NURC-RTH-2006

2006 Research and Technology Highlights

PARTNERING FOR MARITIME INNOVATION

About NURC

Our vision

- To conduct maritime research and develop products in support of NATO's maritime operational and transformational requirements.
- To be the first port of call for NATO's maritime research needs through our own expertise, particularly in the undersea domain, and that of our many partners in research and technology.

One of three research and technology organisations in NATO, NURC conducts maritime research in support of NATO's operational and transformation requirements. Reporting to the Supreme Allied Commander, Transformation and under the guidance of the NATO Conference of National Armaments Directors and the NATO Military Committee, our focus is on the undersea domain and on solutions to maritime security problems.

The Scientific Committee of National Representatives, membership of which is open to all NATO nations, provides scientific guidance to NURC and the Supreme Allied Commander Transformation.

NURC is funded through NATO common funds and respond explicitly to NATO's common requirements. Our plans and operations are extensively and regularly reviewed by outside bodies including peer review of the science and technology, independent national expert oversight, review of proposed deliverables by military user authorities, and independent business process certification.

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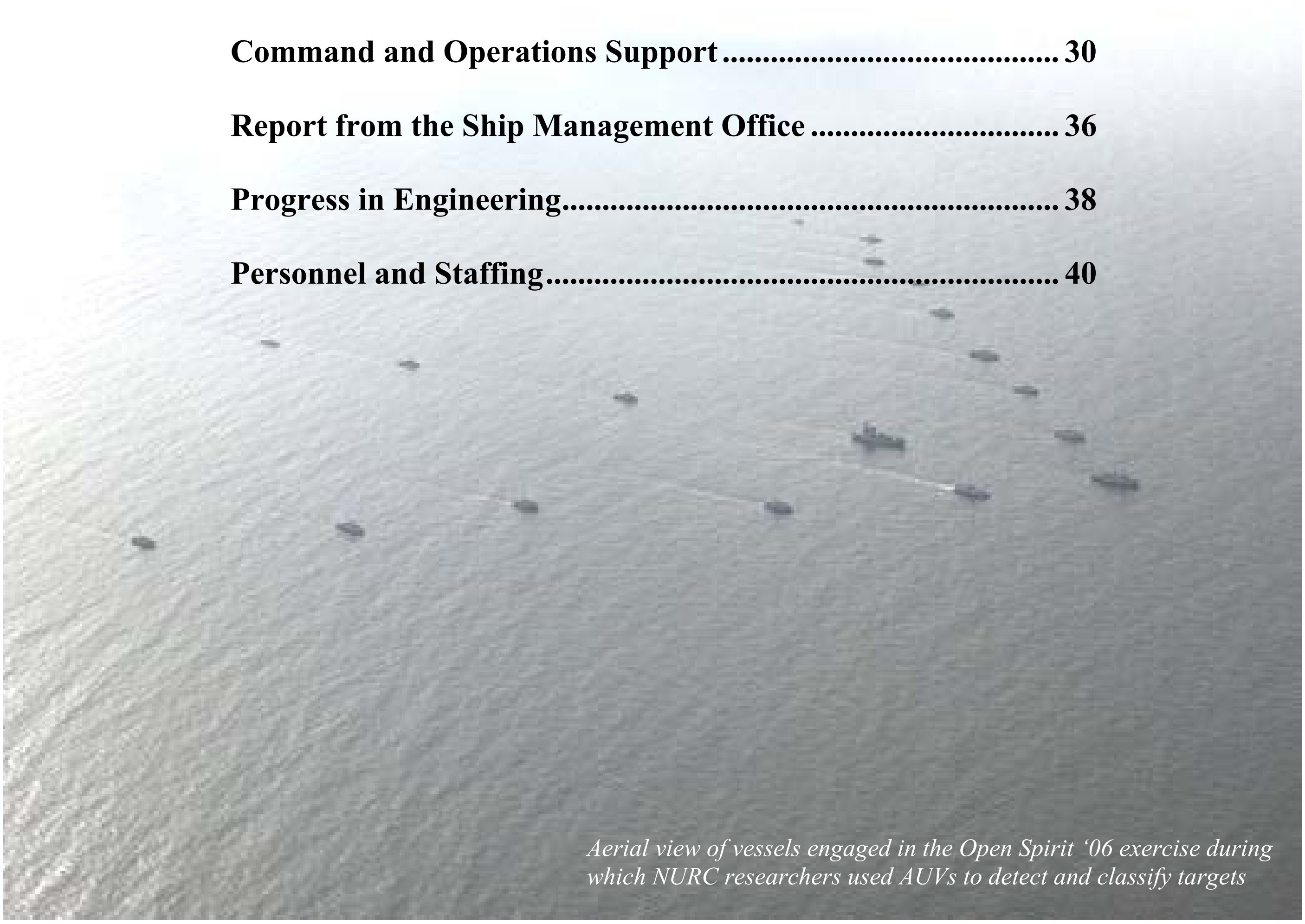


Aerial view of vessels engaged in the Open Spirit '06 exercise during which NURC researchers used AUVs to detect and classify targets

Message From the Director

I am very pleased to publish the 2006 accomplishments of NURC, realised under the leadership of my predecessor, Dr Steven E. Ramberg (USA), who successfully managed the transition of NURC from the Allied Command Atlantic (ACLANT) to the Allied Command Transformation (ACT) within the NATO Command Structure and steered NURC on a new path. The Annual Report of past years has also undergone a "Transformation" to make it more appealing and useful to a broader range of readers, both professional and non-professional, and to the sponsors of NATO RDT&E.

The Centre has maintained its excellence in Undersea Warfare and Military Oceanography while maintaining core technical competencies on behalf of the NATO member states in these currently "disadvantaged" tech-ops areas. The current expansion into other naval / maritime fields of interest for current and future operations, whether in maritime surveillance, protection of harbours and naval forces against asymmetric threats (defence against terrorism), situational awareness or reconnaissance has been fruitful.

