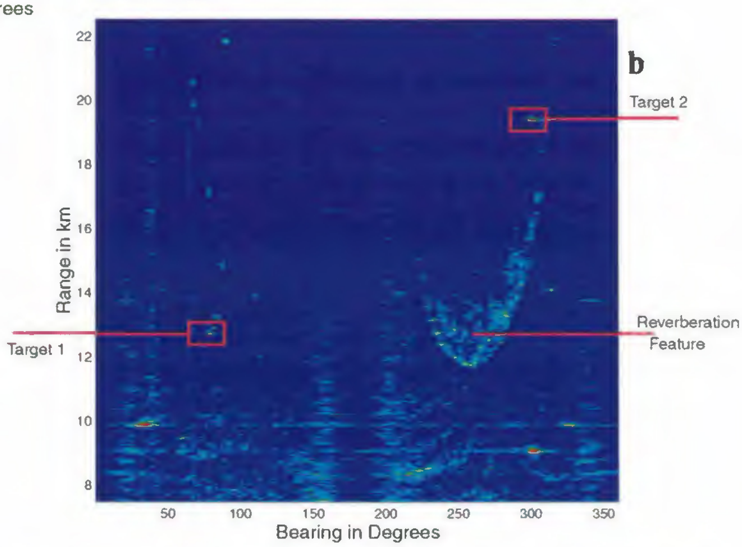


Figure 04-A.1(a) *Range-Bearing Detection display (B-scan) derived from a conventional linear array. All features are symmetrically distributed around the 180 ° degree bearing that corresponds to endfire-aft. The R/L ambiguity problem is evident. 04-A.1(b) The same data analyzed using the signals from the hydrophone triplets. Features have been resolved to port or starboard. Important features have been labelled.*



The decision to procure a cardioid array does not imply that it is, in principle, superior to other concepts such as the twin array approach. It was primarily specified as a research tool to be used at low speeds, for investigating broadband underwater acoustics (clutter/reverberation up to 3600 Hz) and related signal/data processing issues, more efficiently than would be possible with a traditional R/L ambiguous array.

Investigation of the new technology and algorithms, (one of which can be used with the real-time system over a broad range of frequencies) has been facilitated by the use of data acquired during BACCHUS'98 (a JRP with DERA) using the DERA 40 triplet array. Run geometries between Malta and Sicily were combined with known bathymetric and reverberation features, which would allow investigation of left-right discrimination.

The following results from the BACCHUS'99 trial demonstrate the versatility of the triplet array which can be used to improve sonar performance and investigate environmental acoustic problems such as reverberation and clutter.

Figure 04-A.1 shows typical B-scans from BACCHUS'98. Figure 04-A.1(a) shows the range-bearing sonar display as it would be derived from a traditional ambiguous array. Features are replicated to starboard (180°- 360°) and to port (0°- 180°). The bow shaped returns from a reverberation ridge, a feature which has been measured and observed frequently, obscures back-beam targets. Figure 04-A.1(b) shows the same data after the 2-step cardioid BF algorithm has been applied. The reverberation ridge has been resolved to starboard (in agreement with known ground truth) and the bright features between 8 and 10 km have been separated to port and starboard. Similarly, targets of opportunity have been resolved (denoted as target 1 and target 2).

A more quantitative measure of R/L ambiguity resolution is the suppression ratio of the echo level of the true beam *versus* the echo level in the ambiguous beam. It can be derived by analyzing the received signal levels as a function of bearing, i.e., by looking at the directional A-scan. In Fig. 04-A.2, three A-scans are shown containing returns from three different targets (1). Two of the three targets can also be detected in the ambiguous directions (2). In the top scan the return (1) is due to the Campovega oil platform. In the opposite, ambiguous beam, the respective echo level (2) is significantly lower, resulting in a suppression ratio of about 12 dB. The middle scan shows the reverberation ridge clearly displayed to starboard, with no corresponding signal in the opposite, ambiguous beam. In the third scan, a bright, bottom feature can be seen to starboard. The corresponding signal (2) in the ambiguous bearing has been reduced by about 10 dB. One extra feature has been indicated in this figure: passive ship noise has been resolved to starboard. This highlights the possible use of the triplet array in passive mode as well as for active systems and demonstrates the advantage of R/L directivity on the receiver rather than on the source.

Higher suppression ratios than those mentioned have been observed for returns from "point-like" scatterers in specific scenarios. It has been possible to show that this performance can, by judicious choice of algorithms, be extended to scan angles up to 60° from broadside. The suppression ratio is not however the only performance parameter which influences the beam former design. In the presence of poorly correlated noise, the resolution of R/L ambiguity is at the expense of sensitivity. This loss of sensitivity increases with decreasing frequency or decreasing intra-triplet hydrophone spacing. Consequently, for some scenarios, such as flow noise limited operations, the performance of R/L suppression algorithms may be severely degraded. What may be required is a BF concept which allows adaptation to the characteristics of the noise at the triplet hydrophones and to the directional distribution of reverberation/clutter.

To further illustrate the processing gain against reverberation, a target track based on the same triplet hydrophone data set is shown in Fig. 04-A.3 as a 40-ping history, applying the conventional, linear-ambiguous beamformer (a) and the cardioid beamforming algorithm (b). The abscissa and ordinate show range and beam number (discrete bearing values), respectively. Each of the 40 pings has been interleaved on a beam to beam basis. In Fig. 04-A.3(a) returns from the target and the reverberant ridge, although from opposite directions, cannot be separated. The reverberation returns almost mask the target track. In Fig. 04-A.3(b), the target track and the reverberation ridge have been resolved to port and starboard, respectively. Consequently, a much brighter target track can be observed.

Broadband processing

Sonar signals covering a broad frequency spectrum, e.g. 1-2 octaves, have potential to improve sonar performance under reverberation limited conditions for two reasons. First, large bandwidths result in very small range resolution cells. Application of proper "post-detection" integration reduces fluctuations in target echo and reverberation level, resulting in a better SNR at the detector input. Second, large bandwidth signals are suitable for

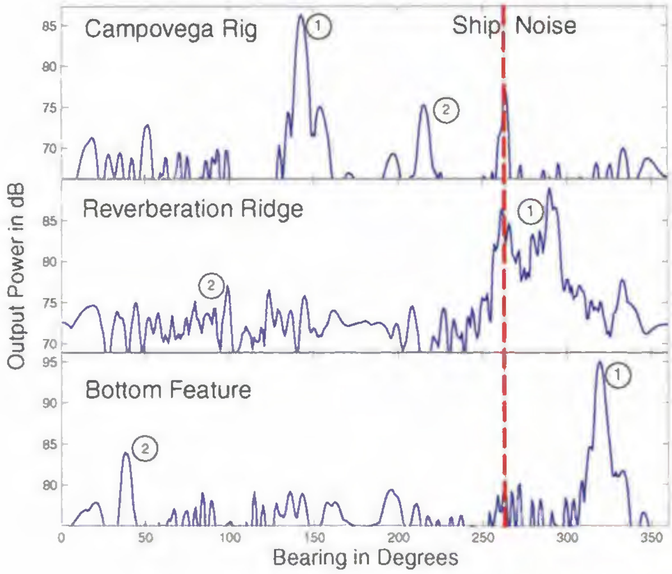
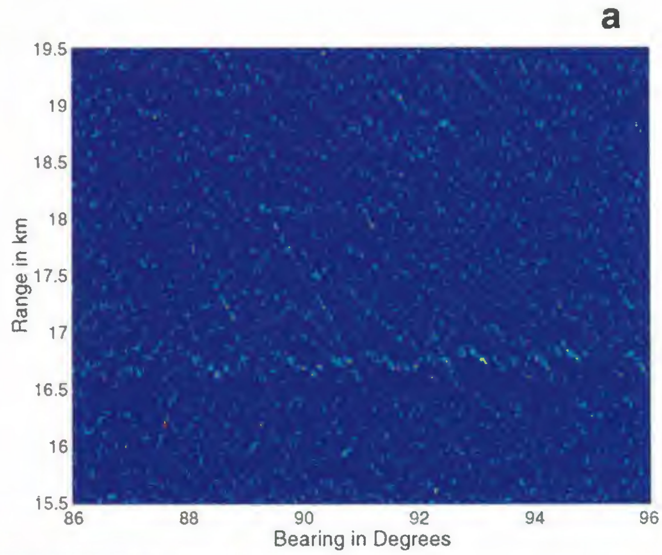


Figure 04-A.2 *Three examples of directional A-scans i.e. received signal levels as a function of bearing using data from the cardioid array. Returns from three targets (1). Two of the three targets can also be detected at lower levels in the ambiguous directions (2). Suppression ratios for target amplitudes in the true versus the ambiguous bearings range from 10 to 12 dB.*



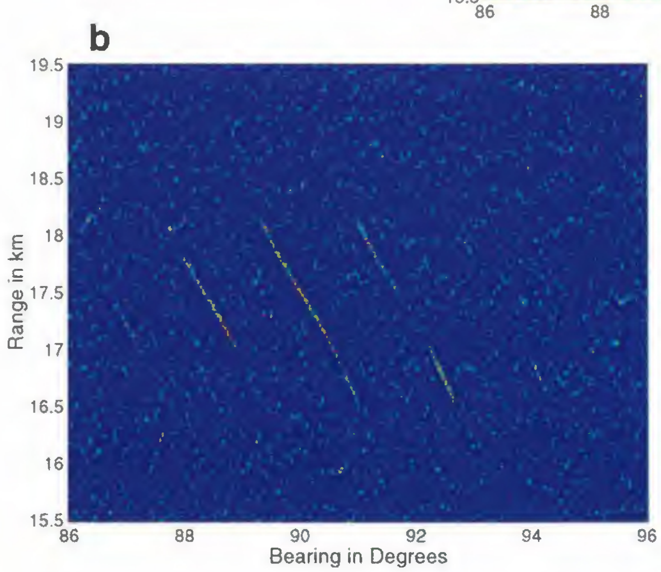


Figure 04-A.3 *Forty pings of data interleaved to give a history of a target track. Multiple tracks in adjacent beams are due to sidelobe leakage. The data were obtained for a target 'apparently' passing through reverberation, i.e., physically the target and reverberation patches were in a pair of ambiguous beams. Traditional processing (Fig 04-A.3a) makes them appear to be physically co-located. Only a weak target track can be seen due to the ambiguous reverberation background overlaying the target returns. (b) Using the triplet array, the reverberation returns and the target echoes are separated into their respective beams and the target can be seen clearly over the entire track.*

applying sub band processing techniques, which exploit the frequency dependence of detection performance. There are indications that detection performance (e.g. SNR) across frequency bands varies significantly with time. The reason for this is that many of the terms in the sonar equation such as transmission loss, boundary backscattering strength, true/ false target strengths, scattering statistics and transmission loss statistics, depend on frequency, time and space. The challenge is to design a fusion concept which combines the SNR from all frequency bands in such a way that the resulting global detection performance is maximized.

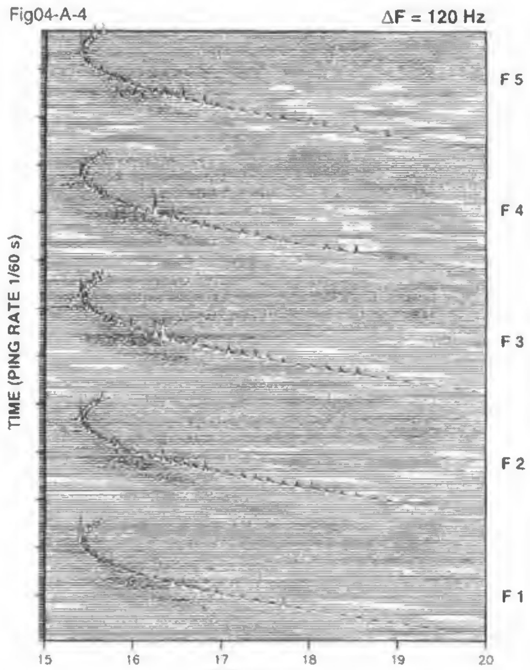


Figure 04-A.4 *Matched filter output signals of five sub-bands arranged with increasing centre frequency from bottom F1 to top F5. Considerable fluctuations in echo shape and amplitude as a function of space, time and frequency are visible and suggest that the underlying statistics may be used for choosing an optimum detector scheme.*

Broadband (1200 Hz) linear FM signals of 12 s duration centred around 3 kHz were transmitted. A sub-band matched filter processing scheme was applied to divide the band into ten sub-bands. Individual echo signals from 5 different sub bands (Fig. 04-A.4) and the signal-to-noise ratios for each sub-band signal (Fig. 04-A.5) are shown for a sequence of 50 and 140 pings, respectively. There is no single sub-band in which the *average* signal shape and SNR is distinctly different from other sub-bands. Ping-to-ping comparison, however, reveals rapid changes of echo shape and SNR. The detection scheme will depend on the underlying fluctuation statistics. The final scheme will be selected after the features corresponding to *false* targets have been examined.

Another advantage of FM sub-band processing is that the relative velocity between source and receiver (range rate) can be estimated based on a single ping observation, i.e. without ping history which

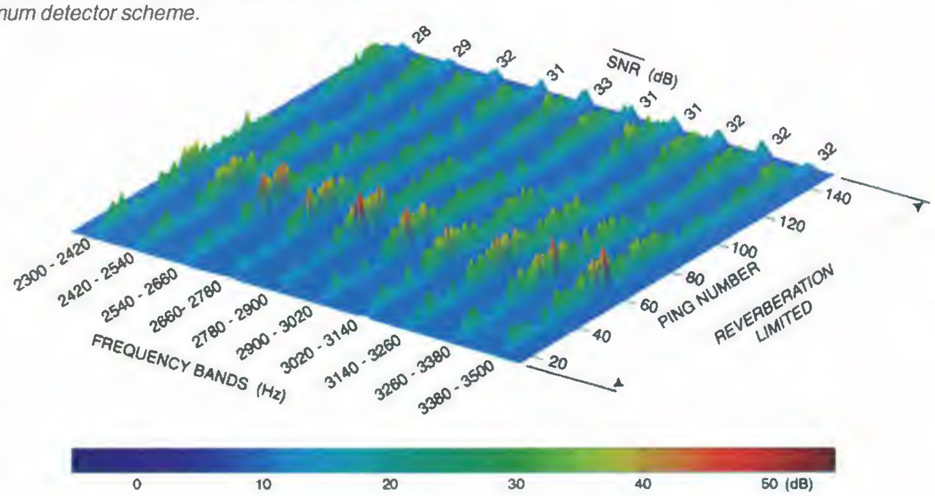


Figure 04-A.5 *SNR as a function of the centre frequency for 10 consecutive 120 Hz sub band signals in a reverberation limited environment. For each sub-band, the average SNR for the entire run is indicated. Although the average SNR is not differing much, it is not obvious that simple cross band averaging is the best detector strategy especially around the low SNR situation around ping 100.*

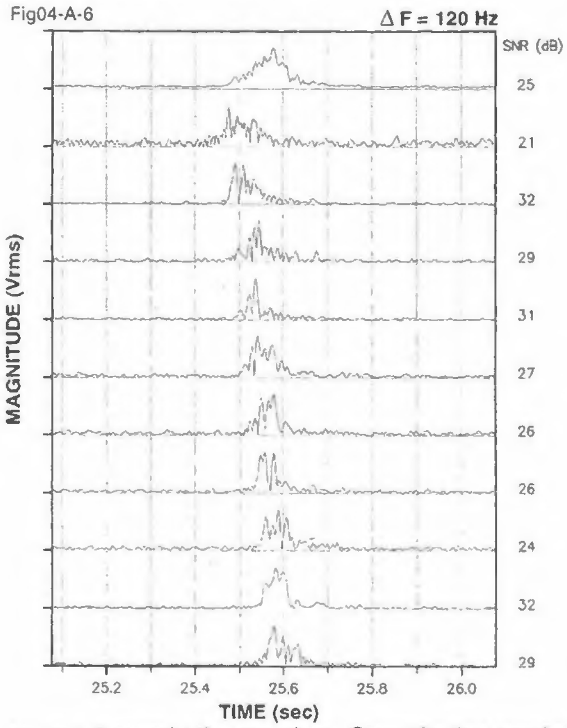


Figure 04-A.6 *Normalized intra-ping sub band echoes signals with SNR estimates for each sub-band indicated on the right of each signal. The differential time delay between the sub-bands is shown. The top plot represents the normalized average of the individual outputs. Note that the echoes from different sub bands are uncorrelated. SNR differences of up to 10 dB, the Doppler-induced differential delays and the relatively low SNR of the sum signal (top of this figure) suggest detector schemes different from simple averaging.*

would allow range rate estimates from inter-ping delay measurements. Figure 04-A.6 shows the decreasing intra-ping delay/travel times between the echoes from the lowest and the highest sub-band received during the closing part of the run. This is explained by combining the facts that the high frequencies are transmitted last (up-sweep pulse) and that during transmission time the target moves towards the receiver. Quantitative analysis of the measured delays has to take into account the well known Range-Doppler ambiguity of the FM pulse. It has been shown that there exists a mathematical relationship between the true range rate and the sub pulse time delays. Figure 04-A.7 presents the comparison between the actual (inter-ping) and the intra-ping rate both without (a) and with (b) Doppler compensation. Without Doppler compensation the range rate which is derived from the differential intra-ping time delays differs from the nominal value by a factor of 2.

Figure 04-A.6 reveals three other interesting facts: First, the echo signatures in each sub band are uncorrelated. Second, the S/N ratio is varying by as much as 10 dB. Third, simple averaging of the sub band signals (top signal in Fig. 04-A.3) provides a SNR of 25 dB, which is much less than the best SNR of the sub band signals. This suggests two detector strategies: "k out of n" rule or sub band averaging *after motion compensation* of the differential delay times.

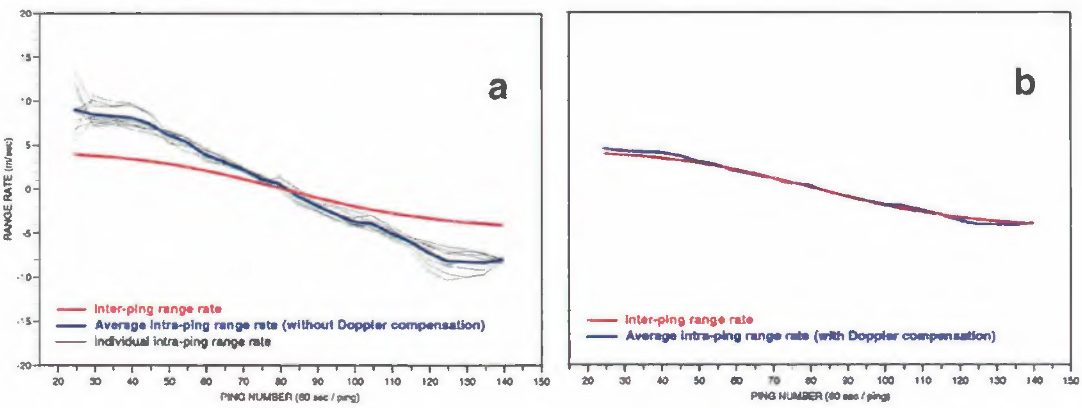


Figure 04-A.7 *Comparison between inter-ping (red) and intra-ping range rate estimation without (Fig. 4-A.7a) and with (Fig.04-A.7b) Doppler compensation. Range rate estimation from sub band delay time measurements within one ping is feasible, but requires a Doppler-independent correction factor.*

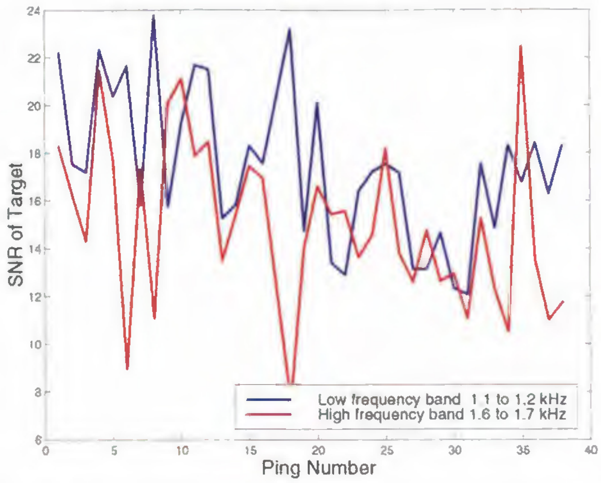


Figure 04-A.8 *SNR for a sequence of 40 target echoes as simultaneously observed in two different frequency bands. The data were taken during the BACCHUS 98 trials and demonstrate that the lower band delivers SNRs which are on average about 3 dB higher than in the higher band. Both frequency bands are 100 Hz wide and separated by 500 Hz.*

An example, which may prove that detection performance is frequency dependant was taken from BACCHUS 98 data. Figure 04-A.8 depicts the SNR for a sequence of 40 echo signals processed at two frequency bands 100 Hz wide and separated by 500 Hz. The lower frequency band provides on average 3 dB more SNR, although the reverberation patch size is larger than for the higher frequency band. A detection scheme for optimally combining the detection results from both bands is still a challenge. The solution again will depend on the in-band SNR fluctuation statistics. More data have to be analyzed to better determine these characteristics.

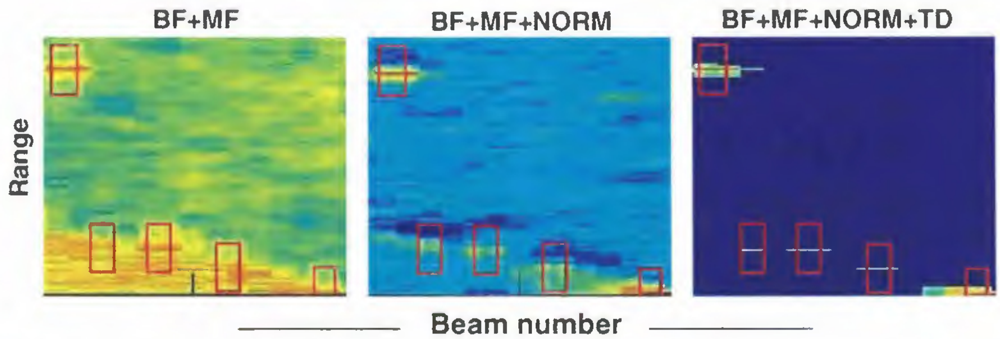


Figure 04-A.9 *Unnormalized Range-Bearing sonar image generated from the receive signal amplitudes of each beam (left), the same data set after normalization (middle), the same data set after thresholding (right). Rectangles are 1 x 1 km. This series of displays allows an operator to classify alarms by reviewing the normalized/unnormalized sonar displays to determine if a contact could be due to e.g., a reverberation edge, similar to the bottom four contacts in the right hand image.*

Measure of performance (MOP)

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

We have defined a new measure of performance which, in a ping of data, makes objects of connected pixels. The aiming point of the object, which is usually the data mass-center, defines the estimated 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.

During the evaluation phase of the MOP a very useful graphical tool for classifying alarms was implemented. The underlying concept, which has been used successfully for some time, is explained in Fig. 04-A.9. The raw sonar image generated from the receive signal amplitudes of each beam (left), the same data set after normalization (middle), the same data set after thresholding (right). The images from left to right contain progressively less information. The operator is alerted by the alarms in the easy-to-scan detection display at the right and can revisit the preceding images concentrating on an area (e.g. 1 × 1 km) around each alarm. Thus he can regain information needed for classification which has gradually been removed during the process of generating the detection display. For the data shown in Fig. 04-A.9 the operator would conclude that the bottom four contacts could be residuals from the returns from a reverberation ridge. The system also allows the operator to examine the relevant sections of the original A-Scan signals.

Page test

The Page test algorithm was designed to detect the beginning and ending of a signal in a stationary background. The Page test has not yet been compared with the standard threshold detector on a large real data set, but it has been compared to the threshold detector for real data, consisting of 164 pings of active FM transmissions, using the measure of performance described above. The result can be seen in Fig. 04-A-10. The red curve shows the Page test detector, the blue curve the threshold detector. The Page test shows superior performance over a large region of sensible parameter values. For example, at 200 false alarm objects, the Page test detector has 20% higher probability of detection than the threshold detector.

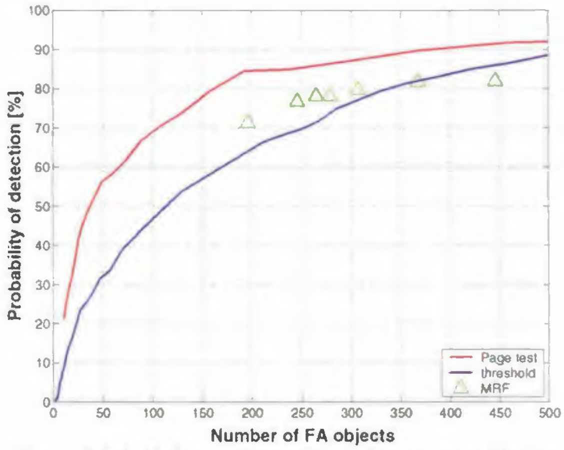


Figure 04-A.10 *Comparison of Page test detector, Markov random field segmentation and threshold detector. The red curve relates to the Page test detector, the blue curve to the threshold detector and the symbols to the Markov random field segmentation. The Page test shows superior performance over a large region of sensible parameter values. The Markov random field segmentation results are between the Page test detector and the threshold detector.*

The interplay between the measure of performance (object counting) and the Page test are shown in Fig. 04-A.11. The fragmented reverberation returns belonging to the same bottom feature, cause many detections in the threshold detector, but are seen to be combined by the Page test into one detection.

Interbeam clutter reduction

Operating a low frequency active sonar in shallow water results in a large number of target like clutter returns. An automatic method of image segmentation using Markov Random Field modelling has been used to reduce clutter. The method looks at detections over range and bearing. It removes small objects which do not exhibit the right signature over beams. Separate detections corresponding to one large object are combined to form one single object. Objects too large to be a submarine can then be removed.

The Markov Random Field model used is based on the physical and probabilistic knowledge of the sonar picture. It assumes that, statistically, a target has, on average, a larger SNR and that, on a local scale, the sonar display exhibits homogeneity. The model is tuned to remove as much clutter as possible while retaining the target.

