



*SACLANT UNDERSEA
RESEARCH CENTRE
SPECIAL REPORT*



**SACLANT Undersea Research Centre
Research & Accomplishments: 1975–1989**

Robert L. Martin

December 1992

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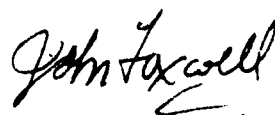
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NORTH ATLANTIC TREATY ORGANIZATION

SACLANT Undersea
Research Centre
Research & Accomplishments:
1975-1989 [NU]

Robert L. Martin

A handwritten signature in black ink, reading "John Foxwell". The signature is written in a cursive style with a prominent flourish at the end.

John H. Foxwell
Director

**SACLANT Undersea Research
Centre
Research & Accomplishments:
1975-1989 [NU]**

Robert L. Martin

Abstract: The SACLANT Undersea Research Centre, originally the SACLANT ASW Research Centre, was established in 1959 to provide scientific and technical advice and assistance to the Supreme Allied Commander Atlantic in the field of antisubmarine warfare and to respond to the needs of NATO nations and maritime commands. A special comprehensive report, M-93, on twenty years of research at the Centre was published in January 1980 by Donald Ross.

This report is intended to be similar in kind in order to document the research and accomplishments of the Centre through 1989, the 30th anniversary of the Centre. It overlaps the stated 20-year period of M-93 in order to more smoothly lead into the work of the 1980s. The numerous Centre documents cited in this report – scientific memoranda and reports, conference proceedings, annual progress reports – together with external publications and corporate memory have provided the source material for this report. The author has attempted to be fully objective in selecting the references and in summarizing the work.

Dr R.L. Martin was Deputy Director of SACLANTCEN from 1 February 1986 until 31 January 1991.

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Acknowledgements: The author is indebted to the quality of the documents used as references herein and to the corporate memory of many of his associates and colleagues at the Centre who reviewed relevant sections of this report in early draft form making many useful suggestions.

1

Introduction

Donald Ross, SACLANTCEN Deputy Director 1976–79 described the formation and growth of the Centre in Special Report M-93, entitled ‘Twenty Years of Research at the SACLANT ASW Research Centre 1959–1979’, dated 1 January 1980. That report describes the dramatic beginnings, growth and research accomplishments of the Centre during the traumatic period of the cold war. His report ends with a short section entitled ‘Period of Reorientation (1975–1979)’ in which he suggests that a general malaise had set in which required correction. Donald Ross, through his initiative in starting a research based history of the Centre and by thoroughly dedicating himself to the task, did a remarkable job in documenting the first 20 years of SACLANTCEN. It is not possible to fully emulate that achievement in this report; it can only build on what was achieved earlier. Other Centre documents [SM-13, M-73, M-104] discuss the formation of the Centre and its early achievements; However, they are selective rather than comprehensive as required of a history. This report will start with 1975 in order to achieve a proper meshing with M-93 and to put the subsequent period of ‘Reorientation’ into perspective with the work of the 80s. It will end with the accomplishments of 1989.

Very little can be added to the introduction to M-93 which would be substantially different, but perhaps a reinforcement of some of those comments is useful to express my personal attitude on the sources of strength for describing the evolution of the Centre program. First of all, the lubrication for Centre progress has to start with a stable financial investment by NATO. Without adequate funds, it is not possible to plan a research program and to develop the necessary resources for the timescales that scientists are contracted, typically 3–5 years. Development of the research program itself gains strength through the involvement of the many NATO nations and commands at its inception and by the local autonomy of the Director in seeing to it that the programme is executed in an agreed-to timeframe. Finally, the many research projects at the Centre gain strength through their mutual inter-

actions and through working level collaboration with laboratories of the other NATO nations and with NATO commands.

With the Centre having reached full maturity by 1980, it is not expedient to partition this report into different periods. It is more appropriate to focus on initiatives, events and interactions that have helped shape the areas of research individually and collectively. Organization and resource development are important in this respect and are addressed separately, resulting in this report being structured along the following lines:

- Organization and Administration
- Environmental Acoustics
- Oceanographic Studies
- Systems Research
- Operations Research
- Technical Support

The identification with the areas of the previous report are clear. Taken together, the scientific program areas provide NATO with a comprehensive attack on ASW issues that is found nowhere else in any single national research center.

2

Organization, Administration and Special Events

Centre management at the directorate, division chief and senior advisor level changed at least twice during the main timeframe of this history. Basil Lythall (UK), who assumed the responsibility of Director in the fall of 1978, was relieved by Ralph Goodman (US) in 1981. In November 1987, Peter Wille (FRG) became Director and will continue in that post until November 1990.

Ross discussed the transfer of four operations research positions to SACLANT in 1977. This resulted in that division becoming significantly smaller and being reduced to group status under the Systems Research Division in September 1979. With the Underwater Research Division, this left the Centre with two scientific divisions each with roughly the same number of scientists. The seven technical support departments were formally brought together under the supervision of the Deputy Director and given division status in 1979. In 1980 the seven departments were amalgamated into five with the Ship Operations Department (SOD) and Scientific and Technical Information Department (STI) being left intact; the Digital Computer Department (COM) was formed by the merging of the previous COM and the Real-Time Departments; Electronic and Acoustic Engineering Department (EED) merged the previous EED and the transducer section of the Mechanical and Transducers Department (MTD), and finally the Ocean Engineering Department (OED) added the mechanical section of MTD. In 1987, with the imminent delivery of *Alliance*, the responsibilities of SOD changed and the title was changed to Ship Management Department (SMD). There were several changes within each of the scientific divisions, which in 1977 had a total of 16 separate projects, managed by 6 group leaders in three divisions; by the end of 1989, there were only 9 projects managed by 8 group leaders in two divisions. A Chief Scientist position was introduced in 1984 and since September 1985 it has been responsible for providing the technical direction of the Military Oceanographic (MILOC) Surveys



Mr B.W. Lythall
UK
Director 1978–1981

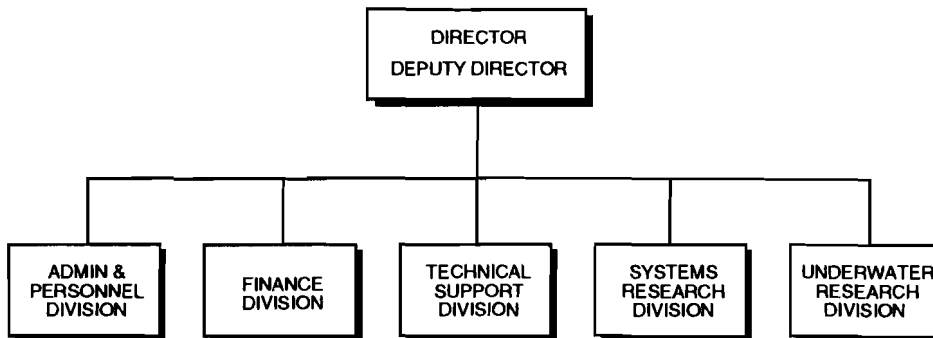
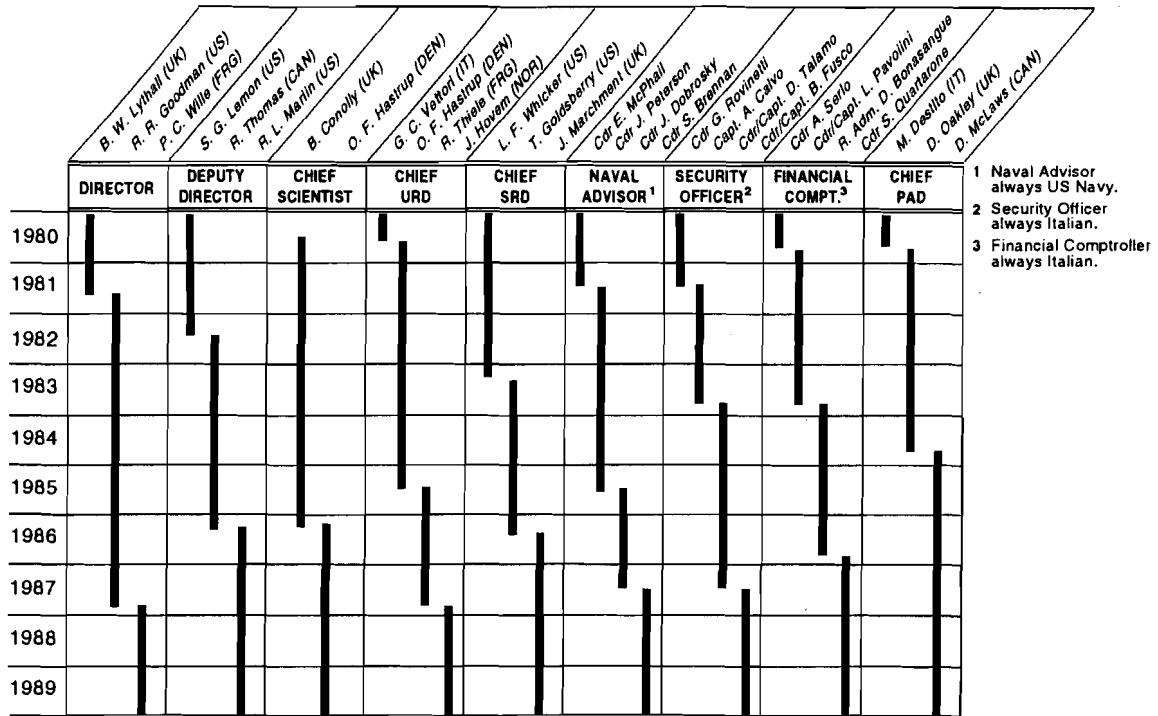


Dr R.R. Goodman
USA
Director 1981–1987



Dr P. Wille
Germany
Director 1987–1990

sponsored by CINCEASTLANT; these surveys will be described under that title later in this report.



Organization of SACLANTCEN.

Personnel and Administration

The number of civilian staff at the Centre remained essentially constant from 1975 to 1989. In 1975 there were 230 authorized posts; four of the operations research positions were transferred to SACLANT in 1977 and in subsequent years some augmentation occurred as a result of NATO manpower reviews to bring the total number of authorized posts to 239 in 1990. In addition, the five military posts to support the administration and the scientific program of work were increased by two scientific officers in 1987.

Two major manpower surveys of the Centre were conducted during this period: one in May 1983, and the second in November 1989. The earlier survey recommended significant organizational as well as personnel distributional changes. By and large, these were not concurred in by the Director and as a result, most of the recommendations were not implemented. By contrast, the survey conducted in 1989 confirmed that the Centre organization was essentially appropriate, identified certain anomalies needing correction, and endorsed the Centre's proposals to meet changed manpower requirements by offsets against contract funds, adding 18 new positions, deleting 4 and upgrading 10 positions. While their recommendations essentially recognized the increased effort required to meet the demands to support SACLANT's mission, their implementation still requires SACLANT and MBC agreement; this is a task for 1990.

It is interesting to note the current and cumulative distribution of scientists at the Centre. Every NATO country participating in the ASW mission of NATO (including France) is currently represented on the scientific staff. The cumulative number of scientists and work years for each nation are also noted for the past 30 years. Separately, the Centre is authorized to hire up to 10 summer research assistants every year, each for a total of three months. Normally, only one is selected from each nation and he or she is a graduate student in one of the technical disciplines of the Centre. This has been going on for over 25 years and many have returned to the Centre for a full-time contract.

In 1983, the Ship Project Department was created as an ad-hoc adjunct to the Centre staff to oversee the construction of the new research vessel. A total of 11 positions were assigned to this function with backgrounds in naval architecture, marine engineering, maritime rules & regulations and quality control. Most of these positions were abolished when the ship was delivered in 1988, but two remained until the end of the initial warrantee period in the summer of 1989.

THE INTERNATIONAL BASIS OF SACLANTCEN
is demonstrated by the composition of the research staff

NATION	Total since 1959	Current
Belgium	7	3
Canada	19	3
Denmark	14	2
France	17	2
Germany	23	2
Greece	6	1
Iceland	0	0
Italy	26	5
Luxembourg	0	0
Netherlands	21	3
Norway	25	1
Portugal	3	1
Spain	0	0
Turkey	2	1
UK	43	9
USA	70	10
	TOTAL	43*

*Technical Support and Administrative personnel bring the total authorised SACLANTCEN staff up to 239, including 7 military officers.

Buildings and grounds

In 1959, the Centre was housed in a building provided by the Italian Navy with 3000 m² of floor space. This building had two floors and the ground floor, in particular, had a very high ceiling. By 1970, this building was permanently expanded to 4500 m² by adding a mezzanine above the ground floor. Later a new scientific building of 1500 m² was built and occupied in January 1976. Since that time, space and improvements have been incrementally obtained.

In 1981, the Centre converted a warehouse in Building 26 into a workshop area for both EED and OED, thereby adding 600 m² of inside space; however, the grounds surrounding that building were also usable for storage of raw material, winches, reels and as a place to stage mooring systems and test cable terminations, thus providing an additional 700 m². This was a very important decision because it freed up valuable space in the main building and provided the space in Building 26 for the hydrophone calibration tank and towed-array assembly facility as well as the space needed to work on and assemble large ocean structures. From 1983 onward to 1989, the MBC supported a 250 million lire permanent increase in the Centre's investment account over a 1981 low of 98 million lire. This funding, together with a hard-working dedicated workforce under U. Varlese, Head of the General Services Branch (GSB), resulted in significant additions and improvements over subsequent years. In 1986, the new scientific building was completed with the addition of six office spaces each on the first and second floor. An air conditioning system was installed throughout the main building and the scientific building between 1984 and 1985. This was good news and bad news: the good news being improved working conditions in the summer, the bad news was the elimination of summer working hours. The outside grounds of Building 26 were roofed over and paved and the inside of the building was retiled in 1987 and air conditioning added in 1988. A new building was provided by the Italian Navy in 1987 with 300 m² and made into an environmentally controlled warehouse to house ship spare parts and instrumentation from the departments. In the same year, the Italian Navy provided an additional space of 300 m² to expand and modify the Centre cafeteria (mensa). Also, during this period, the 11-man Ship Project Team occupied part of the top floor of a separate Building 4; this was vacated when they were disbanded in 1989.

Because of the multitude of arrays and electro-mechanical cables accumulated by EED over the years and stored on reels, the outside space between Build-

ing 26 and an Italian Navy building became quite cluttered and somewhat of an eyesore. As a result, permission was granted in 1989 to use one-third of Building 14 (~ 250 m²), which is attached to the end of the scientific building, to house these reels. In 1987, both OED and COM expressed a need for more space in the main building complex, this was provided by bridging the inside corner of the original and scientific buildings to allow additional space for the OED instrumentation laboratory on the ground floor and office space for four programmers on the first floor.

In 1984, before the scientific building was extended, a large garage was attached to it. It is of a rugged construction built on a strong foundation so that it could support two floors of office space as an eventual extension of the scientific building if needed. Within Mariperman, there is now over 8000 m² of enclosed space assigned for Centre use.

Separately, there are three assigned structures in Val di Lochi, approximately 1 km outside the main gate of Mariperman. These buildings are used for temporary storage of equipment that is being written off and as an area generally for use by the 'pack rats' who think they may have a future use for all or parts of some old equipment. The largest of these three buildings is being refurbished to house an assembly facility for the 256 m towed array.

In advance of the 30th Anniversary of the Centre in the fall of 1989, the Director insisted that the Centre appearance, inside and out, be significantly upgraded. GSB staff were particularly busy that year to complete the retiling of the main buildings, to clear all cabinets and other items out of the passageways and to repaint the entire interior of the buildings. The outside parking and drive areas were repaved and the grounds groomed. Much more was done but this will be discussed in the section describing the anniversary events. However, it needs to be said here, that the Centre is now at a standard of utility and appearance appropriate to its status in the NATO community of science and engineering.



Aerial view of the Centre with shallow water basin.



Clockwise starting at top left: Coffee mess – Luncheon mess – Main conference room – Building 26.

Financial and Capital Resources

The capital resources of the Centre consist of all technical and non-technical equipment and furniture that are moveable, the several buildings and grounds assigned to the Centre by the Italian Navy, and the new research vessel *Alliance* and T-boat. The estimated market value is 22, 14 and 34 billion lire, respectively, for a total of 70 billion lire or ~US\$ 56 million at the early 1990 exchange rate of 1250 lire to the dollar. However, the replacement value of all resources is more than twice that amount, perhaps US\$ 135 million, dominated by the new research vessel *Alliance* which could cost US\$ 70 million to replace.

The Centre's entire budget for the following year is submitted once a year as a comprehensive document to the NATO Military Budget Committee (MBC); somewhat in advance of this, the Centre's Scientific Programme of Work (SPOW) is submitted via SACLANT to the North Atlantic Council. Once approval of the SPOW and, subsequently, the budget is obtained, scientific, technical and fiscal management is performed locally at the Centre and overseen by the directorate. Further, funding requirements are projected out to five years in the future through the medium-term financial plan within budget constraints provided by the MBC. Over many years, there has been very little change in funding for a given year in deviation from that projected in the forecast. This has provided a high level of stability for planning and development of the scientific program and of the necessary resources to support it.

The budget has grown along with inflation and with some real growth over the decade 1980-1989. Most of the real growth was experienced in the early part of the decade. Except for a peak in the 1986-87 time frame to fund a special oceanographic project, the only real growth after 1984 was due to increased personnel costs. Ad-hoc funding was provided for the Ship Project Team (1982-1989) and the ship construction (total US\$ 37 million) 1983-89. Funding was provided in the 1985-1987 time frame to upgrade the shore-based central computer and the real-time sea going system to the WARP-II for installation on *Alliance*. This funding was in general compensated for by reductions in other budget areas.

Funding levels over the decade reflect the NATO commitment to a strong maritime capability to counter the evolving Soviet threat in the 80s. At the very end of this period, actually in late 1989, the dramatic changes initiated in the Soviet Bloc countries had a great impact on the perception of the political threat while leaving intact for the moment the real maritime

threat. As perception and reality evolve in the coming years, so will the financial support of the nations, via the Military Budget Committee, for the Centre.

SACLANTCEN Anniversaries

The Centre's 20th Anniversary was celebrated on 8 May 1979 and is reported by Ross. The 25th Anniversary was celebrated on 3 May 1984 with a buffet party attended by past and present Staff. There was no formal ceremony or speech, but an Open House with guided tours was attended by staff, family and friends. To mark this occasion, the Director published Special Report M-104 containing annotated facsimiles of some of the earliest papers referring to the establishment of the Centre. The papers were made available by one of its founding members and later a Director (1967-72) Ing. Martin W. van Batenburg. The report is noteworthy for its brevity and the time span covered, indicating the intensity and speed with which the Centre was instituted.

The 30th Anniversary, somewhat by contrast, was marked by a more formal ceremony, lunch and Open House on 6 October 1989 followed by a special conference the next week. In advance of the celebration, a current mailing list of all past staff members of the Centre was compiled and invitations to attend the Anniversary mailed out. Project leaders, department heads and administration personnel developed presentations, organized by V. Failla (SPE), for a total of 30 posters each 0.8 by 1.5 m which were mounted on the walls of the corridors for the Open House; collectively they made a colorful and impressive display.

The Director invited NATO nations to loan ancient charts for the occasion and a total of 15 were received and mounted on the walls of the corridor leading to the directorate offices. F. De Strobel, Head OED, provided his private collection of original books on oceanography, dating back to the 18th century for display and he obtained old oceanographic instruments for display in a museum-type arrangement along with the charts in the main corridor. This provided a spectacular display for the Open House visitors and has been maintained for many months since.

The Master of Ceremonies for the occasion was D. McLaws, Chief PAD, with remarks by the Director, CSA Chairman, V. Amoroso, and by the Mayor of La Spezia. The main address was given by Vice-Admiral Papili, IN, Commander of Upper Tyrrhenian District; Vice-Admiral Papili, a young lieutenant on 2 May 1959, was the Italian Navy liaison officer for

the inauguration of the Centre.

After the formal part of the Ceremony, a lunch was provided in the Centre's bayside parking area behind the main building and then the Open House with and without guided tours began. The cooperation of the weather was outstanding with a cloudless sky and spring-like temperatures.

The following week, a conference entitled 'An ASW dialogue within NATO – Maritime requirements vs results' was held. It was organized by the Chief Scientist, O. Hastrup and the Naval Advisor, Cdr S. Brennan USN. It marked the 30th Anniversary by providing a forum for discussion of ASW operational requirements contrasted with research and development efforts. It brought Centre scientists in close contact with military officers from NATO and national commands and was opened with a keynote address by Deputy SACLANT, Vice-Admiral J.L. Weatherall, UKN [CP-39].



30th Anniversary.

Distinguished Visitors

The Centre receives many visitors every year, both civilian and military. Some are working visitors interested in specific projects and others come to the Centre to obtain a broad perspective of our programs and resources and to impart a special perspective of their own. Eminent scientists, such as M.S. Longuet-

Higgins, O.M. Phillips, W. Munk and a host of others came as visitors and to the scientific workshops at the Centre. Many high-ranking civilians from NATO and the nations have come for familiarization with the Centre and for special occasions such as the launching and commissioning of *Alliance*; these include Sig. G. Spadolini, MOD Italy, Mr. A.C. Sjaastad, MOD Norway, Lord Carrington, NATO Secretary General until 1988, Manfred Wörner, his successor, Sir John Graham, UK Ambassador to NATO and Sig. F. Fulci, Italian Ambassador to NATO. The Centre has also been host to the North Atlantic Assembly of Parliamentarians and the NATO Defense Sub-Committee of the North Atlantic Assembly Military Committee, the NATO Military Budget Committee and Flag Officers of the highest rank from most of the nations. Of special note are the visits by the various Supreme Allied Commanders Atlantic (SACLANT), the ultimate authority for the Centre: Admiral H.D. Train II, Admiral W. McDonald, Admiral L. Baggett and Admiral F. Kelso.

Conferences and Information Exchange

The Centre organizes conferences on scientific, technical or operational subjects that are of current interest. These conferences, while scheduled at irregular intervals, occur on average about once a year. In the last 15 years, 14 conferences have been held with seven of them occurring in the 1980s. The most recent topics included bottom-interacting and seismo-acoustics [CP-27], underwater ambient noise [CP-32], silent ship research applications and operation [CP-35,36], advanced ASW sensors [CP-29], future uses of towed and static arrays [CP-38] and, finally, as attached to its 30th Anniversary activities, an ASW dialogue within NATO [CP-39]. These all have or are soon to be reported as part of the Centre's conference proceedings series, which are published as collections of papers presented or, as with bottom-interacting ocean acoustics [*1] and seismo-acoustics [*2], as a NATO Conference Proceedings. These conferences continue to attract participation by the current experts from the NATO nations (scientists, engineers and military officers) in the topics under discussion. In addition, Centre personnel are very active in external conferences, technical and operational meetings and scientific symposia at all levels. In 1987, taken as a typical year, 46 staff members presented papers at 25 different meetings.



3

Environmental Acoustics

In the mid 70s the Centre recognized the lack of communications between oceanographers and acousticians and set about to correct the situation [CP-17]. Experiments designed to jointly investigate acoustic and ocean variability in the same area and timeframe were developed and executed. However, analysis and reporting of results were accomplished independently and to different schedules. Oceanographers reported their results in terms of physical oceanographic processes and acousticians acknowledged the influence of identified ocean features on their data. With the advent of reliable range-dependent computer codes the results of experiments could be modeled providing a causal analysis of acoustic results, but the question of predictability was not being addressed.

Two developments of the late 70s and 80s facilitated bringing the physical oceanographers and acousticians closer together. The single-ray theory, describing the effect of ocean variability (principally internal waves) on acoustic fluctuations [*3] at all scales from microstructure to planetary dimensions, had a profound effect on the two disciplines. The second major development was computer-based physical oceanographic modeling. Progress in the area of ocean numerical modeling was mainly possible because of the orders of magnitude increases in computer power. Initially circulation models were developed in the US at regional or local scales, e.g. for the Gulf of Mexico as driven by the flow through the Yucatan Strait and the Strait of Florida. The evolution of these models led to attempts in the mid to late 80s to provide a direct link between the output of these ocean models and the input of acoustic models for predicting system performance and providing tactical guidance. The development and refinement of archived global databases and the improved interpretation of satellite observations and ability to obtain ground-truth data for evaluation were also essential to progress.

The Centre formally embarked on a joint project in 1990 combining oceanographic and acoustic variability at small and mesoscale dimensions. Because it

is outside the timeframe of this report it will not be discussed as such, but it appeared worth mentioning as an ultimate goal achieved during this report period. The present section deals with environmental acoustics while a discussion of oceanography is deferred to the following section.

Acoustic propagation

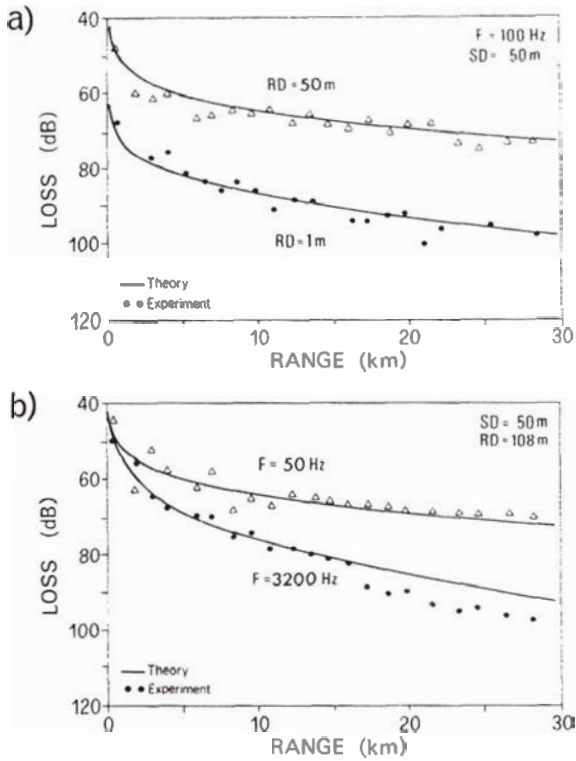
Shallow water propagation studies dominated the Centre's interest during the early part of this period. Experiments were conducted in the Baltic and the southwestern approaches to the English Channel, prior to and as part of the MILOCs, in the Strait of Sicily, and at the test site off the Formiche Islands.

Analysis of data from a 1973 winter experiment, 0.1–8 kHz, at two locations in the Strait of Sicily [SM-100] showed a marked effect on low-frequency propagation (< 300 Hz) due to differences in bottom properties. In the band from 3 to 8 kHz, losses of 8 to 10 dB in night time vs day time transmissions were attributed to the breaking up of fish shoals. The effect of sea mounts on transmission loss below 1.6 kHz was depth-dependent and while loss always increased there was no apparent effect on the spatial coherence of the signals. A summer experiment was conducted in the same area in 1976 and the data stored in the data bank (to be described later) without drawing new conclusions. The Medina Bank area was studied in 1982 and conclusions relative to environmental impact on acoustic fluctuations was drawn [SM-189].

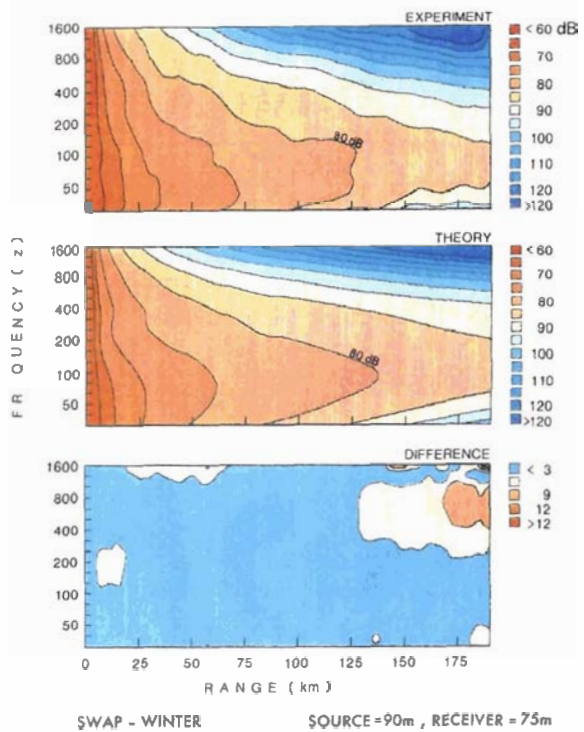
Analysis of Baltic data showed very good propagation conditions above 1 kHz within a marked sound channel which existed to a depth of 25 m.

Measurements at the Formiche test site, 1–6 kHz, were initiated in 1977 and continued through 1980 to study the effect of environmental conditions on the channel spreading function (time and frequency) [SR-46]. Results showed very little time spreading due to the typical dominance of a single path and stable sound speed profile over the range. Frequency spreading grouped below 0.1 Hz and at a little more than 1 Hz; while internal waves on the one hand and surface waves on the other were considered to be the relevant causes, environmental data were inadequate to draw scientific conclusions. Transmission loss itself showed a 10 dB increase on average of summer over winter conditions with an optimum propagation frequency of 25 Hz. An analysis of bottom parameters was initiated to explain this latter result.