Most of the NURC 2006 achievements were generated by the Scientific Programme of Work (SPOW), one of the two Programmes of Work (POW) of the Centre, and the one that is owned by NURC and funded by the NATO Military Budget Committee. The formulation of the SPOW benefits from the inputs of the Scientific Committee of National Representatives (SCNR), an assistance and advisory board which is composed of leading scientists, science and technology managers and representatives of the national Ministries and Departments of Defence. It is chaired by Dr D. Tielbuerger (DEU) who replaced RADM Çubukçu (TUR) in late 2006.

The Scientific &Technology activities are supplemented by Experimentation activities funded by ACT (Norfolk, VA) which, under the guidance of the ACT Deputy Chief of Staff, Gen. J. Soligan (USA) demonstrates the path to transition of technologies in the armed forces.

The NURC mission, included in the NATO R&T Strategy which has been recently framed by the NATO Research and Technology Organization (RTO) in Paris, and approved by the North Atlantic Council (NAC), stops short of a development and acquisition role. This explains why, although the central role of NURC in the military capability development process is in the early stages, NURC is nevertheless involved in the design of Long Term Requirements. Since the technological solutions will have to be implemented in the armed forces given the constraints of the skills in our soldiers, NURC frequently participates in military exercises in order to keep in touch with "real life". In these last stages of the military capability development process, ACT staff under coordination of RADM Kerignard (FRA), and the NATO Naval Armament Group, play leading roles by working with NATO member states to implement NURC achievements.

Finally and most importantly, in his Commanders' guidance to the NURC, my boss Gen. L. Smith (USAF) has required that "*NURC will work closely with the Nations and partner NATO agencies to gain leverage and coordination on common activities, and contribute to NATO interoperability and military effectiveness. ACT requires a balanced effort between solutions for current operations and long term research and technology*". NURC is available to conduct or assist "crash development & acquisition programmes" and to be a depository of non-fully industrialized & operational equipment for use upon urgent request.

On behalf of the NURC, I would like to thank Admiral Sir Mark Stanhope (GBRN), Deputy Supreme Allied Commander Transformation, as he prepares to leave ACT this month, for his leadership and guidance. I would also like to acknowledge the NURC staff, who brought such enthusiasm and curiosity to produce the wonderful research, and the national institutes and companies that have contributed, directly or indirectly, with scientists and equipment without which this research would not have been possible.

François-Régis MARTIN-LAUZER
PhD, RADM (FRA, Eng. Corps, Res.)

2006 in Review

The Centre continues to advance its leadership role, within NATO, in conducting collaborative research in areas that are important to future NATO operations as well as continuing to support training and readiness of current NATO maritime forces. In this document we highlight collaborative sea trial activities and NATO experimentation conducted by the Centre in 2006.

For maritime research, the importance of going to sea to collect data to understand physical processes, to develop and validate models and algorithms, and to assess the performance of systems component technologies cannot be overstated. It is the unique combination of Centre and national scientists working together with an experienced engineering support staff and world class Research Vessels (NRV Alliance, CRV Leonardo) that allows NATO and the Nations to maintain technological superiority in maritime operations and address interoperability at an early stage of development.

Technology by itself does not provide a military capability. It is the co-development of technology and the tactics, techniques and procedures that begins to develop a capability to address NATO military problems of interest. For this reason, NATO experimentation is an important component of the Centre's programme to rapidly exploit new technology and to transform NATO maritime operations.

The Centre's Programme of Work in 2006 focused on the development and demonstration of transformational technologies in five major areas.

For Expeditionary Mine Countermeasures, the Centre made good progress in the development of capabilities to provide unrestricted maneuver of NATO forces across the littoral battlespace by focusing on transformational technologies that can detect and neutralize mines and underwater IEDs (improvised explosive devices) from a distance and that does not put the maneuvering force at risk.

In the area of Port Protection, the Centre focused on the development of technologies that contribute to a layered port and harbour force protection concept, integrating multiple levels of protection, awareness and deterrence. Significant progress was made in dealing with the underwater intruder threat. The work performed during 2006 has put the Centre into position to begin experimentation with technologies and concepts which integrate detection and response.

Efforts in Anti Submarine Warfare continued to focus on the development of multistatics and networking, environmental adaptation, as well advancing knowledge on how underwater sound affects marine mammals and the development of tools to mitigate their effect during NATO exercises.

For Expeditionary Operations, researchers at the Centre began to focus on technologies and techniques to provide environmental information in unknown or denied areas. As part of the ACT Experimentation programme, the Centre experimented with the use of commercial remote sensing for the surveillance of maritime vessels and developed techniques to obtain surf zone imagery from small, commonly operated unmanned aerial vehicles. Two highly complex sea trials were conducted (Dynamics of the Adriatic in Real Time (DART)) in the Adriatic to test and demonstrate the ability to provide real-time high resolution forecasts of shallow water and coastal meteorological conditions. These trials involved over 30 partners representing 15 NATO member nations and 2 PFP nations.

Finally, the Command and Operational group experimented with man portable autonomous underwater vehicles in the context of MCM and Port Protection and continued to provide expert advice and analysis to NATO maritime forces. The group was funded by ACT in 2006 to conduct two operational experimentation efforts. The result of these two experimentation efforts was the development of techniques for the detection of underwater IEDs and the integration of small AUV operations with MCM vessel operations, thereby increasing their effectiveness. Additionally, in response to a request to support a current NATO operation, Operation Active Endeavor, the Centre began to apply previously developed algorithms and techniques for queuing of ship tracking operations.

Douglas Todoroff
Deputy Director and Chief of the Scientific Division

Expeditionary Mine Counter Measures and Port Protection (EMP)

Modern NATO doctrine places great emphasis on expeditionary forces that will be prepared to deploy and operate anywhere in the world. The NATO Response Force is a critical element of these operations, in which rapidly deployable efficient MCM will be crucial. Additionally, for the NATO Conference of National Armament Directors (CNAD), the defence of maritime forces and installations against terrorist threats is the item of highest priority amongst those relating to maritime warfare.

The EMP thrust area aims to advance technologies for countering mines and IEDs, both for expeditionary forces and port protection. The effort necessarily covers a wide spectrum of technologies.