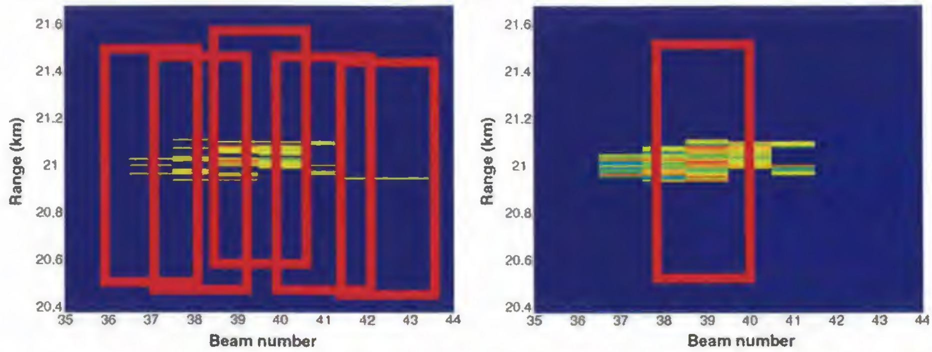


Figure 04-A.11 *Effect of Page test detection (at the right) compared to threshold detector (at the left) on a bottom feature. The threshold detector has fragmented the bottom feature into many separate detection objects. The Page test detector interprets them as one single object.*

In Fig. 04-A.10 the result of the Markov random field segmentation, denoted by the symbols, is compared to the Page test and threshold detector. For the single ping case, performing Markov random field segmentation has no advantage over just performing the Page test detector.

The Markov random field segmentation algorithm was designed to merge separate returns from one geophysical object. As the detection of large geophysical objects is irreconcilable with the detection of a small submarine, use of a single algorithm is not indicated. The Markov random field segmentation can still be used to detect large geophysical objects, which can be removed, providing that size or geological position do not change.

MERCURY 99

The JRP with DERA *Broadband Active Multistatic Sonar*, shares equipment, resources, technology and acoustic data for the purpose of investigating issues related to broadband active sonar, right/left directional receive arrays and active multistatics. A series of collaborative at-sea experiments are being conducted with one major annual sea trial. The objective of MERCURY '99 was to evaluate broadband transmissions, technology and processing techniques.

SACLANTCEN technicians installing transducers and hydrophones on the Italian submarine Sauro in Agusta for the Joint Research Project, Broadband Active Multistatic Sonar experiment

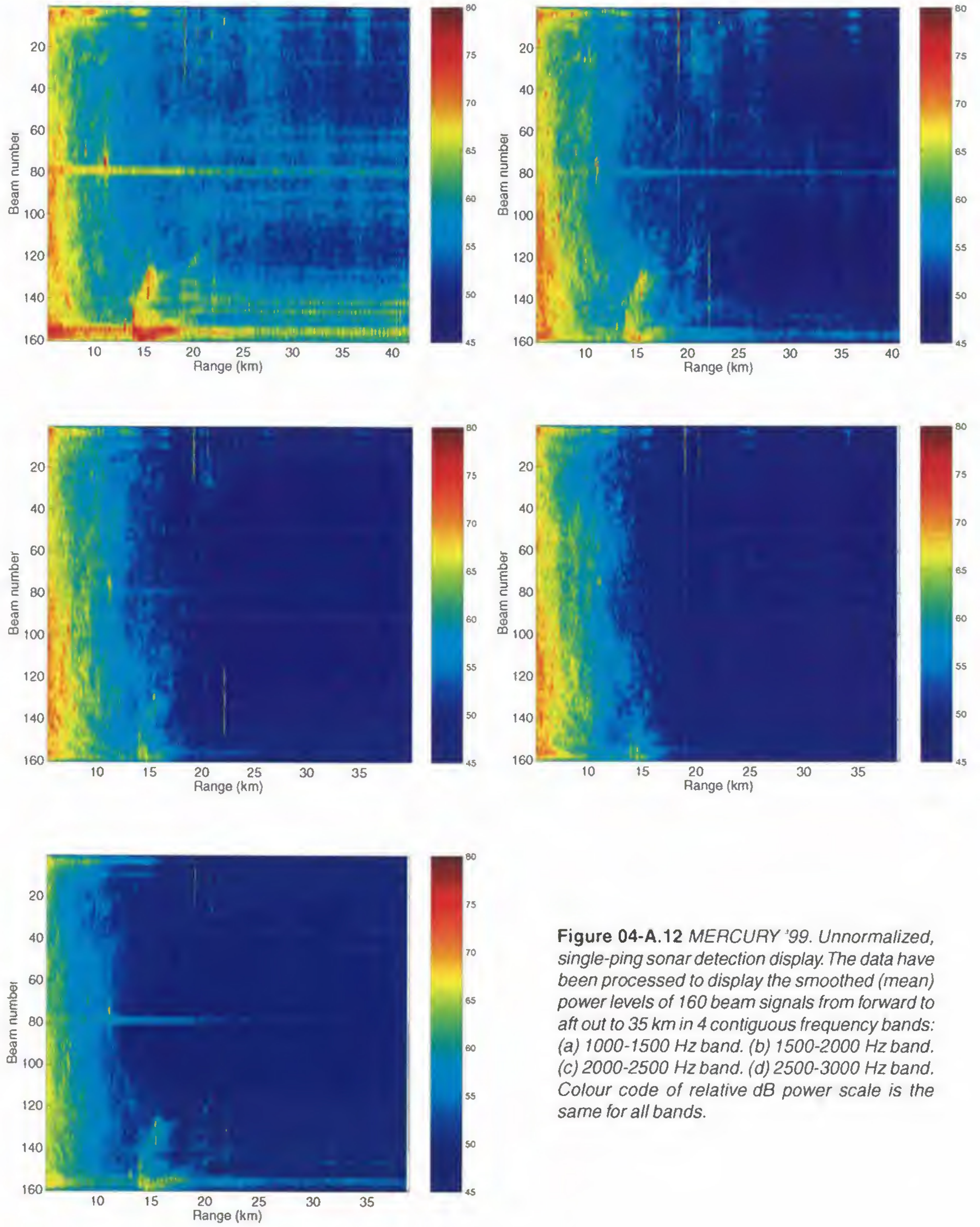


Figure 04-A.12 *MERCURY '99. Unnormalized, single-ping sonar detection display. The data have been processed to display the smoothed (mean) power levels of 160 beam signals from forward to aft out to 35 km in 4 contiguous frequency bands: (a) 1000-1500 Hz band. (b) 1500-2000 Hz band. (c) 2000-2500 Hz band. (d) 2500-3000 Hz band. Colour code of relative dB power scale is the same for all bands.*

The experiment was conducted primarily in the Malta Plateau, south of Sicily. The water depth in this area is 100-200 m, with high levels of reverberation and clutter. Participating assets included the *R/V Alliance* (broadband acoustic source, two broadband towed receive arrays and command and control functions), the *ITS Tavolara* (echo repeater) and the *ITS Sauro* (submarine target). DERA provided the broadband acoustic source and a broadband receive array (including real-time processor). SACLANTCEN provided the broadband R/L directional receive array (including real-time processor), echo repeater.

Data was recorded with broadband (1000-3400 Hz) active transmissions on two separate broadband towed arrays. Figure 04-A.12 shows data from a single transmission. The broadband phone data from the SACLANTCEN array were processed over contiguous frequency bands of 500 Hz bandwidth. One hundred and sixty beams are formed from forward to aft and the smoothed (mean) power levels are shown out to 35 km with the same relative dB power scale. Looking at the overall colour distribution one recognizes features which are different for each frequency band, such as the background noise level and the reverberation returns from the Ragusa Ridge at around 15 km and beams 65-80. Diffuse reverberation, immediately following the direct blast with similar intensity and decay rate show little dependence over the four frequency bands. Other passive and clutter features are also evident in these data. Data such as this will allow evaluation of the frequency dependence of some of the most prominent parameters of the sonar equation.

The photographs on this page show the hydrophones installed on the Italian submarine Sauro

Project 04-A publications and presentations

Haralabus, G. Broadband processing, NG-2 meeting presentation, SACLANTCEN, September 1999.

Haralabus, G., Capriulo, E., Zimmer, W.M.X. SWAC 4: Broadband data analysis using sub-band processing, SACLANTCEN SR-320.

Hughes, D. Aspects of cardioid processing, SACLANTCEN SR-329

Laterveer, R. MRF segmentation for low frequency active sonar: further results, SACLANTCEN SR-330

Levesque, I., Bondaryk, J. Performance issues concerning Doppler-only localization.

van Velzen, M.R., Laterveer, R. Performance measurement in active sonar using object counting, SACLANTCEN SR-331.

__Jochen Ziegenbein__ studied applied physics and mathematics at the Christian-Albrechts Universität, (from which he received his PH.D), Kiel and the Technische Universität, Berlin. From October 1996 until internal reorganization in December 1998, he was Chief of SACLANTCEN Systems Research Division. In January 2000, he became Head of the SACLANTCEN Signals and Systems Department and leader of Project 04-A, Advanced Active Sonar. He has been active in passive/activated towed array, torpedo and mine hunting sonar research since 1970, as Branch Head, Signal Analysis and Classification at the Forschungsanstalt für Angewandte Naturwissenschaften, Wachtberg-Werthoven and Branch Head, Sonar Methods at the Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik, Kiel.

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

__David Hughes__ received his Ph.D. in theoretical physics from the University of Durham in 1987. After working in the fields of signal processing and chaos theory, he moved to DERA (Malvern) in 1993, where he worked on advanced algorithms for radar and sonar applications. Since 1997 he has worked at SACLANTCEN in the areas of signal and information processing.

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

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

Project 04-B. Deployable Underwater Surveillance Systems (DUSS)
(Alliance days – 16, Manning days - 4)

Operational relevance

An active sonar concept comprising a network of small, autonomous sources and receivers designed to optimize multistatic operation against small targets in shallow and coastal waters, with heavy shipping traffic and strong reverberation.

Concept demonstration and performance study

The following goals were achieved:

- Demonstration of the DUSS concept at sea.
- System performance estimation of monostatic and multistatic receivers in a wide range of conditions.
- Assessment of tradeoffs between performance and sonar resources.
- Assessment of coverage extension *via* additional multistatic receivers and target aspect diversity.

Echo fluctuations and diversity

Significant random fluctuations of echoes from real targets and the Echo Repeater were observed, using CW and FM pulses. A statistical analysis of echo signal-to-noise ratio (SNR) was effected, using calibrated, aspect-independent returns from the Echo Repeater. Fluctuations were decomposed into a slowly-evolving, low-pass component (Fig. 04-B.1) and a white random process. (Fig. 04-B.2). The latter component strongly affects detection performance of individual DUSS receivers. It was demonstrated to be uncorrelated in space (buoy-to-buoy), time (ping-to-ping) and frequency (CW pings in adjacent bands). The

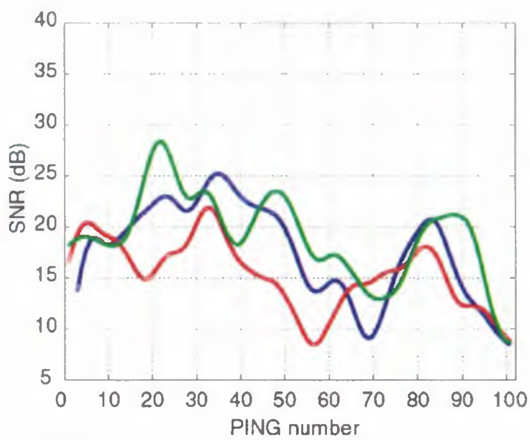


Figure 04-B.1 *Long–term components of signal fluctuations.*

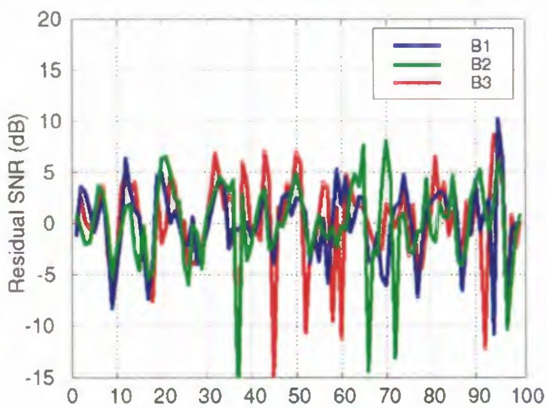


Figure 04-B.2 *Short–term, uncorrelated components of signal fluctuations*

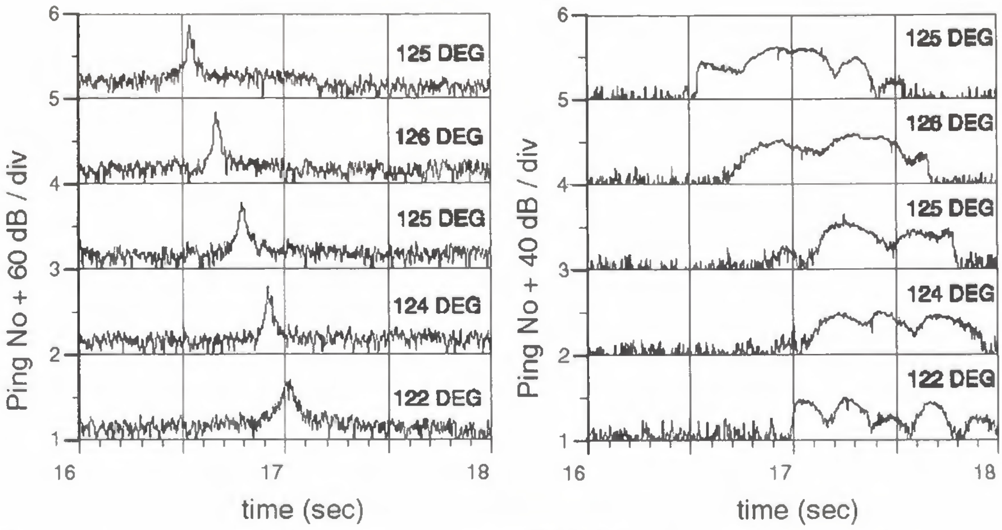


Figure 04-B.3 *A zoom view of echo signals shows that multipath effects come and go from ping to ping.*

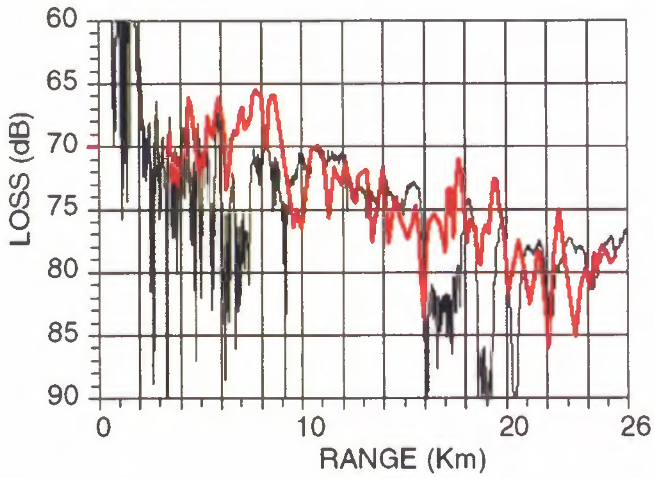


Figure 04-B.4 *A comparison between measured propagation loss (red) and C-SNAP model (black) shows the impact of propagation loss patterns and target movements on signal fluctuations*

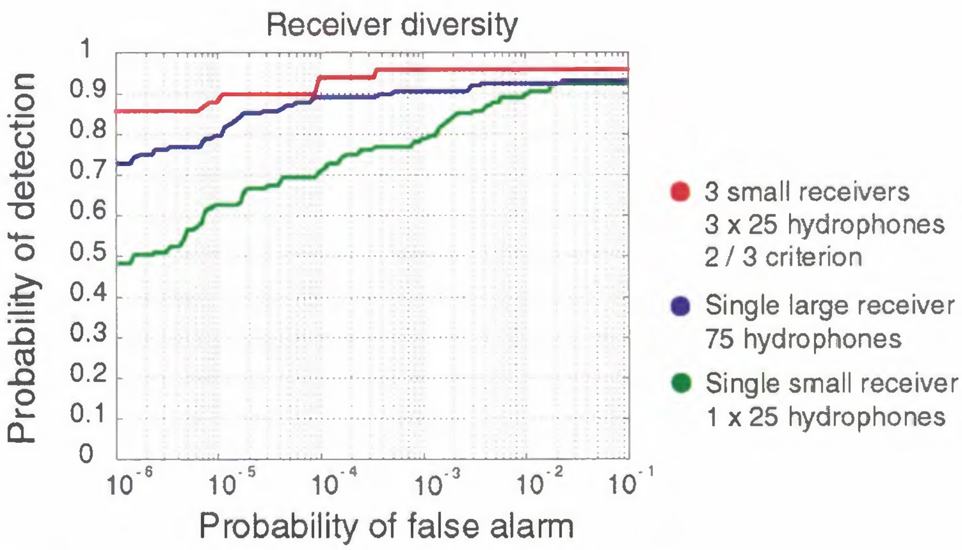


Figure 04-B.5 *System detection performance enhancement when the receivers are integrated into a multistatic system.*

relationships between multipath (Fig. 04-B.3) and measured *versus* predicted propagation loss (Fig. 04-B.4) were analyzed and detection performance improvements were quantified in terms of equivalent SNR gain and ROC curves (Fig. 04-B.5). Such "diversity" gain is additional to the typical "aspect diversity" of multistatic sonar with real targets.

Contact consistency, localization, fusion, tracking

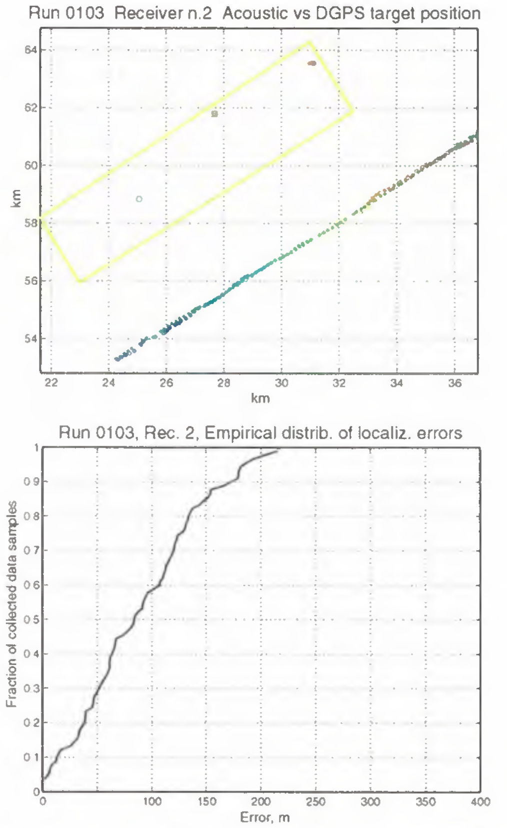


Figure 04-B.6 *Contact localization consistency of DUSS networks was analyzed as a function of system characteristics.*

The DUSS network of deployed transmitters and receivers integrates and reduces acoustic data into a comprehensive, coordinated tactical picture of the monitored waters. This is possible because the contacts from the buoys are geometrically consistent (Fig. 04-B.6). Contact fusion is therefore possible, with enhanced detection performance and target localization performance. The advantages of multistatic systems were demonstrated by comparing passive listening (bearings only), active sonar (time delay) and autonomous underwater vehicle support (AUV) (pinger pulse delay) (Fig. 04-B.7). The option of in-buoy tracking and data reduction prior to data fusion is being studied. The evident advantage consists of reduced and therefore more robust data flow between buoys. The study will quantify overall detection performance, diversity gain and localization precision.

Development of a new DUSS prototype receiver.

A prototype receiver, designed and constructed at the Centre completed engineering tests in December. The system architecture definition has been finalized. A prototype was deployed during SIRENA '99 and GEOSCAT '99.

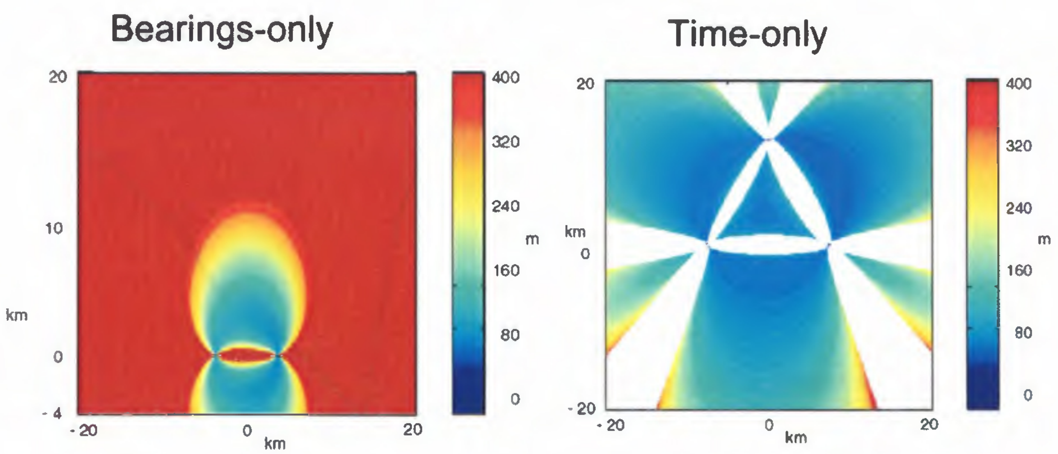


Figure 04-B.7 *Contact localization performance of DUSS networks in passive (bearings-only) mode and in active sonar (time-only) mode. Colour maps show expected localization errors versus target position.*

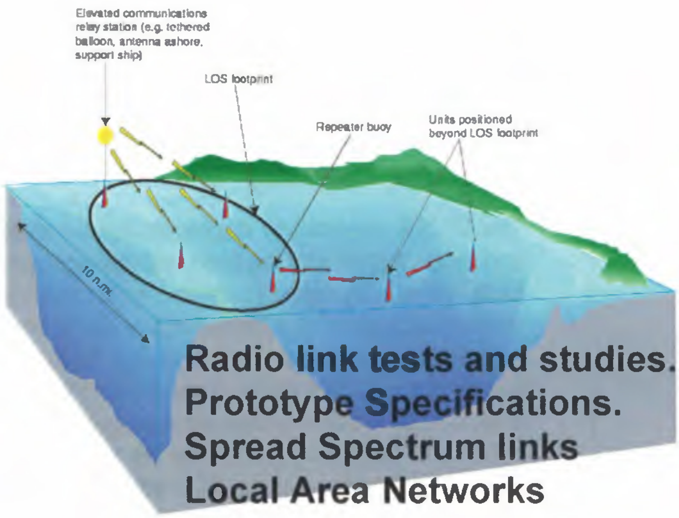


Figure 04-B.8 *Radio network techniques implement the "sonar Internet" of DUSS units for experiments.*

The system parameter tradeoffs and environmental factors affecting long-range, digital radio links were analyzed with the support of E/M propagation modelling.

A theoretical study was carried out on the applicability and potential of spread-spectrum network techniques to DUSS buoys. Sub-systems were procured in order to implement tests at sea and validate the model-based predictions.

Specification, bid and procurement of DUSS transmitter and receivers.

An advance performance specification has been forwarded to potential bidders. The specification will be finalized by the end of the year. Bids will be requested by January 2000 and offers will be finalized by July 2000. Contract award will be completed by summer 2000. A detailed plan of delivery and acceptance tests of the sonar units is in preparation.

The acquisition and real-time processing system were defined. Computer hardware architecture and specifications were finalized and the procurement process was initiated. The software architecture and specifications were defined. Key modules of the existing system were tested on an Alpha workstation.

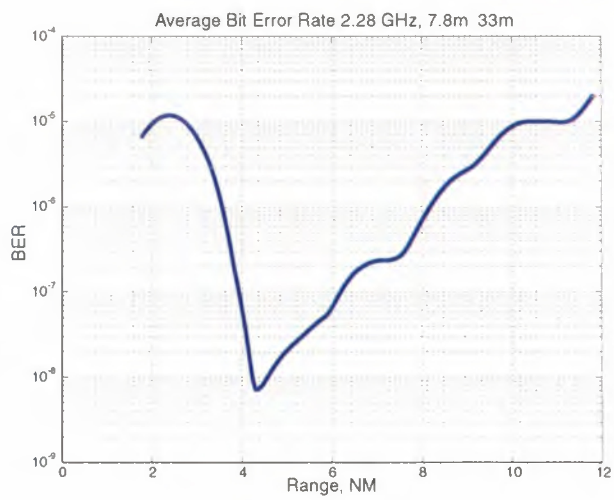


Figure 04-B.9 *Average bit error rate obtained with digital radio link during DUSS'98 tests.*

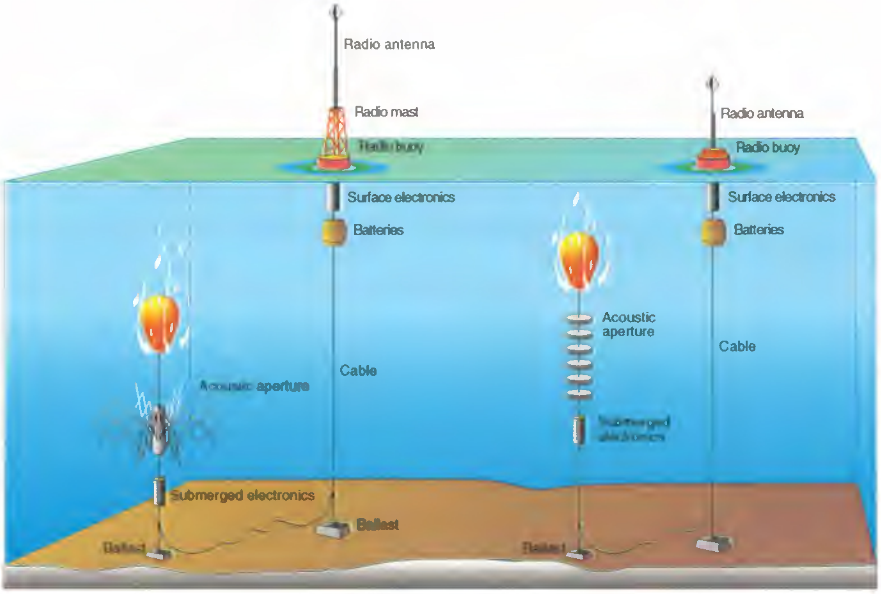


Figure 04-B.10 *New DUSS prototype. deployable receiver and transmitter units.*

Project 04-B publications and presentations

Berni, A., Mozzone, L. The application of spread spectrum communications to REA tactical networks and deployable surveillance systems, SACLANTCEN SM-367.