The southwestern approaches to the English Channel



Flat-bottom area in the Mediterranean Sea. The graphs illustrate that the model accurately describes the variation in field strength over depth as well as with frequency.



Flat-bottom shallow-water area in the southwestern approaches to the English Channel. Experimental transmission loss data are shown in the upper panel and the model result is shown in the middle panel. The lower panel displays the difference between theory and experiment (generally less than 3 dB).

dominated the Centre's attention between 1978 and 1982 as a prelude to development of the MILOC plan for this area and then for the execution and analysis of the results from the MILOC. In 1978 an intensive study of acoustic and oceanographic parameters was made in deep water over the continental slope and across the slope. The identification of cold water upwelling on the slope, excellent shallow water propagation conditions, and an optimum frequency of around 250 Hz in agreement with propagation models had a fundamental impact on the MILOC experiment design [CP-22(Pt 1:15)]. The Centre participated in three phases of the SWAP MILOC in 1980 and 1981. While NATO nations and commands participated in the exercises, the Centre results focused on shallow water reception from shallow and deep (off shelf) sources [SR-66]. There were no surprises in light of the 1978 preliminary survey results and subsequent model predictions. Optimum frequency was in the 100–200 Hz range, propagation was unusually good with optimum frequency propagation loss being only 80 dB at a range of about 120 km; typically a range of 10–50 km has been observed in other areas.

The Centre embarked on the development of a computerized data filing system containing propagation loss vs range together with environmental data collected during the many at-sea experiments conducted. This database permits comparing data in common format and graphical scales, parametric studies with respect to differing environmental parameters, and support to computer-based model development [SM-141]. [CP-27/*1, CP-28(2), SM-199] provide examples of some of the important studies made with all the data available in this manner. Some selected examples of data in shallow water areas are published in [SR-23] and the database is routinely updated [SM-172]. This database was used to develop a simple empirical formula to describe shallow water propagation loss [SM-139]. This formula required a number of subjective decisions to arrive at values for four coefficients and while it was accurate to 'a few decibels' and considered useable within the data set to extrapolate to other frequencies and, with caution, to longer ranges, there is no claim that it is as good as physics-based models such as SNAP. However, once derived either from measured or modeled results, it can be stored as an analytical function for recall from a small computer or even a calculator.

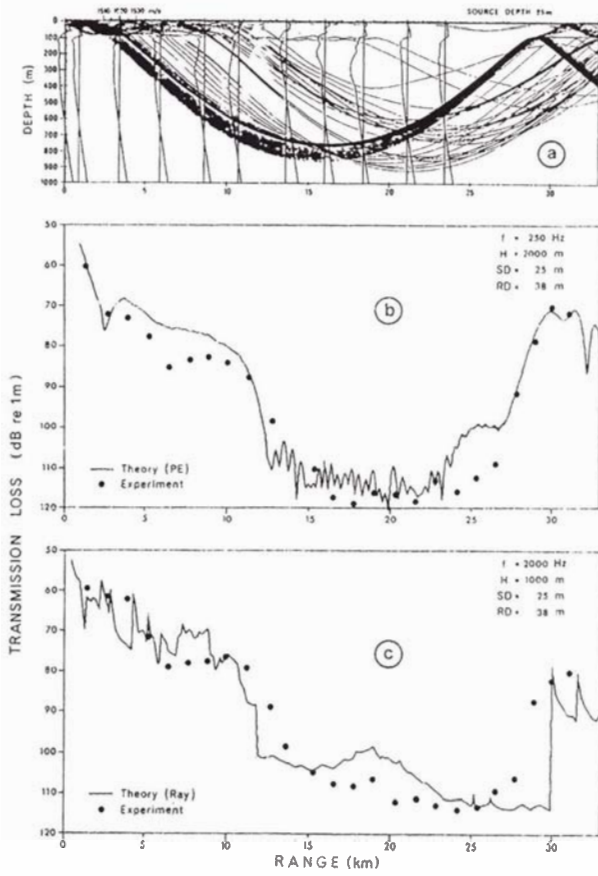
Several deep water experiments were conducted in the Mediterranean to compile a comprehensive database for winter and summer conditions at frequencies as low as 3 Hz but more typically 10 Hz. Some of these

data were collected in concert with oceanographic experiments (in the western Mediterranean) and have been processed and archived in the data filing system with little analysis and no reporting on propagation loss as such. Areas covered include the Balearic Abyssal Plain, the Alboran Sea, Tyrrhenian Sea, eastern Mediterranean, and in the northeast Atlantic off Portugal. While no comprehensive report on results has been written, the data themselves have been used by the NATO Military Oceanographic Group in an extensive evaluation of models. Results are given in the Summary Report of the 21st Meeting of the NATO Group on Military Oceanography, 12–16 May 1986.

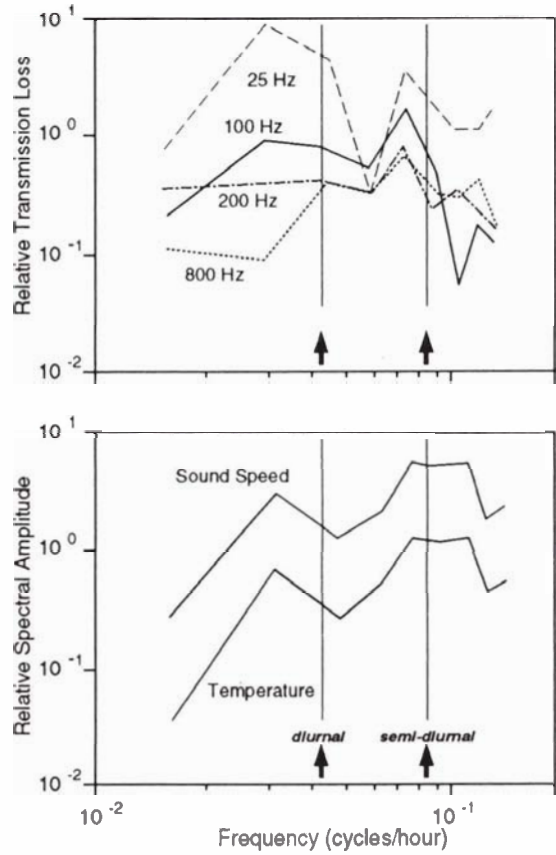
Both shallow water and some of the deep water data have been taken for the purpose of relating acoustic fluctuation with oceanographic variability. The study of the Strait of Sicily, described earlier, indicated the necessity to include the concurrent environmental measurements required in the planning phase. An analytical review of the literature on this subject was reported in 1983 [SM-166]. Several recommendations were made but, of particular interest, was the need for quantitative identification of different (acoustic) fluctuation mechanisms and their correlation with ocean processes. Previously taken data from the Barents Sea and Strait of Sicily, together with concurrent environmental observations were analysed and a clear correlation of the observed acoustic fluctuations with the semi diurnal/inertial tidal periods was noted [SM-189]. These periods were separable in the Strait of Sicily data but not in the Barents Sea results. The SNAP propagation model was modified and showed that the general features of the experimental results could be predicted. Again it was noted that other factors 'appeared' to contribute, but the experiment was not designed to provide the necessary data for analysis.

A collaborative program on fluctuation studies was initiated with the University of Cambridge in 1984 and an initial joint experiment conducted in the Tyrrhenian Sea in October 1985; this experiment was designed specifically to measure the time dependence of the internal wave perturbed profile of the complex acoustic field at frequencies between 200 and 2000 Hz. Extensive and comprehensive environmental measurements (e.g. thermistor chains, CTD, XBT, towed oscillating body (TOB), etc.) were taken during the acoustic experiment.

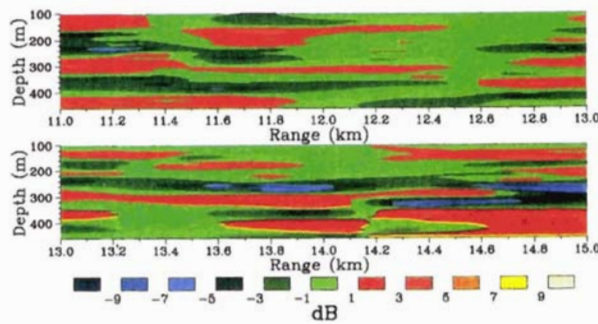
The University of Cambridge (Department of Applied Mathematics and Theoretical Physics, DAMPT) developed theoretical and numerical techniques for fluctuation studies based on data originating at the Centre. A



Deep-water frontal area in the Mediterranean. The leakage of sound out of the surface duct at a range of 12 km is correctly predicted by the models at two different frequencies.



Example of the convergence of the spectra of acoustic transmission loss and oceanographic data, showing resolution of inertial and semi-diurnal fluctuations possible at this latitude.

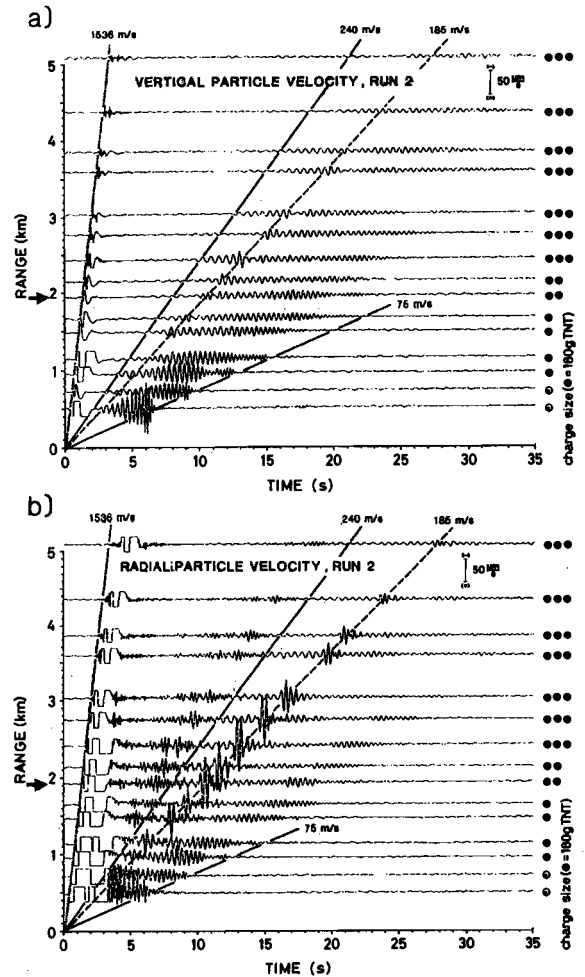


Sound intensity ribbons observed during sea trials.

second experiment with similar goals, but specifically designed to observe 'ribbons of sound' having intensity variations with depth of as much as 20 dB, predicted by the theoretical studies, was conducted in the eastern Mediterranean Sea in July 1986. Preliminary results from this latter experiment showed these sound ribbons with dimensions in the order of 1 km in range and 30 m thick with intensity variations in depth on the order of 10 dB. In the meantime, processing of the Tyrrhenian Sea experiment revealed that the internal-wave theory was not applicable to the sound speed inhomogeneities encountered, this led to an analysis based on a scattering theory which excluded internal wave processes. A time-of-arrival variability analysis showed that mean-surface refracted paths displayed a stochastic variation which was three times greater than that of the direct path [SM-223]. An empirical model of the spatial autocorrelation function (ACF) of the sound speed inhomogeneities was developed and a theoretical structure function for relative arrival times down the vertical array for the direct path was derived using this ACF and favorably compared with the experimental results. In 1989 the scope of the variability studies was broadened to include large-scale oceanographic features (quasi-deterministic) such as fronts and eddies as well as the small-scale statistical phenomena.

Seafloor acoustics

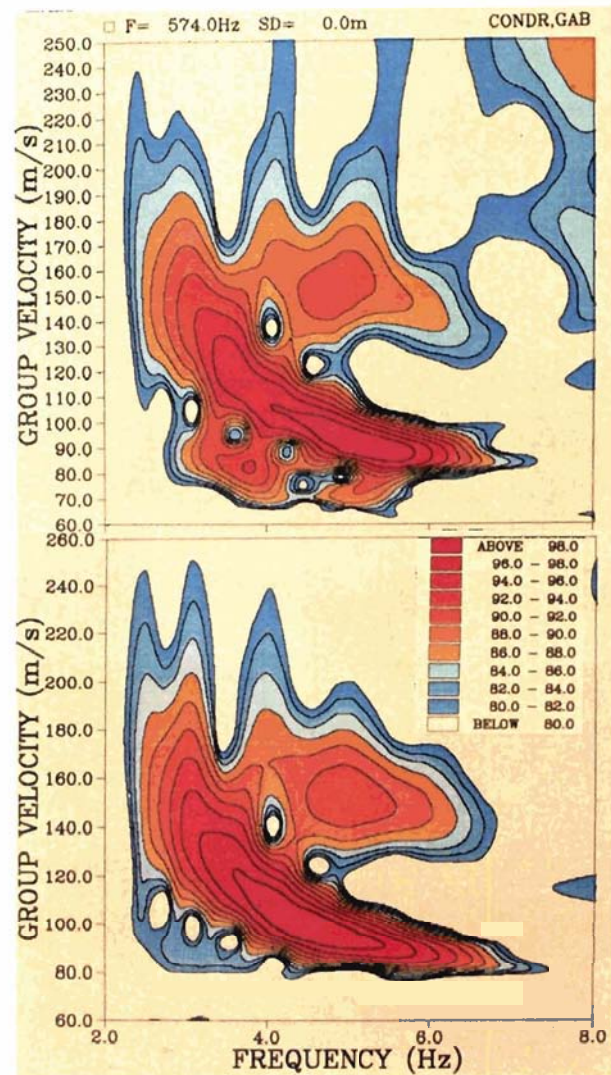
The Centre initiated studies of ocean-bottom interface waves in 1976, in particular Scholte waves, as a mechanism for detecting and determining direction of very low-frequency (~1 Hz) energy in shallow water (well below waterborne compressional wave cut-off frequencies), using a combination of buried geophones and hydrophones [CP-19(11)]. The physical processes involved, which result from the assumption of a very hard bottom which supports shear waves, precluded the use of normal mode models for interpretation; however the fast field program (FFP) codes were applicable (an FFP code is the basis for the SAFARI model). Using the FFP, parametric studies were undertaken [CP-23(7)] to demonstrate conditions under which Scholte wave propagation could provide significant improvements in detection range. In 1979 a review of the seismic wave propagation in the upper seafloor was written [SR-42], a digital ocean-bottom seismometer system was developed [CP-26(1) - also see Section on EED], and results from initial experiments presented [CP-26(2)]. These results confirmed



Time vs distance plots of seismograms recorded with the vertical (a) and radial (b) component of the SACLANTCEN ocean bottom seismograph.

model predictions and showed low speed, 250–90 m/s, interface waves in shallow water at respectively 1.5–5 Hz. The experimental work rapidly expanded with experiments taking place south of Lampedusa Island, between Sicily and Tunisia, and in the Norwegian coastal waters and in the Kattegat, with studies of energy from surface shipping, low-frequency noise, and low-frequency sound sources, as well as explosive sources [CP-32(Pt 1:5)]. Results of four experiments were summarized and provided a good understanding of the physical mechanisms controlling the excitation, propagation and attenuation characteristics of interface waves [SR-71, SM-193]; a separate report was written establishing the feasibility of seismically detecting and tracking ship-radiated energy to reasonable ranges [SR-77]. Results of these studies led to the establishment of a fixed seismic monitoring station (see EED) in the vicinity of La Spezia to collect a large database of noise and shipping-induced interface or other seismic waves. Other test sites were established on the Ligurian Shelf to study the anisotropic behavior of the interfaces waves [CP-37(5,8), *2] and it was concluded that understanding of the conversion process was the key to the anisotropic behavior and this required multi-parameter surveys and use of powerful analysis techniques and models such as SAFARI [see Modeling Section]. Sensitivity to experimental parameters is so great that Snoek concluded [SM-229] that a major continuing effort is needed to advance from the qualitative description of some to the quantitative formulation of all processes involved.

While interface waves were of continuing interest during this period, separate studies evolved on the effect of bottom seismic and absorption properties, in general, relative to their impact on waterborne energy propagation. In particular, cores were routinely acquired and classically analysed to support propagation studies, extensive acoustic reflectivity measurements in the Mediterranean were made [SR-28] and seafloor roughness was characterized [SR-32]. While analyzing results from a 1975 MILOC experiment in the Barents Sea, Hastrup [CP-19(1), CP-21(8)] observed a significant low-frequency attenuation in the water column that was well correlated with the hardness of the bottom; this was important in that while the fact had been reported in a 1955 issue of the *Journal of the Acoustical Society of America* (Kornhauser & Raney) no use of it had been made by the Centre in the intervening years to analyze experimental results. Further it was found that the bottom hardness had a pronounced effect on the optimum propagation frequency [SR-33]; both observations were later supported by acoustic



Gabor-matrixes: the normalized contour plots of the interface wave energy as function of group velocity and frequency for two of four sensors of an ocean bottom seismometer. Color steps in dB.

modeling and had significant impact on design of future experiments [CP-22(Pt 1:15)]. This work led to a conference on Bottom-Interacting Ocean Acoustics at the Centre on 9–13 June 1980 [CP-27/*1] where Centre progress on this problem was reported. Use of the FFP model to analyze results from several experiments [SM-167] quantitatively confirmed that shear properties of the bottom were a major controlling factor in the attenuation of sound below the optimum frequency and to a lesser extent on the optimum frequency itself. Interface waves being important only at very low-frequencies (<5 Hz) and short range (<10 km), were not important in this respect.

As a consequence of the preceding work, investigations based on the BIOT poro-elastic model of sediment parameters were initiated. The model was found to provide good general agreement with observed bottom reflectivity and parametric studies were performed to determine the influence of individual parameters [SM-185]. [*1] in particular showed that relaxation time, which is expressed in terms of permeability/porosity ratio and other sediment parameters, can be used to remotely determine bottom parameters as evidenced by comparison with experimental results. Spatial variability of surficial sediments shows the relative importance of biological and hydrodynamic processes [*1]. A review of recent investigations reported in the literature attempted to put frequency-dependent acoustic observations in context with the BIOT theory [SM-218].

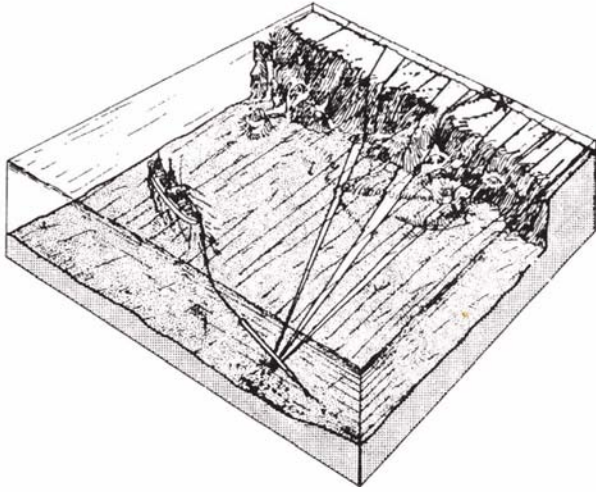
Sediment property measurement techniques were developed starting with classical core analysis, the use of divers to collect bottom samples and eventually the development of in-situ measurement techniques. In-situ measurements of sediment shear speeds were of particular interest. Newly-developed in-situ resistivity probes were used initially together with a laboratory shear and compressional wave measuring system and a sediment permeability system. These techniques formed the basis for a complete surficial sediment measurement system to collect all this information in situ and results compared favorably with laboratory measurements [SM-210]. A downhole sediment parameter measurement system was developed to obtain geoaoustic parameters as a function of depth in the sediment. Initial measurements of compressional wave speed and attenuation were compared with an inverse method. Results were encouraging and development continues as the decade ends.

Reverberation

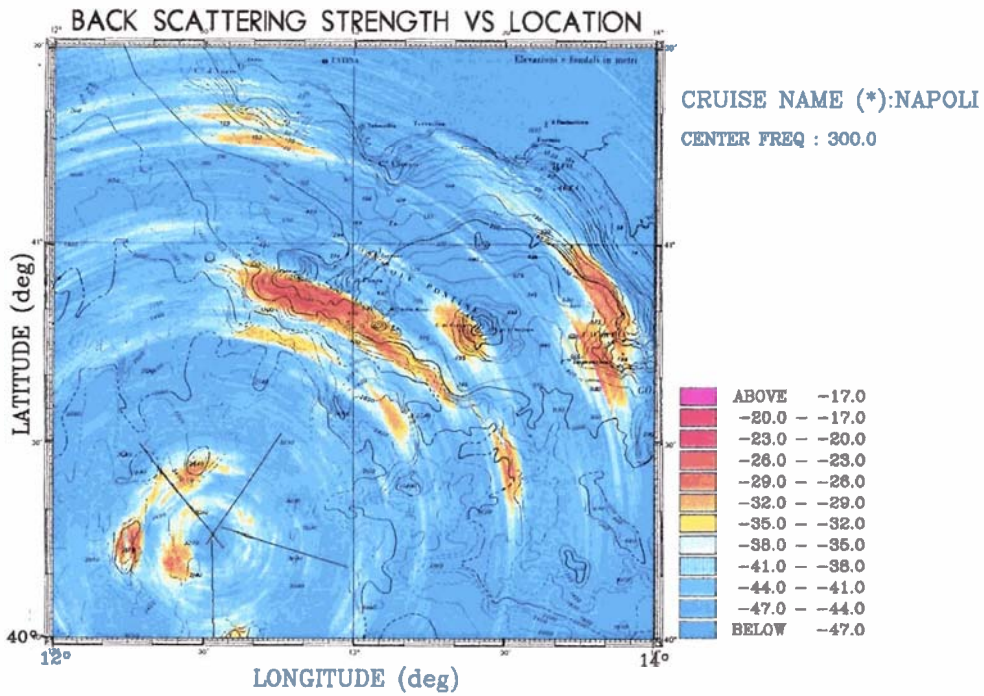
Volume and bottom reverberation studies reported by Ross [M-93], focused on high-frequency (> 2 kHz) and on rough, but otherwise reasonably flat bottoms respectively. From 1975 to 1982 there was a hiatus in reverberation studies and subsequently investigations focused on basin reverberation from strong topographic features and later (1987) on low-frequency (< 1 kHz) volume reverberation.

A NATO MILOC experiment, called 'White Water', designed to support prediction of the length of time underwater acoustic sensors would be blocked after an underwater nuclear explosion (blue-out effect) was initially approved but cancelled in 1983 after international consultations. The Centre initiated a basin reverberation study using lower energy sources and directional receivers. Measurements were made of backscattering from the continental slope west of Sardinia using explosives and the towed array. This experiment was closely followed by four experiments in the Tyrrhenian Sea. Initial results reported [CP-27(8)*1, SM-187] showed little frequency dependence of scattered results. In 1985 additional data were collected in the deep water area of SWAP in the northeast Atlantic and again in the Tyrrhenian Sea this time using both a vertical array and the towed horizontal array. Significant software development was supported by the US Office of Naval Research (ONR) in 1987 to transform the reverberation data collected with the towed array to scattering strength on polar intensity plots to scales of bathymetric charts to facilitate interpretation. This analysis program was first applied to the Tyrrhenian Sea data [SM-221]. Extensive data were also taken during two phases of 'Resolute Support' in the vicinity of Iceland and also in the Levantine Basin. The application of the analysis software to these data again showed the efficiency with which data could be interpolated and reported [SM-226, SM-230, SR-160]. The program is continuing and has been refocused to support the use of activated towed arrays. For this purpose the software has been modified to interpret bistatic reverberation.

The question of volume reverberation at frequencies below 1 kHz was raised in support of the activated towed array program. A joint effort between the Centre (Akal), US (Dulea) and Canada (Stockhausen) was initiated in 1987 using a technique developed by Stockhausen while at the Centre [SM-60]. An experiment was conducted in the Greenland-Iceland-Norwegian Sea area during 'Resolute Support' to collect a database using explosive sources, an upward-looking vertical array and a fish-finding system to



Experimental geometry for directional acoustic backscattering measurements.



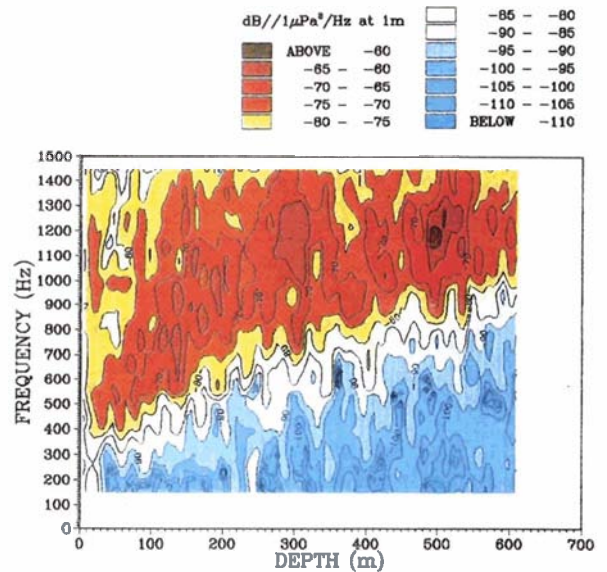
Backscatter maps can be expanded to study areas of interest in more detail. This figure shows the Pontine Islands northwest of Naples. This feature was one of the strongest scatterers measured and also one of the steepest with local slopes estimated to be as high as 15° .

characterize the scatterers. Significant volume scattering strengths were observed to frequencies as low as 500 Hz and reporting will be complete in 1990 [SR-170].

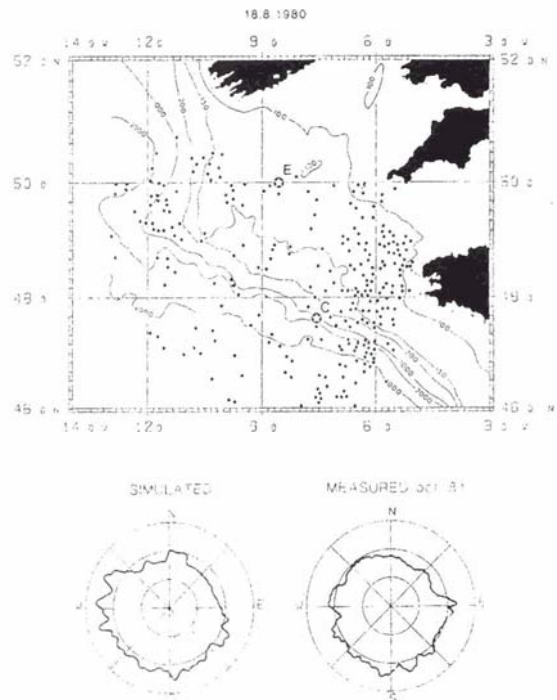
Ambient noise

A 20-hydrophone (667 Hz) towed array was received from the US Office of Naval Research in 1978 and immediately tested in support of the coastal water passive sonar project. This provided the Centre with its first experience with towed arrays although no useful acoustic results were obtained. At the same time a 128-hydrophone towed array, specifically designed by the Centre for directional ambient-noise studies was contracted to Prakla-Seismos, West Germany and received at the Centre in early 1979; it was immediately taken to sea and directional noise data collected in both deep and shallow water [CP-26(4)]. However, the Centre had no special processing algorithms for dealing with the data. R. Wagstaff in the US had developed and successfully used algorithms and models for this purpose in several US towed-array experiments. He joined the Centre in the autumn of 1979 as group leader of the newly-formed Ambient Noise Group and immediately set the group to work on model improvements, theoretical studies of the directional noise response of vertical and towed arrays, installation of directional noise processing algorithms on the Centre's real-time computer, HP21MX, and the conduct of seven at-sea experiments. While the vertical array modeling evolved from previous studies [SM-127] of the response of vertical arrays to signals in an isotropic noise field, this program overall represented a new initiative at the Centre.

During the initial three-year period through the end of 1982, major effort was focused on improving and extending the processing algorithms to obtain the persistent directional noise patterns and their statistics at several geographic locations. Designed experiments included aerial surveillance of shipping in order to provide a basis for evaluation of results. During the 10 years of this project, over 70 measurements at 46 sites have been made throughout the Mediterranean Sea, on either side of the Strait of Gibraltar, in the Iberian Basin and southwestern approaches to the English Channel (SWAP), along the Greenland-Iceland-UK ridge and along the ice edge of southern Greenland. These results are published in a series of identically formatted reports [SR-59, SR-60, SR-67, SR-73, SR-80, SR-145, SR-167, SR-168] all with R. Wagstaff as



Low-frequency scattering strength data from the N. Atlantic covering 100–1500 Hz range.



An example of modeled vs measured ambient noise horizontal directionality at site E in the southwestern approaches to the English Channel, using as shipping input data a distribution of 280 ships obtained by aerial surveillance during towed-array measurements. Spacing of circles: 15 dB.

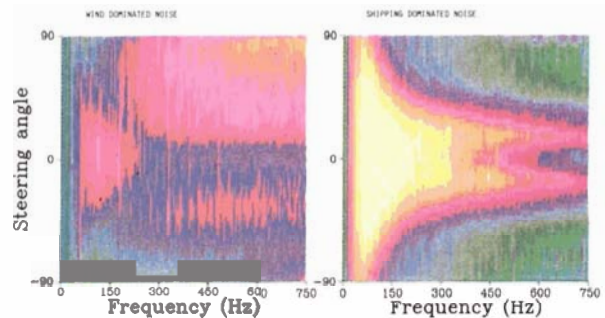
a principal author.