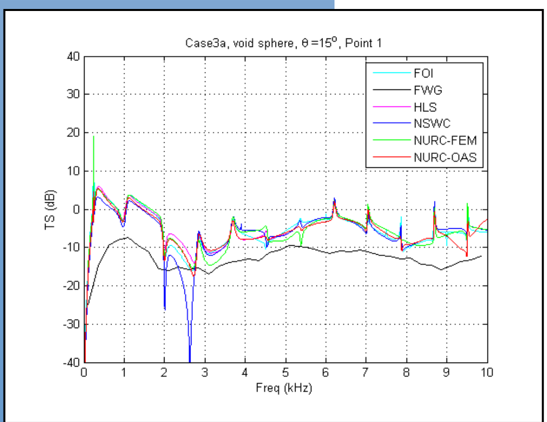
In the signals and systems project, the highlight of the year was undoubtedly the successful collection of high quality synthetic aperture sonar data with the MUSCLE AUV system during the Colossus'06 trial. Another significant technological development is the preparation of the SAS processing software in a form suitable for real-time implementation inside the AUV, to be finalized in 2007.

Participants engaged in an exercise at the Harbour Protection Trials in La Spezia, April 2006

In the area of basic acoustic scattering, low and high frequency target scattering models were developed, including the axisymmetrical finite element model AxiScat which was adapted as a benchmark and trialed successfully at sea.

A beta-version of the Fuzzy Logic Mine Model (FLMM) has been completed in the Mine-Ship Interaction programme. FLMM is being tested before integration into existing underwater software simulation environments. A review of the state of the art in underwater intruder detection technology has been completed, in preparation for the definition of clear concepts of use for their integration into a coherent, layered system to integrated surveillance and response.

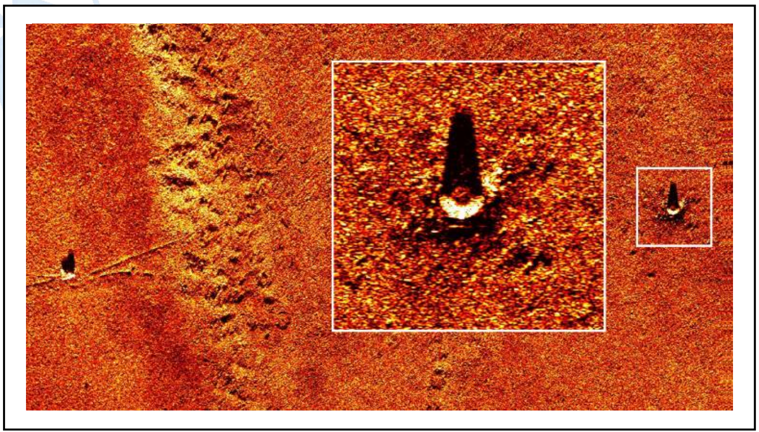
Unmanned systems



Model benchmarking workshop example: Target strength of a spherical target proud on the sea floor, as a function of frequency.

Work within the unmanned systems programme continued to generate knowledge and technology for unmanned minehunting. Work ranged from modelling and simulation studies to sea trials and the development of improved automatic target recognition (ATR) and navigation algorithms.

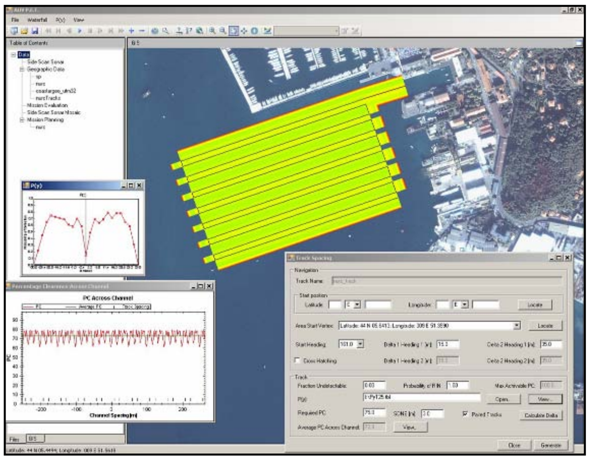
2006 saw the completion of the Centre's AxiScat modelling code which provides high-fidelity target strength simulations for axisymmetric objects at low frequencies. Validation of this model using targets filled with representative mock explosive was provided by the EVA sea-trial. Another highlight was the international modelling workshop, attended by Canada, Germany, France, the United Kingdom, Sweden, and the United States, which identified the state-of-affairs in target modelling within the NATO community.



Besides the development of sonar models, a simulation study evaluating the capabilities of different classes of AUV in a variety of MCM scenarios (including strategic sea line of communications, SLOC, and amphibious operation areas) was also completed. The survey demonstrated that a medium sized AUV with SAS is the preferred solution due to the combination of coverage rate and potential classification performance.

Right: SAS image of a dummy target shaped like a truncated cone of 1 m diametre and 45 cm height

Progress was also made in the development and testing of AUV technology. The COLOSSUS sea trial collected data which was used to analyse SAS performance in shallower waters. A review of AUV navigation technology including an analysis of the benefits of both SAS micro-navigation aiding and contact matching aiding techniques was also completed. There was also progress in automatic target recognition, where work with NATO nations resulted in the production of a new detection fusion approach (with Norway) and a fast SAS image generation model for model based classification (with the Netherlands). Planning and evaluation of AUV missions was addressed with further enhancement of the NURC Planning and Evaluation Tool. This tool uses a novel approach for the evaluation of missions that is based on recorded side-scan sonar data. The tool can now be used to generate ROC curves, P(y) curves, coverage maps, clearance predictions and optimised AUV tracks. The tool was demonstrated during the RIMPAC 06 exercise off the coast of Hawaii where it was used to evaluate missions carried out by the COMINEWARCOM UUV Platoon, and an interim version of the tool has been provided to nations participating in the project for their feedback to enable enhancements to the final version.



Screen shot of the NURC AUV planning and evaluation tool's graphical user interface

COLOSSUS'06 sea trial

The COLOSSUS'06 sea trial was held between the 28 April and 8 June 2006 on the Italian coast near La Spezia. The objective of the trial was to examine the performance of the MUSCLE AUV system which was operated by Thales and Bluefin personnel. The trial was conducted in water depths of between 20 and 80m, and a range of different target shapes were laid in order to examine sonar performance.