Mozzone, L., Bongi, S. Diversity in deployable underwater surveillance systems, SACLANTCEN SR-318.

Mozzone, L., Bongi, S. Diversity in multistatic active sonar. *In:* IEEE Oceans '99 Conference, 1999, Seattle, US.

Mozzone, L., Guerrini, P., Berni, A. Long range, large throughput radio data link for DUSS (Deployable Underwater Surveillance Systems), SACLANTCEN SM-360.

Mozzone, L., Lorenzelli, P., Bongi, S. Target localization with multiple sonar receivers, SACLANTCEN SR-317.

Lorenzo Mozzone *received the Masters degree in electronic engineering from the University of Genova in 1989. He worked for four years with Alenia S.p.a., Genova and has been at SACLANTCEN since 1994. His activity is focused on sonar systems research with specific reference to deployable underwater surveillance systems (DUSS). He has published papers on signal processing techniques, real time implementation and operational research studies on activated towed arrays.*

Project 04-C: Low frequency shallow water reverberation and propagation: adaptation to large bandwidths (Alliance days – 25)

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.

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One of the important issues in bottom scattering is to know where the scattering is coming from, that is whether the scattering occurs at the water-bottom interface or from within the sediment. The ability to distinguish the scattering location has important implications for performance prediction, model and database development and the validation of rapid environmental assessment techniques.

Results

A key result in 1999 was the development of the capability to distinguish the origins of scattering. Figure 04-C.1 shows results from a shallow water area north of the Island of Elba (designated Site S). Measurements at 1800 Hz and 3600 Hz are shown in Figs. 04-C.1a and 1b respectively. The vertical axis represents vertical angle and the grazing angle of beams 13 to 22 is from 5° to 65°.

Corresponding model results presented in Fig.04-C.1c and 04-C.1d predict the scattered field of water-bottom interface scattering. At 3600 Hz, the arrival structure (Fig. 04-C.1d) is similar to that observed in the data (Fig. 04-C.1b). This result indicates that the scattering at 3600 Hz occurs in approximately the upper 10 m of the seabed.

At 1800 Hz (Fig. 04-C.1a), it is apparent that there is a later scattering arrival (starting at 0.08 sec in the highest/steepest beam), not seen in the modelled result (Fig. 04-C.1c). From timing considerations, this late arrival must correspond to a scattering horizon at about 25 m below the water-sediment interface.

Independently acquired geoacoustic data at this site show a sub-bottom feature at 24 m. Figure 04-C.2 shows the sound speed structure *versus* depth in the bottom obtained from a high-resolution geoacoustic analysis. It shows a randomly layered seafloor; the low speed layers are silt-clay and the high-speed layers are sand-shell matrix. Figure 04-C.3 shows shells recovered from a 10 cm layer at almost 5 m depth sub-bottom. The shell layer at 25 m sub-bottom gives rise to the scattering observed in Figure 04-C.1a.

Figure 04-C.1e shows model predictions at 1800 Hz including this deeper layer; a comparison with the measurements in Fig. 04-C.1a appears to confirm its existence and general features. Note that the model shows a time separation between the scattering from each interface, whereas the measured data do not. This is interpreted as further evidence that the scattering along the monostatic branch is caused by the shell-sand layers at about 0.5 m, 5 m and 15 m. Scattering from the sub-bottom layer at 24 m is not observed at 3600 Hz (Fig. 17b) presumably due to increased attenuation and/or reduced transmissivity through the overlying sedimentary layers.

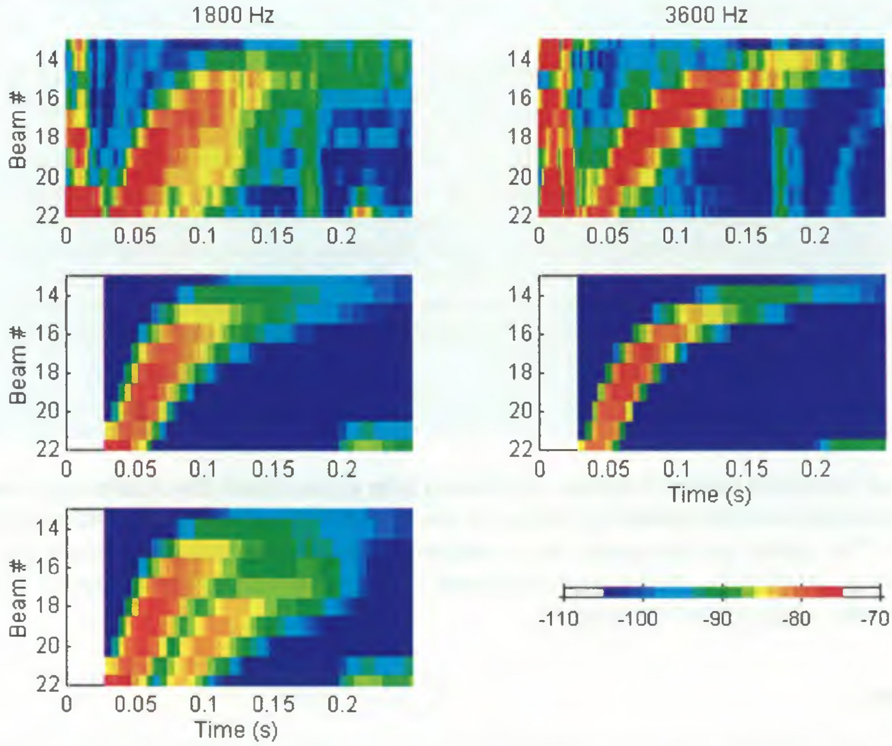


Figure 04-C.1 *Comparison of measured data at: a) 1800 Hz and b) 3600 Hz with modelled results for water-sediment interface scattering c) 1800 Hz, d) 3600 Hz and e) 1800 Hz modelled results with water-sediment interface scattering and interface scattering at 25 m sub-bottom. The lettering sequence follows a left to right, top to bottom order. The quantity plotted is received level minus source level.*

These data can be processed to yield a scattering strength *versus* angle as shown in Fig. 04-C.4 (red curve). Also shown in the figure are bottom scattering data at another site about 10 km away (blue curve) which show a markedly different angular and frequency dependency. Site S bottom scattering strength data (red curve) are strongly dependent upon frequency. The monotonically increasing frequency dependence is perhaps due to the fact that the mean scatterer (sub-bottom shell and coral fragments) dimensions are

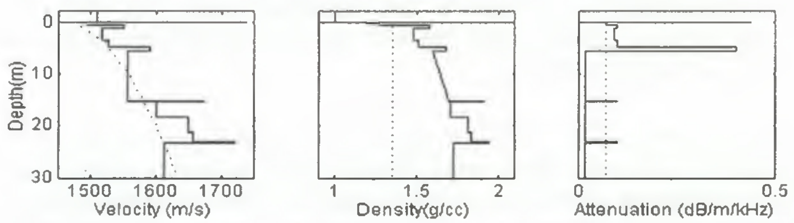


Figure 04-C.2 *Site S sediment parameters. Parameters from Holland and Osler (1998) (solid line) and that used in the model predictions of Figure 04-C.1 (dotted line).*

Figure 04-C.3 *Shell material corresponding to high-speed layer in Figure 04-C.2 near 5 m depth sub-bottom.*

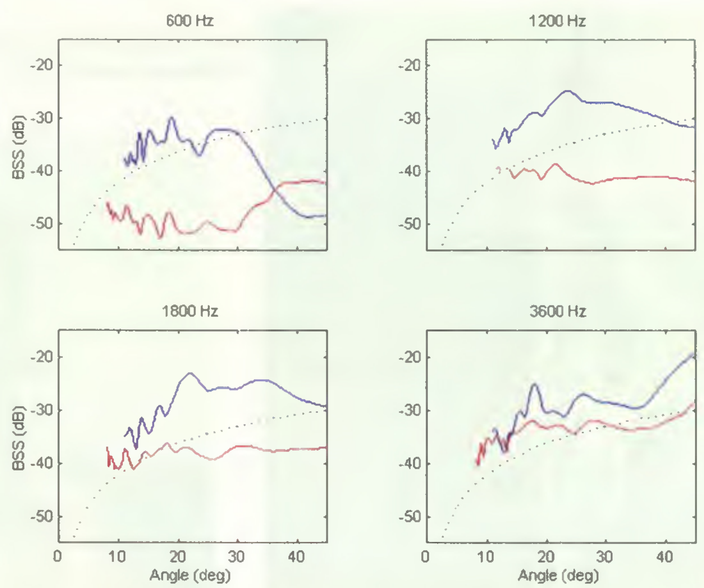
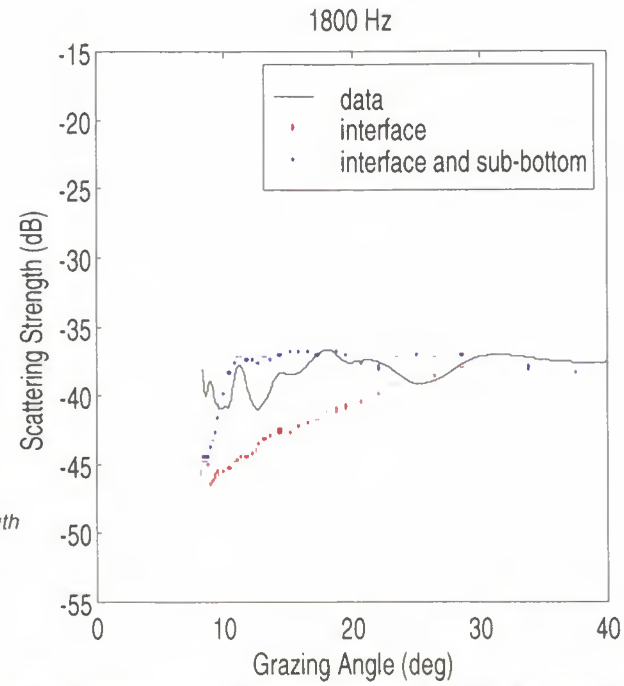


Figure 04-C.4 *Scattering strength results at two sites: silty clay with interstitial sandy layers (red) and sandy with thin silt layer at interface (blue). Also shown is the NATO standard (dotted line).*

Figure 04-C.5 *Scattering strength results at site 2.*



less than a wavelength. The observed angular dependence is flatter than the NATO standard, particularly below 3600 Hz; this may also be due to sub-bottom scattering. Overall scattering strengths are less than or equal to the NATO standard.

Figure 04-C.5 shows the measured scattering strength data at 1800 Hz at Site S with two modelling results. The red dots indicate model predictions using interface scattering. The blue dots include both interface and sub-bottom scattering. Thus, low angle scattering at 1800 Hz is strongly influenced by sub-bottom scattering: in this area down to 25 m sub-bottom.

The 8 m piston corer designed and constructed at the Centre

Improved version of the sound source used in project 04-C experiments

Deployment of instrumentation during GEOSCAT 99

Project 04-C publications and presentations

Holland, C., Hollett R., Troiano L. Bottom scattering measurements in shallow water, (i) SACLANTCEN SM-320, (ii) *Journal of the Acoustical Society of America*.

Holland, C.W., McDonald, E. Shallow water reverberation from a time reversed mirror, SACLANTCEN SR-326.

Osler, J.C., Algan, O. A high resolution seismic sequence analysis of the Malta Plateau, SACLANTCEN SR-311.

Osler, J.C., Algan, O., Holland, C. W. A high resolution seismic sequence analysis of the Malta Plateau. *EOS Transactions*, AGU, 1999.

Osler, J.C., Gualdesi, L., Michelozzi, E., Tonarelli, B. Piston coring capabilities at SACLANTCEN: minimizing and assessing core disturbance, SACLANTCEN SR-321.

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.*

John C. Osler *was born in Montreal, Quebec, Canada on July 9, 1964. He received an honours B.Sc. degree in solid earth geophysics from McGill University, Montreal, in 1986 and the Ph.D. degree in geological oceanography from Dalhousie University, Halifax, in 1993. He was a visiting fellow at the Defence Research Establishment Atlantic, Dartmouth, from 1993 to 1996, where he conducted research in ocean bottom seismology and environmental acoustics. In 1996, he joined the SACLANTCEN as a scientist in the Large Scale Acoustics and Oceanography Group, where he has been involved in a variety of projects in the area of seabed acoustics. His research interests include techniques for determining geoacoustic properties of marine sediments, sub-critical penetration of acoustic energy into the seabed and Quaternary marine geology. Dr. Osler is a member of the American Geophysical Union, the Acoustical Society of America, the Canadian Geophysical Union and the Canadian Acoustical Association. The Canadian Acoustical Association awarded him the Edgar and Millicent Shaw Postdoctoral Prize in 1994 and the Directors' Award in the "Professional over 30" category in 1997.*

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.

Broadband models and shallow water acoustic variability

The PROSIM (PROpagation channel SIMulator) project finished in April 1999. The project was carried out with partial funding from the European Union as a collaborative effort within the Marine Science and Technology initiative, MAST-III. The other partners were Thomson-Marconi Sonar in Nice, TNO-FEL in The Hague, Heriot-Watt University in Edinburgh and University of Wales in Bangor.

The scope of the project was to develop a software package for signal modelling in shallow-water areas with both spatial and temporal variability. The completed package consists of 12 numerical models: 3 oceanographic models, 5 acoustic models and 4 auxiliary tools sharing a user-friendly graphical interface for input and output from the various models. The graphical user interface (GUI) and six of the oceanographic and acoustic models were newly developed during the project. A user's guide describing the background of the models and how to create data inputs and run the models was also provided.

Two major experiments were conducted during the project resulting in extensive environmental and acoustic data from shallow-water regions in the Clyde Sea and the Mediterranean. The objective of the experiments was to assess the degree of time-variability of acoustic signals received over fixed propagation paths and to correlate the acoustic variability with changes in the environment. The experimental data have been used to validate the numerical models in the PROSIM software package.

The primary contributions from Project 04-D to the PROSIM development were:

- a computationally-efficient, broadband, range-dependent, deterministic propagation model based on normal modes
- a model for converting geoacoustic bottom properties to a plane-wave reflection coefficient
- oceanographic and acoustic data from the Mediterranean Sea experiment.

The work in 1999 concentrated on finalizing the data analysis and model validation, preparing written documentation for the final report to the European Union and constructing a web site hosted by SACLANTCEN advertising the final software product (http://www.saclantc.nato.int/mast/prosim/mainpg/). This web site contains a detailed description of the PROSIM project, including all project-related publications in electronic form. Moreover, visitors may download executables of the developed channel simulator for a variety of computer platforms.

In April/May 1999 SACLANTCEN (Project 01-B) conducted another shallow-water experiment (ADVENT'99), which provided additional data on time-variability effects on acoustic signal transmission over a fixed path. The experiment took place on the Adventure

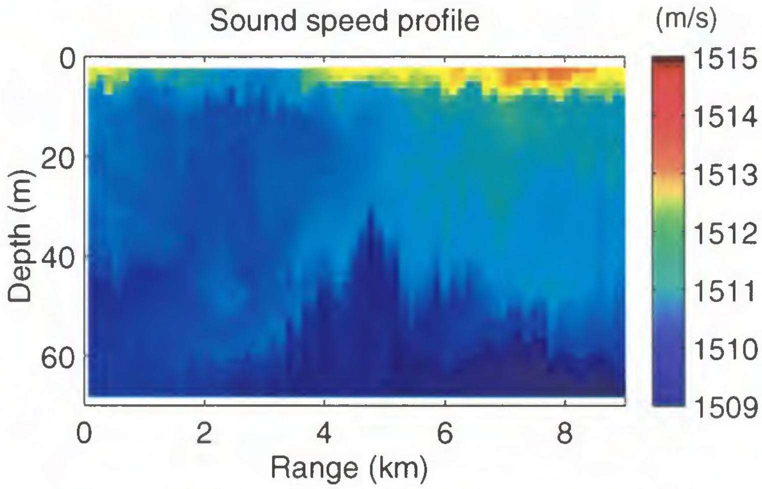


Figure 04-D.1 *Measured sound-speed profiles (towed CTD-chain) along a 10 km track. Some spatial variability is evident and most features were seen to change both position and shape with time.*

Bank off the west coast of Sicily, where an acoustic track with a weakly range-dependent bathymetry was chosen. Three ranges of 2, 5 and 10 km were considered for fixed-path propagation, where broadband signals (200-1600 Hz) were transmitted every minute for up to 18 h. Extensive oceanographic data (current, wave height, sound-speed profiles) were acquired during the acoustic transmissions in order to correlate the oceanographic and acoustic variability. A conductivity-temperature-depth (CTD) chain was towed along the propagation paths resulting in a set of fully range-dependent sound-speed profiles approximately every hour. An example of the sound-speed variation along the 10 km propagation path is shown in Fig. 04-D.1.

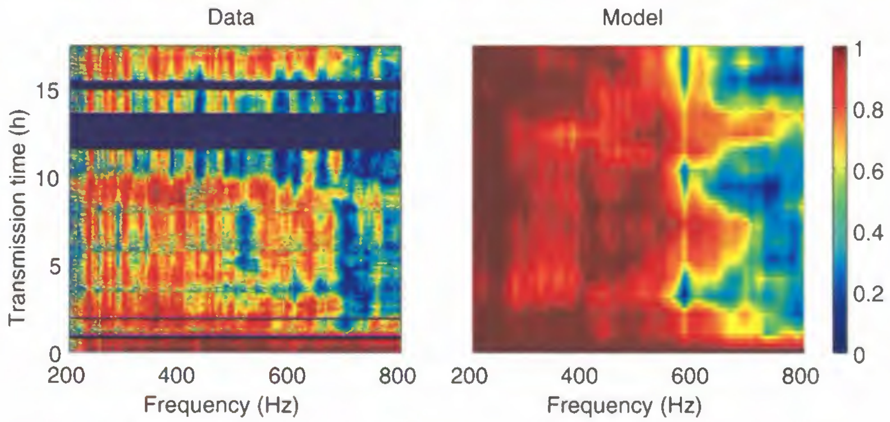


Figure 04-D.2 *Correlation between the first and the subsequent received signals across the vertical array as a function of acoustic frequency and transmission time for a 10-km fixed path propagation. Note in the left panel that signals de-correlate faster at higher frequencies, with the de-correlation time being only around 1 h for frequencies above 650 Hz. Similar effects are seen in the modelled result in the right panel, even though the overall correlation at lower frequencies is much higher here than in the (noisy) data.*

A measure of the time stability of the received acoustic signals is established by correlating the first received signal with the subsequent signals as transmission time progresses. The correlator is the normalized linear Bartlett processor which adds the signals coherently across the vertical array for individual frequencies. The resulting measure of signal similarity has a value between 0 and 1, with 0 meaning no similarity of signals received across the array between two transmissions and 1 meaning two identical signals.

The correlation of the experimental data (Fig. 04-D.2, left panel) varies considerably with time, indicating changes in the propagation conditions as well as in the background noise level. This decorrelation of received signals is stronger at higher frequencies. The low correlation (blue horizontal stripes) occurring every 2 h across the entire frequency band is caused by noise from the ship towing the CTD-chain when it approaches the vertical array.

The effect of a time-varying water column on signal transmission was simulated by the SACLANTCEN propagation model C-SNAP. The measured range-dependent sound-speed profiles over an 18 h time period were included in the calculations. The correlation of the simulated signals (Fig. 04-D.2, right panel) is high at the lower frequencies for the entire time period. A fast decorrelation of the signals is seen for the higher frequencies as observed in the experimental data, indicating substantially correct modelling of the influence of the varying sound-speed structure on sound propagation at these frequencies. The difference between model and data at the lower frequencies may be due to the lack of noise in the modelled signals.

Propagation model validation

The broadband range-dependent normal-mode model PROSIM has been applied to a set of test cases developed for the Shallow-Water Acoustic Modelling (SWAM) workshop held in Monterey, CA, in September 1999. One of the cases considered was simulation of sound propagation across a shelf break from deep to shallow water with range-dependent bathymetry and sound-speed profile (Fig. 04-D.3).

Three different propagation models were applied to this problem: A parabolic equation model (RAM), a coupled-mode model (C-SNAP) and the recently-developed adiabatic normal-mode model (PROSIM). The results are in very good agreement as the signal is

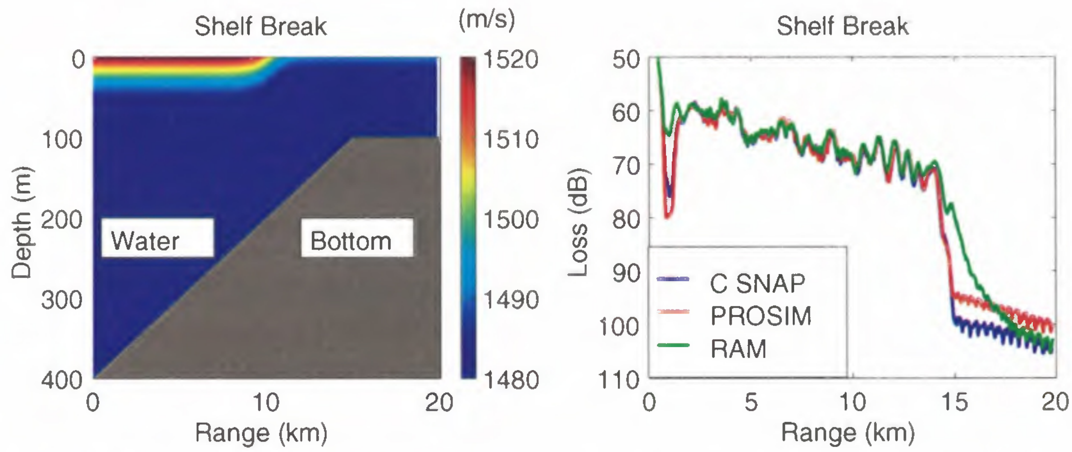


Figure 04-D.3 *Transmission loss as a function of range (source depth = 30 m, receiver depth = 35 m, frequency = 1000 Hz) calculated by using C-SNAP, PROSIM and RAM. Very good agreement between the models is seen out to a range of around 14.5 km for this shelf-break environment. Then levels drop off rapidly and only RAM provides accurate results on the shelf itself.*

propagating up-slope to a range of around 14.5 km (Fig. 04-D.3, right panel). Hence the adiabatic approximation is sufficiently accurate to this range for a frequency of 1000 Hz. Close to the shallow-water area, the predictions from C-SNAP and PROSIM deviate significantly from RAM (correct result), because of the approximations introduced in the mode models.

Bistatic reverberation model development

The reverberation modelling in Project 04-D produces models which can be used to support the interpretation and understanding of active sonar datasets acquired under Project 04-A. It also supports the scattering mechanism extraction efforts in Project 04-C. In both cases the emphasis is on modelling the reverberation process to the maximum fidelity possible, taking advantage of the state of the art in forward propagation modelling to and from the scattering region and utilizing physically reasonable models of the scattering processes. The approach is motivated by the desire to accurately capture in the model predictions the complexity and richness of the angular and temporal evolution of shallow water reverberation. The fact that reverberation is not "White Gaussian Noise" is caused to a large degree by complexity and spatial variability of the shallow water sound channel, as well as by the underlying distribution parameters of the scatterers themselves. For this reason, high fidelity modelling contributes to a better understanding of the "non-Rayleighness" of the reverberation power, which causes the high false alarm rate of shallow water active systems.

In 1999 two new reverberation models were created, 1) R-SNAP for modelling long-range monostatic reverberation in range-dependent waveguides and 2) a volume inhomogeneity scattering enhancement to OASES which is useful for modelling early-time subbottom reverberation in range-independent waveguides. The R-SNAP model has been used to support the interpretation and understanding of the active reverberation datasets collected on the Malta plateau.