Concurrent with the measurement program construction of a general ambient-noise prediction model (RANDI-II) was initiated to include both shipping and wind noise sources with a special option for arbitrary arrays in shallow water [SR-70]. This model integrates a previously developed wind noise model [SR-41] and a normal-mode acoustic propagation model (SNAP) [SM-121], to provide a complex pressure field in shallow water at the array elements. It also has a provision to use measured propagation loss curves in lieu of a model.

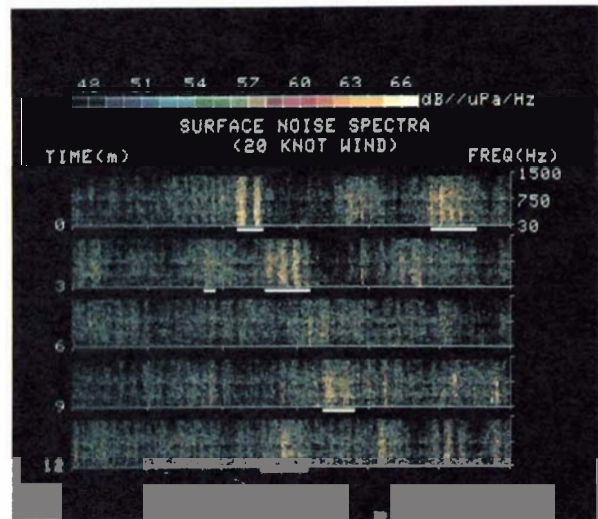
In the mid 80s, under R. Heitmeyer, the scope of the project was widened to include detailed studies of wind-noise, beam-noise fluctuations, and high resolution processing. There were no routine measurements taken during this time but measurements were carried out at selected sites in support of the special studies and for model validation. Emphasis was placed on careful preparation of noise model inputs and the use of a sophisticated propagation model. Direct measurements of the source spectra of 50 merchant ships were obtained. A Mediterranean Sea shipping model was developed and used extensively in the general noise model to evaluate measurements [SR-139, SR-164]. A model for generation of noise by breaking waves (white caps) was also developed [SR-145]. A 64-element vertical array was constructed and used extensively in acquiring ship- and wind-induced noise data, measuring white cap noise and to obtain data sets to evaluate the environmental sensitivity of a matched-field processing technique [SR-140] for source localization. In particular, the vertical array was used concurrently with the towed array in the later 80s at a number of measurement sites for data collection and further evaluation of the RANDI-II model.

While these new studies initiated by R. Heitmeyer were continued into the late 80s, additional data sets of directional ambient noise due to shipping were collected in support of the MILOC survey ('Resolute Support') and of operational commands. R. Wagstaff who initiated the project and continued to develop operational applications of these algorithms for the US Navy, participated in these experiments. In particular he provided the Centre with a VAX version of the algorithms for use with the new WARP-II system; this saved the Centre the considerable effort of migrating the original HP software to the new VAX systems.

The main results of this project were the establishment of a methodology for horizontal noise directionality measurements, several reports of more than 70 measurement sets and a validated prediction model. This



Measured vertical array responses vs frequency and steering angle at sites in the Mediterranean. Right: shipping noise dominated conditions, showing high level arrivals close to the horizontal. Left: high wind (15 kn) conditions, showing high noise levels towards the ocean surface.



The time variation of the surface sound spectrum at a wind speed of 20 kn. These data were received by the upward-endfire beam of the vertical array, and correspond to a circular patch of sea surface. The yellow bursts of sound coincide with video recordings of whitecaps above the array.

model was requested for use by five of the NATO nations and is used extensively by the Centre's Operations Research Group to support tactical studies under wartime conditions. In addition to the collection of noise spectra from 50 merchant ships, a high-resolution shipping density distribution for the Mediterranean Sea has been established. The work on physics of noise generation in breaking waves culminated in a NATO workshop in 1987 which brought together leading scientists in the field of hydrodynamics and underwater acoustics (see [*4]).

Acoustic modeling

Numerical models are important for understanding acoustic phenomena in terms of the physical properties of the sea and its boundaries at the surface and the seabed. They provide an easily accessible synthesis of physical knowledge and both support and benefit from analysis of experimental data. They have become valuable research tools which provide necessary inputs to many Centre projects and are essential for estimating the performance of operational and proposed detection systems, using either on-the-spot measurements of environmental parameters or historical data. In addition, the work of this project contributes towards the development of operational acoustic models, which can provide valuable information to onboard operational commanders.

The development of a new generation of acoustic models started in 1973, with the research effort being established as a separate project in 1979. The primary scope has been to provide the NATO research community with sophisticated tools for studying the frequency-dependent aspects of sound propagation through a complex ocean, with arbitrarily varying sound speed and bathymetry in all three spatial dimensions.

This task has been successfully addressed through the development of a suite of propagation models (PAREQ, SAFARI, SNAP), each model optimized for a particular class of acoustic problems, but with emphasis on the codes being well-tested, well-documented and, most importantly, user-friendly.

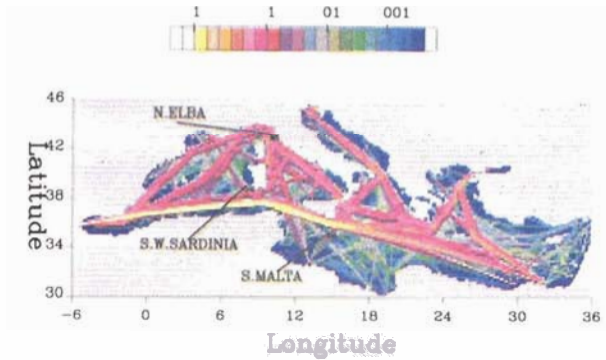
The SACLANTCEN propagation models are currently used in all major ocean-acoustic research centres within NATO. Perhaps more than any other project at the Centre, it has benefitted from and contributed to cooperation with other NATO nations through the acquisition, improvement and export of computer codes. The earlier history [M-93] describes the status of acoustic propagation modeling at the Centre prior to

1974. In that year the Centre obtained a state-of-the-art computing facility (UNIVAC 1106) and rather than convert codes existing on the Elliott 503 computer it obtained complex ray codes (CONGRATS, NISSM) from NUSC already programmed for the UNIVAC system. The Centre also constructed a more elaborate ray code RAIBIC, used for many years after for modeling both propagation and reverberation.

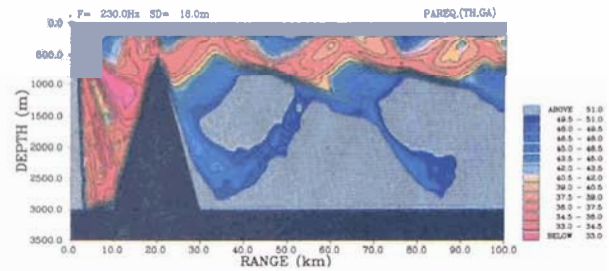
Wave theory modeling was initiated with a normal mode code obtained from NRL [*5]. Considerable effort subsequently went into improving algorithms for computational efficiency on the Centre's computer, generalization of codes to increase applicability and detailed documentation for general use outside the Centre. With these changes, this code evolved into the Centre's SNAP model [SM-121]. In 1984, a numerically efficient modal solver [*6] was implemented within SNAP effectively increasing its running speed by a factor of ten; the model was subsequently renamed SUPERSNAP. In 1986, SUPERSNAP was improved with a range dependent adiabatic (no mode coupling) code. This code was shown to be robust to slow changes in the environment vs range when compared to a benchmark code COUPLE [*7], received from NORDA. In 1988, a general assessment of shallow water acoustic models was performed in support of the NATO Oceanographic and Acoustic Prediction Systems (NOAPS) and SUPERSNAP was ranked first in overall performance among nine different models submitted for the assessment.

A parabolic equation (PE) code [*8] was also received from NOSC [*9] in 1974, modified with some contributions from another US Navy organization, AESD, and formally documented as the Centre's PAREQ model. PE codes result from an approximation to the wave equations that initially limited their accuracy use to a narrow range of angles relative to the horizontal. A wider range of angles was achieved with a NUSC code, implicit finite difference PE (IFDPE) [*10], which was adopted by the Centre as a benchmark code for evaluating the accuracy of PAREQ. The basic changes to PAREQ over the years were primarily concerned with accounting for interaction with the ocean bottom; this essentially had to be accomplished by assigning geoacoustic characteristics to the ocean bottom.

A fast field program (FFP) code [*11] was received from NUSC in the late 70s but not immediately used. However, as a result of the 1980 conference [CP-27/*1] on bottom-interacting ocean acoustics, organized by EMG, the importance of modeling Scholte waves was recognized. These are seismo-acoustic



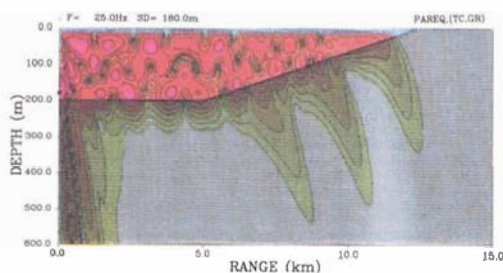
A merchant shipping density distribution for the Mediterranean with a resolution of $1/6 \times 1/6^\circ$ square of latitude/longitude based on Lloyd's Register of Ships and other sources. The position of three sites are shown where detailed noise modeling has been completed.



Sound propagation across a seamount at 230 Hz. This example of strongly range-dependent propagation illustrates the dramatic effects caused by the presence of a seamount along the propagation path. Note that beyond the mount, sound is propagating primarily in the deep sound channel at a depth of around 500 m.

EXPORT OF ACOUSTIC MODELS (1979-88)					
	PAREQ	A	UK:	ARE, Portland	(A,B,C)
	SAFARI	B		ARE, Teddington	(A,B,C)
	SNAP	C		Ferranti	(A,B,C)
				Marconi Underwater Systems	(A,B,C)
				Plessey	(B)
				Royal Signals and Radar Estab	(B)
				The Open University	(B)
Canada:	DREA	(A,B,C)	USA:	ARL, Texas	(A,B)
	DREP	(B,C)		Catholic University	(A,B)
	RRMC	(B,C)		Colorado School of Mines	(A,B)
Denmark:	Technical University	(B)		Defence Nuclear Agency	(A,B,C)
France:	AERO	(B)		Gould	(B)
	GERDSM	(A,C)		Hawaii Geophysical Institute	(B)
Germany:	FGAN	(C)		Lamont-Doherty Observatory	(B)
	FWG	(A,B,C)		Lawrence Livermore	(B,C)
	IABG	(C)		Marine Physical Laboratory	(A,B,C)
	Krupp Atlas Elektronik	(B)		MIT	(A,B,C)
	Marinetechnik, Hamburg	(B)		Naval Postgraduate School	(A)
	University of Hamburg	(B)		NAVOCEANO	(A,C)
Greece:	GETEN	(C)		NCSC	(B)
Holland:	Physics Lab, TNO	(A,C)		NORDA	(A,B,C)
	Inst. Appl. Geoscience, TNO	(B)		NOSC	(A,B,C)
Italy:	Maristat	(A,C)		NRL	(A,B,C)
	University of Genoa	(A,B,C)		NSWC	(B)
Norway:	NDRE	(A,B,C)		Polytechnic Univ of N.Y	(B)
Spain:	RIOA	(C)		Rensselaer Polytechnic	(A)
				Rondout Associates Inc.	(B)
				Univ. of Massachussets	(B,C)
				Univ. of Michigan	(A,B,C)
				US Military Accademy	(C)
				Virginia Tech	(B)
				Woods Hole Oceanographic Inst.	(A,B,C)

Export of acoustic models (1979-88).



Mode cutoff during upslope propagation. At a frequency of 50 Hz the shallow-water waveguide supports three propagating modes in the flat section. However, during upslope propagation when the waveguide gets shallower, all modes are eventually cutoff, with the energy being radiated into the bottom as well-defined beams.

waves induced in consolidated sediments by water-borne compressional waves and are important in accounting for acoustic energy removed from the water column and for describing propagation of shear waves within the sediment. In 1982, a seismo-acoustic model development of the FFP type was initiated. This became the SAFARI model [SR-113]. The initial work was extended to include a broadband pulse calculation and, like SNAP, has been used as an element in developing a noise model. The model was completed in 1986 and subsequently documented and distributed to the nations.

These models all calculate the coherent propagation vs range in complex ocean environments. They have been used extensively as building blocks for noise and operational models and to analyse results from major at-sea trials. In particular, they have been used to analyse results from MILOCs in the Barents and Baltic seas and the southwestern approaches to the English Channel (SWAP) where they demonstrated the importance of incoherent scattering at the ocean bottom into compressional and shear waves. Optimum frequencies for propagation in shallow water were analyzed and related to water depth and bottom properties. In another application, they were used to describe important factors in determining the optimum tow depth of operational towed arrays. When analysis requirements could not be efficiently met by these codes, models from other organizations were acquired and used with little modification. An ocean reverberation model was obtained from NSWG to analyze the reverberation data from high intensity explosives used in the SWAP exercise. GRASS, a range-dependent ray trace model was used together with PAREQ to model propagation over seamounts. Where required, models have been installed on the real-time system to provide onboard capability for analysis of results or for modifying experiments based on in-situ environmental measurements. Most recently, a broad study of the acoustic effects of ocean fronts has been initiated as an internal cooperative effort among the Applied Oceanography, Applied Acoustics and Environmental Modeling Groups.

Improvements in computational facilities have been the necessary ingredient to foster new model developments. In 1983, the Centre initiated a change to the VAX line of computer systems with a VAX 11/750 and an array processing system, the FPS164, which together resulted in computational speed increases of from 20 to 50 times; in the last half of this decade a dual VAX 8600 cluster and an FPS 64/60 provided another order-of-magnitude speed increase. These,

together with improved numerically efficient coding techniques, such as the modal solver mentioned earlier, have had an almost revolutionary impact on the Centre's capabilities to address new problems.

While a pulse code was initiated in 1982, a more intense effort was undertaken in 1988. The initial expedient was to run a particular model at several frequencies within a given band and to use a fourier transform method to obtain the pulse shape at any particular range and depth; by replicating this process at every range/depth a picture of the propagating pulses evolved. In 1989, the problem was tackled directly and a new time domain model, the SACLANTCEN Pulse Acoustic Research Code (SPARC), was developed.

A particular success story in the development of Centre models is the first specific rank result of SUPERSNAP's performance in the NOAPS assessment. As important, however, are the documented improvements obtained in shallow water propagation prediction over the last 30 years. Over these years many experimental data sets of acoustic propagation vs range were obtained concurrently with environmental information. Predictions using the empirical Marsh and Shulkin model and SUPERSNAP were separately compared with each data set and the rms error plotted vs range. SUPERSNAP demonstrated an impressive improvement over the empirical model [SM-199].

4

Oceanography

Military oceanographic surveys

Military Oceanographic Surveys (MILOC), initiated in 1964, were originally designed to improve NATO's knowledge of the physical oceanography in ocean areas of interest. Since 1974, these surveys have focused on the acoustics of these areas with the oceanography providing the supporting environmental database for analysis. MILOCs are initiated by the NATO MILOC main group and executed by a maritime commander, typically CINCEASTLANT, with participation by several scientific and operational components of the NATO nations. Their principal goal is to provide regional acoustic databases and understanding (propagation, ambient noise, reverberation, oceanography, seafloor, etc.) to support improvements in executing NATO's ASW mission. Starting in 1974 a Chief Scientist has been appointed to develop the survey plan, identify necessary resources, execute the at-sea exercise, coordinate the analysis and write the final report on the results of the survey. For the past 15 years, the Centre's Chief Scientist, O. Hastrup, has been the Chief Scientist for all MILOCs. Separately, the Centre has assumed specific technical responsibilities as part of the coordinated international effort and individual accomplishment by the Centre projects are discussed in relevant portions of this report.

A study of the effects of the polar front in the Barents Seas around Bear Island on acoustic variability was initiated in 1973. While officially designated MILOC SURVARCTIC, it was nicknamed 'Rough Start' and was divided into two phases with the Bear Island Study referred to as 'Quiet Sea'; another phase in the slope region, separating the Barents and Norwegian Seas, was called 'Placid Pool'. A 'Quiet Sea' pilot experiment was run in July 1974 and provided experience for the final planning and execution of the principal experiment in July 1975. It is interesting to note that the coordinated analysis and reporting of results from

the participating nations, Germany, The Netherlands, United Kingdom, United States and SACLANTCEN, was completed in 1977 [SR-20] with much of the analysis available within eight months after completion of the field trials.

In 1978 a three-phase study in the southwestern approaches to the English Channel, SWAP, was initiated as operation 'Plain Sailing'. Experiments were conducted in the deep waters of the Bay of Biscay, the shallow waters of the entrance to the English Channel and in the slope region connecting the two. Belgium and France participated as well as the nations involved in 'Quiet Sea'. The summer exercise was conducted in August 1980 and the main winter exercise in February 1981; a final phase was completed in October 1981. There were no particularly surprising results from this MILOC, i.e. observations agreed with predictions, but it is noted that exceptionally good propagation conditions existed in the shallow water areas [SR-72] and the exceptional quality of the database provided increased confidence in the reliability of the Centre's SNAP model. This fact was particularly useful in the activated towed-array program trial in the area a few years later.

Reverberation studies were made in anticipation of a MILOC experiment to be named 'White Water' to study the blue-out effect which could mask sonar systems for sometime after an underwater nuclear explosion. However, due to the high-intensity explosives that were necessary to conduct this experiment, political pressures forced its cancellation. However, the Centre continued this effort with smaller charges in a subsequent MILOC as part of its applied ocean acoustics program.

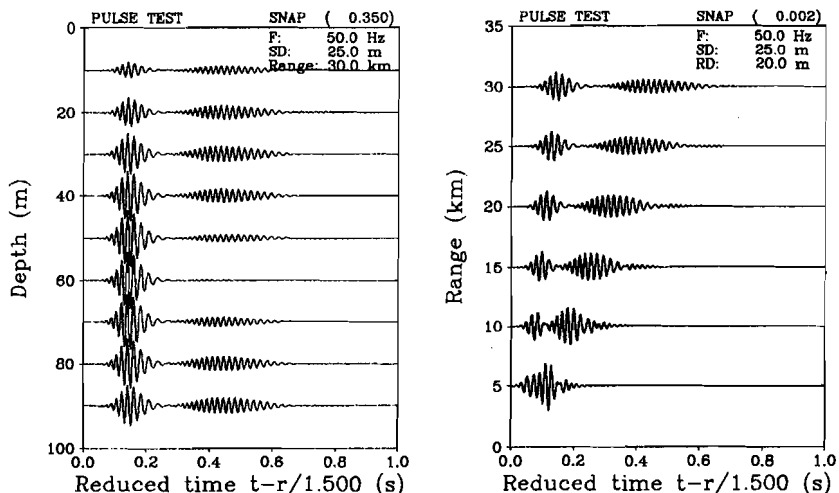
A request by CINCNORTH in early 1983 resulted in a quick response MILOC in the Baltic Sea, called 'Shallow Meadow', with a summer exercise in August 1983 and a winter trial in February 1984. While experiments had been conducted there in the past (late 60s and late 70s), the Baltic is a particularly difficult area for ASW because of the very shallow basin and with low salinity surface waters due to continental run-off sharply contrasted with higher salinity deeper waters [SR-101].

The fourth and last of the MILOCs during this period was also the most ambitious. It was focused on the GIUK gap area and was initiated by CINCEASTLANT in 1984. This MILOC was codenamed 'Resolute Support' and was planned as a two-phase exercise, summer and winter, in July/August 1987 and April/May 1988. However, an important set of directional noise measurements, provided by *Maria Paolina G.* in

1987 were not possible to repeat in 1988 due to the MPG being put off charter after the 1987 experiment and the Centre's new vessel, *Alliance*, not delivered or available for research work until later in 1988. Therefore, a third phase was conducted in April/May 1989 to provide the winter data set of directional ambient noise. Because of the increased capability of *Alliance*, the area of interest was expanded somewhat to include several measurements along the ice edge of southern Greenland. It is now expected that reporting of 'Resolute Support' will be completed in 1991.

TIME TABLE	
	J F M A M J J A S O N D
83	1*
84	2* Draft Outline Plan
85	3* 4* Outline Plan(1)
86	1 Draft OPOD 5* 2 Draft OPOD 6*
87	OPOD Phase1 7* PHASE ONE 8*
88	OPOD Phase2 9* PHASE TWO Environmental1 10*
89	Environmental2 Draft Technical Report
90	11* Technical Report Operational Report
91	Symposium to Discuss Long-term Research Analysis
* Planning Meetings	

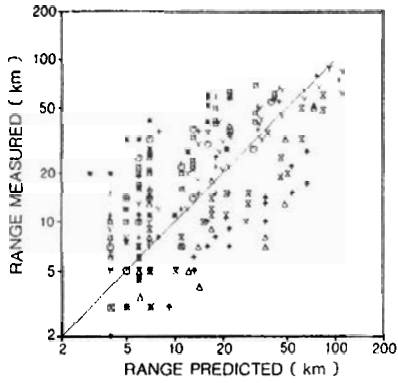
MILOC experiments can require a very long planning and execution phase as this example shows for the latest MILOC experiments in the Greenland-Iceland-UK and Norway gaps.



Pulse dispersion in a shallow-water waveguide. This example illustrates signal dispersion in a homogeneous, 100 m deep ocean. The source pulse is a Hanning-weighted, four period sine wave with a centre frequency of 50 Hz. Note the splitting up of the signal with range into two distinct wave packets. By looking at the received signal over depth at a range of 30 km, it becomes clear that the two arrivals correspond to the first two acoustic modes of the waveguide.

Predicted vs. measured detection ranges for 2 models
(12 sites, 100 Hz - 8 kHz)

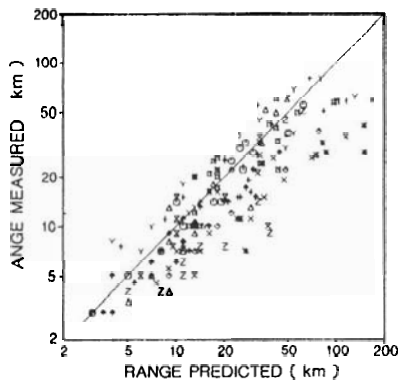
a) Colossus II – empirical model (1960)



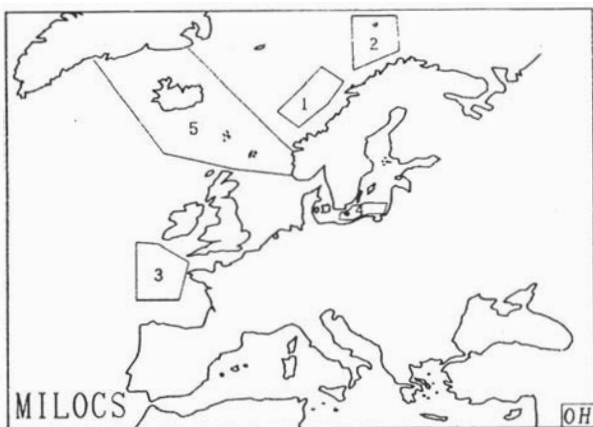
KEY:

- NORTH SEA
- △ NORTH SEA
- × NORTH SEA
- + SWAP
- Y SWAP
- × SICILY
- SICILY
- ⊕ ELBA
- Z MEDINA BANK
- ⊠ VESTFJORD
- * BALTIC
- ⊗ BALTIC

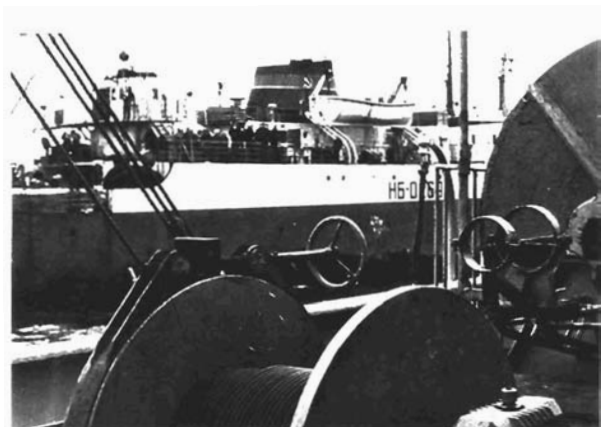
b) SNAP – normal mode model (1980)



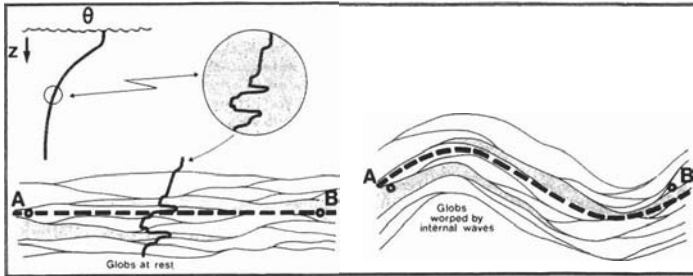
Improvements in shallow-water propagation modeling over two decades. The results are based on blind forecasting for 12 different sites using propagation frequencies between 100 Hz and 8 kHz.



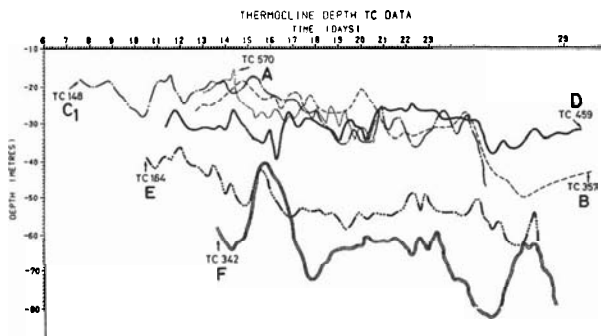
Areas where ocean-acoustic MILOCS experiments have been conducted: (1) SURVNORLANT, 1970; (2) Rough Start, 1974-75; (3) Plain Sailing, 1980-81; (4) Shallow Meadow, 1983-84; (5) Resolute Support, 1987-88.



The conduct of large multinational MILOCS experiments often attracts foreign interest and sometimes even harassment. On some occasions such as this, a collision with a Russian trawler appears to be almost imminent.



Oceanic variability. The sections represent the character of inhomogeneities (globs) that add to the sound-speed variabilities created by internal waves.



Upper-ocean variability. The MILEX mixed-layer experiment was conducted in the Tyrrhenian Sea in October 1980. Thermistor chains and currentmeters were placed as shown on the satellite photograph. The sensors were set to span the mixed-layer and upper thermocline. The accompanying plot shows the deepening of the thermocline at the six stations during the period 6–30 October.

Dynamical oceanography

At the beginning and the end of this reporting period the Centre had specific tasks to understand the effect of ocean microstructure and internal waves on acoustic propagation. The study ongoing in 1975 [M-93] was in the Applied Oceanography Group and entitled AIM (acoustic propagation in the presence of internal waves and microstructure), while the study in 1989 was in the Applied Ocean Acoustics Group and called Propagation Variability Studies [SM-233, APR-89]. However, by the end of the 80s the Applied Oceanography Group was conducting measurements and developing models to predict ocean variability at tactical scales of interest to support acoustic propagation modeling and a truly joint program was established for this purpose.

AIM experiments were carried out in conjunction with the French sponsored COBLAMED program in the Gulf of Lions in October 1975 and September 1976 and consisted of a spatial study of internal waves and horizontally advecting irregularities, a study of the dynamics of small-scale (microstructure) processes, and a study of acoustic propagation (3–12 kHz) to ranges of 10 km in the thermocline. The experiments benefitted greatly from results of other participants in COBLAMED and from the Italian Navy hydrographic ship *Magnaghi*, which towed the newly-developed towed oscillating body (TOB, see OED) to provide real-time contours of ocean parameters to depths of 200 m. A five-element vertical array was used to obtain arrival angles for different paths. Results [SM-126] of vertical and horizontal ocean parameter spectra from the TOB were compared with recent internal wave models, the current meter data showed strong energy of the inertial period of 18 h with internal wave energy for shorter periods, and temperature data was used to characterize turbulence at small scales. Acoustically, large numbers of arrivals for a given 'ray' were observed with time differences of arrival between 2–

5 ms and 20 dB fluctuations in intensity with a rapid cutoff in the amplitude fluctuation spectrum for periods shorter than 2 min corresponding to a range increment of 35 m.

A study of the STEP structure in the temperature profile of the Tyrrhenian Sea observed in 1971 and subsequently studied in the early 70s, continued with analysis of the 1974 experiment. Results reported in the earlier history [M-93] and in SR-24 show remarkable temporal stability of the temperature and salinity characteristics of each layer over the first three years of the study giving rise to their being characterized as permanent structures. In 1978, a further study of the currents in the structure were made with a specially designed horizontal and vertical current meter array, to show that the advection processes, associated with internal wave activity, play a significant role in the maintenance of the homogeneous layers observed. With these final measurements a period of six years of observation was completed and it was noted that the homogeneous layers were thickening and deepening, suggesting there could be a slight warming and increase of salinity in the deep Tyrrhenian water [APR-78].