AUV-based SAS system deployed here was developed according to a high level design provided by NURC

A total of 30 vehicle runs were completed, with the vehicle spending nearly 36 hours underwater and gathering over one terabyte of sonar and navigation data.

Subsequent processing of the data has generated information which was used to support synthetic aperture sonar (SAS), automatic target recognition (ATR) and navigation research.

Processing of the sonar data demonstrated the ability of the NURC narrow vertical beam sonar design to achieve high contrast, 1.6 cm x 5 cm resolution y (in range and cross-range respectively), at ranges out to 170m in only 20m of water. The combination of high resolution and high levels of contrast provide an excellent basis for delivery of improved ATR performance as the project continues.

Expeditionary Mine Countermeasures and Port Protection (EMP)

Other key scientific data gathered during COLOSSUS'06 was navigation performance information for long (>10km) transits performed underwater using an aided inertial navigation system. Analysis of this data, coupled with information gathered from trials held in previous years has been used to: analyse the performance of current AUV navigation systems; evaluate the application of sensor-based navigation techniques to modern AUV-based systems; and evaluate the extent to which AUV navigation technology is able to meet operational MCM requirements.

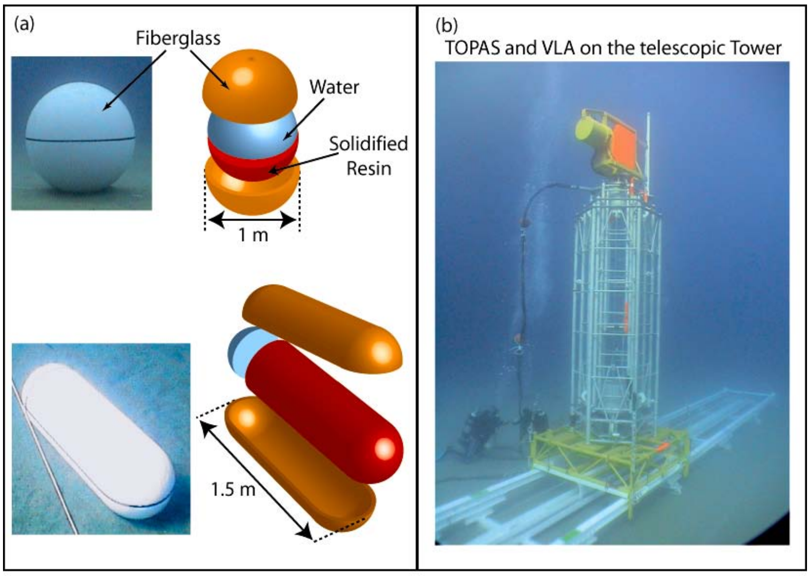
AUV being tested for automatic target recognition and sensor-based navigation

Experiments for the validation of acoustic modelling (EVA) techniques

The EVA'06 Sea Trial ("Experiments for the Validation of Acoustic modelling techniques") was conducted between 9 Oct and 2 Nov 2006 in shallow waters off the North Shore of the Elba Island as part of the 3G5 (Models for Mine-hunting Sonar) programme of work. EVA'06 included participants from the Massachusetts Institute of Technology (MIT), Applied Research Laboratory, University of Texas, Austin (ARL-UT), Marine Physics Laboratory-Scripps (MPL), Naval Research Laboratory, Stennis Space Center (NRL-SSC), Universidad de Las Palmas de Gran Canaria and the Italian Navy. The sea trial is composed of two independent parts: a low-frequency (2-15 kHz, 40 kHz) target scattering experiment aimed at investigating the echo structure of composite targets, and a sediment reflection characterization experiment.

The composite targets shown in Figure (a) below were designed to be representative of objects encountered in MCM and Port Protection applications, but also to be simple enough to allow for the validation of state-of-the-art models such as AxiScat (developed under Project 3G5). The composite materials chosen for the target shells and interior filling add a significant degree of realism compared to the steel and concrete targets employed during previous trials. For this reason, the EVA composite targets can also be used in high frequency experiments (100's kHz) for the acquisition of high-fidelity echoes, such as those needed to develop and train ATR classifiers.

Figure (b) shows the NURC rail and tower on which the TOPAS parametric low-frequency source was mounted. The source was equipped with a VLA for the reception of echoes backscattered from the EVA targets. The tower was connected to a shore lab on the Marciana Marina pier via a 200m cable. The rail and tower setup made it possible to illuminate the targets over a broad range of aspect angles.



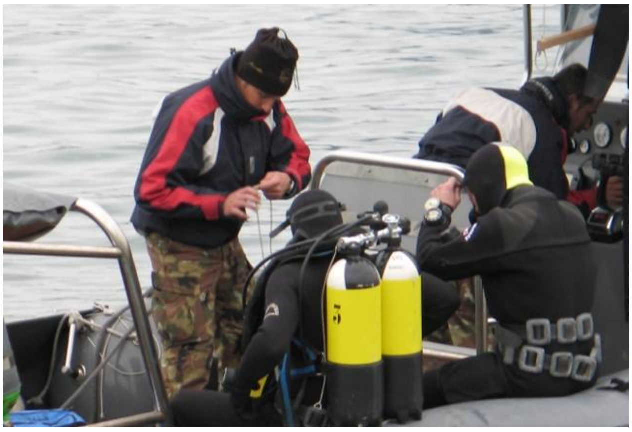
EVA composite targets (a) and TOPAS with VLA (b)

Divers working on the assembly of the rail and tower during EVA'06.

A horizontal array was mounted below the Leonardo for the simultaneous acquisition of multistatic far field echoes along tracks followed by CRV Leonardo using differential GPS navigation. The acoustic near field was also measured 360° around the targets using the NRL SSC rotating PVC dome structure, which was fitted with a 9 element NURC hydrophone array. The multistatic near field data is of fundamental importance for the study of the physical processes that contribute to the formation of low-frequency echo structure of targets.

The bottom scattering component of EVA'06 was conducted by ARL:UT at Biodola Bay. The broadband (5–80 kHz) multistatic bottom reflection data acquired was inverted to obtain frequency- and angle-dependent reflection coefficients. The bottom reflections parameters were correlated to the local small-scale roughness measured by a unique laser sheet line source video detection method using a modified Phantom HD-2 ROV. The EVA reflection measurement data will be used to validate sediment-acoustic interaction models, such as the NURC Boris-SSA code.