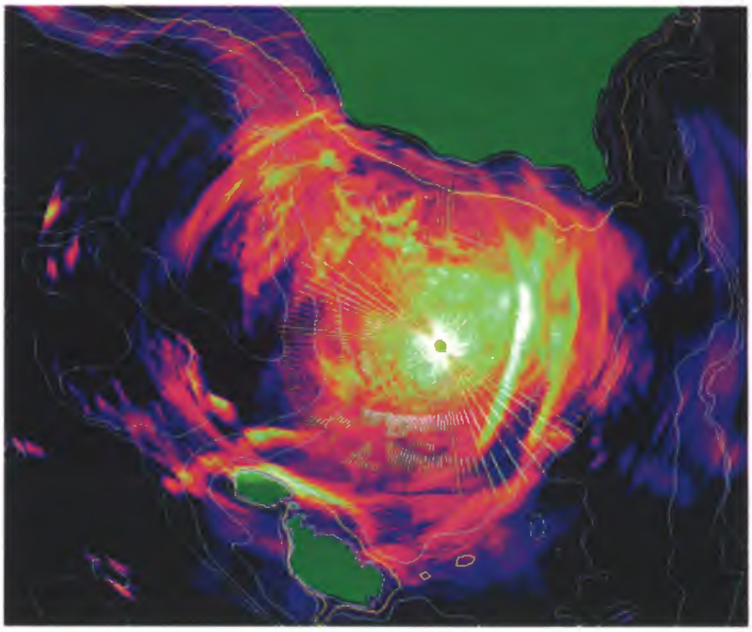


Figure 04-D.4 *Stacked reverberation power measured during the SWAC-1 experiment conducted on the Malta plateau. Unusually strong reverberation is measured from the vicinity of the Ragusa ridge in the Malta channel and from southern Sicily and Malta*

In Fig. 04-D.4 a stacking of reverberation power collected during the SWAC 1 experiment over the Malta plateau is superimposed on the bathymetry. Strong scattering is seen from the vicinity of the Ragusa ridge in the eastern part of the Malta channel as well as from the

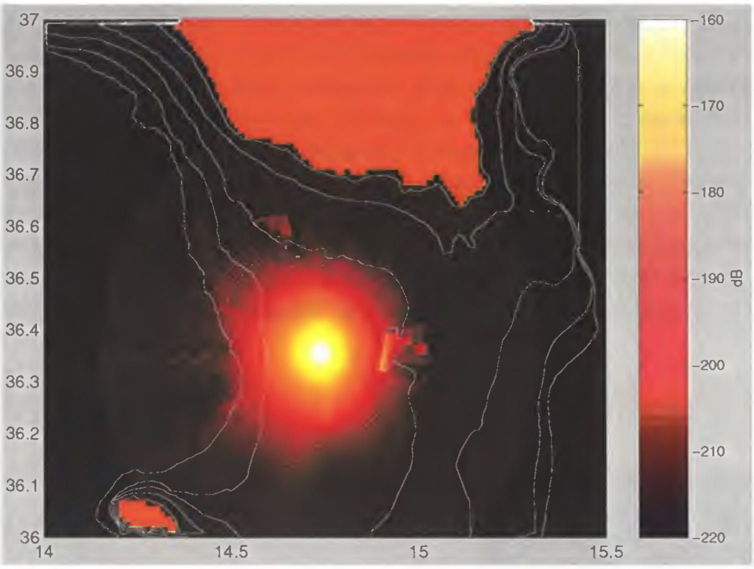


Figure 04-D.5 *Model predictions of monostatic reverberation versus. azimuth for rough sediment scattering on the Malta Plateau. The predictions do not show the strong variability with azimuth visible in the dataset.*

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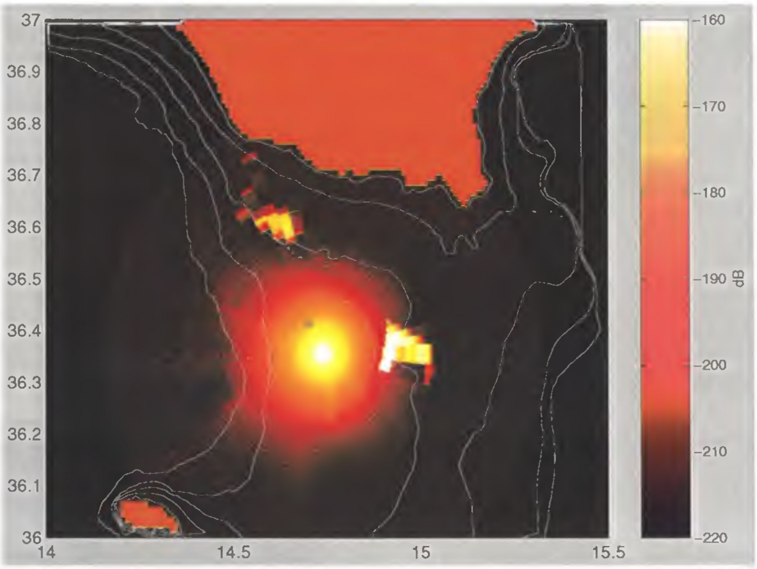

Figure 04-D.6 *Reverberation predictions for the Malta plateau with both rough sediment and rough basement scattering. The predictions show stronger reverberation localized on the Ragusa ridge and off the southern shore of Sicily, in better agreement with the experimental measurements. Boomer surveys indicate that the sediment thickness goes to zero in these regions, enabling the rougher rock basement to be directly illuminated by the incident field. The boomer survey did not extend to the northern escarpment of Malta, thus the prediction is less accurate in this region.*

southern coast of Sicily and the northern slope of Malta. In Figs. 04-D.5 and 04-D.6 monostatic reverberation predictions from R-SNAP are shown for rough sediment (Fig. 04-D.5) and a combination of rough sediment and rough basement (Fig. 04-D.6) scattering hypotheses. The rough basement predictions were obtained using sediment thickness estimates obtained from a boomer survey of the Malta plateau conducted by Project 04-C. The survey showed that the sediment thickness was essentially zero over the Ragusa ridge and on parts of the southern escarpment of Sicily, exposing the underlying rough basement to the acoustic energy of active systems. R-SNAP scattering predictions based on rough sediment scattering alone are too isotropic in azimuth, but when the basement scattering mechanism is added, more features of the data are captured. It is expected that the R-SNAP model will prove useful for understanding and predicting the spatial-temporal characteristics of these types of reverberation data sets in shallow water, where significant spatial diversity in the reverberation may be caused by the inhomogeneity of the underlying geophysical description of the bottom.

The volume scattering OASES module was developed to provide an independent tool for modelling the vertical transmit receive array (VETRA) scattering datasets collected in Project 04-C. These data are usually represented as beam-time evolutions of backscatter (Fig. 04-D.7). From these data it is desired to resolve the scattering mechanism (rough surface *versus* sediment volume scatter) for the various layers in the subbottom, as well as the total scattering strength *versus* grazing angle and frequency. The OASES modelling capability will provide data against which the estimation process can be benchmarked. Beam-time evolutions of backscatter from rough surface and sediment volume inhomogeneity scatterers are illustrated in Figs. 04-D.8 and 04-D.9. The differences between these results indicate that these two mechanisms should be resolvable from one another using the VETRA measurement apparatus.

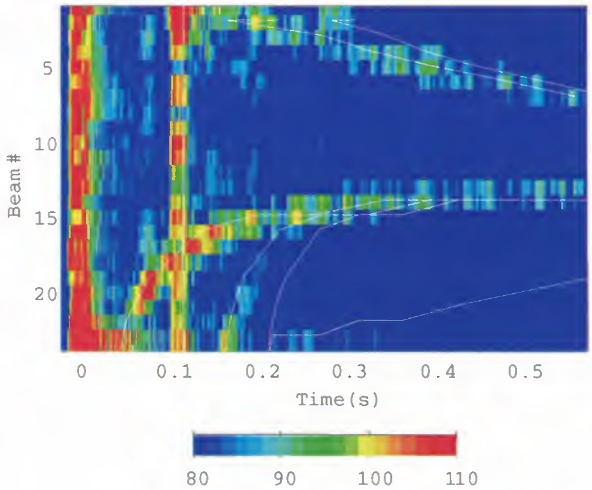

Figure 04-D.7 *Beam-time history of bottom and subbottom reverberation collected by the VETRA apparatus in the Capraia basin north of Elba. At early time the reverberation arrives on the VLA from steep angles, approaching the horizontal at late time. To the direct measurement of the monostatic bottom scattering are superimposed bistatic multipath which give additional information about the bottom scattering kernel, but also cause ambiguity at times after approximately 0.2 s.*

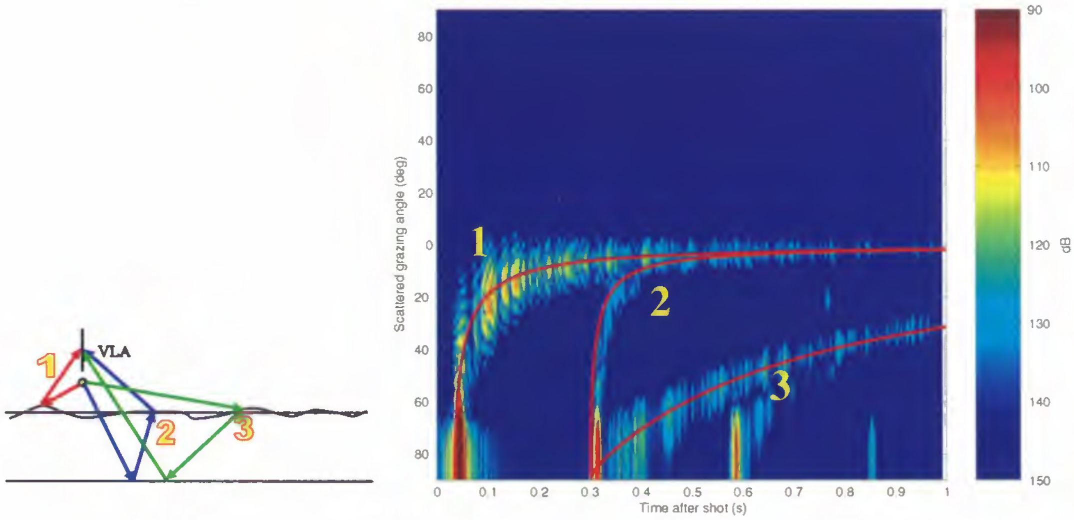

Figure 04-D.8 *Model predications of the time-angle history of backscatter for rough surface scattering for a VETRA experimental geometry. The various trajectories of the scattered field are identified in the accompanying schematic.*

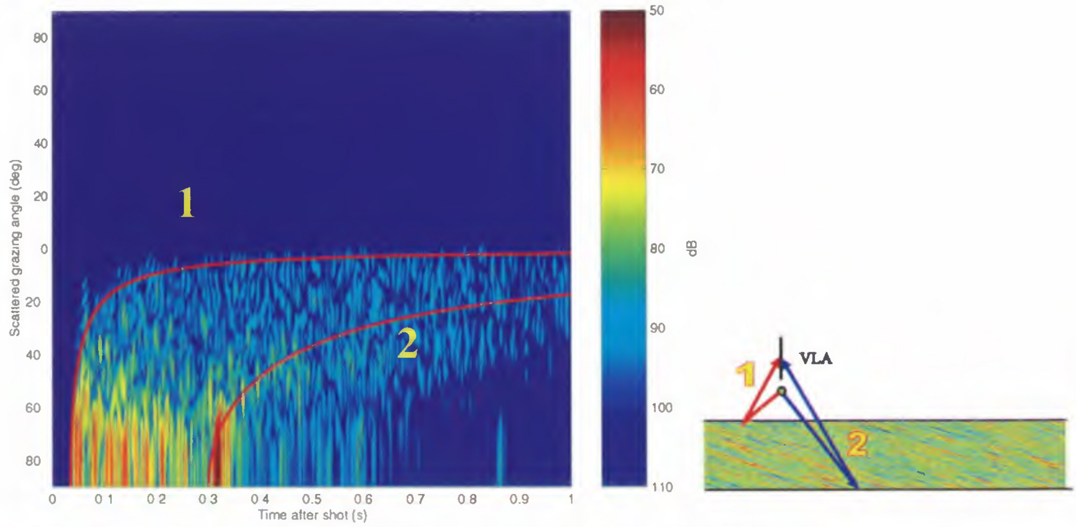

Figure 04-D.9 *Model predictions of the time-angle history of backscatter from volume inhomogeneities in the sediment layer below the VETRA apparatus. The volume scatterers contribute for a range of angles at all times, thus yielding data which are distinguishable from rough surface scattering shown in Figure 04-D.8.*

Project 04-D publications and presentations

Fallat, M., Nielsen, P.L., Dosso, S.E. Hybrid geoacoustic inversion of broadband Mediterranean Sea data. *Journal of the Acoustical Society of America* (submitted).

Jensen, F.B., Kuperman, W.A., Porter, M.B., Schmidt, H. Computational Ocean Acoustics, 2nd edition. New York, NY: Springer, 1999).

Jensen, F.B. Shallow water acoustics. *In:* Steele, J.H., Turekian, K.K., Thorpe, S.A., editors. Encyclopedia of Ocean Sciences. London, UK Academic Press (in press).

Jensen, F.B. Theory of sound propagation in the ocean: A tribute to L.M. Brekhovskikh, invited paper presented at the EAA/ASA meeting, Berlin, Germany, March 1999. *Journal of the Acoustical Society of America,* **105**, 1999:982:1pUW3.

LePage, K.D. Acoustic time series variability due to cumulative effects of perturbative sound speed fluctuations. In: Proceedings of the 5th International Congress on Theoretical and Computational Acoustics, Trieste, Italy, May 1999.

LePage, K.D. Spectral integral representations of scattering from volume inhomogeneities, SACLANTCEN SM-363.

LePage, K.D. Time series variability in fluctuating ocean waveguides. SACLANTCEN SR-319.

LePage, K.D. Volume scattering realizations from ocean sediment sound-speed and density inhomogeneities, paper presented at the EAA/ASA meeting, Berlin, Germany March 1999. *Journal of the Acoustical Society of America,* **105**, 1999:1194:3pUWA1.

Nielsen, P.L., Jensen, F.B. Adiabatic and coupled-mode solutions to the internal waves and shelf break test cases for the SWAM'99 workshop, paper presented at the Shallow-Water Acoustic Modelling Workshop, Naval Postgraduate School, Monterey, CA, Sept. 1999.

Nielsen, P.L., Jensen, F.B. Effects of the time-varying ocean on broadband propagation in shallow water, paper presented at the EAA/ASA meeting, Berlin, Germany, March 1999. *Journal of the Acoustical Society of America,* **105**, 1999:1311:4pUW4.

Nielsen, P.L., Siderius, M., Jensen, F.B. Ocean variability effects on sound propagation in shallow water, *In:* OCEANS'99, Seattle, WA, Sept. 1999.

Sellschopp, J., Siderius, M., Nielsen P.L. Flachwasser-experiment zur akustischen variabilität, presentation of Advent99: A shallow-water experiment on acoustical variability, FWG-Colloquium in Kiel, 1999.

Siderius, M., Nielsen, P.L., Jensen, F.B. Geoacoustic inversion of experimental data from two shallow-water sites. In: OCEANS'99, Seattle, WA, Sept. 1999.

Siderius, M., Nielsen, P.L., Jensen, F.B. Ocean variability effects on inversion of seabed properties in shallow water, paper presented at the International Conference on Stochastic Volume and Surface Scattering: Recent Developments in Underwater Acoustics, University of Cambridge, UK, December 1999.

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.

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.

Thrust 05 Command Support (CDS)

Project 05-A: Command and NATO 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 comprises two Advanced Concept Studies (ACS), which extend the time frame to 2015, Antisubmarine Warfare (led by France) and Mine Warfare (led by Germany).

ASW advanced concepts study

The critical shortfalls in ASW identified in Phase I, provide the focus for the ASW Advanced Concepts Study. The aim of this study is to recommend the most promising directions for Allied research and development leading to affordable system packages in the 2005-2015 time frame, which reduce the most significant ASW shortfalls. SACLANTCEN has provided support to MO2015 activities in ASW from the outset and is a member of the ASW ACS Core Team for Phase II. The ASW ACS is supported by Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Turkey, United Kingdom and the United States.

The first step of Phase II was to review and quantify the most significant ASW shortfalls identified in Phase I projected to persist in 2005-2015, in order to assess their magnitude, ascertain their principal causes and identify areas for R&D. Step 1 was completed in April 1998 with a report.

Step 2 of Phase II which started in April 1998 was concerned with formulating solutions to the most significant ASW shortfalls from Step 1. The solutions generated by means of workshops and brainstorming sessions were either evolutionary in nature or, in some cases, revolutionary. Step 2 was completed with a Mid Course Review (MCR) in April 1999, at which the concepts were reviewed and a sub-set selected for more detailed evaluation in Step 3. Step 3 culminated in a Concept Development Workshop (CDW) in November 1999, where a final selection of concepts took place for refinement and evaluation. Step 4 is concerned with high-level operational assessment of the concepts in preparation for the Multi-National Exercise (MNE) in January 2000. The MNE will comprise two panels, a Military Worth Panel and an R&D Panel, which will provide the final evaluation of the concepts and decide on an R&D road map.

SACLANTCEN contributions to the ASW ACS in 1999 include the following:

- Leadership of the Acoustic/Distributed Deployable Systems Technical Provider Group
- Organization of the Distributed Deployable Systems (DDS) Workshop, held at SACLANTCEN in February 1999
- Writing of concept data sheets for the MCR and CDW
- Performance evaluation of selected concepts for the CDW and MNE.

MW advanced concepts study

The leaders of SACLANTCEN projects:

- 03-A Buried mine detection and classification
- 03-B Large area remote search in coastal waters
- 03-C Mine ship interaction
- provided baseline data sheets on UUV-based minehunting and mine jamming concepts which were reviewed at the evaluation meeting held in September 1999.

NATO defence requirements review

At the beginning of the year the Centre supported both NATO's Strategic Commanders (SCs) in their assessment of force requirements. Anti-submarine warfare studies, started in 1998, were completed in 1999 and transmitted to the staff of the SCs. The studies examined the capability of different force levels to conduct area searches, screening and barrier operations.

Exercise support

Operational relevance

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

DOGFISH

ORD made a significant contribution to the analysis[1] by carrying out all the necessary reconstruction. An existing EXCEL based system, originally developed to facilitate the in-house analysis of low frequency active sonar (LFAS) data, was modified to provide more extensive reconstruction and analysis capabilities. The success of the system, which was used during the analysis conference resulted in a formal COMNAVSOUTH proposal for the SACLANTCEN Scientific Programme of Work (SPOW) 2001 to further develop the system.

BLUE GAME

ORD provided support for the planning of the exercise and fitted participating fast patrol boats with the Electronic Minefield Referee (EMIR) system (see below). Members of ORD attended the analysis conference and carried out a detailed quantitative analysis of the performance of a number of operational NATO minehunting systems within a "controlled" environment[2]. The results, which have been presented at a number of NATO MW meetings, generated considerable interest.

BELL BOTTOMS

ORD attended the synthetic computer war game and contributed to the exercise analysis[3].

Exercise support tools

Maritime Electronic Log (MEL)

MEL was developed for Exercise DOGFISH 1999. Its purpose is to replace the paper versions of FORMEX's 110 and 114 with an accurate electronic log. It was successfully employed during DOGFISH on board 8 submarines and 1 surface ship. MEL features a GIS interface and an interface with commercial NMEA 0183 compliant GPS systems.

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. Originally units had to enter their positions throughout the exercise. Now, for surface units, it is possible to connect a handheld GPS unit which automatically feeds positional data to EMIR. In February, the

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[1] NATO Southern Region Independent Maritime Analysis Team (IMAT). DOGFISH 99 exercise analysis report. NATO COMNAVSOUTH 1999 (NATO CONFIDENTIAL). [COS/AA/99].

[2] NATO Maritime Central Analysis Team (MCAT). Exercise BLUE GAME 99 analysis report. NATO CINCGERFLEET, 1999. (NATO CONFIDENTIAL).

[3] NATO COMNAVNORTHWEST. Exercise BELL BOTTOMS 99 analysis report.

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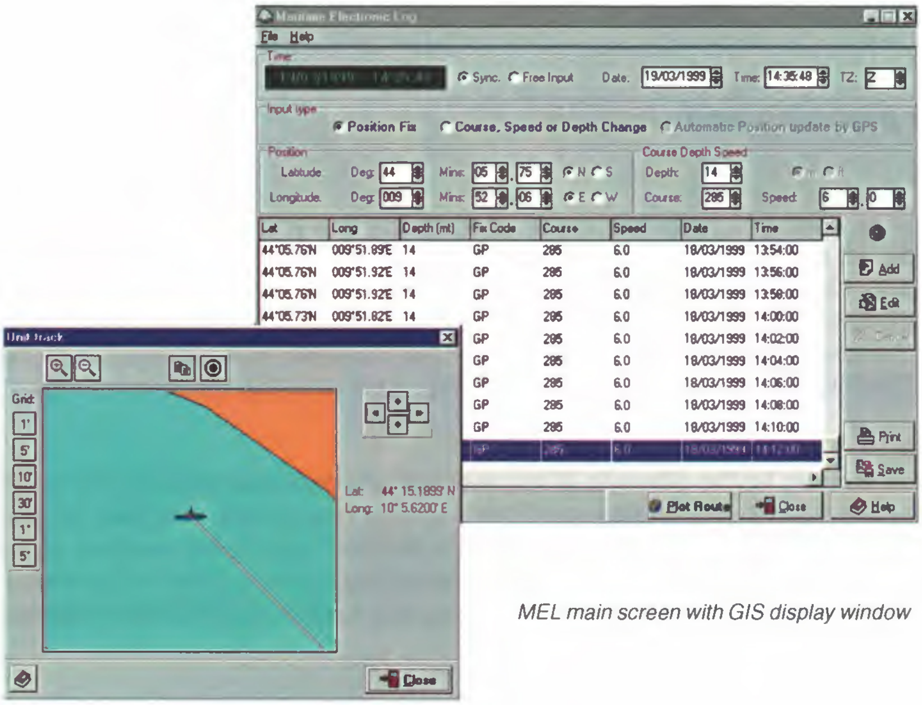
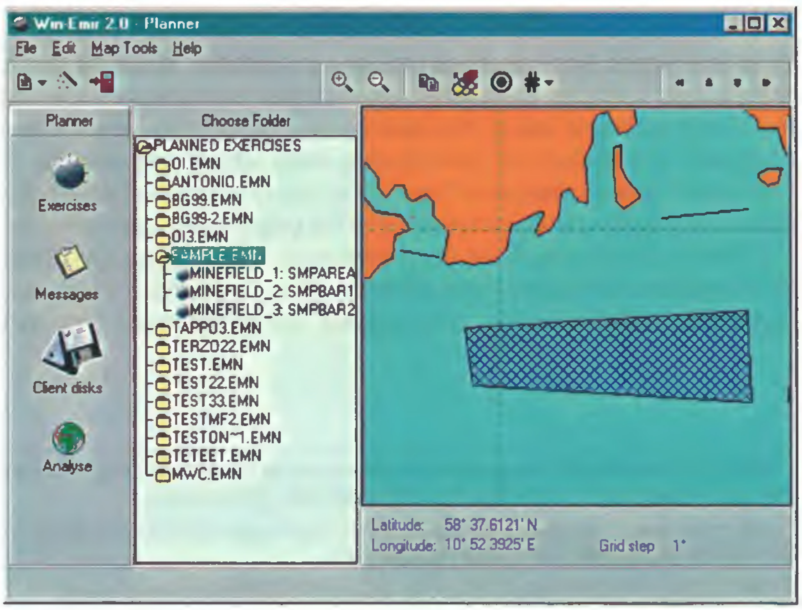


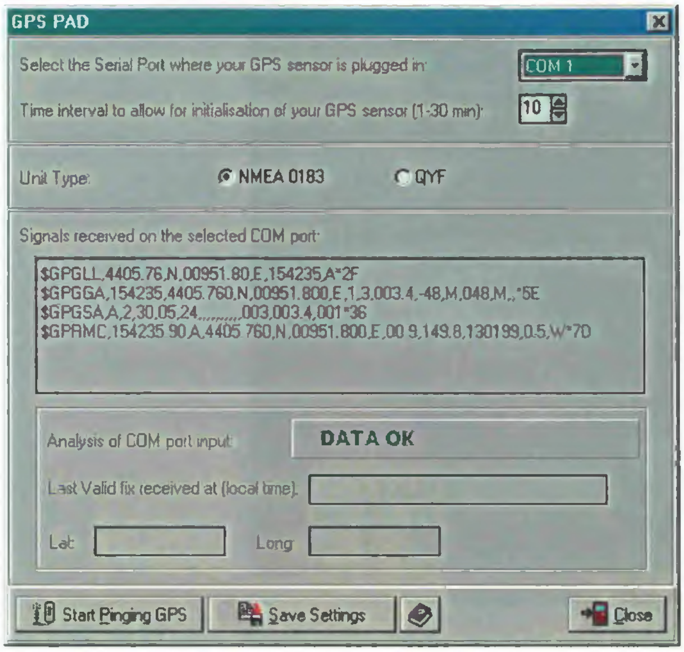
MEL main screen with GIS display window

JMC 961 exercise was supported and EMIR installed on board 2 UK Navy units. This exercise provided useful feedback, which led to several improvements in the software. In April, during exercise BLUE GAME 1999, EMIR was installed on board 20 Fast Patrol Boats (FPBs) and proved to be effective in enforcing monitoring of the mine threat. BLUE GAME 2000 will be supported. A new improved version of the planner program has been developed, which will include a track analysis module.

The UK has established an EMIR User Group the first meeting of which was held in Northwood, UK during November 1999.



EMIR planner main screen and GPS configuration window



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.

Work continues to make the algorithm more general and applicable to any geographic area. The way ahead is to integrate the developed solver with the previously delivered user interface, to document the work done and deliver the end-product by June 99. The format for the data, which defines the performance of each unit in the area, will be clearly defined.

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 incorporates 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 now maintained by the NATO Integrated Software Support Centre (ISSC). During 1999, SACLANTCEN continued to support the MCM EXPERT User Group (MEUG) meetings.

MCM Expert meeting in the SACLANTCEN main conference room

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.

Search and Screening Working Group

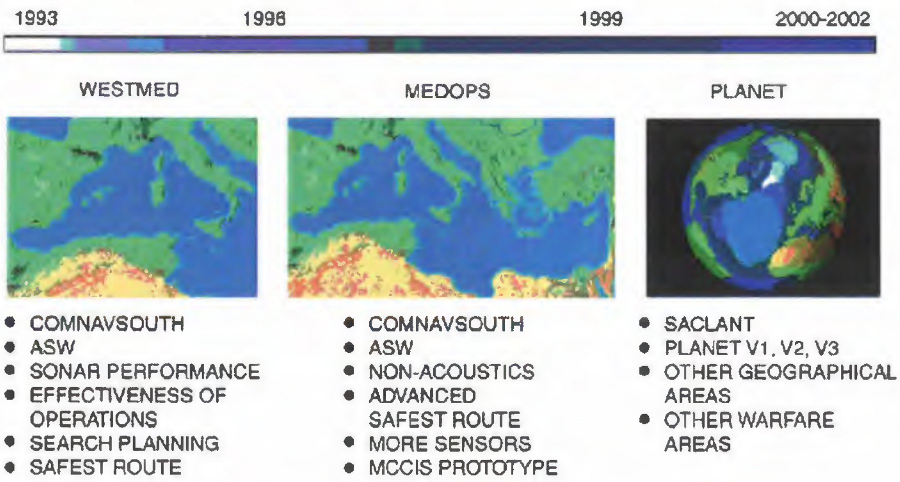
This is a working group under the auspices of the Maritime Tactical Working Group. The Centre has been a regular participant in the proceedings of the group in preparation for 2000, when the Centre will assume the responsibility for developing an area search tactical planning aid.

***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.*

Project 05-B – Planning support for underwater warfare operations

The objective of this project 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 1 shows the relationship and progression of these planning tools.



Evolution of operational and defence planning decision aids at SACLANTCEN.

MEDOPS – Mediterranean Operational Planning Tool

MEDOPS 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.

MEDOPS 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.

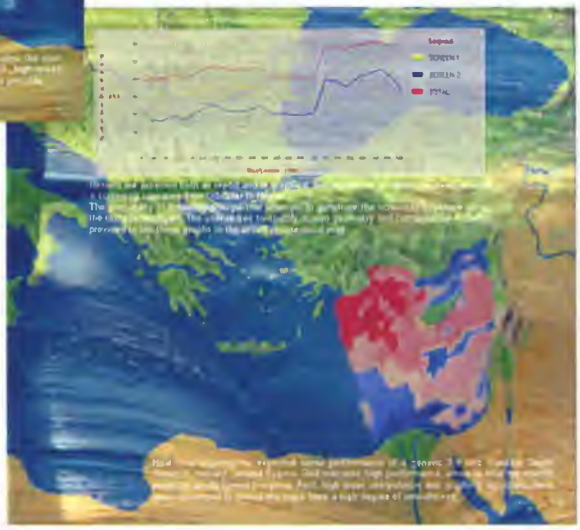
High-resolution vector maps are provided to allow the user to select the proper mission area. Purpose - built, high - speed zooming tools ensure that accurate scenario definition is possible.