A study in the Atlantic approaches to the Strait of Gibraltar, in the Gulf of Cadiz, was conducted to determine the relative importance of internal waves and intrusions to small scale oceanic variability as ultimately described in terms of sound speed variability [SM-122, SR-38]. The towed oscillating body (TOB) was used extensively in the measurements to collect unique two-dimensional descriptions of salt, temperature, density and sound speed vs range. The effect of internal waves were quantified and removed from the data by analysis of their influence on the density field. A clear analysis of variability due simply to the physical makeup of the water (intrusion process or 'globs') could be made. It was found that while these 'globs' could locally dominate the sound speed field they contributed less than 20% to the overall sound speed variance. Overall the results were in good agreement with the Munk and Zachariasen [3] model spectrum of internal-wave induced sound speed fluctuations.

A study of the mixed layer was initiated in 1978 in order to better interpret satellite imagery and to develop a mixed layer model. The mixed layer is bounded by the ocean surface and, at depth, by the start of the seasonal thermocline. Its depth can vary in time corresponding to the influence of internal waves, inertial motions or wind events and in space by the horizontal variations in these phenomena (tens of kilometres). Thus it is

affected by wind stress, upwelling and inertial oscillations in the current field. The predictions of the mixed layer and its variability is important to sonar range prediction. This was the first extensive Centre study that included the use of satellite imagery, ocean modeling, and at-sea experimentation. At the start, a total of ten one-dimensional mixed layer models were reviewed [SR-47] to identify and assess the relative importance of mechanisms considered. Numerical models were then implemented on the Centre's database of 30,000 XBT's in part developed from Italian Navy data in the northern Tyrrhenian Sea, and an experiment, MILEX 80 was designed for this area to collect adequate data for tuning models to the Mediterranean environment [CP-28(7)]. A 'cold patch' of water fanning out from the Strait of Bonifacio into the Tyrrhenian Sea was observed from satellite infrared (IR) images of the area obtained from the University of Dundee and it was thought that horizontal variability in the mixed layer depth (MLD) associated with wind through the strait would be found. This data then could be used to evaluate the one-dimensional models. Six thermistor chains and ten currentmeters were installed in the area. It was found that the satellite-observed 'cold patch' was caused by wind-stress curl giving rise to upwelling referred to as Ekman pumping. This upwelling and horizontal advection dominated the vertical mixing in determining the depth of the mixed layer. While much was learned from this experiment (e.g. the requirement to know the wind field over a large area including the measurement site and the need for an ocean circulation model to account for horizontal advection) the area proved too complex for testing one dimensional models [CP-33(4), SR-75].

A second experiment, MILEX 82, was performed in the Balearic basin, west of Sardinia. Satellite IR imagery showed no strong surface temperature gradient in this region and a low spatial variability in the wind-stress fields was expected; these factors and others made it much more suitable for the testing of one-dimensional mixed layer models. The results of this experiment were reported [SM-213] but model evaluation was not accomplished. The MILEX 82 experiment had a duration of little more than a month (originally planned for three months) but was of sufficient quality to permit interpretation of the effects of inertial oscillations on the mixed layer and thermocline and wind speed changes. Super-inertial (twice the inertial frequency) oscillations were also observed in the data. These higher-frequency components are important in extracting energy from the mixed layer flow and therefore reducing the energy available for

mixing.

Water mass studies

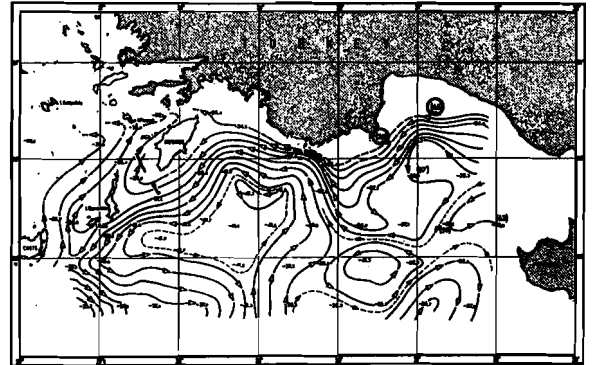
A study in water mass production and distribution in the Mediterranean was initiated in 1977. A cruise in February/March 1974 had the aim of delineating the formation zones of the Levantine Intermediate Water (LIW) and assessing its influence on the general hydrography of the area [SM-92]. Two regions of formation were observed: northeast of Rhodes and the Bay of Antalya. The movement of the core coincided with surface circulation in the area and the LIW flow through the Strait of Sicily was established. In addition, a frontal zone between the Turkish coast and the interior of the Levantine Basin, and the clear connection between surface dynamics and the topography of the northern part of the basin were established. The LIW was traced through the Strait of Sicily fanning out toward the Tyrrhenian Sea with one branch turning toward the Sardinian Channel [SM-65].

Further studies were conducted in the southern Tyrrhenian Sea in summer 1984 to provide detailed observations of the water structure and variability [SM-198]. The Levantine Intermediate Water circulation in the vicinity of the Sardinia-Sicily opening was of particular interest. This very important water mass controls the T-S structure and hence the density structure in the 100-700 m depth range. This was a follow-on to the work of [CP-21(6)] to observe the transition within the layer from the rather active cyclonic circulation around the perimeter of the Tyrrhenian to the very inactive centre region.

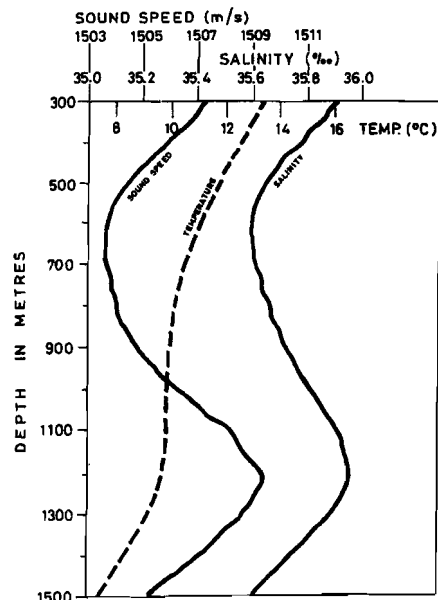
An interpretation of these data together with the hydrographic observations [*12] allowed several new insights on the circulation and variability of the Tyrrhenian and its role within the Western Mediterranean. It was known, for example, how the Tyrrhenian acts as an important mixing basin by modifying incoming water masses: the Western Mediterranean Deep Water that enters through the Sardinia Channel, the Levantine Intermediate Water that enters from the Strait of Sicily, and the North Atlantic Water that flows in from the North African Coast.

A study of the shallow sound channel in the eastern North Atlantic resulting from the high-salinity outflow from the Mediterranean near the depth (~1200 m) of the Atlantic Sofar Channel was reported in 1977 [SM-102]. This Mediterranean core water is made up of the Levantine Intermediate Water and the less saline and cooler western Mediterranean deep water [SM-195].

This feature is very important to sound propagation in that area and, while previously recognized, had received little detailed attention. The Centre analysis of a large database for this area showed a lack of season variability and area influence to 22°W and from the Canary Islands to Ireland.



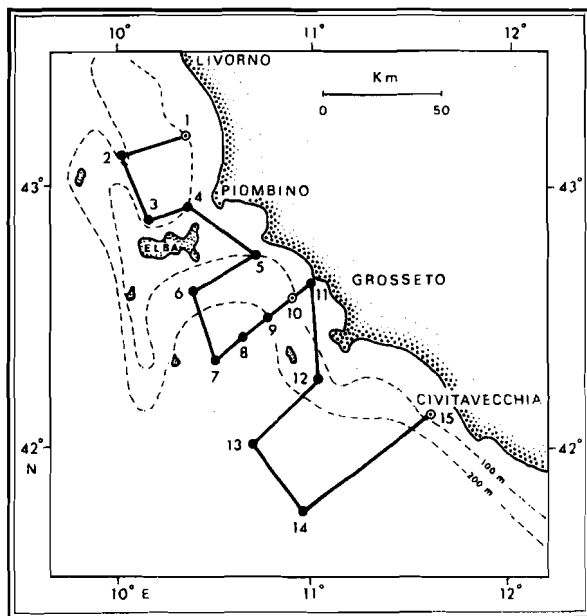
Levantine intermediate water. 1974 observations from the eastern Mediterranean have now revealed that the Levantine intermediate water is formed in an area northeast of Rhodes and in the Bay of Antalya. The chart shows the 500 dbar topography and the deduced current circulation in these and adjacent regions.



Typical sound speed, temperature, and salinity profiles for the eastern North Atlantic 300 n.mi from Gibraltar.

Coastal water oceanography

An investigation into the physical processes that contribute to the spatial and temporal coherence of coastal currents as they affect temperature, salinity and sound speed variability and to the generation of fronts was undertaken. This study included measurement and analysis of currents near Elba and Formiche di Grosseto and at three coastal stations between La Spezia and Civitavecchia [SM-116, SM-117, SM-119] and the development of a numerical model to predict the location of tidally-generated fronts in shallow water [SM-125]. The Formiche data showed current flow to the northwest with fluctuations correlated with atmospheric depressions, indicating a need to include coastal response and atmospheric driving into the model. Results showed that the current near Civitavecchia was produced by local wind forcing, while those in the coastal water off La Spezia were influenced by the large scale circulation of the Ligurian Sea; furthermore the effective bottom friction near La Spezia was an order of magnitude less than predicted. The model was used successfully in the southwestern approaches to the English Channel to describe the location of a thermal front that had been observed in summer months.



Coastal survey off Italy. 100 m and 200 m isobaths as well as hydrographic stations are indicated.

Military oceanographic research

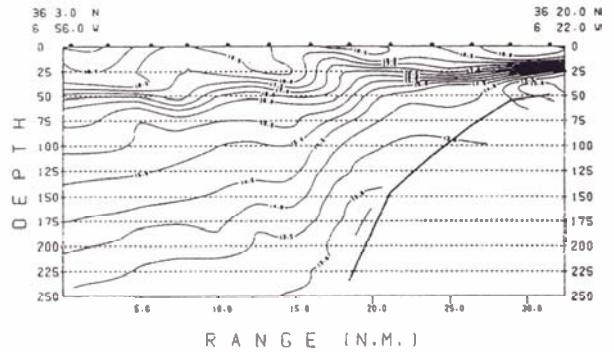
Military oceanography was maintained as a specific task through the early 80s to provide ad-hoc advice and databases to NATO commands and to other projects in SACLANTCEN. Initially, a computer-based volume-scattering strength database consisting of 130 stations in the Mediterranean and the eastern North Atlantic for frequencies between 1.0 and 32 kHz was established. This database provided scattering strength vs depth profiles as well as integrated scattering strength profiles [SM-60, SM-95]. While never officially documented with a user's guide, the database remained available to the Centre on the UNIVAC 1106 and 11/60, but was not transferred to the VAX system during the changeover in 1986.

A major effort over many years was applied to the development of an oceanographic database for the Mediterranean and North Atlantic, initially containing BT, XBT and Nansen cast data, and later conductivity-temperature-depth (CTD) from direct real-time measurement instrumentation. Data were obtained from the US and assistance provided to the University of Bergen, Turkish Navy Hydrographic Office and DND Canada to establish similar databases. A SACLANTCEN cruise referral system and a bathymetric database were eventually added. Software was developed to display the data on a Mercator chart projection, to compress the data in support of user needs and to plot data as iso-contour transects of range vs depth [SM-150, SM-151, CP-28(5)]. A data management system (DMS 1100) was designed for ease of retrieval by users. This database was used extensively to provide products to the nations, such as the Mediterranean Atlas of the Monthly Mean Profiles, with analyses of T-S and SV provided to the Italian Navy Hydrographic Service, and the depth excess chart of the Mediterranean referenced to the surface and to 30 m [SR-16]. It was used in support of Centre cruises and, in particular, was used in analysis of the southwestern approaches to the English Channel (SWAP) and western approaches to the Strait of Gibraltar in advance of the Centre studies in those areas. It has also been used in an attempt to extrapolate temperature from sea surface to depth in relationship to satellite observed sea surface temperature (SST) [SM-132]. Separately, a bibliographic database eventually containing over 800 entries was developed initially for Mediterranean oceanographic studies and later for areas of specific interest such as SWAP, Strait of Gibraltar and Greenland-Iceland-Norway Sea areas [M-99].

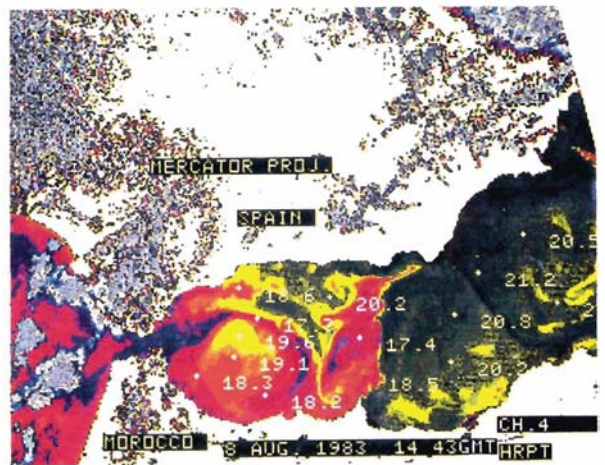
Satellite remote sensing

This effort was initiated in 1975 as part of the military oceanographic research [CP-23(4)], and evolved into a separate Centre project in 1984. Satellite receiving equipment was installed at the Centre and later aboard the research vessel *Maria Paolina G.* to obtain satellite infrared (IR) data to 4 km resolution for research studies; a subscription for computer compatible satellite data tapes was also made to the University of Dundee to provide data to 1 km resolution. The on-line system was initially used in conjunction with the TIROS-N satellite which provided coverage of the eastern North Atlantic and Mediterranean [CP-28(6)]. Software routines were developed to obtain absolute surface temperature on a given channel, to obtain more reliable and accurate SST estimates through broken clouds using successive satellite passes and by combining three IR channels, and to plot the results onto a Mercator chart projection. The STARS image processing system was developed at the Centre as an evolution of these efforts [SR-74], periodically improved, and copies of the routines were provided to several other institutions in the nations. Ground-truth instrumentation was installed on the research vessels *Maria Paolina G.* and later *Alliance* and studies conducted in areas of Centre interest in conjunction with other projects, including the Gulf of Cadiz, Maltese Front, Strait of Bonifacio and Alboran Sea [SM-132, SM-133, SM-154]. An early application was the use of infrared imaging to delineate areas of interest for the mixed layer studies in the Mediterranean and western approaches to the Strait of Gibraltar. Work in the Alboran Sea in cooperation with other oceanographic experiments was summarized in an atlas of colored images obtained during specific periods when sub-surface measurements were obtained [SR-89]. Also a final Mediterranean Sea report on the surface variability in the Aegean Sea observed through the NOAA-7 satellite represents an independent use of satellite remote sensing for analysis of oceanic processes [SR-103].

From 1985 and continuing through the decade, the satellite tasks were focused on the GIN Sea area and formed an integral part of that project. Visual and IR data from the advanced very high resolution radiometers (AVHRR) of the US NOAA polar orbiting satellite were acquired on tape as before and analysed to 1 km resolution; in conjunction with a radiation transfer model the features, variability, and error characteristics of the temperature field were then studied [SM-137] and used in planning GIN Sea cruises. A directory of ground control points [SR-93] with 638



Possible form of data retrieval from data base.



The complex flow of surface waters through the Strait of Gibraltar is clearly visualized in this map of apparent sea-surface temperature as measured on board the satellite by detecting the emitted infrared radiation at a wavelength of about 11 μ m. The spot values are in Celsius degrees.

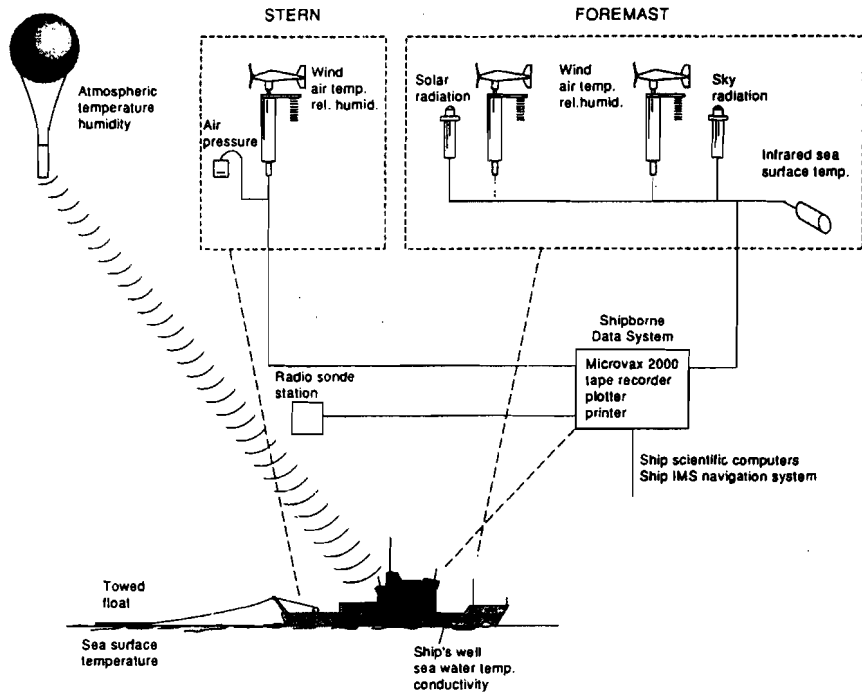
entries was established for use in accurately mapping satellite images to standard chart projections. Recent advances in satellite altimeter measurements prompted the Centre to study the feasibility of in situ validation of satellite altimeter measurements of sea-surface currents in the GIN area [SR-128]. A comprehensive suite of instrumentation was installed on the *Alliance* to obtain ground truth for satellite data evaluation and its flexibility and utility demonstrated during the November 1988 GIN Sea cruise and again in the May 1989 cruise at which time measurements of air-sea heat and momentum exchanges were also obtained in conjunction with UK Meteorological Research over-flights [APR-89,p. 12]. During the latter part of the 80s the remote sensing team interacted with other organizations to discuss satellite measurement problems, to evaluate the along tract scanning radiometer (ATSR) to be launched with ERS-1, to study the altimetry along a repeated arc of GEOSAT between the Mediterranean and Iceland (COMPASS project), to participate in data analysis from the MOSA-1 satellite launched in 1989, and to study the surface variability in the Strait of Sicily in collaboration with the Italian institute ENEA; this latter collaboration was orally presented at the Western Mediterranean Circulation Symposium, March 1988, in Bay St. Louis, Miss.

SWAP regional studies

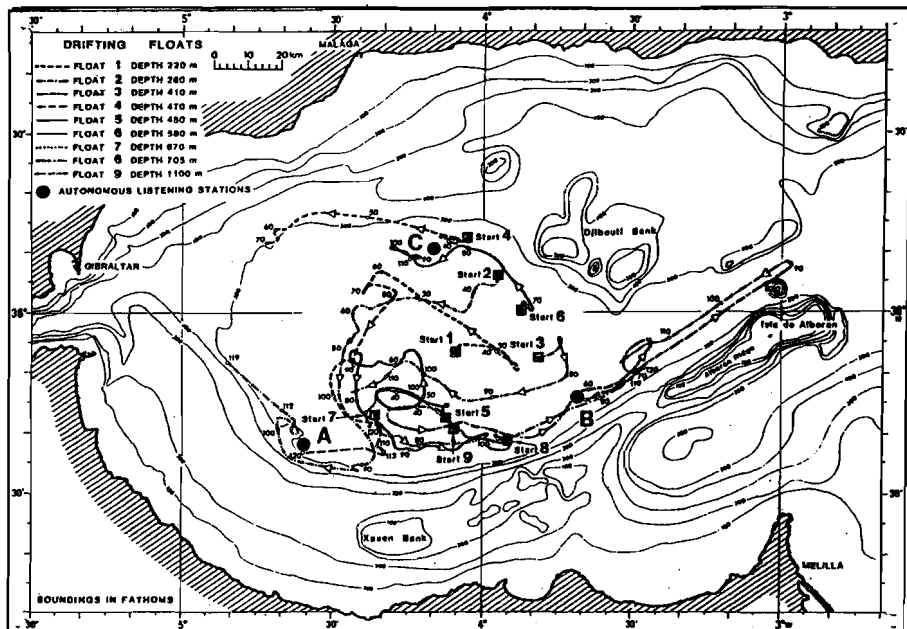
Studies were conducted in the southwestern approaches to the English Channel (SWAP) as participants in the joint France/UK/SACLANTCEN 'Tourbillon 79' experiment of large scale eddies extending to the depth of the Mediterranean tongue of high temperature-high salinity water at ~ 100 m depth [*13, CP-26(5)]. Two surface and ten deep-drifting (Lagrangian) floats deployed by France and tracked over a fifty-day period, revealed an eddy motion in the upper 900 m rotating at 15 cm/s and moving WNW at 2 cm/s with a speed of rotation decreasing to 5 cm/s at 1600 m. The greatest variation of the horizontal sound speed occurs at 1000 m and range-dependent propagation models showed that this would produce a 'blurring' of the convergence zones. An analytical inertial-stratified model was developed and an objective analysis technique was implemented to map the velocity and density field of the eddy.

Alboran Sea

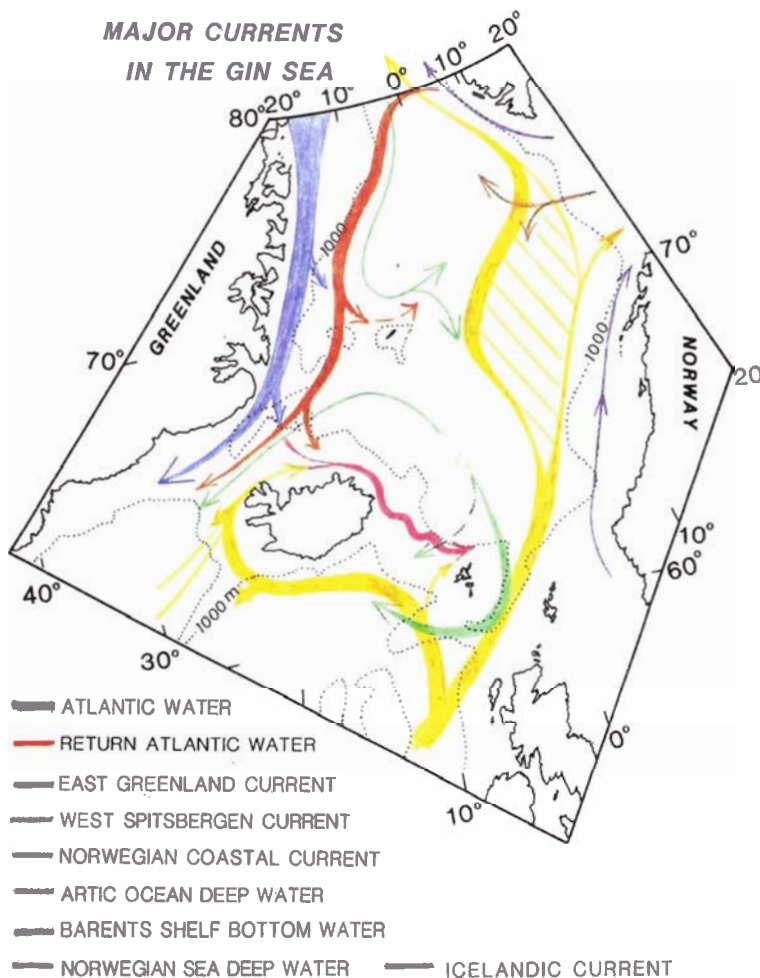
The study of circulation in the Alboran Sea spanned the period 1980-83 and consisted of three major cruises. Building on experience with the French in the SWAP studies, the Centre developed its own free-floating Lagrangian buoy and tracking system for measuring currents at various depths over long periods of time (see OED) [*14, CP-28(8)]. The study also benefitted greatly from previous work in the area [SM-195 Bibliography], from the Centre's recently installed satellite receiving system on *Maria Paolina G.* [SR-74], and from numerical modeling support by the US Naval Ocean Research and Development Activity (NORDA) both for planning and analysis of the experiments. Results [SR-81, SM-195, SM-196, CP-34(2)] showed an anticyclonic surface layer circulation (to 150 m depth) which was subsequently described using an analytic quasi-geostrophic model of mesoscale eddies; this model depends on the assumption of clockwise (anticyclonic) vorticity induced at the entrance of the surface jet at the Strait of Gibraltar. A deep cyclonic circulation of the Mediterranean water at about 2 cm/s was observed from 220 m to the bottom and analyzed with numerical models to result, in part, by topographic forcing. A westward-flowing jet-like current of 12-18 cm/s accelerated to 70-75 cm/s at the Gibraltar outflow and Lagrangian floats originally placed at greater depths crossed the Gibraltar sill indicating strong upwelling of Mediterranean waters at that point. Isotherms sloped steeply with the Moroccan continental rise due to upwelling possibly related to the changing topography. Large-amplitude internal waves were observed west of the Strait of Gibraltar, but no excitation mechanism related to the sill was established. A vertical model decomposition scheme was used to obtain physical oceanographic parameters vs depth and the final reports [SM-195, SM-196] show iso-contours of these for many different transects of the area; these data could be used for conversion to sound velocity profile fields for input to acoustic propagation models.



Instrumentation on Alliance for satellite data validation.



Tracks of swallow floats in Alboran Sea.



The GIN Sea is a semi-enclosed basin of the Arctic Ocean bounded by Greenland and Norway to the west and east, by continental shelf ridges to the south, and by the Fram Strait to the north. Exchange with the North Atlantic is through the Iceland–Scotland Gap and the Denmark Strait. Relatively warm and saline surface water enters the area from the south primarily through the Faeroe–Shetland Channel. It is gradually converted to cold, dense water, which fills the deep basin and eventually spills over the ridges. Polar water enters the GIN Sea on the Greenland side of the Fram Strait. Along the Iceland–Faeroe Ridge, the boundary between the Atlantic and GIN Sea surface waters takes the form of a permanent but highly variable front.

GIN Sea

In 1984, the Centre initiated the Greenland–Iceland–Norwegian Sea (GIN Sea) program to complement the MILOC ‘Resolute Support’ experiment in that area (see MILOC) and to arrive at an understanding of the large- and meso-scale physical oceanographic processes in the area through measurement and numerical modeling. The final objective is the prediction of sound speed fields to support propagation prediction. A major change in ocean scientist personnel occurred almost simultaneously with the initiation of the program, and specifications for data processing software and field trials were written. An intensive review of over 250 reports in the current literature related to this area was conducted [SR-124] and provided the basis for designing the measurement and modeling programs. This built on a previous review of all

work before 1970 [SM-4] in support of MILOCSURV NORLANT.

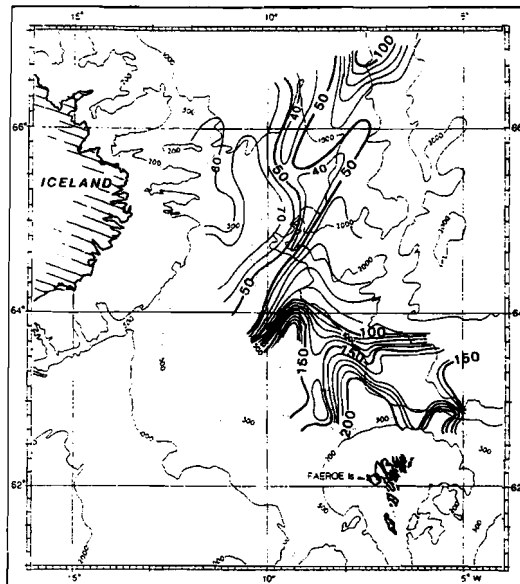
The field program consisted of two major studies resulting in six sea trials; the Atlantic Inflow Experiment (AIE) through the Faeroes–Shetland Channel, and the Icelandic Current Experiment (ICE) from the north to the southeast of Iceland. Inverse, mixed layer, barotropic and barocline models were developed directly and through adaptation of existing models to the GIN Sea area. Finally, objective analysis techniques were developed in order to assimilate observational data distributed irregularly in time and space with different error characteristics into numerical models. The GIN Sea program is by far the most comprehensive and intensive Centre oceanographic study made to date with six scientists, including one for satellite oceanography assigned to the project for the past six

years, 1984–1990. It is quite complete in its overall plan and while reporting of all the work completed to date is still in progress, a few comments of some of its achievements are possible. The results of the first Atlantic Inflow Experiment (AIE) of June 1986 using the Dutch hydrographic ship *Tydeman* was analysed [SM-225] in terms of observed mixed layer depth (MDL) and the vertical structure of sound velocity and its variability relative to governing oceanographic parameters. Data reports for the hydrography (Parts I and III) [in process] and separately for the circulation (Part II) [SM-231] have been prepared. In addition to the Centre personnel, scientists from Italy, The Netherlands, West Germany and United Kingdom directly participated in this first cruise and provided equipment for data acquisition and, later, data analysis. The mixed layer depth was estimated using four different criteria based on temperature change, density change, Brunt-Väisälä frequency and sound velocity, and difference in results was slight. The MLD ranged from 1–76 m over the experiment area, where winds ranged from 2–8.7 m/s, and was shallower and more variable than expected from a wind-driven formulation. It was considered that the difference in MLD results from expectations was the effect of wind stress curl resulting in upwelling and downwelling areas (Ekman pumping) and/or the vertical motions associated with mesoscale quasi-geostrophic features in the circulation of the Norwegian current.