Matryoshka trial



Italian Navy divers prepare to simulate underwater intrusions during the Matryoshka trial

Harbours are home or host to NATO navies. They support trade and tourism, and they handle and store hazardous materials. If adjacent to a major city, they can feature in political or global sporting events. Harbours are therefore a security concern, particularly when there is a threat of terrorist attack. There is a sense of urgency now for improving security against terrorism, in part through threat characterization and advancing technology.

The Matryoshka trial was hosted by NURC in April 2006, with industry (QinetiQ), Defence R&D Canada, and the Italian Navy (COMFORDRAG) participating. The trial earned its name from the series of nested Matryoshka (Russian) Doll, which is how its methodology was first described. The idea was to progressively remove and change the equipment that an "intruding" diver wore, and to measure the strength of the diver's signature at each stage, collecting a complete set of measurements of dry-suit versus wet-suit, open-circuit versus closed-circuit breathers, and body versus bubble cloud, to isolate the main determinants of the diver signature. The in-situ measurement method was specially developed by NURC using a commercially-available intruder detection sonar (QinetiQ) rather than a scientific instrument.

QineticQ's Cerberus sonar being deployed to the harbour seafloor on a 5m tower

At the same time, the performance of the sonar was demonstrated to assess or validate (in part) the state-of-the-art in intruder detection generally. The range of detection and the tracking quality were therefore observed for many simulated intrusions staged over a number of days. Through this and other trials with different sonars, it was confirmed that the technology for underwater surveillance (monostatic active sonar) is ready for operational use, but that one must take changing oceanographic conditions into consideration. These conditions can significantly affect the propagation of sound in the harbour. Reports on the state-of-the-art review and diver measurements are available.

EMP publications and presentations

Peer reviewed journal papers (submitted)

Bellettini, A., Pinto, M. Design and experimental results of a 300 kHz synthetic aperture sonar optimized for shallow water operations. IEEE Journal of Oceanic Engineering (special issue on SAS).

Bovio, E., Cecchi, D., Baralli, F. Autonomous underwater vehicles for scientific and naval operations. *Annual Reviews in Control.*

Groen, J., Hansen, R.E., Callow, H.J., Sabel, J.C., Saebo, T.O. Shadow enhancement in synthetic aperture sonar using fixed focussing. *IEEE Journal of Oceanic Engineering*.

Sparr, T., Hansen, R.E., Callow, H.J., Groen, J.Enhancing target shadows in SAR images. *IEE Electronics Letters*.

Stevenson, M., Tesei, A., Guerrini, P., Folegot, T., Sabra, K., Roux P., Song, H., Kuperman, W.A., Hodgkiss, W.S., Akal, T., An acoustic tripwire based on forward scattering in a time reversal mirror. *U.S. Journal of Underwater Acoustics* (in press).

Tesei, A., Fawcett, J.A., Lim, R. Physics-based detection of man-made elastic objects buried in high-density-clutter areas of saturate sediments. *Applied Acoustics*, Special Issue (in press).

Reports

Bovio, E., Rothenbach, M., Robichaud, R., Yip, H., Baralli, F., Sodhi, M. MX3 Trial Report: Percentage Clearance Trials with Autonomous Underwater Vehicles. NURC-FR-2006-007, NATO Restricted.

Jensen, F.B., Zampolli, M., Tesei, A. Proceedings of the Target Strength Modelling Workshop, 6-8 September 2006, La Spezia, Italy . NURC-CP-2006-003, NATO Unclassified.

Kessel, R. Proceedings of the NURC Underwater Intruder Workshop, 27-28 Feb 2006. NURC-CP-2006-002, NATO Unclassified.

Petillot, Y., Reed, S., Myers, V. Planning and evaluation of MCM missions using AUVs: mixing real and simulated data. NURC-FR-2006-017, NATO Restricted.

Zampolli, M. FESTA User Guide Beta-Version 1.0. NURC-SP-2006-004. NATO Unclassified.

Zampolli, M., Tesei, A., Blotman III, J.B. Scattering from axially symmetric objects: theory, FEMLAB model implementation and results. NURC-FR-2006-010, NATO Unclassified.

Conference presentations

Baralli, F., Bovio, E. Autonomous Underwater Vehicles for MCM Operations. MINWARA Conference, Monterey, May 2006.

Bellettini, A., Myers, V. Towards realistic mission performance prediction: sonar image resolution assessment in theory and practice. MINWARA Conference, Monterey, May 2006.

Bovio, E. AUVs for MCM operations in ports and harbours. RTO Workshop SCI-182 Techniques and Technologies for Unmanned Autonomous Underwater Vehicles (AUVs) - A Dual Use View, October 2006.

Canepa, G., Berron, C. Characterization of seafloor geo-acoustic properties from multibeam data. OCEANS 06, September 2006.

Canepa, G., Pouliquen, E., Lyons, A.P. Underwater digital photogrammetry measurement of small scale roughness: limits to spatial accuracy. OCEANS'06, September 2006.

Canepa, G., Harrison, C.H. Spherical wave scattering from rough surfaces: simulation and experimental verification. 8th European Conference on Underwater Acoustics (ECUA 2006), June 2006.

Canepa, G. The limits of small slope approximation for scattering prediction from rough surfaces at low grazing angles. OCEANS'06, September 2006.

A crane was used to precisely position a target to study the signatures recorded by an underwater intruder detection sonar.

Canepa, G., Pouliquen, E., Lyons, A.P. Underwater digital photogrammetry measurement of small scale roughness: limits to spatial accuracy. OCEANS'06, September 2006.

Evans, B., Baralli, F., Bellettini, A., Bovio, E., Hollett, R.D., Myers, V., Pinto, M. AUV technology for MCM and port protection. RTO Workshop SCI-182 Techniques and Technologies for Unmanned Autonomous Underwater Vehicles (AUVs) - A Dual Use View, October 2006.

Evans, B., Bellettini, A., Hollett, R.D., Munk, P., Myers, V., Pinto, M. Experiments with AUV based SAS systems. Institute of Acoustic conference on Synthetic Aperture Sonar and Synthetic Aperture Radar, September 2006.