Results are provided in report and graphical format. Acoustic sensor performance predictions at high and low frequencies cover 12 months.

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.

Ship, MPA and conventional submarine definition interface.



Evaluation of a screening operation from Gibraltar to Naples and heat map showing the expected sonar performance of a generic VDS around Cyprus.

The major accomplishments of 1999 are:

- MEDOPS evaluation version released in January 1999.
- Steering group meeting in March 1999. (Principle activity: review of MEDOPS evaluation version)
- MEDOPS Version 1.0 released in June 1999 – based on Steering Group review.
- Steering group meeting in September 1999. (Review of MEDOPS Version 1.0)
- MEDOPS Version 1.1 released in October 1999 (Included further software enhancements based on September Steering group review which had not been identified in the March meeting).
- MEDOPS Version 1.1 at-sea validation exercise conducted in conjunction with UKN.

Director SACLANTCEN, Jan L. Spoelstra, presents MEDOPS to Deputy SACLANT, VADM Perowne, (UKN)

Thrust 06 Exploratory Research (EXR)

Project 06-B: Focused acoustic field (FAF) studies (Alliance days – 23, Manning days - 24)

Operational relevance

Although this work is at the early concept demonstration stage, it is already apparent that the operational applications of FAF include multistatic active sonar, low frequency active sonar (LFAS), acoustic communication systems with submarines, air deployable/fixed surveillance systems and the detection of low target strength objects and buried mines.

A high frequency (3.5 kHz) phase conjugation experiment was conducted jointly by SACLANTCEN and the Marine Physical Laboratory (MPL) of the Scripps Institution of Oceanography, University of San Diego, in July. A new, high frequency vertical array (SRA) of 29 source/receive transducers operating nominally in the 3-4 kHz band, an underwater pressure case containing the source/receive electronics, a surface buoy providing battery power, system control and wireless local area network (LAN) connectivity, were designed and fabricated by MPL.

1999 Sea trial

This third experiment (FAF 99) of the Joint Research Project was designed to exploit the concept of phase conjugation (PC) to acoustically focus in the water column. The signal from the probe source is received by the SRA where it is time reversed (the time domain equivalent of phase conjugation) and retransmitted. The focused field is measured by the vertical receive array (VRA) which is contiguous (there may be an out of plane displacement) with the probe source. The first two experiments used 50 m, 450 Hz pulses. Sharp focus was observed at ranges of up to 30 km. Methods were developed and verified to move the focus in range away from the PS position. The PC process was shown to be robust and stable. The experiment was carried out adjacent to Formiche di Grosseto Island and north of the Island of Elba (Fig. 06-B.1). The former provided a link to experiments conducted in 1996 and 1997 while the latter provided a brief opportunity to explore a new environment with different conditions resulting in four major accomplishments:

- High frequency (3.5 kHz) phase conjugation focusing at ranges up to 14 km in flat and sloping coastal regions.
- Acquisition of data to investigate the short-term temporal and spatial properties of the focal region in two different bottom regimes.
- Demonstration of phase-conjugation processing in acoustic communications.
- Demonstration of source/receive array technology operating as a node on a wireless local area network (LAN).

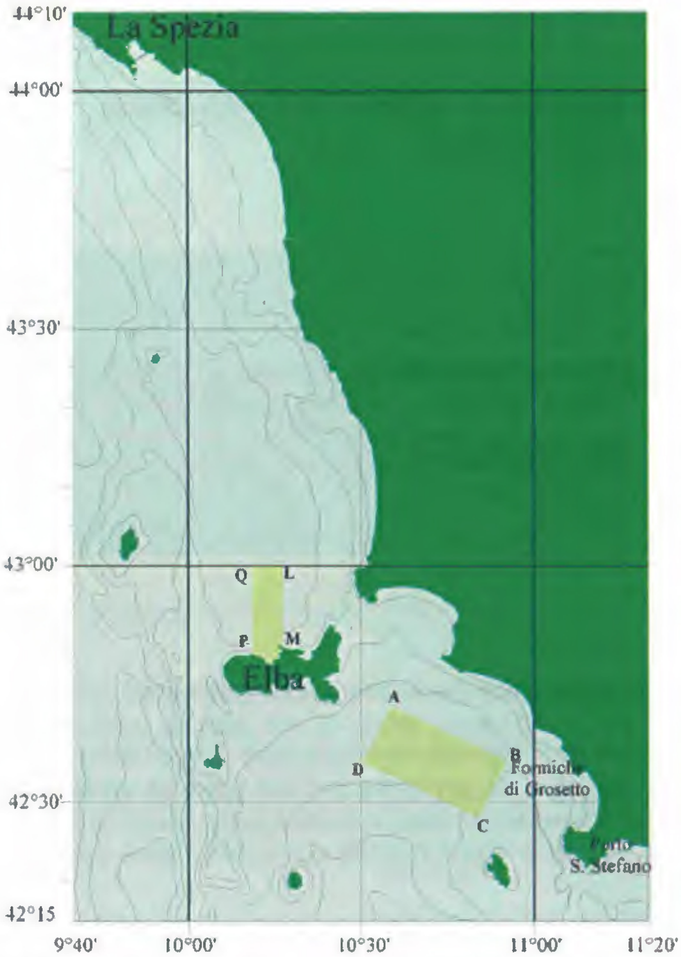


Figure 06-B.1 *Experimental area.*

Results

A schematic of FAF-99 in the vicinity of Formiche showing data (10 msec pulse centred at 3.5 kHz) is given in Fig. 06-B.2. A probe source (PS) co-located with the vertical receive array (VRA) ensonifies the waveguide. The resulting signal received on the source/receive array (SRA) is time-reversed and retransmitted by the same transducers. The degree to which this retransmitted energy refocuses at the source (as observed by the VRA) is used as a measure of phase conjugation processing.

Range and time dependence:

Additional examples of time reversal focusing as a function of range are given in the composite illustration in Fig. 06-B.3. The variation in vertical focusing is due to slight offsets between the PS and VRA at the four ranges. Similar results are available as a function of PS depth in the waveguide. In addition to exploring the range and depth characteristics of the focal region, we also investigated the temporal stability. Although clearly sensitive to environmental fluctuations, focusing was observed to be stable at least in the short-term. Figure 06-B.4 shows a sequence of 10 msec pulses observed by the VRA from SRA retransmissions of the same pulse over a 10 min period at a range of 13 km.

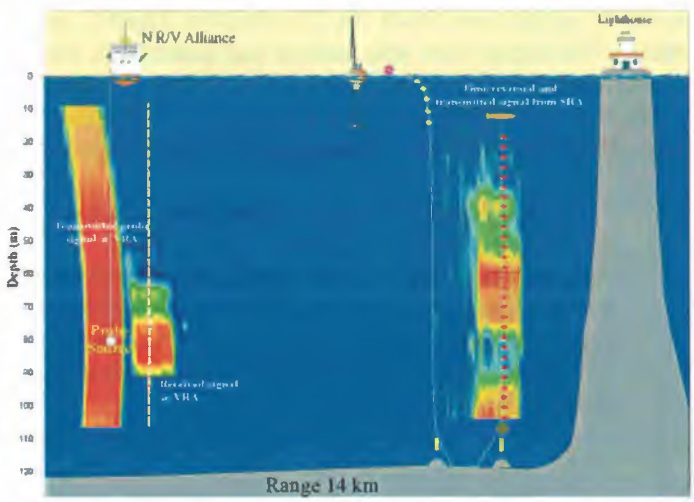


Figure 06-B.2 *The FAF-99 experiment in the vicinity of Formiche illustrating the phase conjugation process with actual data. A probe source (PS) co-located with the vertical receive array (VRA) ensonifies the waveguide. The resulting signal received on the source/receive array (SRA) is time-reversed and retransmitted by the same transducers. The retransmitted energy refocuses at the source as observed by the VRA.*

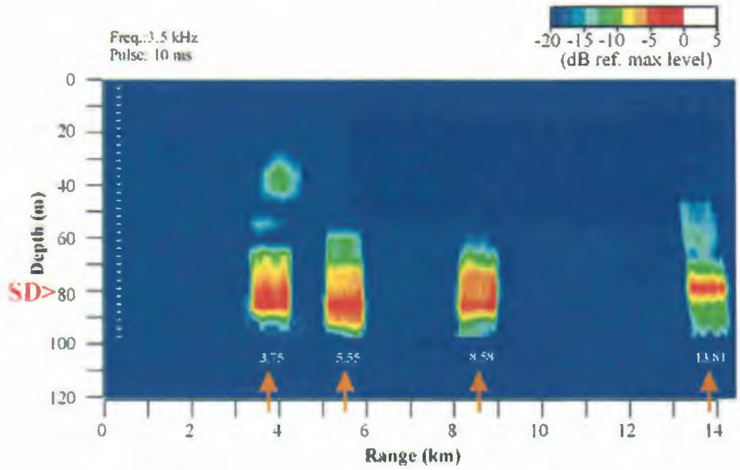


Figure 06-B.3 *Time reversal focusing as a function of range. The variation in vertical focusing is due to slight offsets between the PS and VRA at the four ranges.*

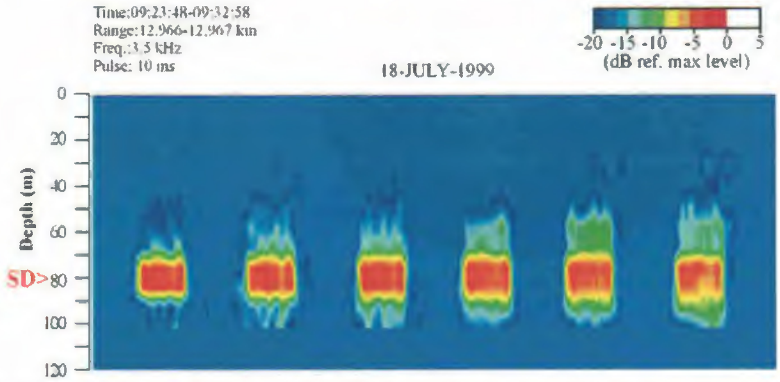


Figure 06-B.4 *Sequence of 10 m pulses observed by the VRA from SRA retransmissions of the same pulse over 10 min period at a range of 13 km.*

Working in the vicinity of North Elba provided an opportunity to investigate focusing in a different bottom environment and to acquire range-dependent data. A particularly interesting result was our ability to demonstrate focusing over a 10 km propagation path from 112 m deep water (SRA) into 32 m deep water (PS and VRA) as shown in Fig. 06-B.5. The focus has a depth extent of ~2m.

Frequency-shifting for refocusing

In earlier 450 Hz FAF experiments, frequency-shifting algorithms were developed to move the focus. It has been demonstrated that these algorithms can be used at 3.5 kHz. Figure 06-B.6 below shows a pulse being "refocused" 400 m from its natural focus and brought back into focus. The experiment is accomplished by frequency shifting the same received SRA pulse as the NR/V *Alliance* (with the SRA) drifts.

Pulse sequences

Data were acquired to study applications of phase conjugation to underwater communications. This first coded sequence was originally transmitted as a total sequence from the probe source and then time reversed and retransmitted from the SRA. In this sequence, a 2 msec probe signal is transmitted from the probe source. The time reversed signal at the SRA is a result of convolving a 50 bit random sequence with the time reversed probe source signal, resulting in a 100 msec sequence. In Fig. 06-B.7, the two-way time reversed sequence (on the right) is compared with a one-way non-time-reversed control sequence (on the left).

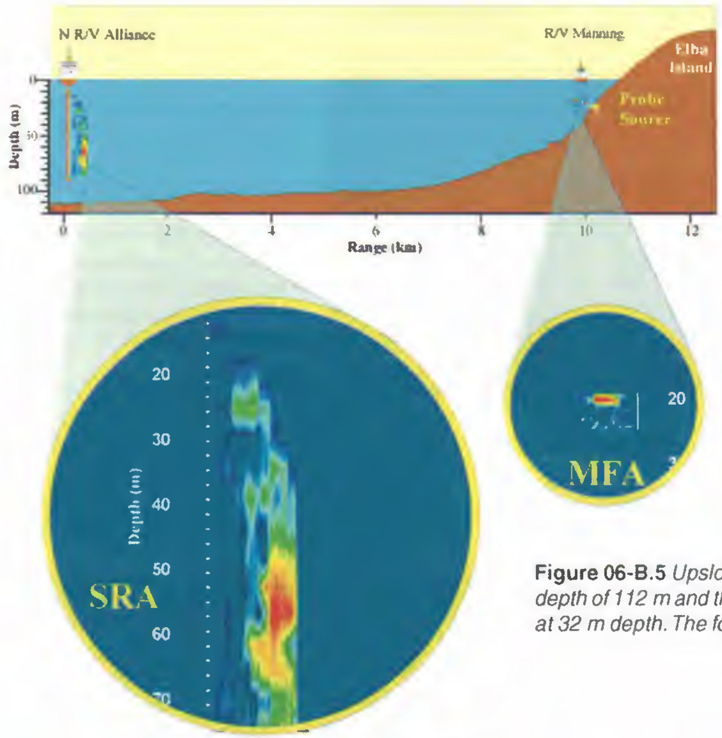


Figure 06-B.5 *Upslope focus near Elba. The SRA was at a depth of 112 m and the PS and VRA (MFA) were co-located at 32 m depth. The focus has a depth extent of ~2 m.*

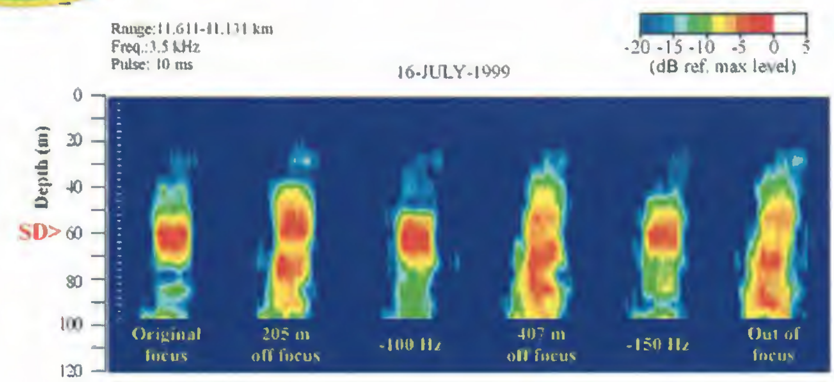


Figure 06-B.6 *Frequency shifting for refocusing.*

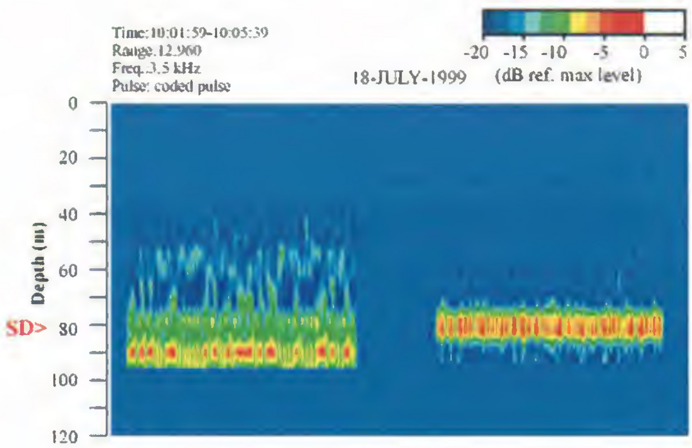


Figure 06-B.7 *A 50 bit random sequence of 2 m pulses. Left column: One way. Right column: two-way time reversed.*

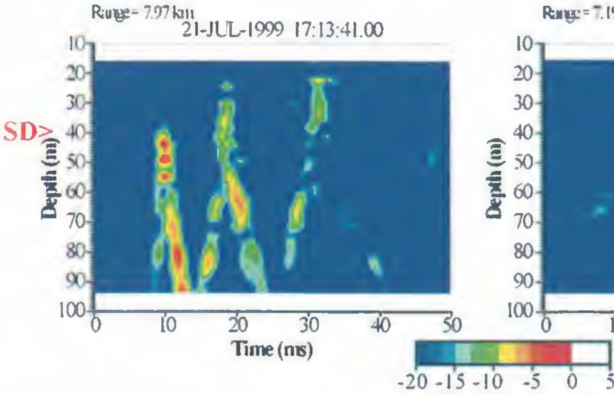


Figure 06-B.8 *Multipath spread of a 2 m PS pulse (source depth 40 m) observed at the SRA over a relatively range-independent, 7.2 km propagation path at a depth of t 110 m near Elba (left). Pulse received at the VRA after time reversal and retransmission (right).*

The multipath spread for a 2 m pulse transmitted over a relatively range-independent, 7.2 km propagation path in 110 m deep water north of Elba was of the order of 30 m (Fig. 06-.B.8). After time reversal and retransmission, the pulse was compressed back to ~2 m duration. Packets of 50 bits were then generated by convolving a random sequence of {+1,-1}'s with the time-reversed reception at the SRA of a 2 m probe source pulse. The time series of these packets received at the VRA is being compared with the received time series of packets generated at the SRA by convolving the random sequence with a 2 m pulse.

Modelling

During 1999, acoustic propagation models were modified to include back propagation for 1999 experimental data interpretation. Figure 06-B.9 shows a comparison between data and model for transmission loss. Figure 06-B.10 shows the simulated focal area for an 80 m deep source at 5 km distance. The results confirm that the focal structure observed is consistent with theory.

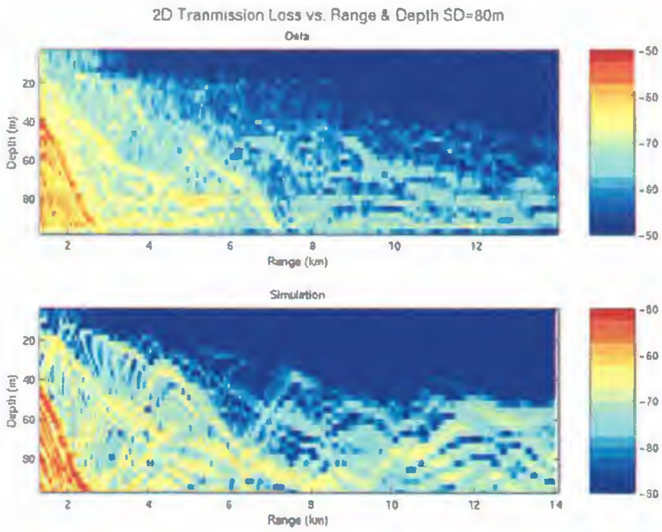


Figure 06-B.9 *TL data- model comparison for 80 m source depth.*

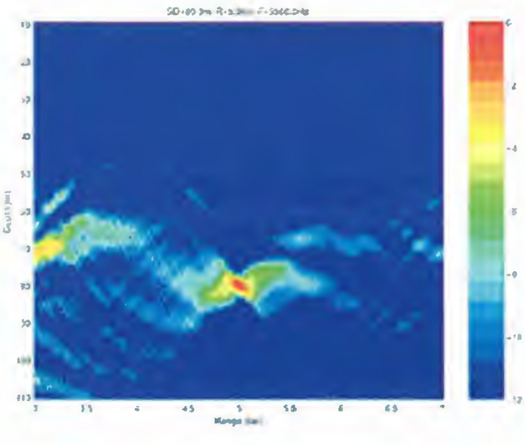


Figure 06-B.10 *Single frequency time reversed spatial focus versus range and depth. The source depth was 80 m and range 5 km.*

6

Project 06-B publications and presentations[*]

Akal, T., Di Iorio, D., Guerrini, P., Boni, P., Ferla, C. Hodgkiss, W.S., Song H.C., Kuperman W.A., Jackson, D.R. Range and time dependence of focused acoustic field and iterative focusing at 450 Hz, SACLANTCEN SR-327.

Akal, T., Di Iorio, D., Guerrini, P., Boni, P., Cavanna, A., Stoner R., Ferla, C., Kuperman, W.A., Hodgkiss, W., Song, H.C., Edelmann, G., Kim, S. Focused acoustic field at 3.5 kHz: Data report for FAF-99 sea trial, SACLANTCEN SM-369.

Kuperman, W.A., Hodgkiss, W.S., Song, H.C., Thode, A., Akal, T., Ferla, C. Phase conjugation and matched-field processing. *Journal of the Acoustical Society of America*, **105**, 1999:1308:4pSP2.

Song, H.C., Kuperman, W.A., Hodgkiss. W.S., Akal, T., Ferla, C. Iterative time reversal in the ocean. *Journal of the Acoustical Society of America,* **105**,1999: 3176-3184.

Tuncay Akal *received BS, MS and Ph. D degrees from the University of Istanbul and George Washington University. Since 1968 he has been principal and senior scientist at SACLANTCEN. From 1992 to 1995 he was Chief Scientist for NATO MILOC (Military Oceanographic) surveys. He was Survey Director of* Rapid Response 1996.

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

[*] Experiments carried out by the Centre were described in: Fink, M. Time-reversed acoustics. *Scientific American*, **281**, 1999:91-97.

Project 06-C: Sound, oceanography and living marine resources (SOLMR)

Operational relevance

*To formulate a **Marine Mammal (Acoustic) Risk Mitigation Policy** designed to limit the exposure of human divers and marine mammals to low-frequency sound.*

Background

The following procedures have been formally instigated during trials:

- Visual and passive acoustic (i.e., listening) monitoring to ensure that marine mammals are distant from an acoustic source
- Slow increase of acoustic power to allow marine mammals sufficient opportunity to leave the test area in the event that visual and passive searches are unsuccessful
- Creation of a database of marine mammal sightings and strandings to identify the migratory behavior of species so that acoustic testing can be conducted in areas where marine mammals are unlikely to be encountered
- Continuous review of the *Marine Mammal Risk Mitigation Policy* to incorporate new techniques and information, e.g., do not plan experiments near known diving areas or marine mammal breeding grounds. The policy requires that marine mammals should not be exposed to sound levels exceeding 160 dB re 1 μPa, which in practice amounts to maintaining a "mammal-free zone" around the source

Advanced passive acoustic sensors, developed originally for ASW are being studied as a means of detection and classification of underwater "biological" sound, in order to reliably establish and monitor that an experimental area is free of marine mammals.

At- sea measurements using dual use technology

Progress in basin wide oceanographic modelling and remote sensing and the ability to acoustically monitor the environment for prolonged periods, allows a multidisciplinary, multinational approach to predicting the population density of cetaceans on a seasonal basis. A multi-year at-sea effort was planned, to evaluate risk mitigation techniques, which use existing monitoring technologies, acquire associated environmental information and to determine the correlation of these parameters.

Dual Use Technology developed at the Centre and satellite remote sensed data were used during the first sea trial, Sirena '99, in the Ligurian-Corsica basin, which was recently designated as the first International Marine Sanctuary in the Mediterranean Sea.

The US Office of Naval Research (ONR) participated by providing funds to map the lower trophic level distribution and to tag cetaceans in order to increase knowledge of whale behaviour.

The Italian Navy provided the research vessel for the oceanographic and lower trophic level measurements and a Sea King helicopter for visual surveys prior to the cruise.

Although it is inevitable that monitoring and observation is subject to significant temporal and spatial discontinuities, it constitutes a valuable supplement to existing models.

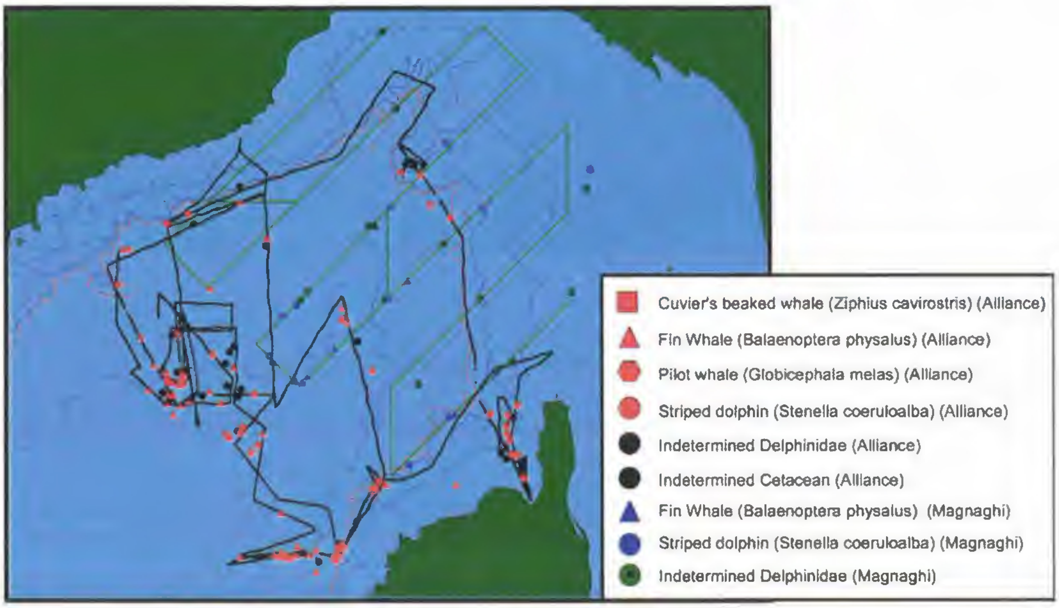


Figure 06-C.1 *Sirena 99 cruise. Alliance conducted acoustic and visual measurements along the track shown in black. The Italian Navy Hydrographic vessel Magnaghi conducted oceanographic and prey field measurements along the track shown in green. The symbols show the visual sighting of the cetaceans by both vessels.*

Figure 06-C.1 summarizes acoustic and visual sightings during Sirena 99 (3394 nautical miles of navigation, 320 hours of visual observations and over 340 hours of real time acoustic monitoring in an 11 day period).