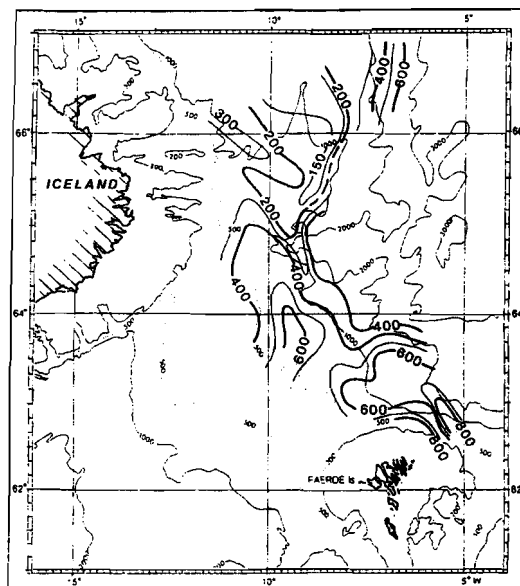
Early in the GIN Sea program the GIN Sea database and management systems were specified. Software to process CTD (ocean profiling system) and currentmeter data (currentmeter data processing system, CURMET) were developed and existing databases (GDEM, *15 and Levitus, *16) were obtained. An objective analysis method based on software from NORDA was developed [M-106] and applied to the AIE data of 1986 [SM-212]; basically the method takes randomly-spaced data fields (in the first application, temperature data) and interpolates them to a gridded system for use in models. Several data interpolation schemes were also evaluated for use in objective analysis procedures and applied to the initial AIE database [SM-217].

Several ocean 'prediction' models were developed. One basic model is referred to as an inverse model; it is basically a procedure for deriving the characteristics of large scale climatic geostrophic currents from hydrographic data. Resulting three-dimensional field distributions are then used to initialize and update ocean circulation models [SR-155]. Results from the AIE were compared with those derived from GDEM using this method.

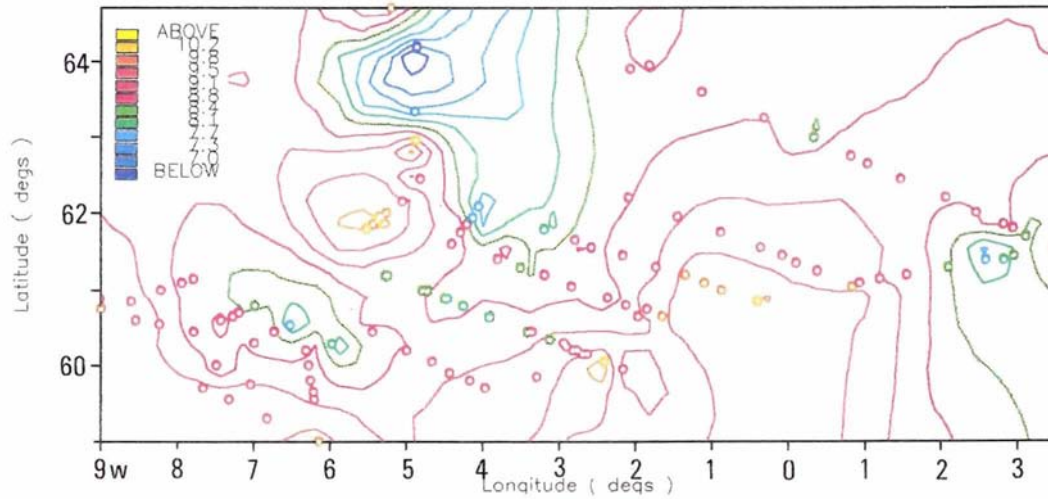
GIN 88 - Mixed Layer Depth



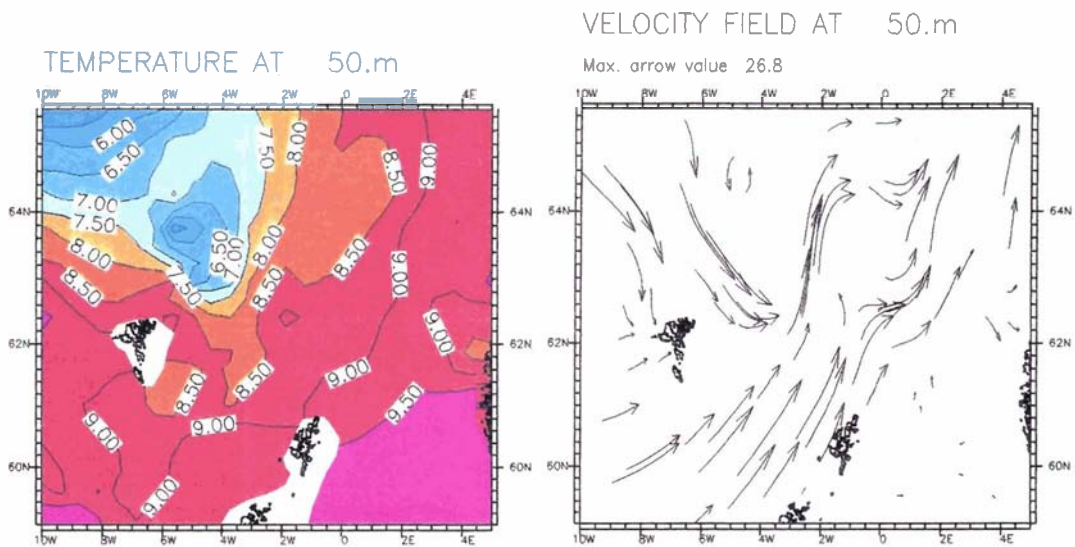
GIN 88 - SV Minimum



Depth of the surface mixed layer and depth of the sound velocity minimum in meters, determined from hydrographic measurements during November 1988. These quantities play a significant role in acoustic propagation in the area.



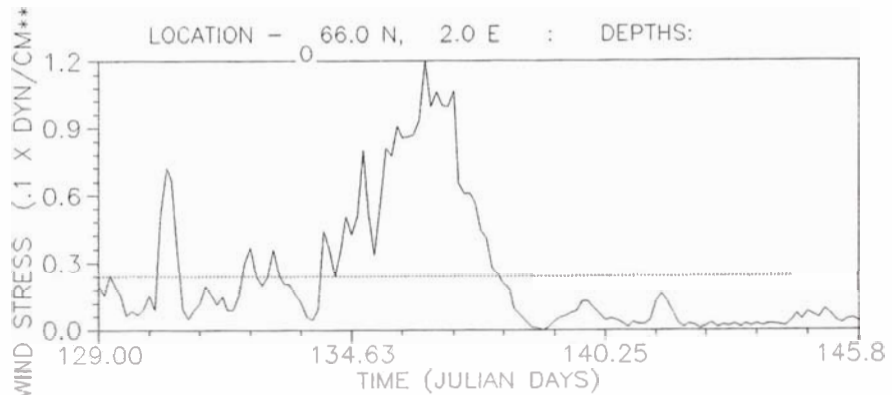
Objective analysis of CTD cruise data for June 1986 in the southeast Norwegian Sea, at the 10 m depth level. The color scales for the CTD measurements (represented by the dots) and the isotherms of the interpolated temperature field are identical. The analysis is based on the optimum interpolation method developed in meteorology (Bennett and May 1987), using spatial correlation functions derived from observations, and a least-squares procedure for minimizing the standard deviation.



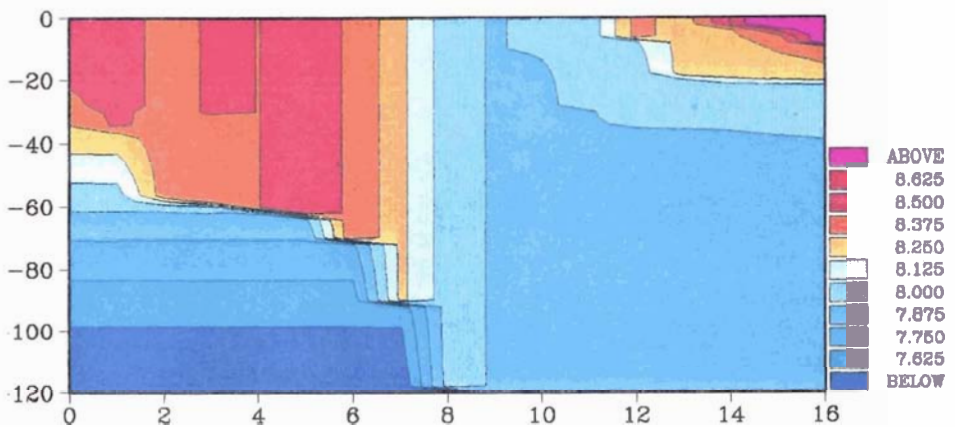
The oceanographic inverse model generates velocity fields driven by an observed density (i.e. pressure) gradient. The solution from the observed density field of the June 1986 cruise in the southeast Norwegian Sea, at the 50 m depth level is shown. The eddy visible in the upper left quadrant is an intrusion of Arctic water dividing the Iceland–Faeroe Front (E–W) and the Arctic Front (N–S). The model has reproduced well the currents moving along these fronts: the eastward moving Icelandic Current and the northward moving North Atlantic Current.

A surface mixed layer model from NORDA was obtained and coupled to the acoustic SNAP mode (see Modeling Section) in 1985 in order to assess the effect of environmental variability and the problems associated with developing such a coupled system. During the course of the program several other mixed layer models were investigated; these include the profile model which predicts evolution of the mixed layer in time and depth, and the bulk models which assume uniform distribution throughout the mixed layer of momentum and heat added at the surface. Ultimately, these models were evaluated by studying the impact of this mixed layer on acoustic variability by using the various models to predict sound-speed profiles along a path and coupling these data to a normal-mode program [SM-227]. Results showed that the gradient of the mixed layer is substantially more im-

portant than overall mixed layer temperature and that different mixed layer models predict large differences in mixed layer depth; mixed layer depth determines the lower frequency limit of importance of the resulting surface channel. A baroclinic model with a barotropic submodel was developed and is currently being improved with the adaptation and modification of a three-dimensional model from UCLA. A time-dependent barotropic model for the GIN Sea was tested and although the general sense of circulation followed the wind-stress curl, the scales of gyros and eddies and the magnitude of water transports were found to be overwhelmingly dependent on the depth and horizontal scales of bathymetry.



TIME EVOLUTION OF MIXED LAYER AT (66.0 N 2.0 E) MAY 1984



Mixed layer modeling of the turbulent surface layers of the ocean at the site of weather ship 'Mike' (Station M) in the Norwegian Sea. Solutions are from the Niller (1975) bulk model. The response of the temperature field is shown for the storm commencing May 9, 1964. Periods of light winds correspond to warming events (days 1-7 and 11-16), and periods of strong winds to strong mixing and cooling (days 7-11). Even during the heating periods, mixing diffuses the heat downward, as evidenced by the downward sloping isotherms at the bottom of the mixed layer.

5

Systems Research

There are two main thrusts in this area of the Centre's program. The first is the development and demonstration of systems concepts as such; the second is the development and testing of temporal and spatial signal processing algorithms for the detection, classification and tracking of submarines. Systems concept development and demonstration projects are typically long term, starting with a concept, purchasing system components, constructing system platforms, conducting sea trials in a variety of environmental conditions and concurrently and finally reporting results; embedded in this process are a number of studies relating to the individual components of the sonar equation, such as target characteristics, reverberation, noise, propagation, etc. The processing tasks are of much shorter duration, from perhaps three months' to three years' duration. They too must investigate the effect of target characteristics and environment on their algorithms.

Systems concept development and demonstration

The major development of the first 15 years in this area was the construction of the MEDUSA arrays to study reliable acoustic path (RAP) system concepts. This project spanned over 10 years from its conception in 1964, through 1976 when the final reports were written on the study of design parameters and operational aspects of the system. Ross [M-93] reports on this project in its entirety.

Subsequently, three major system studies have been undertaken:

- Bistatic towed-arrays (1975–82).
- Activated towed-array (1980–).
- Self signalling ASW sensors (1979–90).

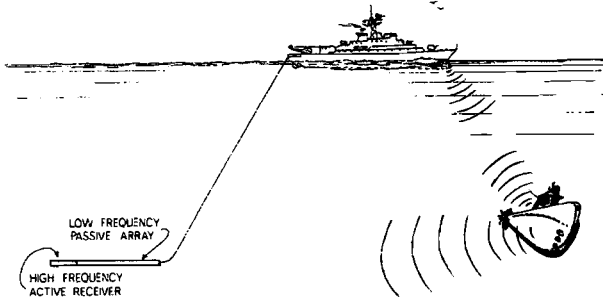
A fourth study on shallow water systems was essentially a study of basic line array performance: vertical, horizontal and towed arrays in coastal waters.

Bistatic system studies

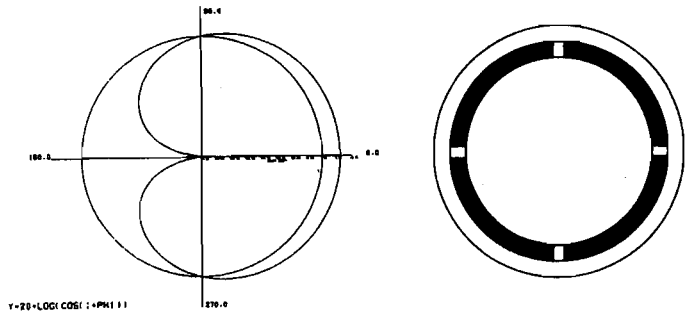
SACLANTCEN first considered bistatic system configurations in 1975 as a multi-static hybrid concept where a single source was employed at a given depth, together with several receivers at different locations and different depths. While this project started as a tactical study it quickly went to sea to test assumptions and develop new ideas. Studies in 1976 indicated a bistatic arrangement could achieve 50% greater detection range than a monostatic system alone, based on specific assumptions of bistatic target strength and reverberation. These assumptions were tested and proved at sea using the nuclear submarine USS *Skate* as a target, the MPG with a deep horizontal array and the Italian minesweeper *Alloro* to drop deep charges to be used as broadband sources to achieve different bistatic angles and submarine aspects. The idea of using deep explosives as sources quickly gave way to studies using the existing hull-mounted sonars, specifically the SQS-26/53, with a towed array on a separate platform but in the sound channel [M-89]. A subsequent experiment near Corsica [SM-140] showed that continuous coverage beyond the first convergence zone (CZ) was achievable with this geometry. Tests with the USS *Sim* as the SQS-26 source ship, the French submarine *Daphné* as the target and the MPG as a receiver with Medusa 2000 system lowered below the sound channel axis showed that good bistatic results were achievable with bistatic angles of up to 60°. Later tests in the Atlantic using an SQS-53 ship and the BITOW array (to be discussed shortly) in a similar arrangement showed that for a deep target a bistatic arrangement provided almost continuous coverage to the second CZ in the Mediterranean Sea, but that no improvement over the monostatic CZ system was achieved when the target was shallow [SR-76].

In 1978 the Centre initiated the development of a short towed array to support the bistatic system study. This array was matched to the SQS-26 frequency of 3.5 kHz and ultimately consisted of 24 hydrophones over a 5 m aperture, each with a vertical cardioid pattern and directivity index of 4.8 dB. The cardioid hydrophones were intended to provide a left–right discrimination for the towed array and the patterns themselves were oriented using a rotation sensor at the front end of the array [CP-23(10), CP-24(Pt 1:16), CP-29(Pt 1:7)]. The array was constructed, tested, and successfully used in at-sea experiments. Compensation for array rotation was reliably achieved. However, difficulty in quality control in the mounting of the hydrophone elements reduced the left-right discrimination to only

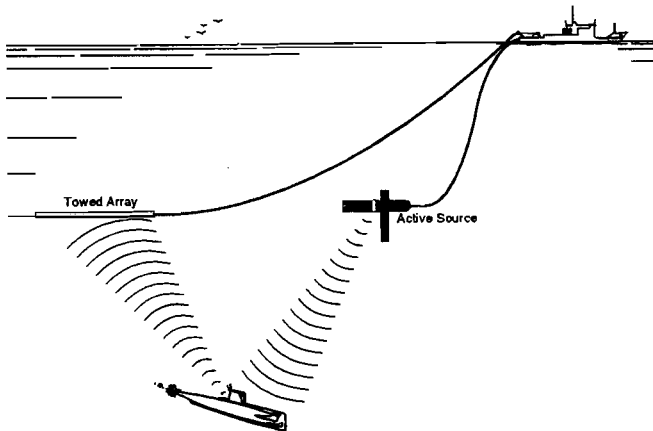
SACLANTCEN M-107



Single-ship bistatic configuration with towed-array adjunct to hull-mounted active sonar.



Bitow element design and resulting pattern.



Activated towed array system concepts. In monostatic mode the source and receiver are collocated or at least deployed from the same vessel. In bistatic mode the source and receiver are separated and can be deployed in a variety of configurations.

12 dB from an expected 25 dB, but the element gain itself was achieved. The hydrophone design, a hollow ceramic cylinder segmented in quarters, was sensitive to flow noise and to resonances, and in addition had low sensitivity. It was felt that below 1.5 kHz flow noise would be dominant and in any case the hydrophones too large to be practical in a towed-array system. G. Connolly, who headed this project for its entire duration, continued his work on cardioid element arrays at NUSC in the US after his return in late 1980. Even with improved element design, flow noise may severely limit cardioid sensor performance below ~ 800 Hz at ship speeds of tactical interest [CP-38(1)].

The findings of this project were quite significant:

- Significant improvements to detection performance of hull-mounted high-frequency sonars could be achieved with the addition of a below layer towed array, used at a different location as bistatic receiver.
- High-frequency towed arrays with cardioid patterns to resolve directional ambiguities are achievable.

The project itself ended in 1981 and comprehensive reports on BITOW [SR-53] and the concept study [SR-76] were written. Both reports have extensive references on the project, and the latter one additionally discusses the supporting signal processing effort to achieve a constant false alarm rate (CFAR) and the software developments necessary to the processing and display of results. This project was particularly impressive in the wide range of skills (operational research, tactical analysis, signal processing, resource development, experimental design and analysis, software developments etc.) and international support (US submarine and surface ships, French submarine, Italian support vessel) that were brought to bear on the problem in a very short time. While this program owed its genesis to the evolution of ideas by the NATO nations, it gave back to them confirmed results of the feasibility and utility of bistatic systems within the context of deep towed arrays and high-frequency hull-mounted sonars.

Activated towed arrays

S. Lemon took the lessons of history and the more recent work on bistatic sonar and developed some thoughts on the 'ideal sonar' system which is published in the proceedings of a Conference on Advanced ASW Acoustic Systems [CP-29(11)] held in 1980. The fundamental drive for his ideas was that submarines were applying coatings to reduce target strengths in the frequency range above 1 kHz and that quieting programs were reducing their radiated levels. Taking advantage of the experience gained in low frequency passive tactical arrays he proposed a system of multiple towed arrays (to resolve ambiguities) working together with a low frequency (100–700 Hz) high-powered towed active source for long range detection. These thoughts were the basis for the activated towed-array project.

In 1981 Tompkins [CP-30(10)] presented the project plan to the SCNR based on these concepts with the initial plan designed around existing resources, e.g. Prakla-Seismos 64 m array developed for the coastal waters project and loaned sound sources, 350 Hz flextensional transducers from the US. The operating frequency was based on considerations of target strength, reverberation, ambient noise and propagation; for propagation the well-known shallow water optimum frequency band (150–600 Hz) was considered important. The experimental plan focused on filling knowledge gaps on low-frequency target strength, signal coherence, reverberation, noise, propagation and on developing databases of environmental and detection statistics in various waters of NATO interest. The project was conceived as working closely with performance predictions and would rely heavily on national resources, such as hardware and submarine support.

Through 1984 seven sea trials were conducted in the Mediterranean at various seasons and in deep and shallow water. Four experiments employed submarines for target strength measurements and also for detection experiments. Good detection ranges were achieved in both deep and shallow water; but more importantly these results compared well with predictions. While HX90 bender bar sources were used at ~ 350 Hz in the earlier experiments, a dual flextensional source was used at 390 and 740 Hz in the seventh test.

These early trials provided a low-frequency database to address the sonar parameter questions posed at the outset [SR-119]. Early experiments showed that temporal coherence in all environments increased linearly with signal length although with some environment and range-dependent degradation relative to theoret-

ical. Spatial coherence across the array aperture, however, was always high. Frequency spreading due to interaction with the sea surface resulted in signal side lobes that were ~ 30 dB down.

Low-frequency target strength measurements conducted with CW, LFM and explosive sources showed good agreement and have the normal maximum of 15 to 25 dB at beam aspect. The off-beam results were poorest at frequencies below ~ 700 Hz but reasonably frequency-independent at higher frequencies [SM-120]. Cooperation between the Centre and France on target strength numerical models and with the UK and The Netherlands on their model tests provided a reasonable basis for understanding the results.

The most difficult environmental effect to include in the prediction model was, and still is, reverberation. The major reverberation results from rough bottom backscattering at low grazing angles, but also from bathymetric features such as seamounts [SR-112]. Reflections from bathymetric features can dominate even when arriving on side lobes. Surface reverberation is normally seen at short ranges only and volume reverberation was not evident in the early tests.

In 1985 two new phases of the project occurred. First, joint trials were held with the French towed-array vessel and French submarine in the Gulf of Lions to get detection data, both in monostatic and bistatic modes of operation. The second trial that year was in the southwestern approaches to the English Channel [SR-120] using the new vertically towed dipole source at 390 and 740 Hz. Further joint trials within and outside the Mediterranean took place in subsequent years: with the US in the Mediterranean using a double vertical dipole source, at 1100 Hz; with the Federal Republic of Germany in the northern part of the North Sea in autumn 1988, with Norway in the Vestfjord off the coast of Norway in autumn 1989 and the last one with the Federal Republic of Germany in the Mediterranean. All tests to date have exhibited good detection ranges that compare well with predicted results when appropriate environmental input data are provided.

Sea trials planned in early and late 1990 and early 1991 are principally in support of the national developments of Germany, The Netherlands and France.

This project has been highly successful and has spawned national development programs in the several NATO nations already mentioned. In particular, the US has taken the idea of multiple-line towed arrays and has completed and tested an experimental system. The Centre has worked closely with FRG and Netherlands to assist them in their active adjunct developments.

Distributed self-signalling sensor fields

The first Centre studies of distributed sensors were undertaken by the ASW Systems Studies Project in 1978 looking at the detection possibilities of a distributed passive sensor field in the southwestern approaches to the English Channel; a summer student also conducted a study of submarine tracking possibilities in a distributed field. Sheldon [CP-26(8)] briefed the SCNR on a concept for distributed sonar systems using self-signalling sensors in October 1979 and later summarised his ideas [SM-147]. Basically the concept was for a passive barrier (choke point) system using thousands of cheap sensors that could autonomously detect, localize, classify and pass this information to a command post via the acoustic channel; high-frequency acoustic and non-acoustic (magnetics, ELF, thermal, chemical) methods were considered from the beginning.

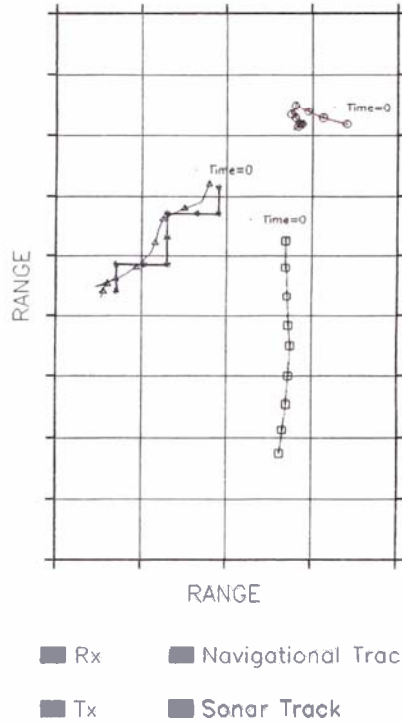
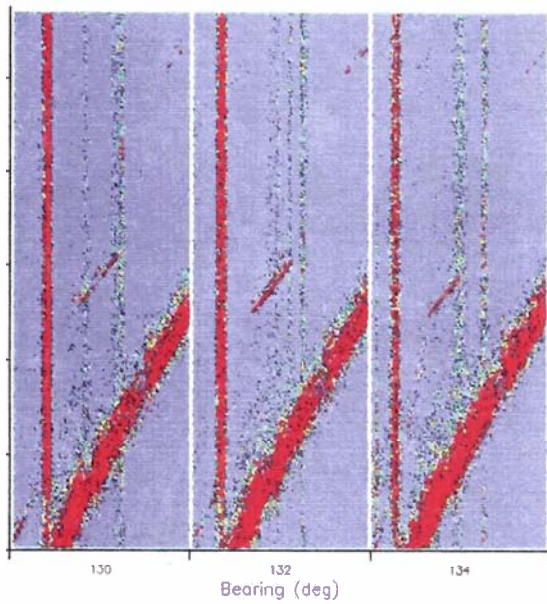
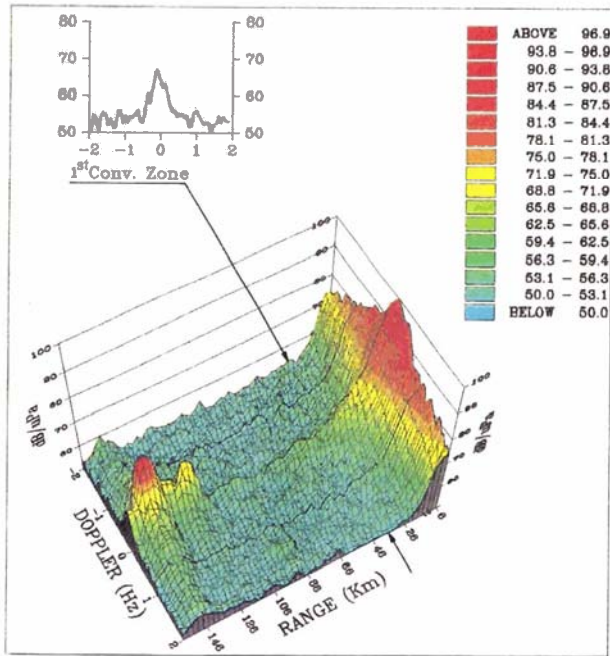
Knudsen [SM-148] developed the concept further and evaluated its detection performance; his design was based on a self-contained battery-operated unit, capable of passively detecting and classifying targets as surface ships or submarines. It would incorporate a magnetometer as an initial detector, a high-frequency, upward-looking echo-sounder for classification, and a low-frequency transmitter for transmitting a coded acoustic signal to receivers more than 60 km away. However, there were too many unresolved questions about the detection algorithms to be implemented before constructing a demonstration system and an experimental phase was planned starting in 1982.

Lloyd and Daintith [SM-159, SM-163] studied sources of high-frequency (30–100 kHz) ambient noise and signal processing techniques in the presence of high ambient levels in the hope of obtaining longer detection ranges (600 m) than permitted by magnetic sensors.

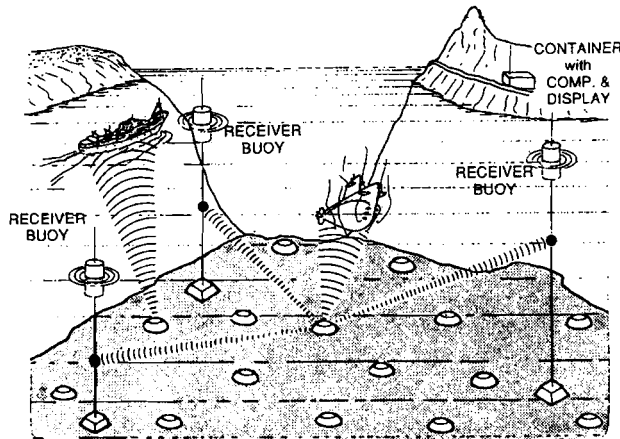
A sensor package containing a magnetometer, an omnidirectional and a directional hydrophone, and an echo sounder for classification was assembled. In 1983–84 two sea trials were undertaken, one with a Greek submarine and another with an Italian submarine. The purpose was to establish detection criteria for magnetics and high-frequency acoustics. These trials gave surprising high-frequency acoustic results which could not be explained properly by flow-noise or other common physical mechanisms.

In 1985 it was felt that Project 22 should have a proper organization. A special group was formed and a Group Leader, A. de Bruijn, selected in September. The first priority was to collect more data on the short-range detection of submarines to establish reliable detection

Spectral time history of received intensities: 8 s, 370 CW transmission; broadside beam; sea-state 2.



Bistatic detection. The bistatic mode of operation allows the receiving vessel to remain covert. This display shows a bistatic detection over a time span of 45 min. The track chart demonstrates the accuracy of detection over a period of 4 h. On the left is a three-beam multi-ping display. The target at mid-range is not to be confused with the strong direct arrival preceding the target echo.