Hollett, R.D., Bellettini, A., Pinto, M. A real-time imaging algorithm for narrow-sector synthetic aperture sonar. Institute of Acoustic conference on Synthetic Aperture Sonar and Synthetic Aperture Radar, September 2006.

Engineering staff deploying a multi-sensor tower during a sea trial.

Hollett, R., Kessel, R., Pinto, M. At-sea measurements of diver target strengths at 100 kHz: measurement technique and first results. UDT Europe 2006, June 2006.

Jensen, F.B., Nielsen, P.L., Zampolli, M., Collins, M.D., Siegman, W.L. Benchmarking range-dependent seismo-acoustic propagation problems. 8th European Conference on Underwater Acoustics (ECUA 2006), June 2006.

Kessel, R.T. The dynamics of information fusion: synthesis versus missassociation. 9th International Conference on Information Fusion, July 2006.

Kessel, R.T., Hollett, R.D. Force protection in ports: integrated surveillance and response against underwater intruders. SCI Nato Symposium "Force protection in the littorals", September 2006.

Kessel, R.T., Hollett, R.D. Underwater Intruder Detection Sonar for Harbour Protection: State of the Art Review and Implications. IEEE International Conference on Technologies for Homeland Security and Safety 2006 (TEHOSS 2006), October 2006.

Myers, V., Davies, G., Petillot, Y., Reed, S. Planning and evaluation of AUV missions using data-driven approaches. MINWARA Conference, Monterey, May 2006.

Myers, V., Evans, B., Hopkin, D., Crawford, A., Fawcett, J., Zerr, B., Hagen, P.E., Flores, M. The CITADEL and SWIFT joint experiments with unmanned vehicles for minehunting and high frequency sensors. MINWARA Conference, Monterey, May 2006.

Myers, V., Pinto, M. Open issues in automated target recognition for high resolution sonar imagery. Institute of Acoustic conference on Synthetic Aperture Sonar and Synthetic Aperture Radar, September 2006.

Myers, V. Probabilistic modelling of synthetic aperture sonar and radar image textures. Institute of Acoustic conference on Synthetic Aperture Sonar and Synthetic Aperture Radar, September 2006.

Pinto, M., Bellettini, A., Hollett, R. A comparative review of high resolution synthetic aperture sonar and radar research. Institute of Acoustic conference on Synthetic Aperture Sonar and Synthetic Aperture Radar, September 2006.

Pinto, M., Evans, B., Myers, V., Bellettini, A., Hollett, R., Munk, P. Towards truly autonomous underwater vehicles for minehunting. Maritime Systems and Technology for Defence, Security and Safety (MAST), September 2006.

Sodhi, M., Swaszek, P., Bovio, E. Stochastic line search using UUVs. 9th International Conference on Information Fusion, July 2006.

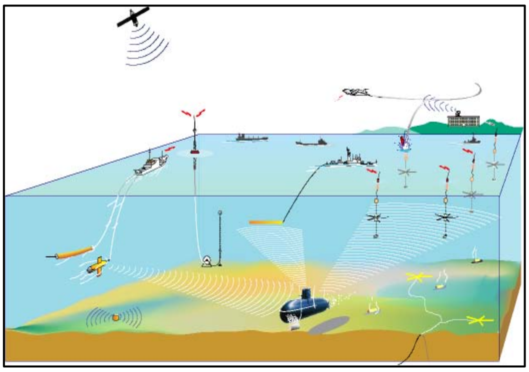
Tesei, A., Zampolli, M., Fawcett, J.A. Acoustic scattering from solid-filled spherical shells: parametric study of elastic effects. 8th European Conference on Underwater Acoustics (ECUA 2006), June 2006.

Zampolli, M., Tesei, A., Jensen, F.B., Blottmann, J.B. Perfectly matched layers for the numerical approximation of the radiation boundary condition in structural acoustic finite element tools. 4th Joint Meeting of the Acoustical Society of America and Japan, Honolulu, November 2006.

Reconnaissance, Surveillance and Networks (RSN)

RSN conducts ASW research in the areas of distributed sensor fields, network-enabled data fusion, active broadband detection and classification enhancement methods, and operational and exercise planning tools.

Activities in the RSN Thrust Area respond to NATO's operational requirements in order to improve the effectiveness of the ASW component of future expeditionary warfare. While the focus remains on shortfalls in littoral undersea surveillance, new requirements for autonomy of sensor platforms, persistence of deployed fields and adaptation to threat and-or environmental changes are driving the research effort.



Graphical depiction of a coalition of maritime networked assets

To this end, two new activities have been introduced: performance of AUV-based active ASW for stand-off barrier operations and automated reduction of false alarms due to shallow water clutter in wideband Low Frequency Active Sonar (LFAS).

In 2006 progress has been made in the areas below.

- Utilising the Deployable Multistatic (DEMUS) system as a test-bed for a future autonomous capability using distributed sensor fields, a new signal and information processing string for a centralized architecture was implemented and tested. Each DEMUS processing chain now elaborates, fuses and tracks the combined outputs of matched filter and Doppler processors. A new, more robust version of NURC's EKF-MHT track-fusion (centralized and/or distributed) algorithm was developed and validated with pre-DEMUS 06 trial data. The system modelling work is now complete in the Multistatic Tactical Planning Aid, MSTPA, and this sophisticated modelling capability was able to satisfy the demanding requirements of the complex sea trials CERBERUS 01 and ADULTS 03, using processed LFAS measurements.

- In the field of LFAS environmental adaptation methods, based on the through-the-sensor environmental assessment methods, the feasibility of a (manual) system concept integration was demonstrated during BABO 06 in the Malta Plateau area. Progress has been made in large-scale area assessment with the effective inclusion of LFAS reverberation measurements in the geo-acoustic inversion scheme.

- Work in non-acoustic reconnaissance and surveillance of port exits or choke points has continued with the development of two new NURC platforms containing electric field sensors in addition to the standard magnetometer + acoustics suite.