Tagging operations from a small vessel were conducted prior to the main portion of the oceanographic and acoustic cruise, but adverse weather conditions prohibited concurrent tagging operations. On the *Alliance*, a dedicated visual survey team conducted visual observations from the flying bridge, which provided a platform 18m above the water line. The acoustic watch was conducted in the scientific lab, where there was constant monitoring of the acoustic display. A comparison of visual and passive acoustic detection methodologies, demonstrated that combining these techniques is most effective. Visual watch is restricted during high seas and low/no light conditions. Passive

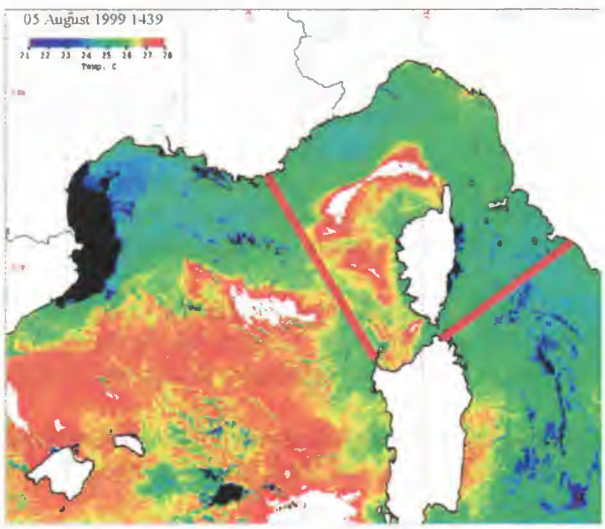


Figure 06-C.2 *Representative sea surface temperature during the Sirena 99 cruise period (5 August 1999). Red lines outline the boundary of the Ligurian Sea Cetacean Sanctuary.*

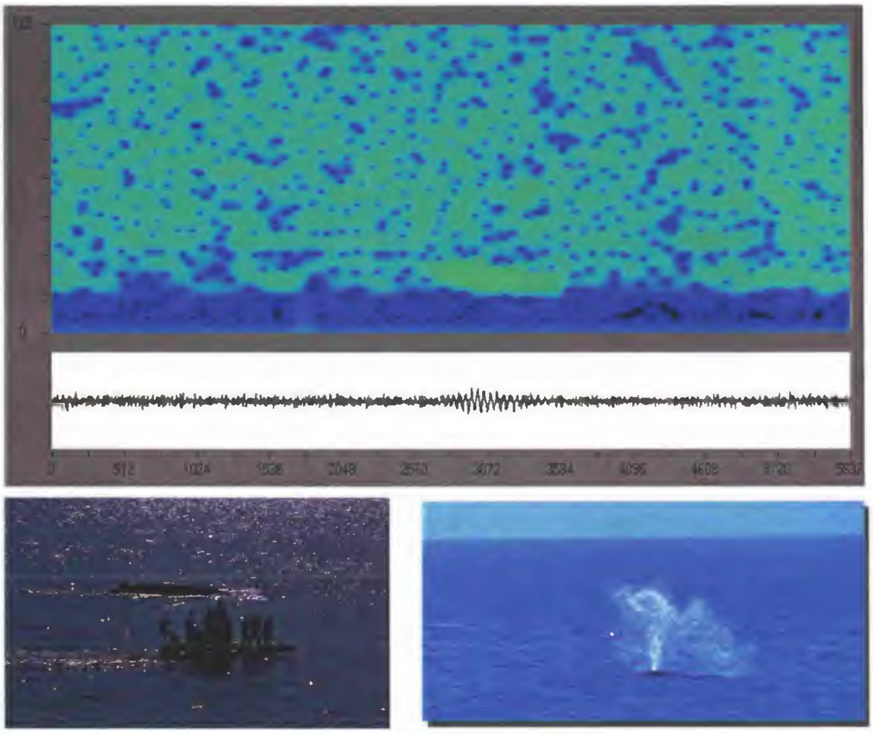


Figure 06-C.3 *A one second, 25 Hz - 18 Hz low frequency, down sweep signal from a fin whale. Photographs show visual sightings.*

acoustic techniques are effective for detection, localization and tracking only when the animals vocalize

Remotely sensed data (SeaWIFS ocean colour and AVHRR sea surface temperature) were acquired in real time at SACLANTCEN. Ancillary physical satellite data from the Colorado Center for Astrodynamics Research (CCAR) were used to interpret mesocale physical and biological oceanography in the Ligurian Sea during the summer, where upwelling provides a nutrient rich cetacean feeding area. (Fig. 06-C.2). The concurrent oceanographic and lower trophic level measurements are being integrated with the satellite images in a geographical information system (GIS). Sirena 99 demonstrated the feasibility of the establishment of a comprehensive GIS-based database of marine life in conjunction with relevant physical/biological parameters.

Eight species of cetaceans are commonly found in the Mediterranean. These include: Fin Whale (*Balaenoptera physalus*), Sperm Whale (*Physeter macrocephalus*), Cuvier's beaked whale (*Ziphius cavirostris*), Long Finned Pilot whale (*Globicephala melas*), Risso's dolphin (*Grampus griseus*), Bottlenose dolphin (*Tursiops truncatus*), Common dolphin (*Delphinus delphis*) and Striped dolphin (*Stenella coeruleoalba*). Sightings of ten other species have been reported. Cetaceans emit a variety of sounds, clicks, grunts and whistles with widely differing time and frequency characteristics.

During Sirena 99, acoustic and/or visual detections were made of five common Mediterranean cetaceans, including fin whales, alone or in small groups on most days at ranges of up to 9 km. Figure 06-C.3 shows a very low frequency, fin whale signal, detection of which is difficult, due to high background noise levels in this frequency band. Long finned pilot whales were encountered once, when two pods were seen in close proximity to the *Alliance*. Figure 06-C.4 shows wideband whistles recorded from a single individual.

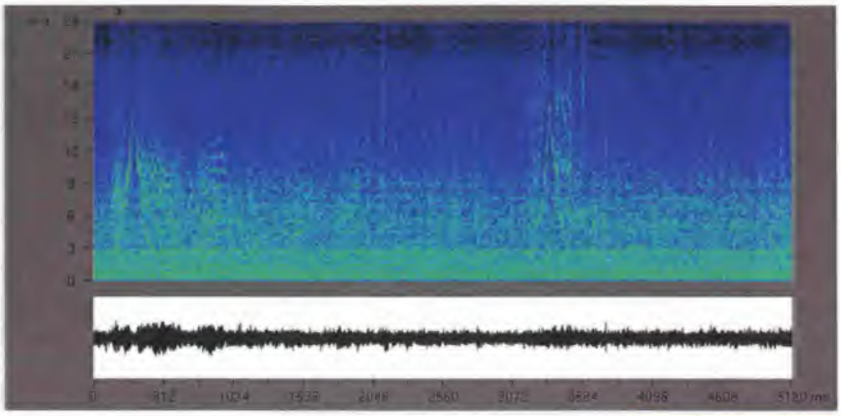


Figure 06-C.4 *Broadband whistles from a long finned pilot whale. Photograph shows visual sighting of two adult juvenile*

Vocalizing animals can be localized. Figure 06-C.5 shows the position of a sperm whale 10.5 nautical miles from the *Alliance*, exploiting the capacity of the towed array to distinguish azimuthal direction over time as the ship moves. Several manoeuvres were executed to cross fix the animal *via* target motion analysis (TMA). As the whale was outside the authorized operating area, visual identification was not possible. Figure 06-C.6 shows acoustic localization of a fin whale using trilateration, using time of arrival (TOA) differences from separate sensors to cross fix the source. The location estimated from this localization corresponds well to the estimated range and bearing of a visual observation minutes earlier and indicated on the figure.

Passive localization is moderately effective. Marine mammal vocalizations cover a very wide frequency range and vary from extremely narrowband to extremely wideband. Bearing information from a towed line array is useful, e.g., as a cue to visual observation, however the critical parameter for mitigation is the range. TMA is effective for single animals that vocalize regularly. The effectiveness of trilateration of time-of-arrival information for any species, using simple equipment, is limited only by sensor configuration and characteristics.

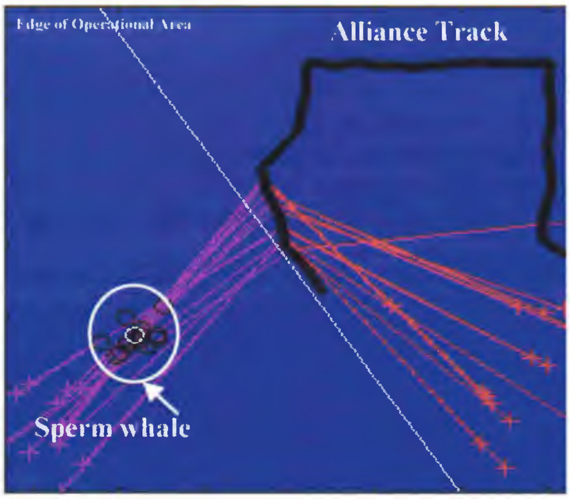


Figure 06-C.5 *Position estimate of a sperm whale measured as a distance from the Alliance. The lines ending in crosses are the beam directions at various times along the tracks. The beams on the left side of the image converge on the area indicated by the circle. The beams on the right of the image diverge.*

Cetacean database (in partnership with the Centro Studi Cetacei)

The Mediterranean cetacean database was conceived to determine areas of high and low cetacean population density in the planning stages of trials using high power sound sources. The database is designed to accelerate data entry, integration and dissemination, based on an interactive WEB server. The server will incorporate an interactive geographic visualization system allowing data to be searched by area. The database consists of several thousand records of sighting and stranding data in Italian waters and on Italian coasts.

Eleven years of stranding data (2000 records from 1986-1996) have been digitized. Figure 06-C.7 shows the data, sorted by family. The data may be summarized and plotted by species, year, season, geographic area and/or cause of death. The causes of these events include entanglement in fishing nets, animals which have been deliberately killed and natural death. More than 4000 Italian sighting records have been added to the original database.

Sirena sea trials will continued systematic monitoring coupled with environmental measurements to provide the understanding of cetaceans in their environment. The database will be extended to include other regions in the Mediterranean.

For public outreach and education, the Centre has established working relationships with the Acquario di Genova, the University of Pavia, the Istituto Centrale per la Ricerca Applicata al Mare, (ICRAM) World Wide Federation for Nature and the Centro Studi Cetacei to disseminate SOLMR products.

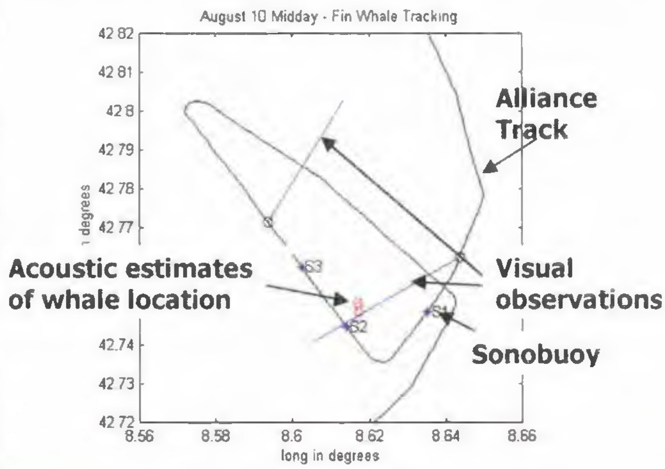


Figure 06-C.6 *Acoustic localization of a fin whale using trilateration.*

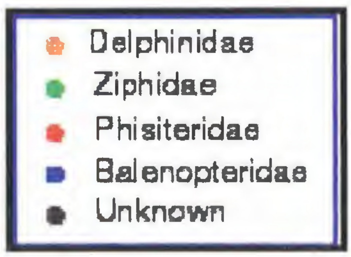


Figure 06-C.7 *Location of cetaceans (see key) stranded along the Italian coast 1986-1996.*

Project 06-C publications and presentations

Bondaryk, J.E., D'Amico, A., Portunato, N. Techniques for Passive Detection and Localization of Marine Mammals using Wide Aperture Arrays. *Journal of the Acoustical Society of America,* 1999, 106, 1999:2188:3aABA2.

D'Amico, A., Bondaryk, J.E., Fossati, C., Manghi, M., Pavan, G., Portunato, N., Priano, M. Acoustic detection and localization of marine mammals in the Ligurian Sea. CSC Annual Conference, Milan, 11-12 November 1999.

D'Amico, A., Bondaryk, J.E., Portunato, N. Passive Detection and Localization of Marine Mammals in the Ligurian Sea. *Journal of the Acoustical Society of America,*106,1999:2164:2pAB13.

D'Amico, A., Fossati, C., Pavan, G., Podesta, M., Application of Graphical Digital Tools to Stranding Information: Mapping of the Strandings off the Italian Coast, 1986-1996, Proceedings of the European Cetacean Society 13th Annual Conference, Valencia, Spain, April 1999.

D'Amico, A. Sirena '99 - Quick look presentations and preliminary data, SACLANTCEN CD-27, October 1999.

Fossati, C., D'Amico, A., Manghi, M., Pavan, G., Podesta', M., Portunato, N., Priano, M., Teloni, V. Marine mammals and oceanographic parameters: The Geographic Information System as a tool for their organization and integration in the Mediterranean Sea. CSC Annual Conference, Milan, 11-12 November 1999.

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 (SOLMR) 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 SOLMR 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.*

A Ship Management Office, NRV Alliance and T Boat Manning

R.V. Alliance

The outstanding operational availability of the *Alliance* allowed participation in 8 major scientific experiments during 1999, including testing for the Mammal Risk Mitigation Policy. As all operations took place in the Mediterranean, the ship remained on heightened security alert status throughout the year, due to NATO operations in Kosovo.

Notwithstanding an average of 200 experimental sea days *per annum* since 1989, the vessel is in excellent condition, with no signs of steel plate consumption at recent ultrasonic tests. *Alliance*, with continued, directed investment, will operate successfully for twenty years.

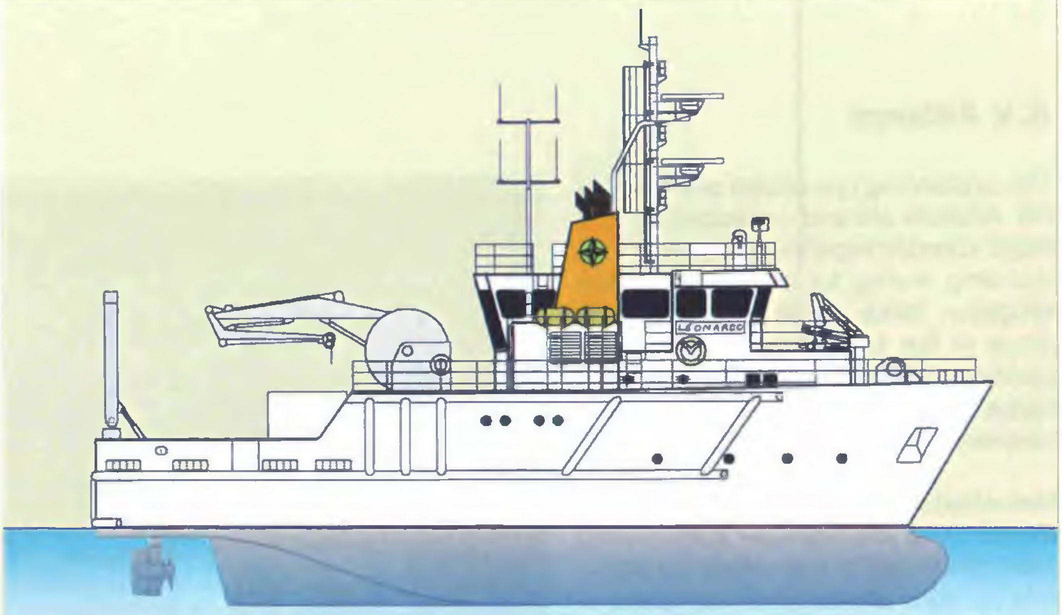
The Ship Management Office has attempted, within the limitations of resources, to heighten the marketing profile for *Alliance* by attending two defence related exhibitions: Underwater Defence Technology (UDT), Nice (France) in June and Defence Systems and Equipment International (DSEi), Chertsey (UK), in September.

The success of the marketing strategy may be judged by the six-day charter to the Italian Navy during 1999 and the 34 charter days in 2000, bringing the total number of charters and charter days since 1997, when the chartering programme began, to 10 and 123 respectively.

SMO continues to participate in and contribute to the Research Vessel Operators' Committee (RVOC); this group comprises a significant number of the UNOLS (USA) and other national marine managers of research vessels and is a professionally illuminating and knowledgeable forum which meets at least once a year.

T-Boat Manning replacement

The pursuit of funding to design and construct a replacement for the 46 year old T-Boat *Manning* has met with success. As a result, a significant proportion of SMO resources have been devoted to developing Mission Profile Statements, Requirements Document and Indicative General Description for the proposed vessel. Following an international competition the Design and Project Management contract was placed with the Consulting Naval Architect company Burness, Corlett and Partners. A period of six months dedicated to design and specification will precede a further International Competition for the construction phase in October 2000. Delivery is scheduled for the final quarter of 2001.



CREW:	To be determined
DIMENSIONS:	27.5m / 8.5m / 2.4m / 260 tons
RANGE:	1500nm at 11 knots
PROPULSION:	Diesel electric dynamic positioning, one silent condition 0-5 knots
STATUS:	Italian public vessel NATO operated classed by ABS and RINa

Chris Gobey entered the Britannia Royal Naval College, Dartmouth, in 1961. His subsequent career included a period of loan service with the Royal New Zealand Navy and four years as commanding officer of HMS Hecate in the Falklands, South Georgia and Antarctica. He was deputy leader of a joint services expedition to the northern ice cap of Chile. He has been Head of the Ship Management Office at SACLANTCEN since 1986.

An impresssion of the new Building 14, which when completed, will, in conjunction with the new pier, bring about significant cost savings and improved efficiency in equipping and preparing the Alliance and the coastal research vessel Leonardo, which will replace the Manning in 2002.

The site of the new pier.

B Annual Bibliography of SACLANTCEN reports with abstracts

In addition to 8 journal papers, 52 conference presentations, 4 CD-ROMs and one book (listed under the appropriate project), the following SACLANTCEN reports were published

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SM-359

Hermand, J.-P.
Broad-band geoacoustic inversion in shallow water from waveguide impulse response measurements on a single hydrophone: theory and experimental results.

Performance models such as the Allied Environmental Support System (AESS) require environmental input parameters such as the geoacoustic properties of the battlespace. The models ingest the input parameters from databases to predict the ASW and MCM performance in the operating area. These databases have a scarcity of data, particularly in littoral environments. A Rapid Environmental Assessment (REA) technique has been developed which allows for the determination of the geoacoustic properties without resorting to large acoustic receiving apertures. The method is based on reception of broadband acoustic signals and modelling the littoral environment between the acoustic transmitter and a signal receiving hydrophone. In addition, the technique has been extended to drifting sonobuoys such that the bottom properties of the battlespace can be determined remotely. This report presents the measurement and modelling results and demonstrates that the bottom features can be resolved.

SM-360

Mozzone, L., Berni, A., Guerrini, P.
Long range, large throughput radio data link for DUSS (Deployable Underwater Surveillance Systems).

Two mono-directional radio telemetry systems are described operating from a buoy to NRV Alliance at frequencies of 0.4 and 2.28 GHz. Digital data at 2 Mbps were transmitted close to the sea surface, collecting information on error statistics and propagation loss versus buoy distance, antenna height and radio parameters. A candidate system was configured for both frequency bands and the goal of 10 n.mi range was achieved. Field tests were supported by computer simulation for validation and a better insight into the results. An additional test assessed the performance of a low-power, full duplex, spread-spectrum radio link, operating at the data rate of 128 kbps, up to 3.5 n.mi. The experiments and conclusions provide useful input to the design of a Deployable Underwater Surveillance System (DUSS) for scientific and operational purposes.

SM-362

Tesei, A., Maguer, A., Fox, W.J.L., Schmidt, H.
Measurements of acoustic scattering from partially and completely buried spherical shells.

Recent work at NATO SACLANT Undersea Research Centre has concentrated on investigating the use of low frequency sonars (2-20 kHz) in order to better exploit scattering features of buried targets that can contribute to their detection and classification.

Part of the recent GOAT'98 experiment performed off the island of Elba, involved controlled monostatic measurements of scattering by spherical shells which were partially and completely buried in sand, as well as suspended in the water column. Analysis is mainly addressed to a study of the effect of burial on the dynamics of backscattered wave families, which can be clearly identified in the target responses. Data interpretation results are in good agreement with theory.

SM-363

LePage, K.D., Schmidt, H.
Spectral integral representations of scattering from volume inhomogeneities

In-situ measurements of scattering strength can be obtained by analyzing the early-time, high angle reverberation from bottom and sub-bottom features. In order to provide insight into the mechanisms which cause bottom reverberation and to their distinguishing characteristics, it is necessary to have a capability for modelling both the rough surface and the volume scattering mechanisms. For high-angle, early-time backscatter, the most appropriate approach is to use a spectral integral representation, which naturally includes the continuous spectrum important for this angular regime. A rough surface scattering theory developed earlier in this framework has provided important insights into wave scattering and penetration physics at the seafloor. Here a consistent representation for the subbottom scattering is developed and implemented in the same spectral integral code, OASES.

SM-364

Holland, C.W., Hollett, R., Troiano, L.
Bottom scattering measurements in shallow water.

Sonar performance predictions of reverberation in shallow water rely upon good estimates of the bottom scattering strength. However, little is understood about bottom scattering in shallow water in the frequency range 400 – 4000 Hz, particularly its dependency upon frequency and its relationship to the physical properties of the seafloor. In order to address these issues, new measurement techniques have been developed to probe the frequency and angular dependency of bottom scattering strength. The measurement techniques also appear to be capable of revealing the physical mechanisms that give rise to the scattering. Several experimental techniques will be described, including use of coherent and incoherent sources (lightbulbs). The general experimental approach is also described which includes auxiliary acoustic and geoacoustic measurements designed to allow exploration of the relationship between bottom scattering and the physical properties of the bottom. Measurement and modelling results for two shallow water sites are presented. At one site, the scattering appeared to arise from at or near the water-sediment interface. At the other site, scattering from a 25 m sub-bottom horizon is clearly apparent in the data at and below 1800 Hz.

SM-365

Fioravanti, S.
An efficient SAS processor

This work describes the design and the implementation of an efficient, high-speed SAS processor able to receive the navigation system data for an accurate generation of the synthetic image. The SAS beamformer is a pixel-based one working in the time domain with real or complex data (in-phase and in-quadrature). The adopted approach allows the generation of physical images during the process. The report explains the technique developed for a fast phase reconstruction with complex beamforming.

The SAS processor makes use of Taylor approximation for an improvement in the computational speed. The analysis of the region of validity of the approximation is mathematically computed depending on the order of the Taylor expansion.

The algorithm has been implemented in standard ANSI-C language and intensively tested on an HP-C180 workstation with simulated and real data.

An accurate analysis of the computational efficiency is reported.

SM-366

Hermand, J.-P., Nascetti, P., Cinelli, F.
Inverse acoustical determination of photosynthetic oxygen productivity of posidonia seagrass.

As part of geoacoustic inversion experiments (Yellow Shark) in the Giglio basin, off the west coast of Italy, low frequency, broad-band propagation measurements were performed in the winter and spring of 1995 over a dense and extensive prairie of Posidonia seagrasses which surrounds Scoglio d'Africa, a minor island of the Tuscan Archipelago. The purpose of the measurements was to determine the applicability of model-based, geoacoustic inversion techniques developed for marine sediments to the monitoring of oxygen synthesis by Posidonia.

A dual-flextensional acoustic projector and a 4-element vertical receiving array were positioned at 1541 m distance in an isobath (25 m water depth), dense and homogeneous part of the Posidonia prairie. The waveguide impulse response was measured during one day by 1~min repeated and alternated transmissions of 3 s chirp signals with frequency bands 0.1-0.9 kHz and 0.8-1.6 kHz.

The water sound speed profiles calculated from repeated CTD measurements were slightly downward refracting and exhibited little temporal variability except for mild surface heating in the afternoon. Contemporaneous oxygen and CTD profiles as a function of daytime and season were obtained in 1997 to support the present study.

B

In this paper acoustic, solar radiation, oxygen and CTD data are analyzed and discussed. The analysis shows strong correlation between photosynthesis and the impulse response of the acoustic waveguide. The most evident feature is an abrupt and marked change of attenuation and time dispersion characteristics at the onset of photosynthesis. Frequency- and depth-dependent rapid variations of received energy (2-5 dB) and time spread (3-10 ms) are observed. The time of occurrence and rate of change of these variations are consistent with solar time and oxygen concentration measured in situ. The phenomena is attributed to bubbles of photosynthetic oxygen formed on the Posidonia leaf blades. The bubble layer creates an absorbing, dispersive, low-speed, thin parallel waveguide which modifies interaction of acoustic energy with the Posidonia "matte". It is demonstrated that, after sunrise, low-order modes begin to travel in the seagrass layer, absorbing a portion of acoustic energy from the main waveguide. A similar effect can occur in a near-surface waveguide when supersaturation (undissolved oxygen) conditions obtain.

Modeling results indicate that the inverse problem of determining gas and oxygen void fractions in the seagrass layer could be solved. Parameters such as surface density and photosynthetic efficiency of Posidonia can be derived from the variations of inverted void fractions.

These results may be applicable to the monitoring of the state of health of Posidonia and other seagrasses in the Mediterranean and other oceans

SM-367

Berni, A., Mozzone, L.
The application of spread-spectrum communications to REA tactical networks and deployable underwater surveillance systems.

The present document is a part of an ongoing study on advanced communication techniques in support of Rapid Environmental Assessment (REA) and Deployable Undersea Surveillance Systems (DUSS). It aims at the definition of data transmission architectures for both scientific data acquisition at SACLANTCEN and for operational concept demonstration.

Emerging methodologies for Anti-Submarine Warfare (ASW) and Rapid Environmental Assessment (REA) increasingly rely on communication technology, in order to exchange information with other naval units or military commands ashore.

The specific requirements (such as ranges and transmission data rates) are addressed. They vary from 2.4 kbps to 2 Mbps and from 10 to 20 n.mi. In addition to that, all military applications have common requirements in terms of reliability, availability and security. The eligibility of classical and spread-spectrum radio communication techniques to the fulfillment of such requirements is discussed and shown. Performance is estimated and compared.