Field of distributed sensor units detecting an approaching submarine; when a sensor unit detects the submarine it emits a simple acoustic signal which is picked up by receiver units.

Cruise	Environment area	Environment season	Target	Type	Achieved ranges (km)
1/90	MED	Win	Narval (Sp)	D+P+B	40
1/89	VEST	Sum	Ustein (NOr)	D	31
2/88	GIN	Win	U26 (Ge)	D+P+B	15
1/86	MED	Sum	Amfitriti (Gk)	D+TS	45
2/85	SWAP	Sum	Oracle (UK)	D	130
1/85	MED	Sum	Ouessant (Fr)	D	40
2/84	MED	Sum	Papkolis (Gk)	D+TS	76
2/84	MED	Sum	Walrus (UK)	D	32
1/83	MED	Sum	L.D. Vinci (It)	D+TS	73
2/82	MED	Sum	-	PROP	-
1/82	MED	Win	Romei (It)	D+TS	>20
2/81	MED	WIN	Flore (Fr)	D+TS+P	>20
1/81	MED	Win	-	PROP	-

algorithms. Therefore a long series of trials was initiated with the assistance of a variety of submarines. The sensor platform was rather large and could only be deployed by the MPG. This was felt as a drawback, since it was also intended to operate in waters other than the Mediterranean. Another platform was designed and constructed in 1987 which could be used from any reasonably sized and equipped ship, so that experiments could be performed in various parts of NW Europe.

Ten sea trials have been performed, seven in the Mediterranean and three in northern waters, with a wide variety of submarine types. Norway, Germany, Denmark, The Netherlands, Greece, Italy and France have contributed to supply submarines. Apart from the *Maria Paolina G.* and the *Alliance*, other support ships used were the *Kronsort* (FRG), *Vernøy* (N), *Falster* (DK).

The scientific results can be divided into two parts:

- Magnetic signatures.
- High-frequency acoustic data.

The use of a tri-axial magnetometer has led to extremely interesting signatures, which can be used to detect, track and even classify submarines under noisy conditions. Much work was devoted to tracking algorithms using Kalman filtering and to least-square algebraic detection algorithms. An experiment was undertaken by the Signal Processing Group to measure the spatial coherence of atmospheric magnetic noise over distances of a few kilometres, and this will be reported in 1990.

Acoustic detection is more problematic. High-frequency (> 10 kHz) radiated noise, contrary to earlier expectation, appears not to be a reliable detection phenomenon. Moreover the ambient noise is generally too high for reliable detection based on sound pressure levels. Much work has been devoted to develop reliable detection algorithms based on transients in the signals of the transiting submarine or methods based on the slope of the signatures (Hunt detector). Work in cooperation with NUSC [SM-201] using bi-spectrum techniques which E. Sullivan developed while at the Centre was ongoing at the end of 1989.

In addition, ORG undertook a study in the operational effectiveness of a small sensor field with a torpedo pod as the main counter attack weapon. Many interesting features were investigated about the optimum detection range of a sensor unit and about the mutual distance of the sensor units.

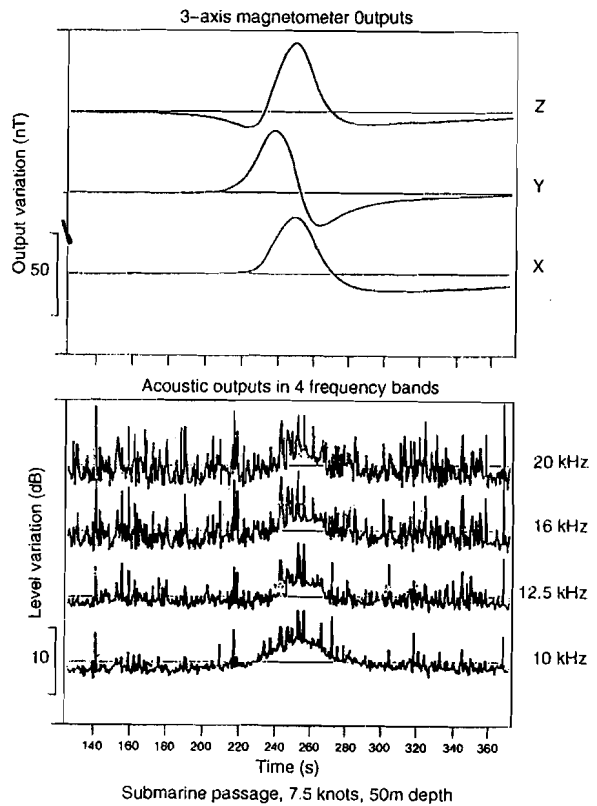
At present, a set of 20 sensor units is being constructed for a system demonstration experiment in 1990. After that experiment the project will be terminated.

Shallow water sonar project

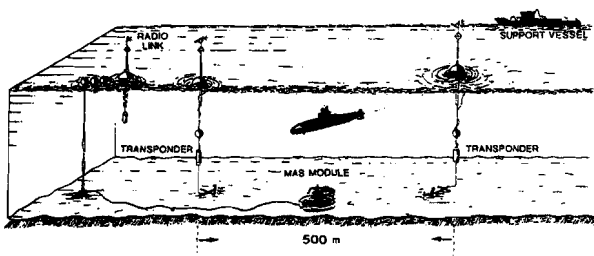
The Centre initiated a shallow water propagation project in 1968 which continues to this day as part of the applied ocean acoustics work and the seafloor acoustics projects. In the middle 70s a shallow or coastal water sonar project was established to determine the limitations of possible system applications to these areas of NATO concern. Earlier work off Elba and the Strait of Sicily showed good horizontal coherence [SM-69] and low angular uncertainties [SM-73] in shallow water. A good understanding of propagation was obtained and shallow water models based on a range-dependent normal mode method (SNAP) and on the parabolic equation (PE) were initiated and are reported under the environmental modeling section of this report.

This prior work led to studies of generic systems in coastal waters. In particular the Centre established a shallow water test site in 1976 at the Islands of Formiche di Grosseto southeast of Elba, in an area of nearly constant water depth of 150 m, to develop and test new techniques in addition to getting a fuller understanding of relevant physics. A fixed test site permitted an exhaustive environmental characterization for use in system studies. The sonar and parameters studies project focused on studying vertical, horizontal and towed-array performance in this area [SM-127, SM-134]. At the start of these studies, data from 53 shallow water propagation measurements were banked on computer files to assist in evaluation. Analysis showed that greater differences in propagation were obtained between frequencies and between seasons than between areas of different bottom types. Also a reverberation model was developed from data obtained on the 'French Ester' program. All this to provide some direction to the system studies. Spatial coherence of vertical arrays, the use of conventional beamforming and mode matching techniques and the effect of target range on relative performance was investigated and fundamental relationships established.

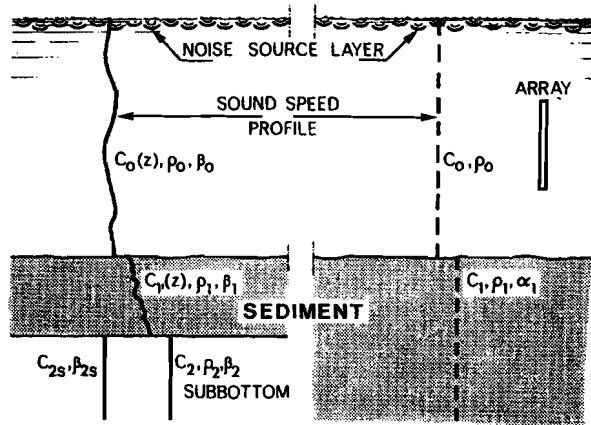
The study with horizontal arrays confirmed that expected gains were achievable but that in off-broadside directions degradation could be expected due to differing vertical arrival angles. A 20-hydrophone (667 Hz)



Magnetic and high frequency acoustic signatures of transient diesel submarines passing over a MAS module in shallow water.



Experimental setup for determining acoustic and magnetic signatures of a transiting submarine with a measuring module on the sea bottom. Data is transferred by means of a cable along the sea bottom and a radio link buoy. Navigation transponders guide the submarine across the module.



Some factors effecting vertical array systems in shallow water.

towed array was received from the US and used to demonstrate that good discrimination against shipping could be achieved. A study of shallow water convoy defence using towed arrays was undertaken.

Noise gain and signal-to-noise gain (array gain) of these arrays were studied [CP-23(6-9)]. The frequency range of surface vs distant shipping influence on vertical arrays was established as a function of sea state, a surface noise model developed to evaluate the wind noise effects, and a maximum likelihood model development initiated to maximize array gain for specific signal and noise fields. Models showed highly variable vertical array gains which could be improved by several dB by matching to the strongest mode.

An investigation into Scholte waves relative to acoustic waves in shallow water indicated that detection using acoustic energy was more reliable, but that these interface waves were important for classification; also energy direction on these waves can be obtained with single geophones rather than using long horizontal arrays as required for acoustic energy.

While no specific shallow water system concept evolved from the generic system studies, they served the Centre well in that they initiated the towed-array acquisition, the ambient-noise project, some environmental modeling tasks and investigation of seafloor studies.

Submarine detection, classification and tracking

Signal processing techniques are studied at the Centre under this project title and they relate to the temporal and spatial characteristics of both passive signals and active echo structure from targets embedded in generalized noise and/or reverberation background. Some of the tasks (e.g. temporal techniques) are of short duration and have general applicability to a wide variety of systems. Others, particularly spatial processing techniques, have a narrower range of application and are often studied in conjunction with or in direct support of a particular system project; to some extent the work under this latter heading is discussed in context with the system project which it directly supported.

Work in the early 70s concentrated on active sonar research. Topics of interest were: multi-ping processing, target echo structure, signal design and acoustic channel impulse response studies in order to derive target classification and tracking information in both deep and shallow water. Target clues were enumerated, multi-clue classification schemes developed and the

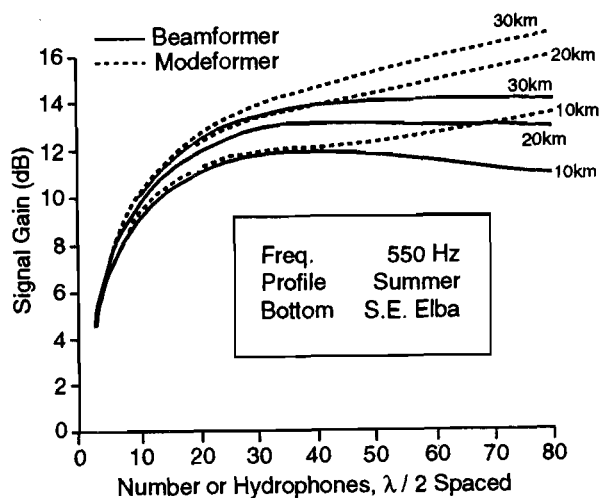
accuracy to which clue parameters had to be known were calculated. Results were reported at a SAC-LANTCEN conference on submarine echo properties [CP-18] and as a Centre publication [SM-87]. Work in these areas continued into the late 70s with detection algorithms tested on submarine echoes from bistatic sea trials.

With respect to signal design, particular effort was continued on exploring space/frequency classification techniques through investigation of signal designs for coherent and incoherent processing. These studies were both theoretical and experimental, culminating in recommendations for specific pulse types, depending on the processing scheme used. It further showed an analogy between temporal and spatial processing schemes that would, in addition, permit more target information to be extracted [SM-155]. This was principally a theoretical task with some experimental data analysis for evaluating results.

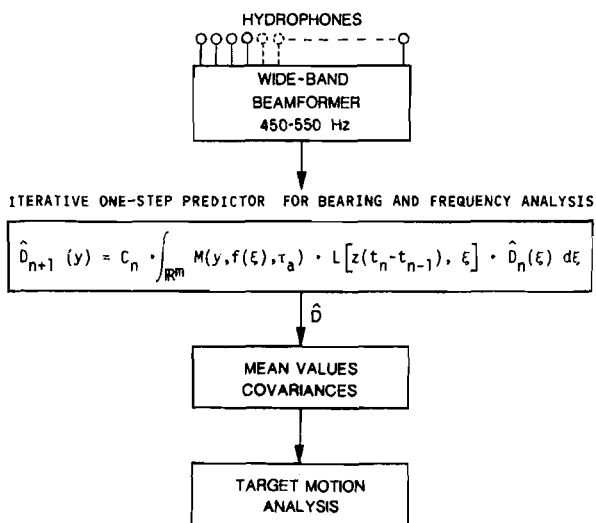
The study of target motion parameters continued using non-linear algorithms. Several of these algorithms were compared [CP-30(9), CP-32(14)] using numerical experiments and later some successfully tested with real data. Principal effort was devoted to identifying algorithms for improved target ranging and tracking but with some hope that they would also be useful for initial detection; however this latter application proved to be unfeasible in light of extent of computational capabilities [CP-32(14)]. These studies aroused Centre interest in other applications of these techniques.

In the late 70s, new tasks relating to spatial processing for passive arrays were initiated. In particular, gain and resolution of both horizontal and vertical linear arrays, as well as adaptive and non-adaptive array-processing techniques were topics of investigation. These studies were initially undertaken in coordination with the shallow water and bistatic projects and later with the activated towed array project [SM-146]. Generalized high-resolution methods were applied to range and depth estimation, attention was given to the use of frequency/wave number analysis to exploit dispersive sound transmission, and extended Kalman filter techniques were investigated for estimating target motion parameters.

Techniques for suppressing towship noise were developed [CP-30(7), SR-129]. This study evolved to include source decomposition and used techniques that included a reference hydrophone, a reference beam and modification of eigenvectors in conjunction with algorithms for conventional and maximum likelihood beamforming [SM-158]. There were significant practical problems in implementing these algorithms partic-

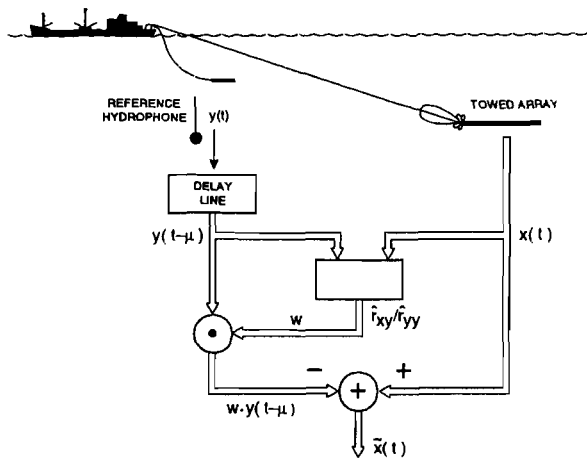


By matching to signal propagation modes rather than using a beamformer, significant improvements in signal gain can be achieved for a shallow water vertical array system.



- \hat{D} = Estimated cpdf
- M = Density function of driving noise
- C = Normalizing constant
- ξ = Average manoeuvre time
- L = Likelihood ratio from t_n to t_{n+1}
- y = Bearing or frequency variables

Study of target motion parameters.



Own-ship noise suppression – basic concept.

ularly when operating in shallow water and innovative modifications were required which incorporated models for ambient and flow noise and for discrete sources. Final experiments in deep water showed some limited success. In particular, with a localized source and minimum multipath effects it is shown that as much as 20 dB suppression could be achieved [SR-129].

An investigation into the use of parametric sonar for underwater communications was initiated as cooperative project with the Technical University of Denmark, Prof. L. Bjørnø, and the US Navy Underwater Systems Center (NUSC) in the US. Denmark conducted model tank studies at the 1/500 scale which provided input to the design of Centre experiment. One-tenth scale tests were scheduled in the Gulf of La Spezia using a parametric source provided by NUSC, New London. It was originally planned to have a full-scale test but this proved beyond the scope of available resources at the time. However, three trials in local water established that the advantage of a parametric source was that it is less subject to fluctuation and time and frequency spreading than a conventional array. A supporting theoretical study showed that this could be accounted for in terms of the modal excitation characteristics of the acoustic channels [SR-45].

Non-acoustic investigations started out as a separate project in 1977 to investigate possible exploitation of current technology for short-range barrier-type systems. Work on ELF/EM detection of the field generated by dissimilar metals on submarines, originally investigated by the Centre in the early 60s, was revisited in light of recent developments to support ELF communications. Magnetic anomalies due to submarine perturbation of the earth's magnetic field were also considered with improvements in magnetic sensor sensitivities. Also Scholte wave excitation was studied under this topic. None of this work reached the experimental stage as a coherent project and by 1980 the topical investigations were subsumed into shallow water seafloor projects and, as appropriate, into the self-signaling distributed sensor project.

Split beam processing techniques were initially investigated to obtain improved bearing estimations [SM-165]. The study ultimately included maximum likelihood and autoregressive processing as well as the SACLANTCEN Wagstaff-Berrou (WB) algorithms (see Sect. 5), the eigenvector modeling and conventional and split beam techniques to achieve high-resolution beamforming. Eventually nine different high-resolution techniques were evaluated, all theoretically and some experimentally at sea [SR-104, SR-110].

A related theoretical study on synthetic aperture techniques to achieve high resolution showed that it could perform better than conventional beamformers at frequencies lower than 1 kHz and at ranges shorter than ~ 10 n.mi [CP-34(6)] for active systems and for any far field source for passive systems. Synthetic aperture studies emerged again in the late 80s from both a theoretical and an experimental perspective. This new study [SM-214, SR-154] was based on a concept of overlapped correlator and is robust in the presence of signal fluctuation for hydrophone signal-noise level greater than 0 dB. Tests with experimental towed-array data were successful in extending a 32-element array under tow to an effective 512-element array thereby yielding a significant improvement in bearing resolution. This work is on-going with an at-sea experiment planned for 1990.

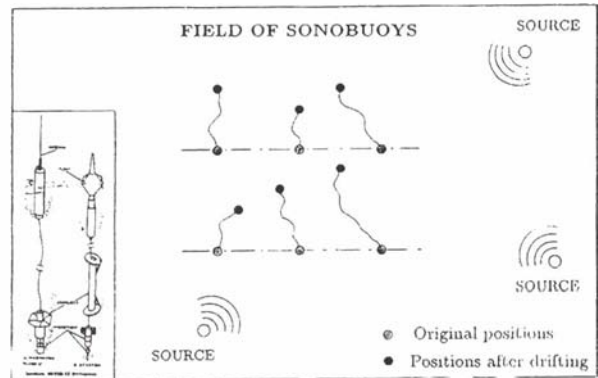
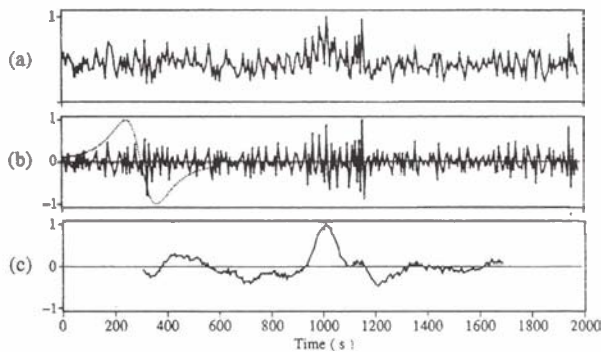
An effort to integrate environmental information into signal processing algorithms was initiated. It demonstrated that given adequate environmental data source range in shallow water could be reasonably well estimated using a vertical array and a normal mode modeling approach. In addition, the sensitivity of the estimate to environmental input error was investigated. Best results were obtained with generalized least-square-type estimators but a large vertical aperture was needed for accurate wave/number estimation [SR-138]. Processing schemes were developed to exploit the non-stationary aspect of high frequency (10–100 kHz) noise signal of a submarine passing over a bottomed receiver. One scheme was tested against real data from the distributed sensor project and shown to be superior to an energy detector or a Hunt detector. A new method for adaptive detection of acoustic transients improved over earlier techniques and will be reported shortly.

A Kalman filter tracker/detector in support of short range magnetic detection of a transiting submarine was developed and tested. It worked well in moderate to high S/N levels using an iteration algorithm to reduce effects of measurement non-linearities. A second phase of this work was a pilot experiment to measure spatial coherence of geomagnetic noise at scales of 1–2 km. While the experiment was conducted in late 1989 the report was written in 1990 [*17].

In support of Project 20, a study of the delay-doppler resolution of large time-bandwidth product linear FM waveforms was undertaken. The main results were the analysis of the replica correlation losses for these pulses and the development of a technique to estimate range and doppler in the presence of multipath propagation [SR-142].

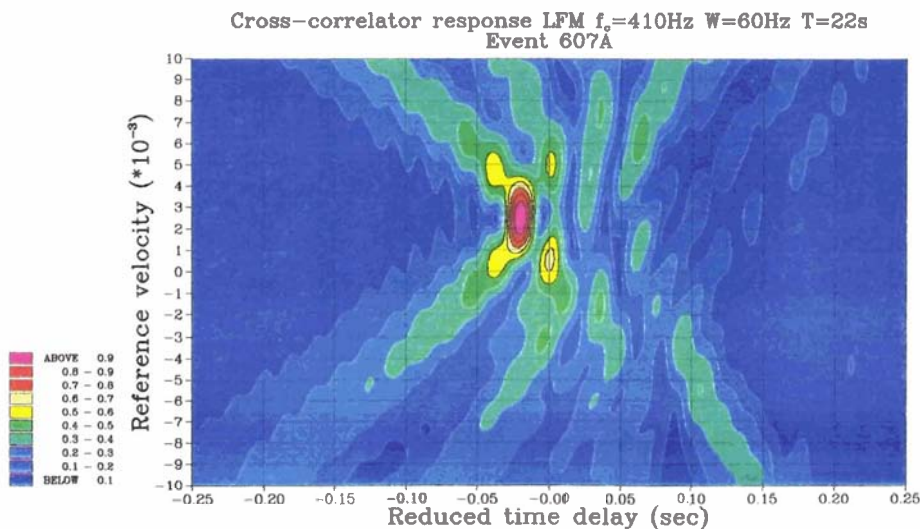
Work was begun in 1988 on a technique to localize

broadband sources using sensors whose positions were not precisely known. The technique is able to find the relative bearing to at least three broadband sources using an array of sensors of unknown location. The study is aimed at localization using sonobuoy fields, but a preliminary test using a towed array was conducted. This test demonstrated that the algorithm could work with sea test data [SR-163]. Two sea tests using sonobuoys have been conducted; the results of these tests will be reported in 1990.



The Hunt-detector showing (a) the input envelope; (b) conversion to signal rate; and (c) the detector output.

A field of passive sonobuoys is dropped in the water. They are drifting from their original positions because of waves, current and wind. Under the condition that at least three broadband sources are present we are able to estimate the sonobuoy locations and the source bearings.



Display of cross-ambiguity diagram of real data. Shows good coherence over pulse duration, no error on radial velocity and four subsidiary peaks of the auto-ambiguity function. Shallow water - R: 40 km LFM TW: 1320.

6

Operations
Research

At a meeting on the 'Formulation of ASW Requirements' in 1970, SACLANT directed the Centre to focus its major operations research efforts on command-sponsored studies. As a result, studies during the ensuing decade were categorized as force effectiveness, tactical studies and exercise research. Work on tactical studies as a category continued until 1983 in support of system concept developments and are discussed in that section of this history. The Centre's effort in exercise studies was generally limited to the planning and analysis phase of fleet exercises and with little or no participation in their execution.

In 1977 SACLANT decided that this latter work was better carried out at their headquarters and subsequently transferred four scientist positions to Norfolk. This significantly reduced the personnel strength in the Operations Research Division from ten to six, resulting in it being reduced to group status in 1979.

Force effectiveness studies

Before 1970 there was no consistent theme to the work of the Operations Research Group. In 1970 with the direction from SACLANT, a series of command-sponsored studies on the employment of NATO ASW forces commenced and continues to this day under the heading of force employment studies. However, since 1979 they have changed somewhat in type, emphasis and frequency. A consistent pattern and theme emerged with the force mix studies typically being paired with NATO exercises, thereby focusing the studies into geographical areas of command interest. The consistent question posed is: given the ASW assets available, the assumed threat in number and types of submarines, the operational task (e.g. defense of re-supply/reinforcement, Re/Re, shipping) – how should ASW units be deployed to optimize results against the threat?

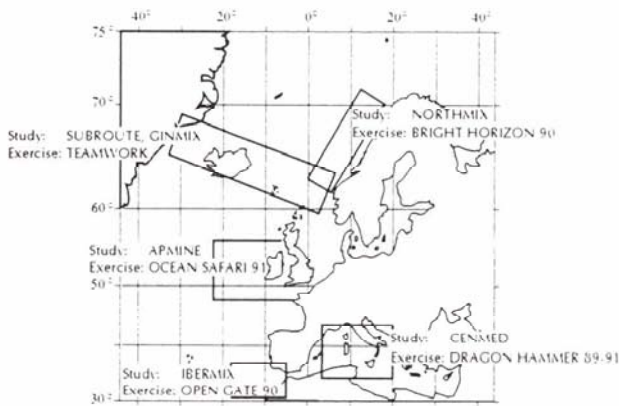
There is often a second part of the study to examine the possible effect on ASW operations of introducing

near future ASW systems such as low-frequency active sonar.

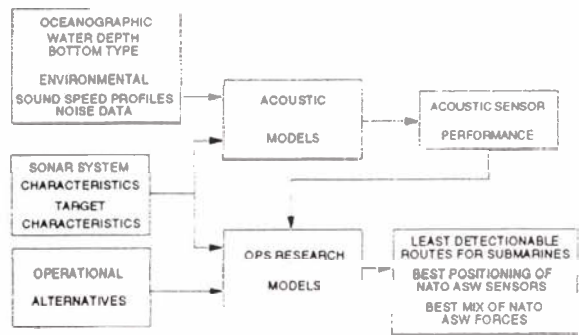
Post-1979 studies contain detailed modeling of the performance of individual sensors, platforms and weapons. This was not done in the earlier studies. Much use is made of the products of other groups in SACLANTCEN, such as propagation loss models, ambient-noise models and recorded measurements of ambient noise. A comprehensive series of ASW search and attack models has been developed within the group for use in these studies.

Because of the evolving threat, changes in available forces and the introduction of new systems, some of the studies have been repeated with change in emphasis and others have expanded from their initial terms of reference. The Anchor study on defense of Re/Re shipping was revisited in 1983; LANTSLOC, focused on the North Atlantic sea lanes for different environmental conditions (seasons) and used convoy and defended lane concepts as a point of departure for the study. Defense of shipping in the English Channel was studied in the late 70s as a barrier concept and evolved into the southwestern approaches (SWAP) study associated with the MILOC SWAP survey. The Gibraltar force mix study [SR-48, SM-149, SM-161] initiated in 1978 followed on from the earlier Defense of Naval Forces study and the CENMED study [SR-106, SR-108, SR-109] for the Italian Navy.

20 studies have been conducted since 1975. They are somewhat self-explanatory and many follow a similar pattern in their execution. The command and communication (C²) study was quite different in that it was Centre sponsored; it evaluated the impact of C² procedures used in 'Ocean Safari 85' [SR-125] on timelines of target prosecution after initial detection. The MEDASMINE study [SR-135, SR-136] developed tactics for the use of CAPTOR mines to assist other ASW forces; it is the first known evaluation of mines in developing ASW tactics.



The Centre conducts operational research studies and analyses exercises throughout the NATO maritime area. Studies contribute tactical improvements which can be tested in exercises, and exercises contribute quantitative inputs (ranges of sensors, probabilities of success, etc.) for use in studies.



A very general outline of the approach used for the studies is shown. Centre acoustic data and models are used to predict sonar performance which is coupled with Centre operational data and models to answer operational questions.

Operations Research studies conducted since 1975

Force employment	Dates	Area	Objective
Defense of Naval Forces	ended '75	Mediterranean	Naval Defense
Force level requirements	ended '75	North Atlantic	Submarine force level requirements
Deception techniques	ended '76	English Channel	Tactical deception methods develop
Defense of shipping	ended '76	English Channel	ASW barrier effectiveness
SWAP	1977-84	SWAP	Optimize ASW forces
Anchor	1978-79	North Atlantic	Force attrition and protection
IBERLANT	1978-79	Iberian Basin	Effects of environment on sonar performance
GIBRALTAR	1978-81	Straits of Gibraltar	Sea control
Environmental routing	1979-81	NE Atlantic	Environmental factors for search and attack
CENMEDI	1980-88	Central Mediterranean	Force mix for RE/RE shipping
SENSORMED	1980-84	Mediterranean	Environmental impact on sensor performance
LANTSLOC	1983-88	NE Atlantic	Naval escort effect
CHOKEMED	1984-88	Mediterranean	Force mix for submarine detection
C ² Study	1984-88	Any	ASW command and control analysis
MEDASMINE	1986-88	western Mediterranean	CAPTOR mines in ASW tactics
NORTHMIX	1986-	eastern Norwegian Sea	Force mix in Norwegian coast
GINMIX	1988-	GIN gaps	Force mix optimization
IBERMIX	1988-	Iberian Basin	Towed arrays in ASW tactics
Subroute	1988-	GIN gaps	Submarine use of environment
APMINE	1989-	UK	Mining in ASW tactics UK waters



Centre analysts participate in NATO exercises. Shown is the ITS Garibaldi, which often acts as an ASW command ship in NATO Southern Region exercises.