- Following the successful completion of the Focused Acoustic Fields (FAF) trial series, where it was shown that 15 KHz multiple input / multiple output (MIMO) communications were feasible, the high-level design of the "Modem-on-the Rope" is now complete. This will primarily enable testing various network topologies or underwater communication protocols with great deployment/ recovery and programming flexibility. Additional applications involve the networking of long term environmental monitoring sensors, such as those designed for marine mammals.

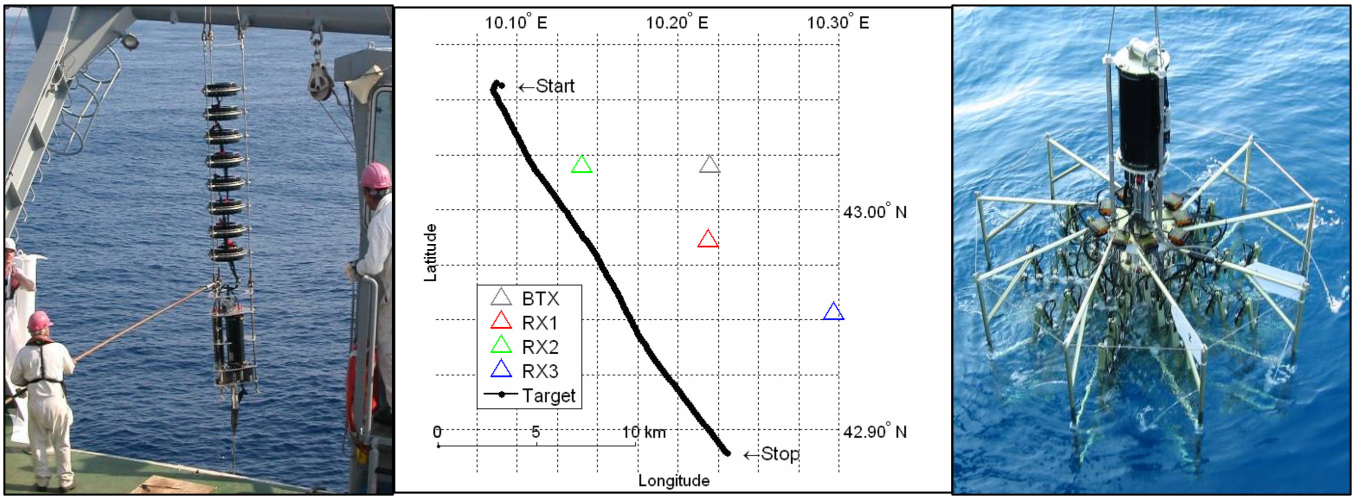
- Upgrades to the Centre's modelling capabilities in the marine mammals risk mitigation programme have included:

  1. the incorporation of the acoustic propagation model, Bellhop, which accounts for depth-dependent sound speed profiles and range-dependent bathymetry in the frequency spectrum used by tactical sonars,
  2. links to ocean databases other than the Mediterranean Sea.

  Additionally, automated methods for marine mammal detection, classification and localization sensors (specifically for Cuvier's beaked whales) were tested at sea during SIRENA 06. This will serve, in the near future, to support the development of the Mediterranean Sea habitat model through the use of autonomous platforms such as the newly acquired spray glider.

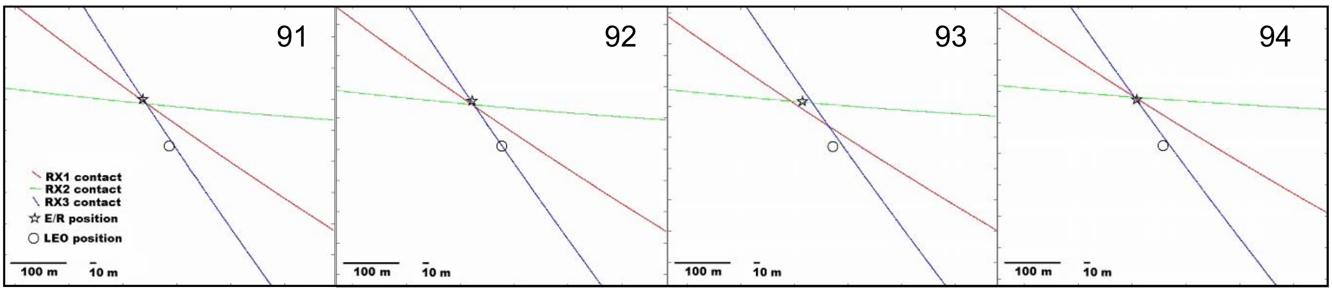
Multistatic sonar trial — Pre-DEMUS 06

A major advantage of a multi-static set-up (compared to mono-static sonar) is the dramatically increased localization accuracy. With data gathered in an engineering trial to check the reliability of the Deployable Multistatic Sonar (DEMUS), high-precision target tracking at large distances was successfully demonstrated. The trial was conducted in February, north of the Isle of Elba, and involved NRV Alliance, CRV Leonardo, MV Krill (CETUS) and Menkab (University of Genova).



DEMUS consists of an acoustic source (left) and three acoustic receiver buoys (right). This multi-static system was deployed in shallow water and covered a large surveillance area (middle).

For the fusion of target contacts, signal echoes from all receiver buoys containing time-delays and Doppler-frequency shifts were utilized. As an excerpt of the complete data set, a short sequence of the acoustic target track reconstruction is shown below. The crossing point (or small "crossing area") of the three colored lines determines the position of the target echo, the star is the known "ground-truth" position of the echo source. As in this excerpt the localization accuracy of the acoustic track reconstruction can be maintained to be within a few meters for the complete data set. This accuracy is more than ten times higher than the accuracy that a mono-static system is able to achieve.



Multistatic localisation accuracy after fusion of contact data from three DEMUS receivers

BABO '06 sea trial

Reconnaisssance, Surviellance and Networks (RSN)

Engineering staff deploying equipment during the BABO '06 sea trial

The BABO '06 sea trial was conducted under the auspices of the Environmental Adaptation Programme, which has as its main objective the improvement of LFAS performance in the littoral through exploitation of local environmental conditions.