Spread-spectrum techniques offer such features as interference rejection, anti-jam capability and low-density power spectra for covert operations: field tests of spread-spectrum equipment have successfully been conducted in 1998 during SACLANTCEN experiments GOATS 98 and DUSS 98. The availability of commercial off-the-shelf (COTS) products including sophisticated communication protocols also represents a relevant issue for scientific applications. Such features as the creation of a multi-point, error–free, packet switching Local Area Network (LAN) deserve to be carefully investigated in their impact on DUSS and REA applications.

SM-368

Tesei, A., Pinto, M.
Application of aided inertial navigation system to synthetic aperture sonar micronavigation.

In order to improve navigational accuracy, critical to successful SAS processing, a high-quality Aided Inertial Navigation System (AINS) is investigated, which consists of an inertial navigation system (INS), Doppler velocity log and intermittent DGPS fixes, the data of which are fused by an extended Kalman filter. Although the strapdown INS recently acquired at SACLANTCEN is one of the best available, the accuracy of positioning remains insufficient, in particular for high-frequency SAS.

Through a navigational simulator/estimator provided by NDRE (Norwegian Defence Research Establishment), the analysis of expected performances of the AINS has been performed. In particular, the short-term residual errors of position displacement and attitude have been analyzed in terms of dominant components and their sources. Preliminary results show that the attitude error is estimated to be negligible due to the very low values of gyro bias and white noise. The position error is shown to be dominated by an evident quadratic drift due to accelerometer biases.

Aiding the AINS-based navigation with SAS motion compensation techniques is foreseen to significantly reduce this critical error component. The design, development and test of the combined SAS-AINS architecture will be the main objective of next activities.

SM-369

Akal, T., Di Iorio, D., Guerrini, P., Boni, P., Cavanna, A., Stoner R., Ferla, C., Kuperman, W.A., Hodgkiss, W., Song, H.C., Edelmann, G., Kim, S.
Focused acoustic field at 3.5 kHz: data report for FAF-99 sea trial.

Two low frequency (~450 Hz) Focused Acoustic Field (FAF) experiments previously were carried out in 1996 and 1997 in ~125 m water adjacent to Formiche di Grosseto (a small island approximately 100 miles SW of SACLANTCEN). These experiments demonstrated that FAF is both feasible and stable at low frequencies in shallow water and that focusing of the retransmitted energy is possible at ranges of at least 30 km. Also demonstrated was the ability to shift the range of focus to ranges other than that of the probe source by a simple method involving a frequency shift of the received time series prior to retransmission.

As an outgrowth of the successful low frequency phase conjugation experiments, a high frequency (3.5 kHz) FAF experiment was carried out within the Joint Research Project between SACLANTCEN and MPL in July 1999. Experiments were carried out adjacent to both Formiche di Grosseto and N of Elba Island. The former provided a link to our previous experiments while the latter provided a brief opportunity to explore a new environment. During this experiment we demonstrated the high frequency FAF at ranges out to 14 km in both flat and sloping coastal regions, the short-term temporal and spatial properties of the focal region in two different bottom types and the initial demonstration of phase-conjugation processing in acoustic communications.

In this memorandum we present the experimental procedures and acoustic and environmental data collected during the July 1999 experiment. An additional CD containing the data is provided.

SM-370

Noseworthy, D.
Seismic stratigraphy of the Capraia Basin, Northern Tyrrhenian Sea.

The distribution and thickness of sediments within the Capraia Basin, Northern Tyrrhenian Sea, have been mapped using high-resolution seismic reflection data. The data were studied within the geologic framework determined by previous works conducted in the Northern Tyrrhenian Sea. This study was especially influenced by the work of Brizzolari et al (1991). Collectively these studies show that sediment above the basement in the Capraia Basin consists of at least two seismic units, deposited since the Mid-Upper Pleistocene.

Unit 1 is correlated with Brizzolari's et al., (1991) unit B and unit 2 with his unit C. Unit 1 lies unconformably below unit 2 and covers a vast area within the Capraia Basin. As determined by Brizzolari et al., (1991), the deposition of unit B and unit1 was strongly influenced by Mid-Upper Pleistocene glacio-eustatic fluctuation. Subsequent rise and fall of sea level within shallower regions of the basin, especially between 115-100 m water depth, resulted in the deposition of stacked sedimentary successions (of unit 2) which display strong erosional character and discontinuity. Basinward, unit 1 thickens drastically, from 10 – 80 ms twtt, into a package of aggregated to slightly progradational reflectors. Conversely, unit 2 thins basinward. It is limited geographically to the northwestern region of the Capraia Basin. As determined by Brizzolari et al., (1991), the geometry of unit 2, is strongly influenced the depositional setting. Unit 2 is composed of a thin (1- 15 ms twtt) package of stratified reflectors, which taper westward. Studies have shown that successions correlating with unit 2 are predominantly composed of sediment transported into the basin by modern day feeding sources, with dominant influence coming from the Cecina River, located northeast of the study area. Brizzolari et al., (1991) interpreted unit 2 to be the result of present-day highstand sedimentation in the Capraia Basin, deposited since the Holocene.

SM-372

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

Posidonia oceanica meadows are the most important ecosystem for the life cycle of coastal Mediterranean benthos having a fundamental role in the primary production of the neritic system and a decisive influence on other vegetation and animal communities. The P. oceanica meadows are presently undergoing a slow, but progressive regression throughout the Mediterranean and generally, the most common cause of regression is enhanced turbidity and the consequent reduction of water transparency. The first step towards the safeguarding of such important coastal environments is that of defining their extent and state of health. Echographic survey allows general maps to be obtained, but accurate seafloor characterization requires knowledge of the acoustic properties of seabed vegetation.

In this report we present some of the microscopic characteristics of P. oceanica leaves. The presence of air channels running the length of each leaf blade and the presence of cellulose that is the main constituent of cell walls are assumed to be extremely important for explaining the strong high-frequency scattering of Posidonia meadows. A preliminary study has been conducted that represents a first attempt to quantify the air within the leaves of P. oceanica and to consider it as a function of the plant life cycle. An order of magnitude of the volumes of the different elements considered and their relative importance expressed as percentages has been given. The values obtained have been *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 from the present work will be the development of a model for the acoustic scattering of P. oceanica derived from one developed for gassy sediments. The final result could be a fundamental tool to improve the present capabilities of acoustic instruments and make it possible from an ecological point of view to obtain fast and large-scale information not only on the extension of the meadows, but also on the density and height of the plants. On the other hand, from an operational point of view it could improve the performances of mine-hunting sonars.

SR-310

Zerr, B., Tesei, A., Maguer, A., Fox, W.L.J., Fawcett, J.A.
A classification technique combining aspect dependence and elastic properties of target scattering.

Discrimination between man-made and natural underwater objects and between man-made objects of different characteristics are the key objectives of target classification. The current approach is mainly based on the analysis of the target signature imaged by high resolution (typically <20 cm) high frequency (typically <100 kHz) sonars. To estimate the potential of alternative classification schemes based on more detailed acquisition of target echo features, SACLANTCEN has investigated low frequency (10 kHz) sonar systems with high fractional (or relative) bandwidth (2-20 kHz).

The classification method relies on two features of the target echo: aspect dependence and elastic scattering. The two dimensional reflection map, reconstructed from multiple aspects, serves as the basis for pre-classification. For objects of external shape recognized as man-made at the pre-classification stage, resonance information is extracted by autoregressive spectral estimation techniques and further processed for particular aspects (e.g. broadside). The analysis of the resonance scattering provides an estimate of some geometrical and physical target parameters (i.e. shell wall thickness and material and inner fluid properties) and can be improved by introducing the object dimensions, estimated from the reflection map. This report, which describes the classification methodology and the results obtained with steel cylinders, demonstrates the potential of the method.

SR-311

Osler, J., Algan, O.
A high resolution seismic sequence analysis of the Malta Plateau.

A high resolution seismic study of the Malta Plateau was conducted to characterize the Quaternary sediment layers, mapping their regional extent and determining the environmental conditions during their deposition. Seismic stratigraphic analysis indicates that there are six seismic units (or depositional sequences) bounded by erosional unconformities. The basement surface, that is an erosional truncation in some places, indicates that a hiatus probably occurred during Messinian to Early Pliocene. The terminations of all the sequence boundaries onlap the acoustic basement in a landward direction, revealing an overall relative sea level rise. The termination of the internal strata (reflectors) in Units 2,3 and 4 have an oblique parallel pattern and toplap at their upper surface, characteristic of periods of sea level stillstand and/or a decrease in the rate of sea level rise. It is anticipated that this depositional history would cause the physical properties of the sediment in the immediate vicinity of the erosional unconformities to differ from that in the adjacent sequences. Within a given sequence and with respect to the other sequences, it is anticipated that the physical properties of the sediment are relatively homogeneous, with the exception of the uppermost sequence, Seismic Unit 1.

Carbonate buildup structures are observed at the boundary between Units 2 and 3 in the northwest part of the study area and imply a very shallow water depositional condition during their formation. The uppermost layer, Unit 1, is the most extensive geographically and gets thicker towards the coast of Sicily. The parallel configuration of its internal reflectors and the progradational character of the unit suggest that it is comprised of coastal sediments deposited during the Holocene highstand of sea level. In the shelf-slope transition, sequences are deformed by mass movements that might be attributable to tectonic activity in the region. Several basement outcrops were observed in the study area. Some have northwest-southeast trending lineations, as observed on Sicily, while others are isolated structures, possible dikes or salt domes.

SR-312

Watermann, J.
The magnetic dipole moment of RV *Alliance*.

A SACLANTCEN magnetometry sea trial was performed in September 1998 in the northern Tyrrhenian Sea in the vicinity of the Formiche di Grosseto islands. One of the trial objectives concerned the measurement of the magnetic dipole moment of the NATO research vessel Alliance with an array of fixed Ocean Bottom Magnetometers. The Alliance sailed with constant velocity along three specified tracks in reciprocating directions. The magnetic signature of the Alliance was subsequently extracted from the magnetic field data recorded during the experiment. From the magnetic signatures taken from six successive runs, quantitative magnetic dipole models were derived. A comparison *between the magnetic signatures obtained from northwestward and southeastward runs yields estimates of the permanent and induced magnetic dipole moments in the horizontal plane. In the vertical direction, only the total magnetic dipole moment can be determined. The positions of the OBMs, uncertain to some extent, were fictitiously varied such that the horizontal components of the permanent magnetic dipole moment and the vertical component of the total dipole moment remained constant during the experiment. The induced horizontal dipole moment tended to increase steadily and monotonically in a northward direction. Explanations of this phenomenon are discussed.*

SR-315

Maguer, A., Fox, W.L.J., Zerr, B., Tesei, A., Bovio, E., Fioravanti, S.
Buried mine detection and classification (Research Summary 1996-1999)

The applicability of low-frequency sonar (2-16 kHz) to buried mine detection has been investigated. Experiments were performed on sound penetration into sediment, buried target detection and broadband multiple aspect classification. The results of the experiments are given in this report and compared with modelled results.

One of the main results is our success in understanding the physical mechanisms contributing to subcritical penetration into sediment. It has been demonstrated that the evanescent wave was dominant in the lower frequencies [2-5 kHz] of our bandwidth of interest [2-16 kHz]. Roughness scattering dominates at higher frequencies (above 5 kHz) for our bottom type (RMS roughness 1.5 cm, cross-ripple correlation length 25 cm). Although roughness scattering has been shown to be one mechanism for explaining "anomalous" penetration into sediment, its potential for detection and classification of buried objects is unclear due to the low level and the lack of coherence of the received signals. It is demonstrated that sound speed variation with frequency, could exist for permeable sandy bottoms, which could influence the design of a buried mine sonar.

The detection of buried targets is shown to be very effective at above the critical angle. At subcritical angles, detection becomes difficult. Significant gains in signal-to-reverberation radio below critical angle were obtained either by emphasizing a relatively narrow band of frequencies at the lower end of the transmitted bandwidth (below 3 kHz) or by using a larger physical array or synthetic array processing which improve the sonar resolution. Simulations have shown that lower frequencies (of the order of 0.5-1 kHz) are essential to the detection of buried targets at low grazing angles and that the de3tection at those frequencies will only be effective for shallow buried targets.

A method based on multiple-aspect target echo analysis in time and frequency domains, which considers the rigid and resonance responses is presented. Its potential was demonstrated in simulation and on real data (exercise mine, cylinders and rocks) for proud targets and for buried spheres

SR-316

Siderius, M., Snellen, M., Simons, D., Onken, R.
Environmental assessment in the Strait of Sicily: measurements and analysis techniques for determining bottom and oceanographic properties.

In October 1997, the EnVerse 97 shallow water acoustic experiments were jointly conducted by SACLANT Centre, TNO-FEL and DERA off the coast of Sicily, Italy. The primary goal of the experiments was to determine the seabed properties through inversion of acoustic data. Using a towed source, the inversion method is tested at different source-receiver separations in an area with a range-dependent bottom. The sources transmitted over a broad-band of frequencies (90-600 Hz) and the signals were measured on a vertical array of hydrophones. The acoustic data were continuously collected as the range between source and receiving array varied from 0.5-6km. An extensive seismic survey was conducted along the track providing supporting information about the layered structure of the bottom as well as layer sound speeds. The oceanic conditions were assessed using current meters, satellite remote sensing, wave height measurements and casts for determining conductivity and temperature as a function of water depth. Geoacoustic inversion results taken at different source/receiver ranges show seabed properties consistent with the range dependent features observed in the seismic survey data. These results indicate that shallow water bottom properties may be estimated over large areas using a towed source fixed receiver configuration.

SR-317

Mozzone, L., Lorenzelli, P.
Deployable underwater surveillance systems. Target localization with multiple sonar receivers.

Deployable Underwater Surveillance Systems (DUSS) are a network of small multistatic transmitter / receiver sonar nodes. This study analyzes the contact localization capabilities of DUSS in term of range, time and bearing error. This information is used in Monte Carlo simulations to estimate the accuracy of multistatic localization methods suing 2 or 3 receivers. Simulations are validated by real data. Time – only localization of active sonar echoes with 2 receivers produces error estimates of 150 m at 10 km. Active pinger localization with 2 receivers produces average errors of 83 m at 10 km. Bearings – only passive localization with 2 receivers produces average errors of 250 m at 10 km. Buoy separation, buoy localization accuracy, acoustic travel time estimation, beam width and compass accuracy are the most critical system parameters. The use of three receivers further improves accuracy.

SR-318

Mozzone, L., Bongi, S., Ziegenbein, J.
Diversity in deployable underwater surveillance systems.

A multistatic network of autonomous active sonar transmitters and receivers, such as the DUSS (Deployable Underwater Surveillance Systems) currently being studied at the NATO SACLANT Center, often provides multiple contacts of the same target. The present paper examines receiver diversity ("spatial diversity") on a multistatic system, where three independent, spatially separated sonar receivers detect the same target, insonified by the same FM or CW pulse (in a symmetrical configuration) and the contacts are merged together after detection.

Real data collected South-East of the island of Elba (Italy), during "DUSS'97" tests with SACLANTCEN's experimental system are analyzed. The statistical characteristics of measured background noise and reverberation are estimated. Signal to Noise Ratio (SNR) series of echoes from a towed Echo Repeater are analyzed and decomposed into slowly-varying and rapidly-varying components. The degree of inter-receiver cross-correlation is estimated and related to the corresponding overall detection performance of the multistatic system. Experimental distributions of detections and false contacts are computed and experimental Pd - Pfa (Probability of detection – Probability of false alarm) curves are extracted. Receiver Operating Characteristic (ROC) curves are produced with Monte Carlo simulations of a classical statistical model and adopted as a reference.

The analysis is extended to time diversity, comparing single-ping to multi-ping detection. Frequency diversity is also addressed by comparing the classical single - frequency CW pulse with a "stepped CW", i.e. a sequence of three short CW sub-pulses at different frequencies, combined together after detection.

A previous paper demonstrated the feasibility of post-detection fusion of contacts received at different sensors. ["Localization and fusion of echoes with deployable multistatic active sonar: evaluation of feasibility using experimental data", L. Mozzone, S. Bongi, 4th ECUA "98, Roma].

The performance enhancement produced by the three types of diversity studied here is quantified in the experimental data and confirmed by simulations. An increase of Pd varying between 35% and 50% is found (with Pfa of 10-5...10-6) when contacts from three independent receivers (or frequencies, or pings) are combined together. The same improvement is expressed in terms of an equivalent increase of echo SNR ranging from 7 to 8 dB.

SR-319

LePage, K.D.
Time series variability in fluctuating ocean waveguides.

The variability of signals propagating through an uncertain sound speed structure is addressed. Signals are assumed to travel in a narrow band adiabatically in modes and to experience fluctuations in sound speed which are characterized according to the vertical and horizontal distributions of these fluctuations. The sound speed fluctuations are assumed to affect only the phase speed and the group speed of the modes in a perturbative way. The changes in the local phase and group speeds are expanded for small perturbations to the sound speed. Sound speed perturbations are described in terms of their statistical characteristics. Vertically, the sound speed fluctuations are decomposed into empirical orthogonal functions (EOFs), while horizontally they are assumed to be correlated on some horizontal length scale much smaller than the propagation ranges of interest. Thus the cumulative phase and group speed fluctuations over the propagation path are assumed to be distributed Gaussian according to the central limit theorem.

The framework outlined above is used to derive the first and second moments of the signal envelope received over an ensemble of ocean realizations following the distribution properties outlined above. Since the mean and variance of the expected signal are obtained in the time domain, the stability of model arrivals in time can be predicted for a variety of different sound speed fluctuation distributions. Since the phase and group speed fluctuations are linear in identical terms involving the inner product of the mode shape functions with the EOFs, the fluctuations of these quantities are entirely correlated. However, as the different EOFs express themselves differently on each set of propagating modes, the modal interference structure becomes less certain due to the fluctuations. The theory estimates this degree of decorrelation as a function of the signal, waveguide and fluctuation parameters.

In order to benchmark the theory, the first moment of the short time average of the signal intensity is also predicted using realizations of propagation through an ensemble of sound speed fluctuations consistent with the statistical description. Excellent agreement is found between these self-consistent Monte-Carlo estimates of the signal variability and the closed form expressions.

SR-320

Haralabus, G., Capriulo, E., Zimmer, W.M.X.
SWAC 4: Broadband data analysis using sub-band processing.

The frequency dependence of broadband active detection/localization is examined. The analysis is based on 1200 Hz (2300-3500 Hz) LFM signals acquired during the SWAC 4 sea trial. A sub-band matched filter scheme is devised according to which a replica of the transmitted pulse is segmented into ten 120 Hz sub-bands and processed independently through a matched filter detector. Comparison of target detection and ranging results indicate comparable *performance for all sub-bands. However, ping-to-ping variability of the ten correlator outputs suggest that the detection performance may be improved by employing incoherent processing schemes. Signal-to-noise ratio is proved to be controlled mainly by noise (reverberation is the predominant noise source) rather than signal variations. The signal intensity remains proportional to the distance between source and receiver due to favorable propagation conditions. Doppler effects and sub-band detection synchronization problems which may lead to performance degradation in large time-bandwidth signal processing are addressed. A method to estimate range rate (relative velocity between source and receiver) based on single ping differential time delay between sub-band MF outputs is developed. This intra-ping technique is an alternative to the standard inter-ping method which requires multiping detection history.*

SR-321

Osler, J.C., Gualdesi, L., Michelozzi, E., Tonarelli, B.
Piston coring capabilities at SACLANTCEN: minimizing and assessing core disturbance.

Piston and gravity coring and techniques used to collect samples of seabed material. There are many variables that can be adjusted when operating a piston corer, such as free-fall height, core liner material, weight, piston friction, rigging and winch speed. In order to develop a capability at SACLATNCEN to collect longer cores with minimal disturbance, the aforementioned variables were adjusted in a systematic manner in order to determine their relative effects. During the Coring Engineering Trial in March 1999, multiple cores were collected at an experimental site in the Capraia basin, north of Elba Island, where a geoacoustic model has been developed based on a time domain inversion of wide-angle reflection data and frequency domain modelling of bottom loss data. The disturbance of the seabed material during the coring process may have an adverse effect on its physical properties, such as sound speed, magnetic susceptibility and bulk density. Accordingly the amount of compression in each core has been estimated by an analysis of magnetic susceptibility data, correlating and aligning nulls in the response. Laboratory measurements of sound speed and bulk density on three of the cores have been compared with each other and with the geoacoustic model.

From a seabed dominated by silt and clay material with some thin layers containing shells, the properly configured piston corer was able to recover cores of 5 to 6 m in length with a compression of approximately 10%. When it is not properly configured or does not function properly, the compression may be considerably higher, 25 to 35%. Critical factors in the operation of the piston corer included the piston design, the piston friction against the liner, the strength of the shear pins, the cable lengths and the winch speed. Factors that are less significant include the liner material and free-fall height. The laboratory measurements of bulk density are higher that those determined for the geoacoustic model, but may be explained, in part, by the compression of the material during coring.

SR-323

Tesei, A., Maguer, A., Zerr, B.
.Multiple-aspect acoustic scattering analysis of fluid-filled cylindrical targets in water.

Research on mine classification has been focusing for some years at SACLANTCEN on new methods based on the broadband analysis of target echo at low to intermediate frequencies in time and frequency domains.

The proposed methodology has been presented in previous works being limited to multiple aspect target scattering analysis of rigid features in the time domain, integrated with single-aspect (broadside) elastic feature analysis in the frequency domain. This approach allows first the classification between man made and natural objects based on target external shape and rough estimation of its size and then, if the target is classified as man-made, its eventual identification by estimating internal target parameters, such as filling, shell wall material and thickness. This low-frequency approach allows therefore discrimination between objects of the same shape and size, but with different internal structures.

The present work proposes an extension of that approach to the multiple-aspect analysis of both rigid and elastic features also in the frequency domain. This extension is addressed to make the basic method more robust and accurate. Its potential is demonstrated here on simulated and real data for targets in the free space (i.e., suspended in the water column). The low-frequency approach should allow the method applicability also to partially and completely buried targets, as will be demonstrated in future work.

Hence, future modelling and experiments will be dedicated to the extension and validation of the methodology for the classification/identification of targets either lying proud on the sea bottom or buried in the sediments. Further, methods for the automatic extraction of the selected scattering features will be investigated.

SR-324

Zerr, B., Tesei, A., Maguer, A., Houston, B., Sletner, P.A.
Proud target classification based on multiple aspect broadband low frequency response.

The aspect dependence of the acoustic signature has been demonstrated to be an essential indicator to the discrimination between man made and natural underwater objects. A classification method has been define using the variation with incidence angle of the acoustic waves scattered by an elastic object. As the experiment conducted in a basin on free field cylinders has given encouraging results, more realistic acoustic measurements have been conducted *on natural and manufactured objects positioned on the seabed. The external shape, extracted from its reflection map reconstructed by tomography, allows selection of candidate objects for detailed analysis of their scattering properties. The resonance scattering analysis, limited to selected aspects in its original version (e.g. broadside for a cylindrical shape) has been extended to incorporate aspect varying features. The variation with incidence of the acoustic wave diffracted by object discontinuities has also been introduced. This paper reviews the classification technique and describes the SACLANTCEN-NRL TASCOE (TArget Scattering in COntrolled Environment) experiment conducted in water depth of 15 m at Marciana Marina (Elba, Italy) in October 98. The results obtained from the data analyzed show that the aspect dependence of the acoustic waves scattered by elastic objects (ka 2-20) allows clear discrimination between manufactured and natural objects.*

SR-325

Levesque, I., Bondaryk, J.
Performance issues concerning Doppler-only localization.

Target localization can be achieved using only frequency information obtained from source-receiver platforms. The numerical method proposed achieves machine precision accuracy in computing target position and velocity from multiple simultaneous Doppler-shift measurements. The area over which localization can be performed depends very strongly on the configuration in which the sensors are placed and the drop-off in performance is step-like. A negligible decrease in performance is encountered when switching from "N-source, N-sensors" to a "N-sensor, single-source" configuration. The number of sensors to be used is an important criterion and it is found that increasing this beyond 4 is only worthwhile with certain layout configurations. Uncertainties in the sensor locations decrease the area over which accuracy is acceptable; a 10-meter uncertainty translates into a 5% loss in coverage. Noise in the Doppler information decreases accuracy gradually; one should expect an error 3 times greater with the addition of 10% noise.

SR-326

Holland, C.W., McDonald, B.E.
Shallow water reverberation from a time reversed mirror.

The ability to re-focus energy using a time reversed mirror in the ocean has been demonstrated by Kuperman et al. (1998), Song () and others. The metric in these experiments has been the focal spot itself. Another potentially useful metric of the time-reversed mirror concept is the reverberation. Exploring the reverberation has at least two important aspects. First, the reverberation is an important consideration for potential tactical applications inasmuch as it is the target illumination-to-reverberation ratio that is important rather than just the characteristics of the spot size. Second, the time-reversed mirror has the potential to be useful as a scientific tool to study shallow water bottom scattering. This report presents results from shallow water reverberation measurements at 3500 Hz designed to meet these two goals. Reverberation reduction was not observed when the focus was in the water column (far from the boundaries). In fact, an increase in the reverberation was observed. One conclusion from these results is that in order to exploit the FAF concept for systems concepts, (perhaps substantial) azimuthal resolution is required. The data do show a successful demonstration of a focused field at the seafloor boundary. Thus it appears that FAF can be exploited as a scientific tool for studying long range scattering in shallow water.

SR-327

Akal, T., Di Iorio, D., Guerrini, P., Boni, P., Ferla, C., Hodgkiss, W.S., Song, H.C., Kuperman, W.A., Jackson, D.R.
Range and time dependence of focused acoustic field and iterative focusing at 450 Hz.

A phase conjugate "mirror" time reverses the incident signal precisely returning it to its original source location. This phenomenon occurs independent of the complexity of the medium. The time reversal process can be accomplished by the implementation of a retransmission procedure. 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 can occur on a time scale less than the dominant fluctuations. the medium variability will be eliminated since one back propagates and "undoes" the variability.

SACLANTCEN and MPL under a Joint Research Program are investigating phase conjugation process on Focused Acoustic Fields (FAF) since 1996. Focusing at 450 Hz was demonstrated in a 1996 experiment. 1996 experiment was the first demonstration of focusing with a phase conjugate array in an ocean environment. The following year a second experiment has been carried out where, we extended the range of focus from the earlier result of 6 km out to 30 km, verified a new technique to refocus at ranges other than that of the probe source and demonstrated the time dependence of the FAF successfully with extensive environmental data.