Exercise participation

A major change in ORG activities since 1980 has been the Centre's frequent participation in NATO exercises, either at sea in ships, flying in MPA or at a NATO maritime headquarters. This participation has mostly been in connection with the force mix studies listed above, but on other occasions has been requested by NATO commanders for a specific reason, such as examining towed-array operations.

On several occasions the Centre has been asked to suggest an ASW concept for testing by the exercise planners. When these suggestions have been accepted, the Centre assists with the planning, observes the exercise and then assists with the analysis. The most recent occasion was in exercise 'Dragon Hammer 89' when outline plans for the deployment of ASW units in a choke point operation, designed to detect submarines attempting a covert transit of the Strait of Sicily, were accepted. Three ORG members took part in the operation, which lasted for 60 h. The participation in this exercise and previous exercises in the same series is linked to the CENMED study.

Participation in Atlantic exercises, such as 'Ocean Safari' and 'Teamwork', has usually been requested by SACLANT. Four members of ORG and a Programme Officer took part in 'Ocean Safari 85'. This was the largest number ever sent on an exercise. The relation between some of these exercises and force employment studies are shown in the table.

In addition to the studies and exercise participation, ORG has recently initiated operational studies in support of the activated towed array and the distributed sensor projects.

ORG is now well known as specialists in force mix studies. There has been a sustained demand for them which appears likely to continue. Messages and letters of appreciation received from NATO Commands on completion of studies have indicated that they have been of considerable value in refining and improving NATO plans.

Recently, briefings on the MEDASMINE study to several different NATO mining groups and IEG-3 have attracted much interest. The request for the new APMine study (mining in the western approaches to the British Isles) was obviously influenced by these presentations as well as the study reports.

A pilot study on the potential use of expert systems (a subset of artificial intelligence) to detection, tracking, and classification was conducted. Software was acquired and modified and results obtained on simulated active sonar. It was concluded that there was high future potential for this technology but that it had

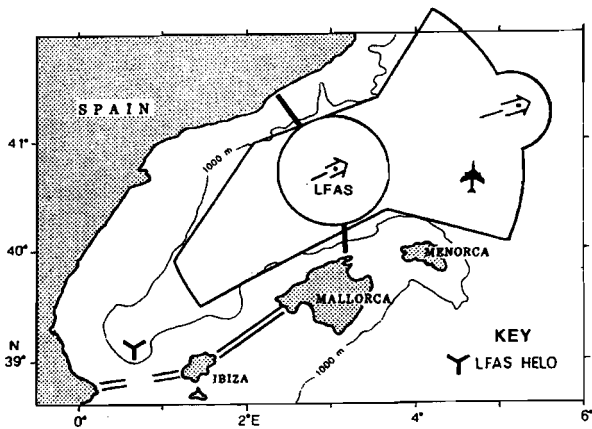
to await much higher speed parallel processors [CP-33(10)]. The concepts were applied to a specific tactical problem leading to fuzzy target evaluation and tracking [SR-123] to demonstrate the utility of this technology to tactical commanders.

Systems Concept Analysis

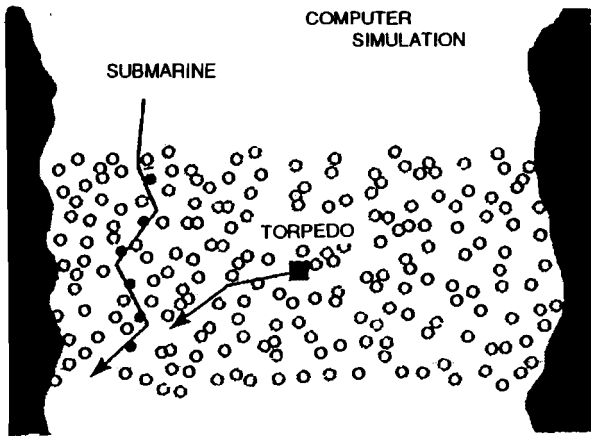
The OR Group assists the systems research groups by evaluating their concepts in the frame of operational scenarios. For instance, after an outbreak of hostilities between the Warsaw Pact and NATO, high-value units (HVUs) (e.g. escorted aircraft carrier groups and convoys) will cross the Atlantic Ocean from North America in order to reinforce and resupply (Re-Re) NATO forces in Europe. Soviet nuclear submarines pose a serious threat to such NATO Re-Re. Such threats must be detected, classified, localized and neutralized before they get within firing range of HVUs. The current practice of employing passive sonar to detect noise radiated by submarines is becoming increasingly difficult as the Soviets learn how to reduce the passive signature of their submarines. An alternative means by which to detect 'quiet' submarines is to employ low-frequency active sonar (LFAS), a means now under system development at the Centre. LFAS offers new hope due to its long ranges and lack of dependence on submarine self-noise.

The Centre effort to study and develop LFAS is supported by operational studies, which seek methods of deployments yielding the highest probabilities of detecting submarines, both with LFAS alone and in conjunction with other ASW assets.

Another analysis was performed for the Distributed Sensor Project. Threat submarines must often traverse narrow passageways in shallow water which renders ineffective traditional ASW tools such as ship-borne sonars, towed arrays, and ASW torpedoes which use deep search patterns prior to homing. A field of many low-cost short-range sensors may be laid in which sensors signal (acoustically or optically) to a central point upon detecting a target. An advantage over long-range sensors is that the target is automatically localized and tracked while it is being detected.



Extension of MEDASMINE study incorporating future low-frequency active towed-array systems in addition to a mine barrier. Envelope function shows area covered by the towed arrays and solid straight lines are the ASW mine barriers.



The Centre estimated the operational effectiveness of the system by means of a computer simulation. Sensors, submarine and torpedo were represented mathematically in the computer and allowed to interact. Circles show randomly chosen sensor locations. Black circles are sensors detecting the target. Submarine and torpedo tracks are shown.

7

Technical Support

The coherent development of resources at the Centre has been heavily impacted by both the organizational changes of the late 70s and by the continued rapid advancement of technology in the western world. The initial organizational changes were referred to by Ross. A further change was made in 1981 which reduced the number of support departments from seven to five. The Digital Computer Department under P. Blavier was combined with the Real-Time System Department under R. Seynaeve and the latter was given responsibility for the management of the combined organization. The mechanical and drafting section of the Mechanical & Transducers Department was transferred to the Oceanographic Engineering Department under F. De Strobel and the electro-mechanical and transducer effort was transferred to the Electronics and Acoustics Engineering Department under A. Barbagelata. In 1986 M. Mastrosanti, Head Ship Operations Department, retired and, after interim assignment to G. Zaccari, this post was assumed by C. Gobey in 1987 as Head Ship Management Department; this new department title is intended to carry a change in ship support management with the delivery of *Alliance* and the contracting of a ship management firm to man and operate the new vessel. Finally, the Scientific and Technical Information Department underwent no changes in function during this period but management changed from J. Bethell through 1985, R. Cameron for the succeeding three years and at the end of 1989 Head STI was R. Bernier.

The stress on the organization given here is made advisedly. It took the development of resources out of the direct control of scientists, who because of their short-term contracts had short-term goals, and put it under the control of the directorate with the Deputy Director also designated Chief TSD. This new organization did not detract from the provision of directed support to the scientific projects but rather made that support more comprehensive and at the same time permitted the coherent development of resources not possible in the framework of short-term goals.

Doing this was only possible because of the unique financial and management framework of NATO and SACLANTCEN in particular.

Separately, the development of integrated circuit technology revolutionized the computer and instrumentation industry. As dramatically as computational power (speed, data handling and storage) increased, the size of the processing equipment was reduced. Software to support these systems grew rapidly. New special purpose and general purpose hardware and software systems were developed both to support centralized computer systems and to support the direct acquisition and processing from specialized sensors. This new technology also required less electrical power and permitted transmission in the form of digital data stream via radio frequency and via cable at extremely high data rates; depending on the application, these techniques were able to eliminate the need for cable or to reduce their size. The improvements in satellite communication and navigation also had their impact. The revolution in sensor design must also be mentioned. Many sensors, such as transducers, became smaller and more easily packaged; other sensors, such as current meters, improved through the use of acoustics rather than mechanical methods. The ability to provide and maintain better calibration of instruments was also an important contribution in this period.

Other technical events had a major impact on the SPOW and therefore on the development of resources. As already mentioned, the Soviet Naval threat became most severe during this period with the discovery that their submarines had achieved a high degree of quieting in advance of intelligence forecasts. This became the 'mother-of-our-invention' of a number of instruments to counter this threat.

In June 1981 a very serious accident occurred onboard the *Maria Paolina G.* during a mooring recovery operation. A heavy pulley, used in the recovery of the mooring cable was suspended to an A-frame in the outboard position; due to the sudden fracture of a stainless steel bolt, it was projected inboard killing one Centre technician, B. Matteucci, and a young crew member, who were following the recovery operation. This accident, in addition to the fatal consequences for the two unfortunate men, had a serious impact on the future life of the Centre, at least from the technological point of view.

In fact, the search for reasons which could have been at the origin of the accident, and the highly motivated effort to avoid future similar events led to a better definition of responsibilities in the relation between the ship and the TSD together with the establishment

of new procedures for test of material and components used in the scientific research program. More relevant, however, is the fact that as a direct consequence of that accident, a continuing effort is being exercised by TSD in order to satisfy the need of the research program for at sea operations, realizing systems and developing their operating procedures, in such a way to obtain the desired performances without sacrificing the safety of personnel and equipment.

All this is said as prologue to this section of the history of the technical support departments in order that a framework for their evolution be stated at the outset. While the technology revolution permitted much more to be done, it also demanded higher and more diverse skills of the engineers and technicians performing the work. By the same token, the evolution of the threat demanded more intense activity by the support personnel. Of course, much of this activity was generated by the innovative ideas and program proposals of the nations, but that is clear and properly documented in those relevant sections of this report. Special report [M-105] describes the major technical resources of the Centre as of the start of 1989.

Ship Management Department & Ship Construction Project

The big news of the last decade and a half was the acquisition of the research vessel *Alliance* to replace the research vessel *Maria Paolina G.* (MPG). The MPG served the Centre well from the time she was first chartered in 1964 until she was returned to her owners on 18 September 1987. While much of the research with MPG was in the Mediterranean, repeated requirements to participate in military oceanographic exercises in the northeast Atlantic occurred in the late 60s and throughout the 70s and 80s. In the 80s, other program requirements for the GIN Sea project in the Greenland-Iceland-Norway gap further increased the time MPG spent in northern waters far from the Centre. In 1980 the Centre exercised an option to extend its charter until 1984. However, it was recognized at that time that a further extension would not be possible because the ship would then be 29 years old and the crew accommodations could not be brought up to international standards, thereby making it difficult to hire and retain qualified personnel. In 1981, the Centre received Military Budget Committee (MBC) approval to search for a replacement vessel.

A concerted effort in 1981 concluded that the only realistic replacement option was a new construction. This

new ship was eventually named *Alliance*, but to bridge the gap until her delivery, MPG's charter was extended until 1987. During the last 13 years (1975-87) of her service to the Centre, MPG spent 1,970 project days at sea. She spent up to four months in a given year (1975) outside of Mediterranean waters as far away as the Barents and Norwegian Seas and repeated visits in subsequent years to the southwestern approaches to the English Channel and to the Greenland-Iceland-Norway gap. In addition, there were extensive field trials throughout the Mediterranean with intensive measurements in the Alboran Sea.

In 1981 the MBC authorized an ad-hoc study of research vessel replacement options to (a) borrow a ship from a NATO nation, (b) reconfigure a relatively new merchant vessel, and (c) specify and build a new ship. It was quickly reported that the only viable approach was the construction of a new ship and approval was given to develop preliminary specifications and to initiate an international competitive bidding process to determine intentions of firms to bid on a final set of specifications. In 1982 the MBC approved a project to design and build a research vessel and convened an international group of experts to develop a full set of specifications which were sent out to over 100 companies who had indicated an interest to bid on the construction. A bidder's conference was held in August 1982 and a closing date for receipt of bids was set for March 1983 with a completion date of early 1986. The successful bidder was Cantieri Navali Riuniti, later retitled as Cantieri Navali Italiani, which fortuitously was located adjacent to the Centre in La Spezia, Italy. Subsequently, the Centre negotiated a fixed price contract of US\$ 37 million and a delivery date of March 1986. While the price remained firm there was a succession of changes to the delivery date with eventual launch on 9 July 1986 sponsored by Lady Carrington, wife of the Secretary General. The ship was finally delivered on 15 April 1988 and commissioned on 6 May by SACLANT, Admiral Lee Baggett.

The launching ceremony on 9 July 1986 was attended by the Secretary General, Lord Carrington, the Minister of Defence for Italy, Sig. Spadolini, Admiral Lee Baggett, SACLANT and by many NATO and national flag officers and NATO representatives, including the Deputy Secretary General and the members of the MBC.

The principal specification for the ship construction related to low radiated noise in a variety of operating conditions from drifting to 16 kn and with and without a towing load of up to 20 t. This range of requirements

necessitated three propulsion arrangements:

- (a) Two main diesel generators for high speed, high load conditions which provided power to the d.c. propulsion motors;
- (b) A silent ship auxiliary generator which also provided power to the propulsion motors for medium speed (12 kn) as well as for house-keeping and for the laboratory.
- (c) A battery bank which provides power for limited housekeeping and for the laboratory while in a silent drift condition.

In order to ensure that the overall noise specifications were met after construction was completed, stringent low-vibration specification and testing requirements had to be imposed on each component of machinery to be installed.

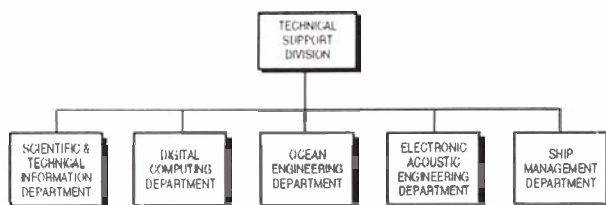
A Ship Project Office was approved and established in 1983 and J. Heslop chosen as its head. J. Heslop was the Project Manager for construction of the Canadian R/V *Quest* in the late 60s. He was authorized a team of 11 to manage the construction project and was fully staffed by 1984. During the course of the construction, 85 change orders were issued. Most of them dealt with changes to the original specifications and each had to be traded off with other items in those specifications in order to stay within the authorized budget.



R.V. Maria Paolina G.

Staying within the delivery schedule proved impossible. The silent ship concept placed stringent vibration noise limitations on all machinery from the main diesels, down to fans and pumps of all kinds. It was difficult to find suppliers and once procured units were built, the project team, augmented by a marine machinery noise control expert under contract

from Bolt Beranek & Newman, Boston, Mass. needed to make vibrational measurements to determine if the levels were low enough so that in concert with all other machinery, the radiated noise specifications could be met. One change order, for example, required that the quiet ship auxiliary generator originally specified as a diesel-generator to be installed on the level above the main deck be changed to a gas turbine generator installed one deck higher. Once the ship was fully outfitted, and all major problems with the physical plant resolved, the builder was required to obtain at-sea radiated noise data under a variety of operational conditions which demonstrated conformance with the general specifications. This requirement resulted in exceptional delays between October 1987 and April 1988 because weather conditions in the La Spezia area resulted in ocean noise levels that essentially masked the ship-radiated noise levels which were to



SACLANTCEN TSD organization.



R.V. Alliance.

be measured at the quieter operating conditions. SACLANT finally negotiated change order #77 that resulted in the Centre accepting delivery on 15 April 1988 and assuming responsibility for executing the radiated noise trials within the next 90 days. These trials were completed in June 1988 in the Bahamas at the Exuma sound range operated by the US Navy. On return to La Spezia, outstanding problems were worked on and the ship outfitted with Centre scientific equipment for the sea trials program. On 29 September, *Alliance* departed for a nine-week deployment in the North for activated towed array experiments with West German ship *Planet* in the northern North Sea followed by GIN Sea experiments slightly further to the west.

In the first full year of operation the *Alliance* spent 228 days at sea with no loss time due to ship mechanical problems. However, on delivery, the ship had many outstanding problems, some major but most of them minor, which put a heavy load on the ship's engineers to maintain the operational schedule. Most of these problems were resolved by the end of 1989 and only a few remained to be corrected in 1990.

As mentioned earlier, it was decided that a ship management company would be hired to man and operate the *Alliance*. International competitive bidding started in July 1985. Eighteen bids from several nations were received, evaluated by an ad-hoc group of experts drawn from the nations and site surveys made to evaluate the tenders. As a result, the contract was awarded to Denholm Ship Management, a firm in Scotland, and signed on 13 May 1986. It was then possible to begin hiring ship's officers, to start the security clearance process and begin the training program particularly for the engineering and electro-technical officers. Many other issues within the contract framework had to be resolved such as identifying an Italian crewing agency and the method, standard and contracting of a catering firm. Because ship delivery dates were uncertain and in fact did not occur for another two years, the hired Denholm officers were also used extensively to assist the Ship Project Team in identifying problems with installed equipment, while the numerous other pre-delivery activities were all completed by the on-site Base Manager.

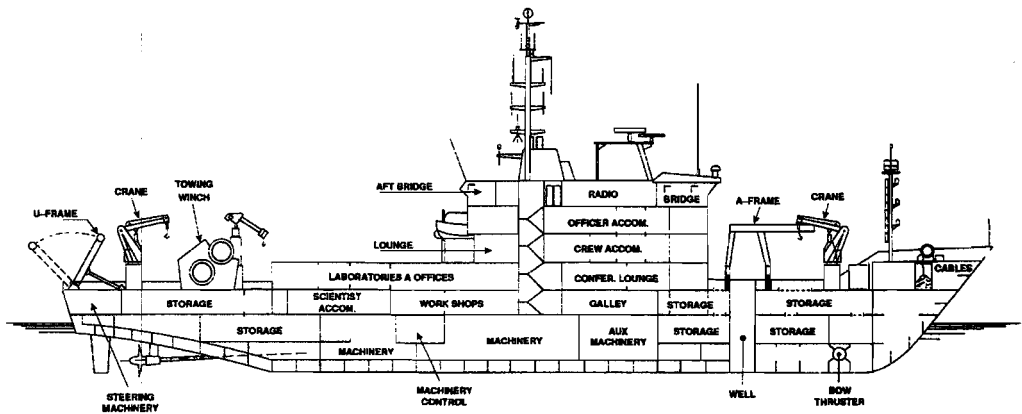
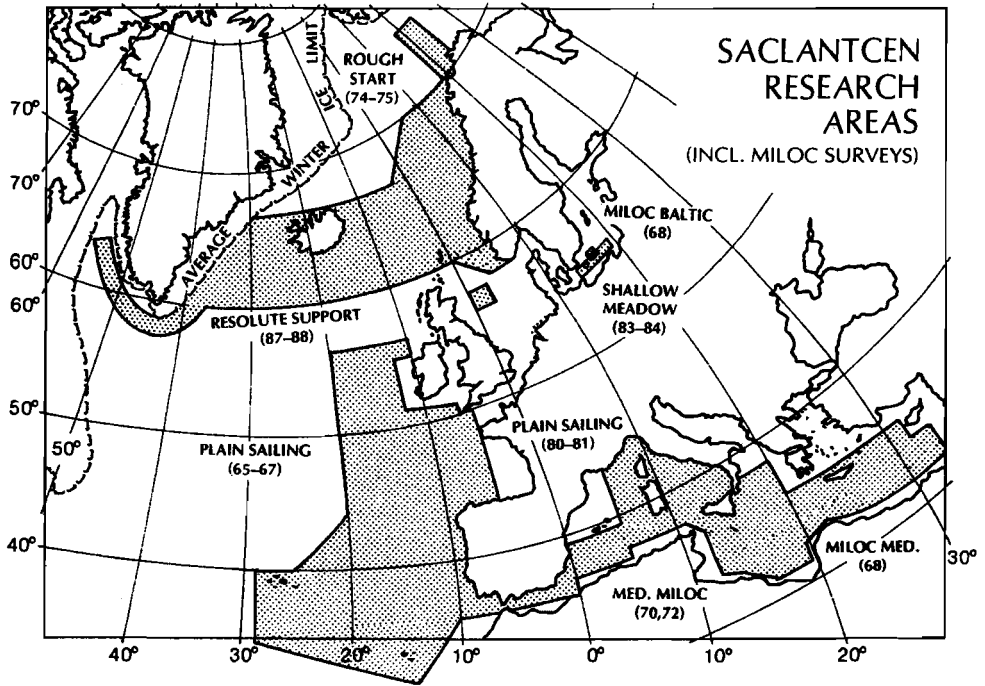
A further set of problems had to be resolved. These were the Memoranda of Understanding (MOU) with the Federal Republic of Germany and with Italy. During the process of construction, SACLANT polled the NATO nations to determine which of them would offer their flag to the vessel. Eight initial offers were received but an additional proviso that the ship have

Alliance milestones

1981, May	MBC authorizes Replacement Vessel Study Group
1982, Oct	MBC approves ICB design & build specifications
1983, Mar	Bids opened and CNR, Italy, selected
1983, 10 Oct	After negotiations, fixed cost (US\$ 37 million) contract signed with CNR
1983, Dec	Ship Project Office established within the Centre
1984, 27 Sep	Keel laid
1985, 2 Aug	Federal Republic of Germany selected as Flag State
1986, 12 Feb	R/V <i>Alliance</i> chosen as name for new vessel
1986, 13 May	Contract signed with Denholm for R/V <i>Alliance</i> management
1986, 9 Jul	<i>Alliance</i> launched by Lady Carrington wife of Secretary General
1988, 15 Apr	<i>Alliance</i> delivered to the Centre and Denholm assumes management
1988, 6 May	<i>Alliance</i> commissioned by SACLANT (Adm. Lee Baggett)
1989, 30 Jun	Ship Project Office disestablished after warrantee period

Specified noise operating states

State	Speed (kn)	Duration	Power supply
1 Quiet drift	0	1 h on 6 h off	Batteries
2 Semi-quiet drift	0	12 h on 4 h off	Silent ship service generator
3 Semi-quiet tow	6	12 h on 4 h off	Auxiliary propulsion and silent ship service generators
4A Cruise	5	continuous	(as above)
4B Cruise low-speed tow	8	continuous	(as above)
4C Cruise	10	continuous	(as above)
4D Cruise high-speed tow	12	continuous	Main propulsion and ship servicegenerators
4E Cruise transit	16.3	continuous	(as above)



R. V. Alliance general arrangement.

public vessel status reduced the offers to Germany and Italy. In 1985 SACLANT, Admiral W. McDonald, selected Germany as the flag state. An MOU with Germany was entered by which the Master and Chief Mates (initially three in all), would be of German nationality and Germany could exercise the right of annual inspection of the ship for conformance with safety standards. Because the ship would fly the German public vessel flag but would be home-based in La Spezia, Italy, a separate MOU with Italy was necessary to facilitate operations within the Italian territorial waters.

In its first full year of operation, starting 29 September 1988, *Alliance* achieved 228 days at sea with two months in the North Sea and approaches to the Norwegian Sea in late 1988, three weeks in the Iberian Basin in February 1989 and a further three months in the Greenland–Iceland–Norway gap area from mid-April to mid-July of 1989. Several other tests were conducted in the Mediterranean. Extreme weather conditions were encountered, up to sea-state 11 on some of the passages but all reports indicated that she handled well with work possible even up to sea-state 8. Her extreme quietness was evidenced from the start and proved valuable to all experiments.

This section could not be complete without mentioning the evolution of the T-boat *Manning*. It was originally delivered in 1974 and has been the workhorse of the Centre for all local coastal water studies, principally those related to the seafloor. It is manned by 3 Centre Staff with A. Spairani as master since delivery. It has been deployed as far away as Sicily and in 1987 made its first voyage outside of Italian waters to work off Cap Ferrat, France. It is an old ship but like the farmer's ax (same ax but two new heads and five new handles) it has been modified extensively with spaces modified and 2 t lead ballast installed in 1976, new engine and generator installed in 1979 and hull plates replaced in 1984. A fathometer and speedlog, a radar, VHF transceiver, Loran C and SATNAV navigation systems were installed in the late 70s together with forward and stern cranes. In 1985 a stern U-frame was permanently installed to take freefall cores in shallow water and in 1987 a pump jet azimuth thruster was purchased from Shottel Inc. and installed in 1988; it has been used extensively for position keeping and for low speed (0–4 kn) propulsion and has proved to be a great asset.



Weather deck aft.



The Work Boat Manning.

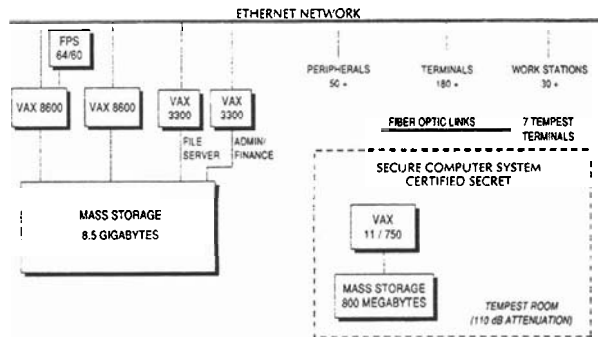
Digital Computer Department

This department has had extensive growth during the last decade. The capability reported in 1980 is essentially that available in the late 70s as described briefly by Ross [M-93].

Over the last ten years the Centre computer resources and the application of computing across all Centre activities have considerably increased reflecting the rapid development of the computing field itself and the great importance of this technology in sonar research. The central computing facilities evolved from a UNIVAC computer and 10 interactive terminals, occasionally operated in standalone mode for classified processing, to an integrated network of VAX computers of various sizes, augmented with an array processor, and interconnected with over 30 VAXstations, 200 terminals and 50 printers and plotters, and with a dedicated standalone VAX computer system supporting classified processing. All functions of the Centre – scientific, technical, administrative – now have computer support.

Installed in 1974, the UNIVAC 1106 was a real workhorse for the Centre for 5 years. It was eventually replaced in 1979 with a UNIVAC 11/60, which was augmented in 1982 with a new FPS-164 array processor controlled by a VAX 11/750 that provided a factor of 30 in speed for the modeling applications. In 1983 the Centre was among the first to decide to make use of the new computer networking technology and an ethernet local area network was installed which was to be a key element in the distribution of the computing resources. At that time it had also become obvious that it was inefficient and uneconomical to support several different types of computers and that a certain degree of standardization was required. This led eventually to selecting the VAX/VMS systems as the basic building block for the Centre computing in that this computer architecture was able to support all the current and foreseen requirements and was establishing itself as a standard in the research community. A progressive standardization of the Centre computing environment was therefore started. In 1983 and 1984 the Hewlett-Packard computers used in the real-time applications were replaced by VAX 11/750s and another VAX 11/750 was installed in a Tempest room for the classified processing. The standardization continued in 1986 with the replacement of the UNIVAC 11/60 by two VAX 8600s operating in a cluster. In 1988, the FPS 164 was replaced with a FPS 64/60 array processor to meet the requirement for increased computer power for acoustic propagation and water mass modeling. At the same time the advent of

SACLANTCEN CENTRAL COMPUTING FACILITIES 1989



The dual VAX 8600 cluster and the FPS array processor.



WARP-I in operation during a sonar trial (1980).

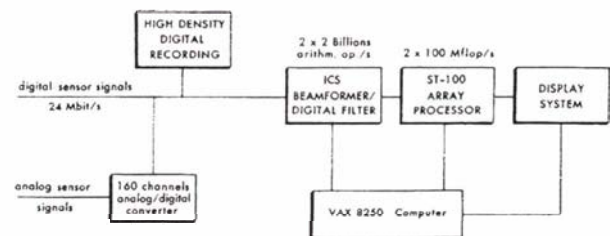
VAX workstations with CPUs completely compatible with the larger VAX computers allowed a new level in the distribution and the integration of the computing power through the installation of VAXstations on an increasing number of scientist desks. Simultaneously, tasks such as administrative computing and computer aided design were moved to dedicated VAX processors. All this computer equipment is connected to and communicates through the Centre's network. A similar computing approach was taken on the *Alliance*, which was fitted with an ethernet local area network and VAX equipment giving a working environment similar to the one available on shore.

For many years, one of the major aspects of the Centre's computing activity has been the development of specialised computer systems for data acquisition and real time processing in sonar and environmental experiments at sea. The most powerful such system in the late 70s was based on a MAP-300 array processor and a digital beamformer which, together with the Hewlett Packard 21MXS, formed the basis for the Centre's wide application real-time processor (WARP-I). This system was extensively used in many experiments. It evolved in accordance with the requirements of the program of work into the early 80s and reached final configuration in 1982. At this time, the design for its successor, WARP-II was initiated; this new system was brought on line with two orders of magnitude more power at the time of delivery of *Alliance* in 1988. The digital beamformer and programmable filter operate at 2 billion arithmetic operations per second permitting formation of 256 acoustic beams from 256 hydrophones in the band from 0 to 2000 Hz. This is followed by an array processor programmable in high-level code and operating at 100 million floating point operations per second. These special processors are supported by a VAX computer and several VAXstations. Two identical systems are permanently installed on the *Alliance*, a third is resident at the Centre for experiment preparation and further processing of raw data collected on high-density digital recorders and optical disks, while a fourth reduced version is used mainly for development.

The lower end of the development of acquisition/real time processing systems consists of portable processing systems which evolved during the same period from HP-1000 computers to the MicroVAX-based systems in use today. These portable systems were developed primarily to support field work that did not employ the MPG or later *Alliance* but used instead ships of the nations, T-boat *Manning* or remote shore facilities.

Software support to the scientific programs evolved from the integrated oceanographic system for acoustical data acquisition and monitoring and the GEOS system for acoustical data from geophones (both developed in 1979 and 1980) to over ten software systems in 1989 supporting oceanographic, acoustic and system projects at the Centre. The software support to the administration has grown even more dramatically with three programs in 1980 and 23 separately identifiable programs in 1989.

It is clear that this progress could not be achieved without a great deal of interaction and cooperation between the software personnel of COM and the administrative and scientific customers in the Centre.



WARP-II configuration.



Dual WARP-II installation on the R/V Alliance.

Ocean Engineering Department

The Ocean Engineering Department has responsibility for providing oceanographic instrumentation and their calibration, mechanical design and fabrication, and at-sea support for scientific trials including scientific diving. This department was formed in 1980 from the then existing Oceanographic Engineering Department and the mechanical section of the Mechanical and Transducers Department.

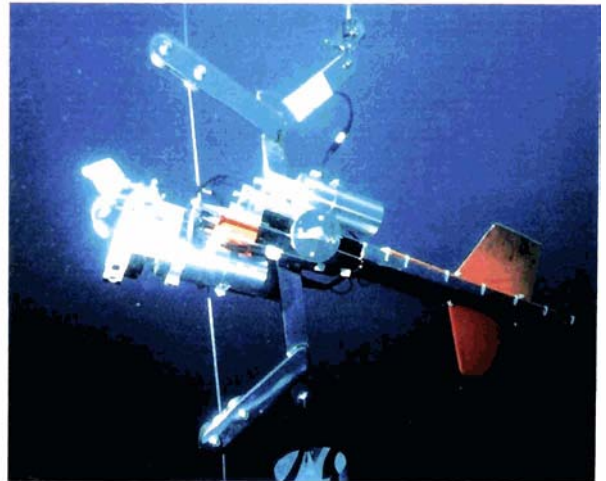
In the mid 70s, the Centre was already at the forefront in providing novel instrumentation systems such as the towed-oscillating body, completely digital data acquisition systems for temperature depth and salinity profiling (TDS), and an excellent sensor calibration facility. In the late 70s and 80s, capabilities in all areas were upgraded to provide advanced state-of-the-art systems and facilities to the Scientific Programme of Work.

In the buoy technology field, large international oceanographic experiments have called for at-sea deployment of a variety of oceanographic buoys, surface spar and taut-moored, as well as subsurface types, pushing the department into advanced design of these structures, computer modeling of their static and dynamic behaviour and evaluations of long-term corrosion problems. The range of oceanographic instrumentation designed, procured and operated, expanded dramatically, especially in the area of current measurements.

In the early 80s, investigation of the Alboran Sea deep-sea circulation called for the procurement of a new generation high-resolution acoustic currentmeter to be installed on many lines, as well as the design and construction, in cooperation with Woods Hole Oceanographic Institution, US and Centre of Oceanography Brest, France, of quite a number of low-frequency acoustic Swallow floats for Lagrangian measurements. The SACLANTCEN engineering version of these floats consisted in an extremely accurate low-frequency acoustic pinger housed in a glass sphere and ballasted, to be positioned at any depth in equilibrium with the surrounding water mass. The floats were made recoverable for repetitive redeployment until the required depth was obtained within the desired accuracy. Their motion was tracked acoustically by submerged fixed receiving stations.

This technique has been largely implemented through the years by many successful deployments with depth accuracy better than 10 m. This result was made possible by the setting-up of dedicated laboratory calibration techniques and facilities.

In fact, from 1977 the department oceanographic cal-



Towed oscillating CTD package.



Density bath for depth setting of ocean current drift floats.

ibration facility has acquired improved precision and accuracy in results and has expanded into new areas, reaching its present capability in 1988. Advanced bridges for temperature and conductivity measurements have been added to the facility, such as the Neil Brown TC transfer standard procured in 1977, the first of its kind in Europe, and later paralleled to the new automatic thermometer bridge model 1250, by the same manufacturer. The distilled-water triple-point cell had been used to get accurate controls of standard laboratory platinum thermometers in the vicinity of 0°C and in 1985 a gallium melting point standard was added to obtain primary standard accuracy near 30°C. However, the heart of this dedicated laboratory was a SACLANTCEN-designed three-stage thermally-controlled calibration bath of modular concept and extremely high thermal stability and homogeneity. The modular design allows the use alternately of a 400 litre calibration bath for CTD work and a 1000 litre bath for Swallow float accurate laboratory balancing. The first version of these baths was realized in the early 80s, while the present one was realized in 1988.

A comprehensive water and sediment analysis laboratory is operated by OED. Instrumentation to obtain salinity, dissolved oxygen content, nutrients, pH and many other properties for the purpose of core analysis is employed to support oceanographic analyses. Sediment porosity, grain size, frame pressure, etc., can also be determined. Other instrumentation developed includes a drifting vertical current meter, bore hole drilling equipment and an underwater hammer for obtaining shear wave speeds in sediments, together with a variety of devices used for sea bottom deployment or recovery of oceanographic and acoustic systems, such as pop-up buoys, lightweight acoustic releasers,

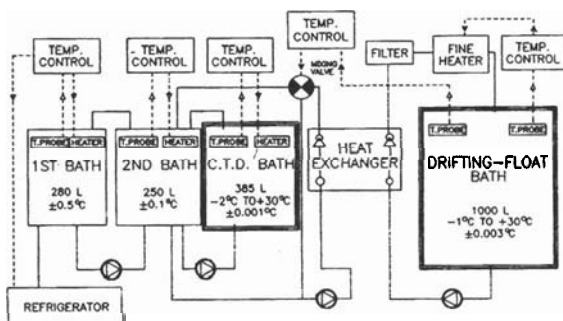
double releasing frames, etc.

Perhaps the most dramatic acquisition in the 80s has been the acoustic doppler current profiling system (ADCP). The equipment was purchased in 1987 and a mooring system designed for long term deployment at a given position. Using a 75 kHz transducer to emit sound and obtain the backscatter from water mass elements as a function of depth, it measures current speed and direction up to 128 points in the water column for a total range of ca. 500 m. This one unit, in effect, replaces one mooring with 128 conventional currentmeters attached, all requiring individual data readout, calibration and inter-comparison. Besides providing a significant increase in data acquisition and efficiency in processing, the equipment comes with software which permits display of the results.

Significant achievements in the mechanical design area have also been obtained. More innovative designs have evolved in the last 15 years and since the installation of a computer-aided design system, it is possible to design and construct more complicated systems in house. Mooring system designs continue to be a major effort in the department. With the aid of computer modeling techniques, more sophistication can be applied in the analysis of static and dynamic drag. A particular winch was designed and constructed in 1983 at the Centre to tow a low-frequency sound source mounted in a tow body. In 1985 an innovative design and construction of the sound source system was achieved. This design permitted the sound source to be constructed as a stacked dipole. This dipole would be in line with the tow body when resting in its cradle before launch and after retrieval but when it was lowered into the water and towed at depth, the dipole would rotate 90° thereby becoming vertical and steering a null in the downward direction; this proved exceptionally effective in reducing the 'fathometer' effect of the multiply bottom-surface reflected energy. In 1988, the then new computer aided design system was used to design a new winch for use on the *Alliance*. This involved a method for pulling the source up into the cradle and then rotating the cradle to make the source readily accessible for servicing. Because the winch had to be installed in a very narrow and restrictive area on the stern, special attention had to be paid to the design of a mounting pad on the deck. Again this was done with the CAD system and the design was dynamically analyzed using a finite-element structure model program at the University of Bologna.

Scientific diving support to the projects were officially instituted in 1974. In 1979, a complete review of

C.T.D. & DRIFTING-FLOAT CALIBRATION BATHS

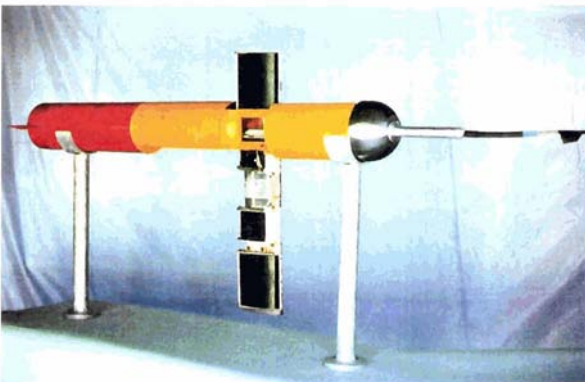


Temperature control system for CTD and drifting float calibration baths.

practice and procedures for scientific diving was undertaken and the Centre played a leading role in the development of a code of practice to be adopted within the Italian underwater research community. Scientific diving [SM-175] continues to play an important role in coastal water research, particularly with respect to seafloor acoustics.



Acoustic doppler current profiler under launch.



Vertical extent source. The aperture created by the vertical arm provides enough low-frequency directivity to significantly reduce the close-range fathometer effect, hence allowing detection of close-range targets.

Electronic & Acoustic Engineering Department

EED supports the SPOW through the procurement or in-house design, development and construction of electronic and acoustic system for at-sea data acquisition. Its electronic branch provides for design, prototyping and testing of state-of-the-art circuits for data acquisition and digital telemetry, while maintaining an instrumentation calibration and maintenance laboratory with high precision time, frequency and voltage reference standards.

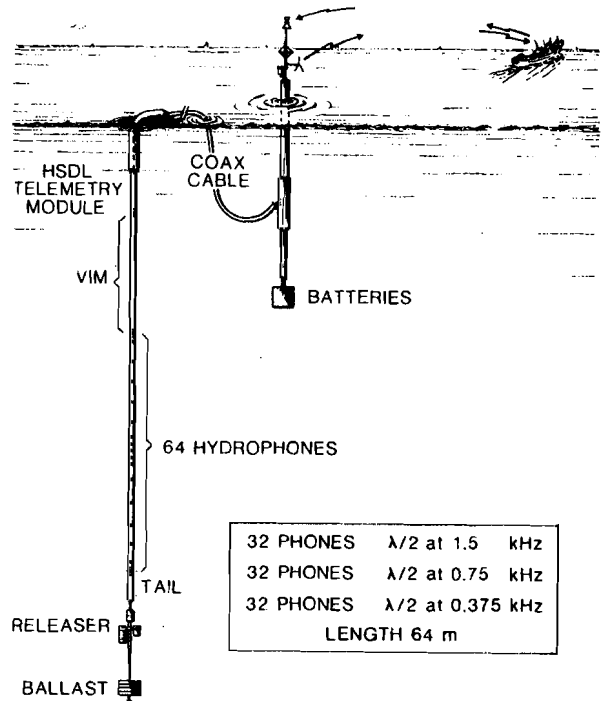
Its acoustic branch runs calibration facilities that accommodate single sensors and the in-place sensors of towed arrays, while the systems branch carries on acoustic array design and assembly, giving also full support to sea operations. In fact a large portion of the effort spent by EED is in operation of acoustic systems both in the laboratory and at sea. EED is also responsible for the care and use of explosives as acoustic sources.

The department operates a remote facility on the islands of Formiche di Grosseto, near Elba, originally established in 1976 to support a shallow water test range and more recently used to support a variety of projects carried out in coastal waters and requiring shore-based support.

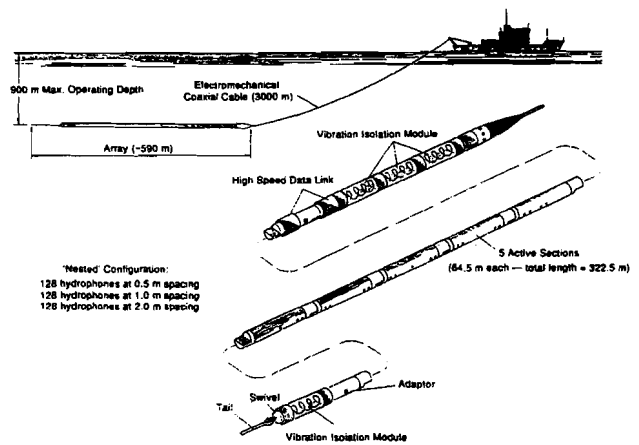
In the late 70s conventional multi-conductor cables were required: analogue telemetry and self-recording technology was used to construct acoustic arrays in a variety of configurations with data acquisition tailored to project requirements. RF/FM telemetry was used where short-term measurements not influenced by the radiated noise field of the support vessel were required and self-recording was used where long-term in situ data acquisition was necessary. The first towed array at the Centre was procured under Centre design from Prakla-Seismos in West Germany. It consisted of 128 hydrophones and preamplifiers hardwired in the array with a 64-m aperture. Through the use of different cable coupling modules it was possible to select any one of 4 uniformly spaced sub-arrays of 32 elements each while the analogue signal was hardwired through the towcable signal conditioning and analogue to digital

converters onboard the tow vessel. A new towed array, 256 m long with 256 hydrophones variably spaced, has been designed and constructed. Three 128-element arrays, with hydrophone spacing of 0.5, 1.0 and 2.0 m, can be simultaneously received on the tow vessel. While the hydrophones are hardwired within the array, the signal conditioning circuits and A/D conversion takes place at the front end of the array, where a 24 Mbit/s digital data stream is transmitted through a coaxial tow cable to the ship to be interfaced with the programmable beamformer. The array design was started in 1985, the wet end constructed and assembled in 1987-88 and subsections used in late 1988 in support of the activated towed-array project and later to measure directionality of noise. To date, it has only been used in the hardwired tow cable configuration; the 24 Mbit/s high-speed digital link (HSDL) is expected to be completed and tested in 1990. The array will then be available to study directional noise fluctuation and, in conjunction with the WARP-II system, for array shape 'correction' studies and as a higher gain or higher resolution survey tool for activated towed array and noise directionality measurements.

Since the earlier period of the 70s, in applications where RF/FM telemetering sonobuoys were used, the Centre rapidly developed a succession of telemetering and remote controlled systems initially using analogue but very soon passing to digital techniques. In 1980-82 a VHF ship-to-shore data link was designed and developed to transmit data from MPG to the Centre and the use of a satellite link was investigated. While the use of the satellite link was not pursued for the relaying of acoustic data, the Centre now routinely uses a commercial satellite link, ARGOS, for transmitting oceanographic data from remote oceanographic buoys to the Centre. In 1984 a VHF relay link was established to telemeter data from a bottom-mounted triaxial geophone via a telemetering buoy moored in local coastal waters and relayed to the Centre from a station located on a mountain top with line-of-sight to both the buoy and the Centre. Command and control of floating hydrophone systems using digital telemetry links were used in 1983. An ambitious project to use 6 Mbit/s high-speed radio link from a floating 64 hydrophone vertical array to the MPG was initiated in 1981 with an 8-hydrophone, 0-8 kHz array; it was completed in 1984 with 64 hydrophones, 0-2 kHz and routinely used since then. A remote controlled moored acoustic source (RECMAS) was completed in 1985 and successfully used in 1986. In this buoy a microprocessor signal generator, remotely programmed by radio, sends a variety of different



The array consists of three sub-aperture segments with an acoustic length of 16 wavelengths at design frequencies of 1500, 750 and 375 Hz. The 64 hydrophones are connected to digital telemetry equipment that sends a 6 Mbit/s data stream to a surface radio buoy and then to the receiving ship.

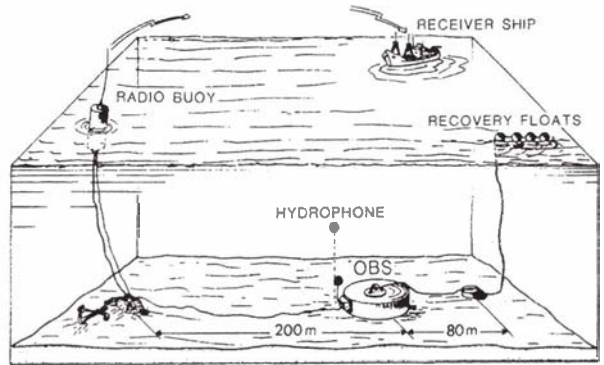


The SACLANTCEN towed array (256 hydrophones).

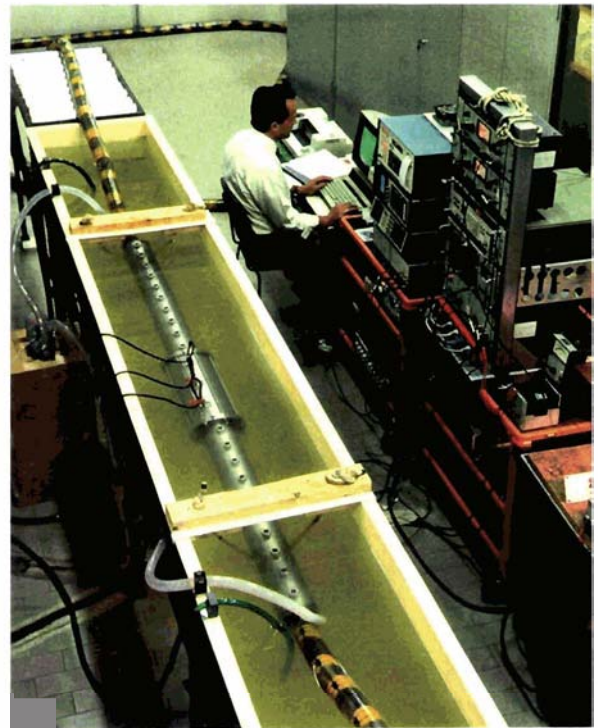
signal codes to a power amplifier feeding a variable depth transducer. A propane thermoelectric generator maintains the charge on the batteries supplying power. Transducer developments here also advanced in novel ways. An attempt was made in 1980–82 to build a high powered low-frequency source using exploding gas technology; this proved unreliable and the project was abandoned in favor of commercial sources. The Centre now uses flextensional sources at 350, 750 and 1000 Hz for the activated towed-array project and lower power ceramic sources for broadband studies. The Centre towed array uses commercial hydrophones. However, the Centre designed its own hydrophone for the 64-element oil-filled vertical array. These hydrophones consist of hollow cylinders filled with oil in communication with a pressure exposed tank through a capillary tube, to allow compensation limited to the static pressure. These hydrophones were then manufactured locally and have a broadband acoustic response which is pressure insensitive in the range 0–1000 m. A hydrophone element with a cardioid pattern to resolve direction was developed in 1979–80 and eventually employed in a 24-element array in 1980–81. A very successful project was the design and construction of a 3-axis digital ocean bottom seismometer to study water sediment interface waves. It had improved reliability, simpler operation, and very high dynamic range. The design is still in use. The most recent transducer developments were accomplished in support of making in situ compressional and shear wave measurements of sediments. Traditional methods in use are to mount sediment core samples in a shore-based laboratory instrument that compares shear wave speed with waterborne speed. To make the in situ measurements it was necessary to design a 60 kHz shear wave transducer from ceramic benders constructed in a sandwich design that takes the form of a narrow disk with sharp edges to permit easy embedment into the sediments. Four of these, together with embedding compressional wave transducers, are mounted on a frame, lowered so all transducers are in the sediment layer and then pulsed to obtain relevant acoustic speeds.

Finally, the changes in acoustic calibration facilities must be mentioned. With workshop space provided in Building 26 (1981) a calibration tank was procured and installed. It was then possible to calibrate hydrophones and transducers in the frequency range > 2000 Hz. In addition, high pressure chambers were acquired to test small units for depths up to 3000 m.

A method was needed to calibrate towed-array hydrophones after installation in the oil filled hose. In



The Digital Ocean Bottom Seismometer is a compact digital, triaxial seismometer developed to study ELF-acoustics (1–100 Hz) in shallow water. It contains three 1-Hz geophones, a hydrophone, a compass, two voltmeters, a thermistor and pertinent electronics. The floating point conversion format (the transmitting signals in digital form to the radio buoy and then to receiver ship) allows a dynamic range of 120 dB to be achieved.



Towed array calibration tank.

1984, the US Underwater Sound Reference Detachment of US Naval Research Laboratory in Orlando, Florida provided the Centre with a basic element and methods for calibrating an array by pulling it through a hollow tube immersed in water. The tube was constructed with the transducers and reference hydrophone in the centre and several ports on either side in which 'acoustic resistors' were inserted to attenuate the acoustic wave propagation down the tube in either direction and thereby eliminate interfering standing waves. The Centre completely refurbished the element and rebuilt all the acoustic resistors. It has been used successfully for the last five years and permits full calibration of a 64-element array in two to three days.

Scientific & Technical Information Department

STI has the functional responsibility for editing and publishing Centre documents, maintaining and operating the classified and unclassified libraries and searching for and acquiring external technical and scientific documents as required by Centre staff. In this sense, it is the interface between all external organizations and SACLANTCEN for the transmission and receipt of formally prepared information.

In the mid to late 70s, the Editor received report drafts in typescript form accompanied by rough sketches. The texts were edited and figures were manually finished or redrawn by the illustrators. Once changes were agreed to by the originator the text was retyped in the approved Centre style, figures were manually mounted and the document was submitted to the Director for approval before printing.

A standalone word processor was available to STI for the first time in 1979. The following two years, all divisions had access to word processors. This greatly reduced the labor involved in editing and retyping reports. Even then, however, great effort went into printing the many equations with their math characters. By 1986, with the proliferation of computer terminals at the Centre, a number of the scientists began typing their own reports directly into the computer using word processing software. At that time $T_{E}X$, a technical document compiler, was introduced into the Centre. This program was designed specifically for mathematical typesetting and greatly facilitated the rendering of equations in scientific reports, while simultaneously providing for an order of magnitude quality enhancement.

STI embarked on an ambitious program in 1987 to develop a consolidated software system for text format-

ting. This documentation system was made available for use by Centre staff in 1989. Specifically STI has:

- Generated a fairly extensive $T_{E}X$ macro package which supports the various categories of SACLANTCEN documents through distinct formats/styles – especially with regard to classification labeling, page tagging and output for compliance with NATO security regulations.
- Provided easy-to-use macro calls as generic markup, accessible to both secretarial and scientific staff.
- Enabled merging of interactive and batch-generated graphics elements into the text by standardizing output on *PostScript*.
- Automated various administrative aspects which had previously been manpower-intensive.
- Established a parallel system for unclassified and classified environments.

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and the 'sgn' function is defined by

$$\text{sgn}(x) = \begin{cases} -1, & \text{if } x < 0; \\ 1, & \text{if } x \geq 0. \end{cases} \quad (43)$$

The absolute-value signs under the square root in (41d) are necessary in order to have valid expressions in both cases. The only difference between the two cases is the sign of the imaginary part of the complex Fresnel integral. The ranges of τ_i and the corresponding limits of integration t'_{i-} and t'_{i+} to be used in (41b,c) are given in Subsect. C.3 of Appendix C.

For the special case of a reference signal matched exactly in doppler to the i th echo signal ($\eta_i = \eta$), the preceding formulas break down and expression (40) becomes

$$\begin{aligned} \Phi_i(\tau_i, \eta_i) &= A_i \eta_i \text{rect} \left[\frac{\eta_i (t' - \frac{1}{2} \tau_i)}{T} \right] \text{rect} \left[\frac{\eta_i (t' + \frac{1}{2} \tau_i)}{T} \right] \\ &\times \exp(j2\pi f_c \eta_i \tau_i) \int_{-\infty}^{+\infty} \exp(j2\pi \eta_i^2 \beta \tau_i t') dt'. \end{aligned} \quad (44)$$

which after calculation given in Subsect. C.2 of Appendix C yields

$$\Phi_i(\tau_i, \eta_i) = R_i \exp(j\Theta_i) \text{sinc}(z_i), \quad (45)$$

where

$$z_i = \pi \eta_i \beta \tau_i (T - \eta_i |\tau_i|), \quad (45a)$$

$$R_i = A_i (T - \eta_i |\tau_i|), \quad (45b)$$

$$\Theta_i = 2\pi f_c \eta_i \tau_i, \quad (45c)$$

for $|\tau_i| \leq T/\eta_i$.

By letting $i = 1$, $A_1 = 1$, $\Delta_1 = 0$, $\eta_1 = 1$ and $\eta = 1 + \delta$ in the expressions (41) and neglecting δ^2 wherever it appears added to unity, the delay-doppler auto-correlation function normalized to unit peak energy may be written as

$$\Psi(\tau, \delta) = R \exp(j\Theta) \exp(j\theta) |F(z_2) - F(z_1)|, \quad (46)$$

where

$$F(z) = C(z) + j \text{sgn}(\beta \delta) S(z), \quad (46a)$$

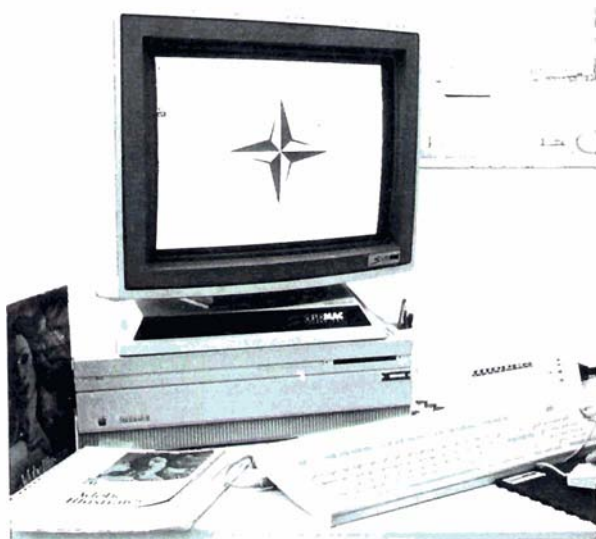
$$z_1 = P(t_1 + Q), \quad (46b)$$

$$z_2 = P(t_2 + Q), \quad (46c)$$

At the beginning of 1989 STI was equipped with two Macintosh graphics workstations with scanners for digitizing line art and halftones. The illustrator received training to use this new technology and has subsequently migrated almost entirely from the traditional means of graphics preparation.

All reports are now sent to STI by electronic mail over the Centre's local area network. They are reformatted and edited by the editorial staff and increasingly graphics elements are merged electronically into the text. When final corrections have been agreed to, STI can quickly incorporate the changes and put the report in final form for approval.

Printing techniques remain essentially the same as they were in the late 70s except for the growing demand for color printing. Offset presses are still in use, a new press having been purchased in 1987. While an odd color plate occasionally occurred in reports of the earlier period, the first extensive use of color was in 1985. Improvements in ink-jet printer technology in the 80s enabled scientific results to be graphically represented with a visually satisfying third dimension in the form of color contours. Contouring, of course, has been used extensively in the past but the use of color allows a much faster assimilation for the reader and is therefore much preferred. However, reproduction on color work is labor intensive. Four-color separations are required and one day's drying time between printing each color. At this writing, color xerographic technology appears to be of satisfactory quality and a number of systems on the market are



Computer-based graphics are replacing traditional draughting.

under investigation by the Centre.

Through the mid 70s, information was obtained by means of printed abstracting and indexing journals. If a report was needed, then a letter of request was sent out to the appropriate organization and the information returned via the same means.

Exploitation of the scientific literature was improved with access to the Dialog on-line computer-based bibliographic information services during the 80s. One of the most heavily used on-line files, the unclassified report literature, has subsequently been superseded by a compact disk version which permits substantial savings in computer-connect time and telephone charges. In 1989 the Centre was promised delivery of compact disks from the Defense Technical Information Centre which will for the first time allow systematic searching of the classified report literature. Other CD-ROM products such as dictionaries and the full text of military standards and NATO STANAGS are being procured.

In 1979 software was provided by COM for library housekeeping and by 1984 a database had been compiled of all Centre documents.



The library has a 3000-volume collection of bound scientific journals and books and 4000 documents.

References

The text makes citations in two ways:

1. Citations to external publications

These are indicated by asterisked numbers and are referenced below.

2. Citations to SACLANTCEN publications

These are indicated by document identifiers as follows:

- **M-** Special Report series 1962–89
 - **CP-** Conference Proceedings series 1970–89
 - **SR-** SACLANTCEN Report series 1974–89
 - **SM-** SACLANTCEN Memorandum series 1973–89
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<i>Abstract</i> <p>The SACLANT Undersea Research Centre, originally the SACLANT ASW Research Centre, was established in 1959 to provide scientific and technical advice and assistance to the Supreme Allied Commander Atlantic in the field of antisubmarine warfare and to respond to the needs of NATO nations and maritime commands. A special comprehensive report, M-93, on twenty years of research at the Centre was published in January 1980 by Donald Ross.</p> <p>This report is intended to be similar in kind in order to document the research and accomplishments of the Centre through 1989, the 30th anniversary of the Centre. It overlaps the stated 20-year period of M-93 in order to more smoothly lead into the work of the 1980s. The numerous Centre documents cited in this report – scientific memoranda and reports, conference proceedings, annual progress reports – together with external publications and corporate memory have provided the source material for this report. The author has attempted to be fully objective in selecting the references and in summarizing the work.</p>		
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