In this report we present the results of the final low frequency (445 Hz) Focused Acoustic Field (FAF) experiment and describe the iterative time-reversal process developed with low frequency FAF data.

SR-328

Sellschopp, J.
Rapid environmental assessment for naval operations.

Rapid Environmental Assessment (REA) is a methodology that is being implemented in order to close knowledge gaps and to provide useful environmental information in a tactically relevant time frame. REA surveys are set up for operational needs rather than to give a full scientific picture. Emphasis is on an optimal organizational structure, fast data processing tools and modern data communication channels. Distributed data processing and product generation is complemented by a particular data fusion centre in an Internet-like network.

Specific instrumentation for REA is developed under the premise of immediate data availability. New scientific methods will reduce the time spent for data collection. Techniques, concepts and procedures must be tested, trained and developed in REA exercises that may or may not be connected with military exercises. The Rapid Response surveys are described as examples for extensive REA effort prior to naval exercises.

SR-329

Hughes, D.
Aspects of cardioid processing.

It is well known that conventional active towed arrays suffer from 'The Ambiguity Problem' in which it is impossible to distinguish returns from port or starboard. Although operational methods for overcoming this problem exist they are time-consuming and cannot be used for a single ping. One proposed method of coping with these difficulties is to use a triplet array in which the direction of arrival of a signal can be ascertained on a single ping.

This report details a broadband algorithm which has been developed and is currently being used at the SACLANT Undersea Research Centre. The algorithm was specifically designed to be used on a delay-type beamformer in which shading cannot be applied at the beamlevel. A second algorithm employing the full-flexibility of a 3d beamformer is also described and the two algorithms are compared for their performance in terms of left-right suppression and SNR for which analytical expressions are computed. It is shown that both of the algorithms have desirable, but different features. The algorithms are applied to data taken from the trial BACCHUS'98 and the results obtained are used to help validate the theoretical results and to give an indication of the performance which is achievable for the triplet system. We show that for the Centre algorithm a typical achievable left-right suppression is greater than 15dB.

SR-330

Laterveer, R.
MRF segmentation for low frequency active sonar: further results.

The use of low frequency active sonar in shallow water leads to large numbers of clutter detections.

This high false alarm rate can overload automatic tracking and classification algorithms. Traditional detection algorithms operate on each beam output individually searching for targets at all ranges. However, the target echo and bottom features may extend over several beams, either because a reflector is extended over space or because of the sidelobe structure of the beamformer. This suggests the association of detections over bearing, e.g. apply image processing to the range-bearing sonar data.

A previous study described an automatic method of image segmentation based on a Markov random field (MRF) model to reduce clutter. The segmentation is treated as a labelling problem, assigning to each range-bearing cell either a target or background label, removing small objects which do not exhibit the correct signature over beams. Separate detections corresponding to one large reflector are combined and removed if they are too large to be a submarine .

In this report, the algorithm is evaluated on additional data. On a single ping basis the MRF segmentation shows slightly lower detection performance at the same number of false alarm objects as the Page test detector. MRF segmentation still shows potential for fixed feature removal over multiple pings and will be studied in the feature.

SR-331

van Velzen, M.R., Laterveer, R.
Performance measurement in active sonar using object counting.

At present two measures of performance (MOP) are frequently being used at the Centre for the evaluation of detection algorithms in Low Frequency Active Sonar (LFAS) data processing. The performance of the basic processing elements of every active sonar, consisting of beamforming, matched filtering and normalization, is expressed by the standard Receiver Operating Characteristic (ROC) curve, which relates the probability of detection to the probability of false alarm per range-bearing cell. However, for highly time varying data or after some clustering has been applied to the data, performance is usually expressed as the probability of detection versus the number of false target like objects per ping. The existents of two MOPs depending on the type of data or the level of processing is unsatisfactory as it prevents quantifying the improvement achieved at every successive processing stage.

To obtain the ROC curve for experimental data, target echo and background are often separated, using a priory knowledge of the target position, to measure the probability of detection and probability of false alarm separately. For an objective measure of detection performance target and background should not be separated as this may hide some cross effects like the increased false alarm probability due to side lobes in the beam direction of the target echo.

A final measure of detection performance should also be a function of the accuracy which the actual position of the target can be found. This could show, for example, the improved detection performance due to fine bearing estimation. Positioning errors also plays an important role in multi-statics where detections from different platforms will have to be compared.

In this report we propose a method that counts all connected objects in the data and defines a unique point in each object that defines the exact location of the detection. The method can be applied at every stage of processing, is a function of the accuracy with which the target location can be found and no target location information is being used in counting detections and false alarms. The resulting MOP gives the probability of detecting the target within a box around the actual target position versus the number of false alarms per ping.

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.

C Organization and staff members as of 1st January 2000

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Director :	J.L. Spoelstra (NL)
Deputy Director :	W.J. Jobst (US)

2 OFFICE OF THE DIRECTOR

Senior Administrator (Planner/Coordinator)	D. Bennett (US) (from July)
Administrator (Health & safety)	R. Molteni (IT) (from Oct)

3 ASSIGNED MILITARY

Naval Advisor	Cdr E. Long, USN (until June) Cdr B. Williams, USN (from July)
Scientific Division Coordinator	LCdr J.R. Staveley (UKN) from July)
Security Officer	Cdr C. Gabrini, ITN (until August) Cdr G. Piaggio, ITN (from September)
Budget Officer	LCdr R. Reilly (USN)
ASW Programme Officer	Cdr B. Egenberg (NON)
Mine Warfare Officer	LCdr J.R. Staveley (UKN) (until June) LCdr O. Molino, ITN (from July)
ADP Security Officer	Lt J.G. M.Shannon (USN)
MILOC Survey Officer	D. Schaa (Civilian) (GE)

9 FINANCE OFFICE

Controller:	M. Baldassari (IT) (until January) L. Parise (IT) (from February)
Fiscal Officer:	J. Jenkins (US) (until August) M. Newman (US) (from August)
Internal Auditor:	G. Lambie (UK)

10 PERSONNEL & ADMINISTRATION OFFICE

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Logistics & Supply	U. Varlese (IT)
Information Services	A.W Green (UK)

11 INFORMATION TECHNOLOGY OFFICE

Head of ITO	R. Seynaeve (BE)
Senior ADP Systems Spec	P. Colucci (IT)

12 SHIP MANAGEMENT OFFICE

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T-Boat Captain	A. Spairani (IT) (until August) A. Iacono (IT) (from September)

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Deputy Director

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Principal Scientist	T. Akal (TU)
Principal Scientist	D. Burnett (US)
Principal Scientist	J.P. Hermand (BE)
Principal Scientist	J. Watermann (GE) (until April)
Principal Scientist	C. Harrison (UK) (from March)
Senior Scientist	O. Bergem (NO) (until February)
Senior Scientist	M. Ferla (IT)
Senior Scientist	C. Holland (US)
Senior Scientist	K. LePage (US)
Senior Scientist	R. Tyce (US) (from August)
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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)
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Scientist	G. Arcieri (IT)
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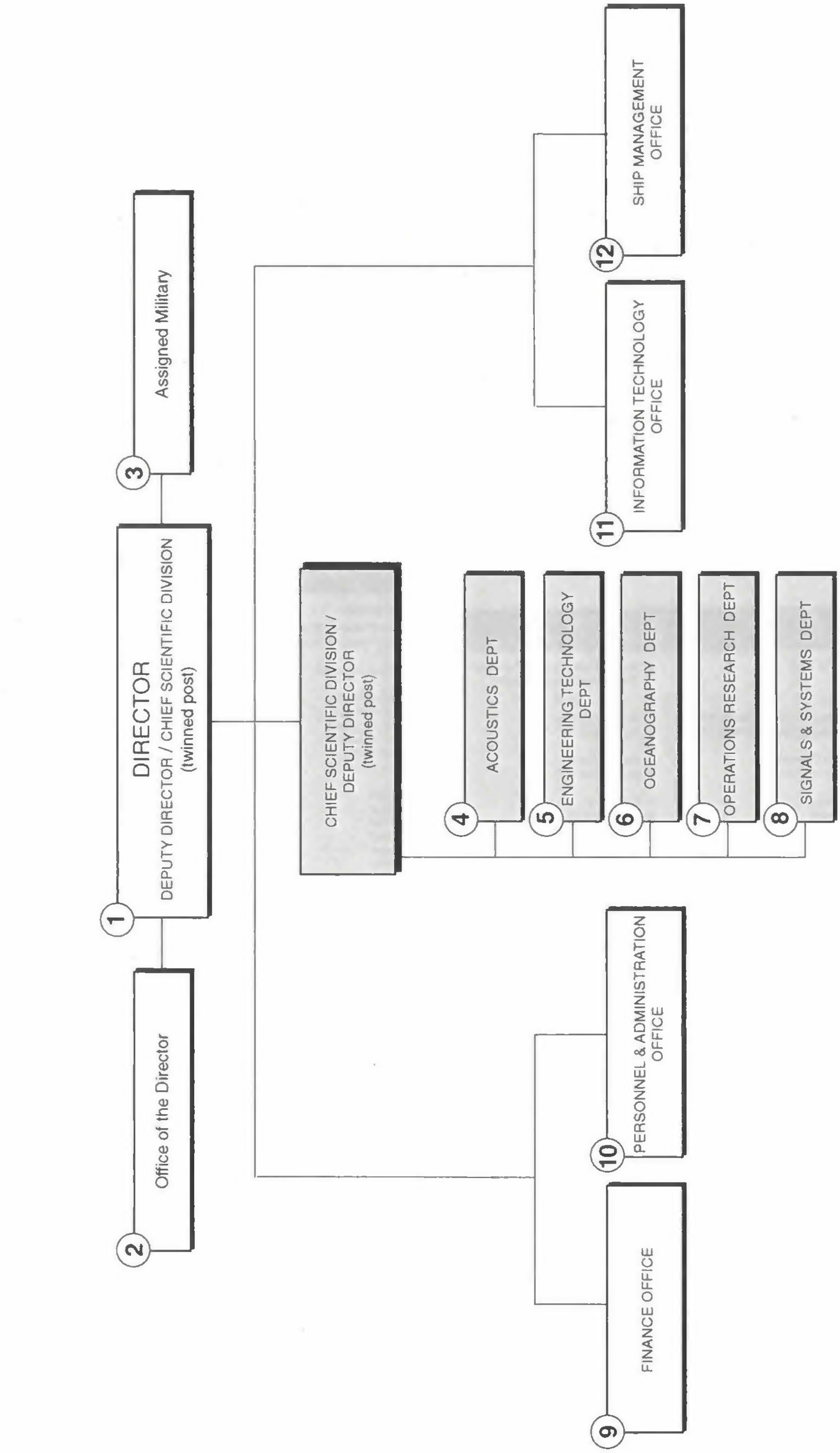
Senior Scientist	D. Grimmett (US)
Senior Scientist	D. Hughes (UK)
Senior Scientist	A. Maguer (FR) (until October)
Senior Scientist	B. Zerr (FR)
Senior Scientist	M. Van Velzen (NL)
Scientist	A. Bellettini (IT) (from December)
Scientist	J. Bondaryk (US)
Scientist	S. Fioravanti (IT)
Scientist	G. Haralabus (GR)
Scientist	R. Laterveer (NL)
Scientist	L. Mozzone (IT)
Scientist	A. Tesei (IT)
Sr Admin (Scientific Specialist)	E. Bovio (IT)
Sr Admin (Scientific Specialist)	W. Zimmer (GE)



1 DIRECTOR
DEPUTY DIRECTOR / CHIEF SCIENTIFIC DIVISION
(twinned post)
2 Office of the Director
3 Assigned Military
CHIEF SCIENTIFIC DIVISION /
DEPUTY DIRECTOR
(twinned post)
4 ACOUSTICS DEPT
5 ENGINEERING TECHNOLOGY DEPT
6 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

D Visitors and meetings

Visitors

January	Professor Roberto Schmid Professor Mario Pavan Dr Gianni Pavan	University of Pavia
March	Group of Italian Navy officers (ASW and MW specialists)	ITN Academy, Livorno
	Officers from Italian Navy Hydrographic Institute of Genova	Hydrographic Institute of Genova
	Jack F.J. Venneulen	TNO-FEL Netherlands
	Dr Tsih Yang	NRL Washington, D.C.
	Dirk G. Simons and Mirjam Snellen	TNO-FEL Netherlands
	Richard J. Brind and Alex S. Penfold	DERA, U.K.
April	RADM L.C. Baucom, USN	SACLANT ACOS Plans and Policy
	VADM Manlio Galliccia, ITNA	Commander in Chief, Upper Tyrrhenian District, La Spezia
May	Group of Norwegian Navy officers (ASW and MW specialists)	Norwegian Tactical Training Establishment
	Dr M.I. Yarymovych	Chairman, NATO Research and Technology Board, Paris
	Dr E.A. van Hoek,	Director, NATO Research and Technology Board, Paris
June	Mr J. Johnsen	SCNR Norway
	Mr Thorsen	NDRE Oslo
	Dr H. Schneider and Dr Anton Homm	FWG Kiel
July	Dr J. Keil Dr B. Kittredge	Executive Director, NUWC Newport Deputy Director, NUWC Newport
August	Dr. D. Wyn Williams	Operations Director, Sea Systems, DERA
September	Dr Richard W. Spinrad	Technical Director, Office of Oceanographer of Navy, U.S.
	Thomson Marconi Representatives	France
	Prof. F. Absil and CDR P.K. Veldhuis	Netherlands Naval College
	Mr. F. Asbeck	Western European Satellite Centre
	Dr G. Notarbartolo di Sciara	President ICRAM
October	RADM Dino Franco Vené, ITNA	President of MARIPERMAN, La Spezia
	RADM Paul Gaffney, II, USNA	Chief of Naval Research
	French Officers from FS *DE GRASSE*	
November	RADM Gino Bizzari, ITNA	COMFORDRAG, La Spezia
	ADM E. Bengtsen CDRE J. Parker CDR G. Stamp	SACLANT HQ
	VADM Jose Romero Iglesias, SPNA	Deputy COMNAVSOUTH
	Visit of STANAVFORMED ASW Officers	
December	Dr Wyn Williams Mr Michael White Mr N. Fisher and Mr. J. Downing	UK member SCNR DERA MOD UK

Meetings


FIRST MEETING FOR
REA SUPPORT TO
LINKED SEAS 2000
SACLANTCEN 26-27-28 January 1999
List of Participants


MO 2015
DISTRIBUTED
DEPLOYABLE
SYSTEMS
WORKSHOP
SACLANTCEN
10-12 FEB. 199


OPERATIONAL PLANNING SOFTWARE
STEERING GROUP MEETING


MCM
EXPERT
USER
GROUP
MEETING n° 5


MO 2015
MILITARY
STEERING
GROUP
MEETING
MEETING
SACLANTCEN
14-15 Apr. 1999

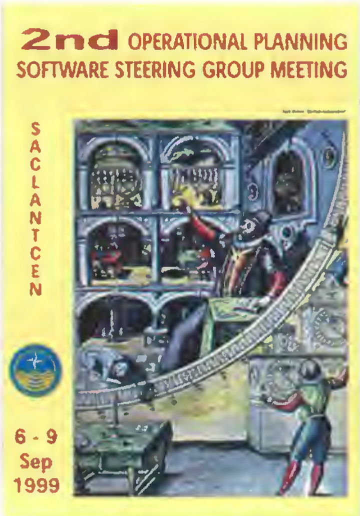

1959
1999
attendees

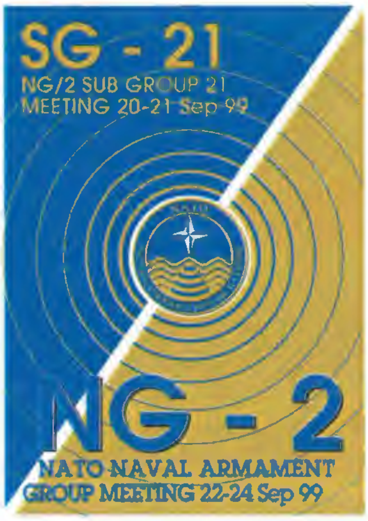

SIRENA 99
SEA TRIAL
PLANNING MEETING
31 MAY 1 JUNE 1999


SOUND, OCEANOGRAPHY &
LIVING MARINE RESOURCES
JRP
MEETING
2/3 JUNE 1999


UNDERWATER
WARFARE
WORKSHOP
1-3 SEP 99

Meetings


2nd OPERATIONAL PLANNING
SOFTWARE STEERING GROUP MEETING
SACLANTCEN
6 - 9
Sep
1999


SG - 21
NG/2 SUB GROUP 21
MEETING 20-21 Sep 99
NG - 2
NATO NAVAL ARMAMENT
GROUP MEETING 22-24 Sep 99


75th
SCNR
MEETING IN
CARTAGENA
5 - 8 OCTOBER 1999


JRP
MINE DETECTION
& CLASSIFICATION
4 - 5 November 1999

E Scientific Committee of National Representatives and National Liaison Officers

BELGIUM *National Representative*	**LCDR Claude L. Renard, BENA** Section Systèmes d'Armes Lutte anti-sous-marine de l'Etat-Major de la Marine, Brussels
CANADA *Acting National Representative* *National Liaison Officer*	**Mr Warren C.E. Nethercote** Deputy Director-General, Defence Research Establishment Atlantic, Dartmouth, Nova Scotia **Dr 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 Daniel Long** 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*	**Captain Anastasios Sklavidis, HENA** Hellenic Navy Hydrographic Office, Holargos, Athens
ITALY *National Representative* *National Liaison Officer*	**Rear Admiral Dino Nascetti, ITNA** Direttore, Arsenale Militare Marittimo, La Spezia **Commander Carmelo Di Natale, ITNA** MARISTAT, Rome
NETHERLANDS *National Representative* *National Liaison Officer*	**Mr Coenraad M. Ort** 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
PORTUGAL *National Representative*	**LCDR E. Ferreira Coelho, PONA** Instituto Hidrografico, Lisbon

SPAIN *National Representative*	**Captain Jorge Juan Moreno Sanmartin, SPNA** JEFE Spanish MCM Flotilla, Cartagena
National Liaison Officer	**LCDR Juan A. Rico Palma, SPNA** Instituto Hidrografico de la Marina, Cadiz
TURKEY *National Representative*	**Eng. Captain Nazim Çubukçu, TUNA** Head of the Department of Navigation, Hydrography and Oceanography, Istanbul
National Liaison Officer	**Eng. LCDR H. Basaran, TUNA** AKAG Bsk, Gölcück/Kocaeli
UNITED KINGDOM *National Representative*	**Dr. D. Wyn Williams** Operations Director, Sea Systems Sector, Defence Evaluation and Research Agency, Portsdown West
National Liaison Officer	**Mr David Lewis** DSc(SEA)3.3., Ministry of Defence, London
UNITED STATES *National Representative*	**Dr Eric O. Hartwig** (NRL 7000) Associate Director of Research for Ocean and Atmospheric Science and Technology, Naval Research Laboratory, Washington D.C.
Alternate National Representative	**Dr Steven E. Ramberg** (ONR-32) Head, Ocean, Atmosphere and Space Science and Technology Department, Office of Naval Research, Arlington, VA
National Liaison Officer	**Commander Scott M. Tilden,** (ONR 321B) Littoral Warfare Advanced Development, Project Manager and Military Deputy, Sensing and Systems Division, Office of Naval Research, Arlington, VA
SECGEN NATO *Representative*	**RADM Guillermo Leira, SPNA** Deputy Assistant Secretary General, Defence Support, NATO Headquarters, Brussels
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 (Operations),
Representative	**Rear Admiral Eivind Bengtsen, DANA** Assistant Chief of Staff (Resources),
Acting Representative	**Commodore Jeremy Parker, UKNA** Deputy Assistant Chief of Staff (Operations)
Acting Representative	**Captain Eugene Alleman, BENA** Deputy Assistant Chief of Staff (Resources)
Liaison Officer	**Commander Gordon Stamp, UKNA**

F *Personnel by category and nationality*

Personnel Strength by category and nationality at 31 December 1999 (With aggregate Scientist Numbers 1959 – 1999)

COUNTRY	SCIENTIST **	SUPPORT STAFF AND TECHNICIANS	SKILLED WORKERS (C GRADES)	ADMINISTRATIVE AND FINANCIAL	MILITARY	TOTAL	TOTAL SCIENTIST NUMBERS*	TOTAL SCIENTIST MAN YEARS
BELGIUM	1	1	-	-	-	2	10	92.5
CANADA	-	-	-	-	-	-	23	97.5
DENMARK	2	1	-	-	-	3	17	138.0
FRANCE	3	-	-	-	-	3	24	154.0
GERMANY	3	2	-	-	-	5	29	127.0
GREECE	1	-	-	-	-	1	8	29.0
ITALY	6	65	15	25	2	113	31	233.5
NETHERLANDS	4	-	-	-	-	4	25	122.0
NORWAY	1	1	-	-	1	3	28	100.0
PORTUGAL	0	-	-	-	-	0	3	12.0
SPAIN	1	-	-	-	1	2	1	0.5
TURKEY	1	1	-	-	-	2	2	36.0
UK	8	6	-	4	1	19	54	300.5
USA	13	3	-	1	3	20	100	357.5
TOTAL	44	80	15	30	8	177	355	1800.0

** Including Director and Deputy Director
* Since 1 May 1959

Underwater Warfare Workshop, 1 - 3 September, 1999

SG-21 and NG-2 meetings, 20 - 21 and 22 - 24 September, 1999

NATO SACLANT Undersea Research Centre
Viale San Bartolomeo, 400
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Address for mail from USA and Canada:
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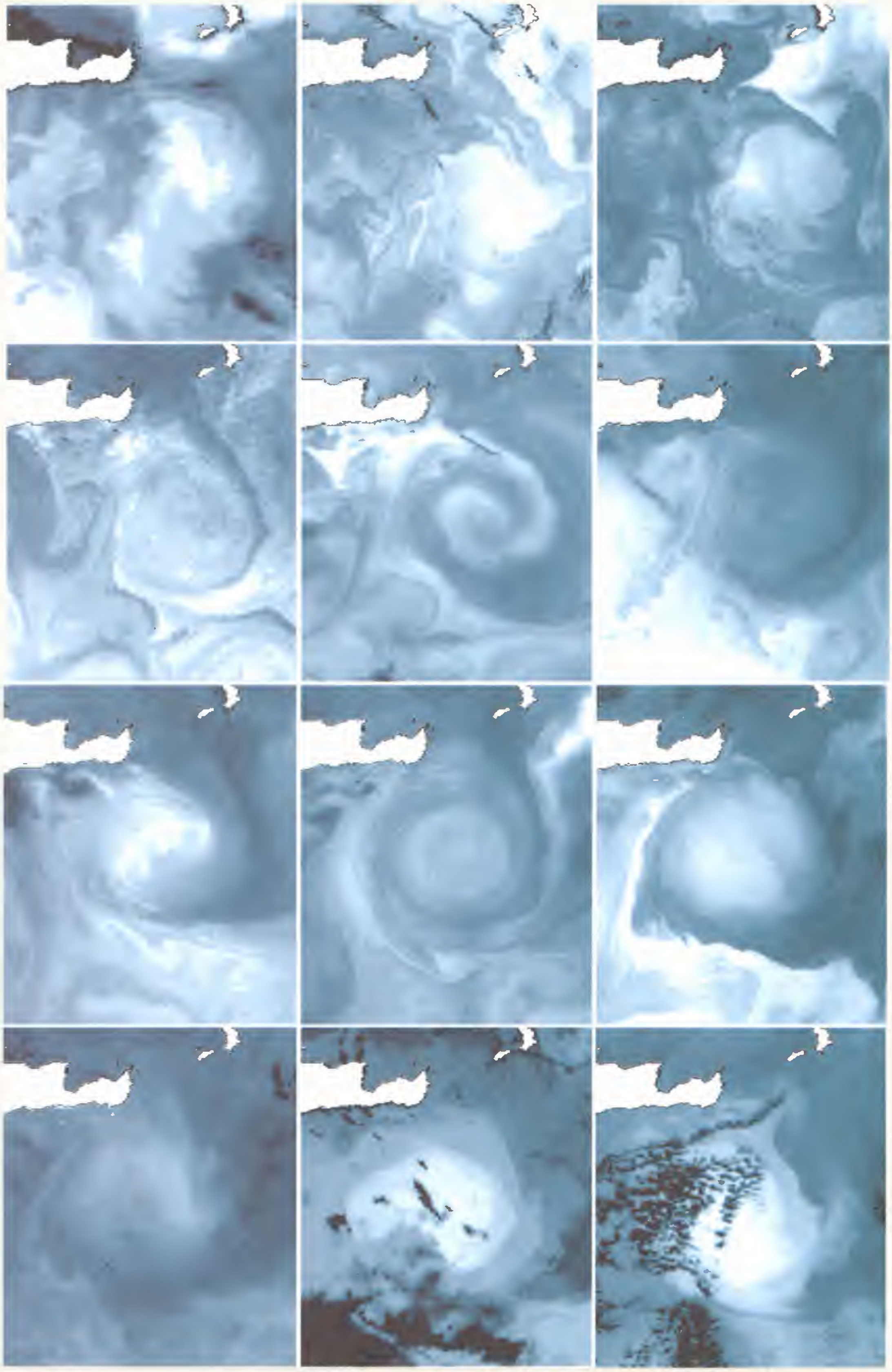
telephone +39 0187 5271 or 527 + known extension
facsimile +39 0187 527 700
http://www.saclantc.nato.int
email: library@saclantc.nato.int

Applying science to NATO maritime operational requirements since 1959



Monthly infrared images of sea surface temperature, during 1999, from the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite sensor depict an anticyclonic gyre in the eastern Mediterranean Sea, southeast of Crete. The images commence in the upper left with January and end in the lower right with December. Dark blue designates cooler surface temperatures, black represents cloud cover. Shown is the Ierapetra Gyre with clear seasonal variations. Maximum temperature differences occur in the summer when cooler water flowing southeast from the Aegean Sea mixes with the warmer Eastern Mediterranean water. There are gyres throughout the western and eastern Mediterranean, which are a result of atmospheric forcing and complex dynamics of water masses entering and leaving the Mediterranean Sea. Satellite remote sensing is one component of Rapid Environmental Assessment (REA), which provides valuable information on sea surface parameters in littoral and deeper water. Progress is being made in applying these data to the prediction of oceanographic variables which affect undersea warfare operational capabilities, (see pages 7 and 16 to 21).