The specific objectives of BABO '06 were:

1. testing sub-band processing techniques in order to enhance broadband detection performance,
2. applying through-the-ASW-sensor (TTS) inversion algorithms to obtain *in situ* bottom parameter estimates,
3. acquiring data to identify new or investigate known bottom scattering features by bathymetric and side scan surveys in high clutter areas where detection is likely to be challenged,
4. comparing real and modelled data to verify the on board modelling capability for tactically relevant times.

Task (i) was provided through the 4C3 (Broadband Environmentally Adaptive Sonar Concept) project, tasks (ii) and (iii) through the 4C2 (Through-The-Sensor Environmental Assessment Concept) project and task (iv) via the 4C4 project. BABO '06 was a brief sea trial experiment and was conducted in preparation for the Clutter '07 and BASE '07 experiments in 2007 and in support of the new 4C5 (Wide-band LFAS Clutter Characterization) project related to clutter characterization.

With regard to broadband signal analysis (4C3-task (i)), sub-band processing techniques were applied to demonstrate that detection performance can be enhanced through frequency agile techniques where wide bandwidth returns are divided into smaller sub-bands, suitable to the particular environment, which are processed in parallel. Detection improvement relative to the full bandwidth case can be obtained in two ways: firstly by identifying sub-bands, i.e. frequency regimes, with higher SBR with respect to the full bandwidth (this may be attributed either to higher signal or lower clutter/background return) and secondly by reducing clutter interference through clutter information fusion for each sub-band. The latter is demonstrated in Figure 1. The left plot shows a contact map obtained during BABO '06 in which contact clues from each sub-band are used to reduce clutter interference. The middle plot shows the same map corresponding to the full bandwidth in which the number is false targets (see area (a)) and the noise contacts are higher than previously (see area (b)), while the actual target track (see area (c)) is less populated than in the sub-band case. The overall detection performance of the full bandwidth (blue) is compared with that of two sub-band schemes (red and yellow) based on clutter persistency, shown in the right plot. The advantage offered by sub-band signal processing is evident, as for the same false alarm rate sub-band processing provides higher probability of detection.

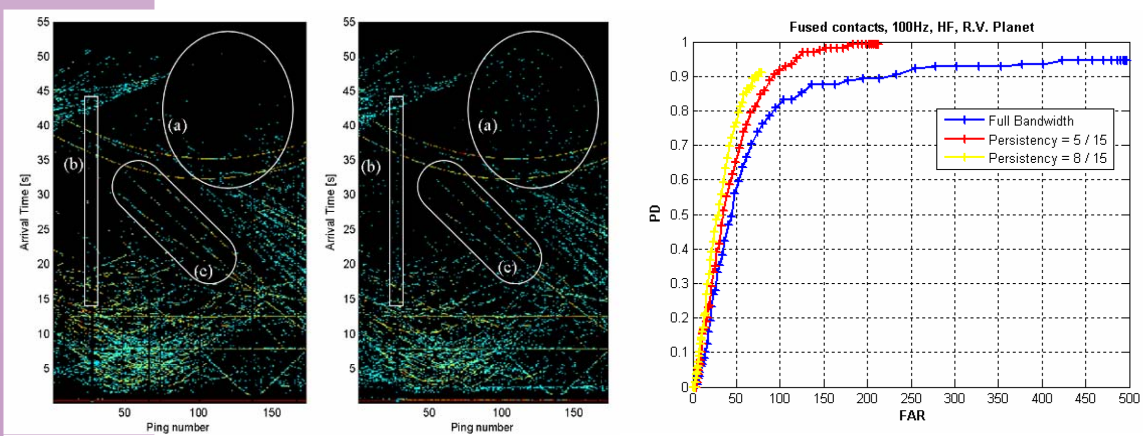


Figure 1: BABO '06 data. Sub-band detection performance comparison (red and yellow) with full bandwidth analysis (blue) based on Receiver Operating Characteristics plots.

With regard to 4C2, a bathymetric survey was conducted by NRV Alliance using the newly installed Atlas hydrosweep MD-2 system to identify clutter features detected in previous sea trials on long-range sonar displays. This survey was supported by the German research vessel RV Planet conducting sub-profiling and side scan measurements. The bathymetric survey was confined to cover an area of 220 km2 [Fig. 2 (a)] and the processed swath bathymetric data are shown in Fig. 2(b). The acquired sub-bottom profiles and side-scan images (Fig. 3) clearly show exposed bottom features consistent with the Atlas swath survey.

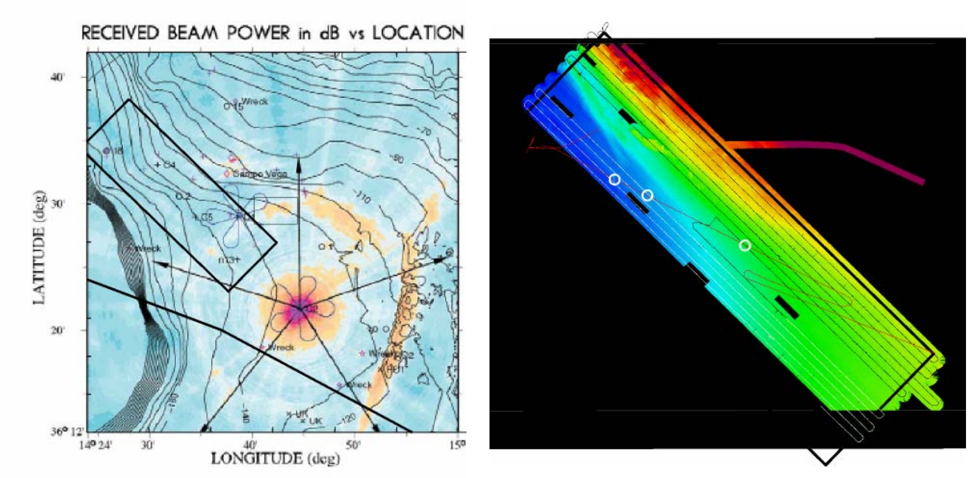


Figure 2:
(a) Left: Location of bathymetric survey indicated by black box and;
(b) Right: Processed Atlas swath bathymetric data.
In (b) the red track diagonal to the survey box indicates sub-bottom profiling and side scan measurements performed by RV Planet. The white circles are bottom features causing clutter returns in previously acquired sonar displays.

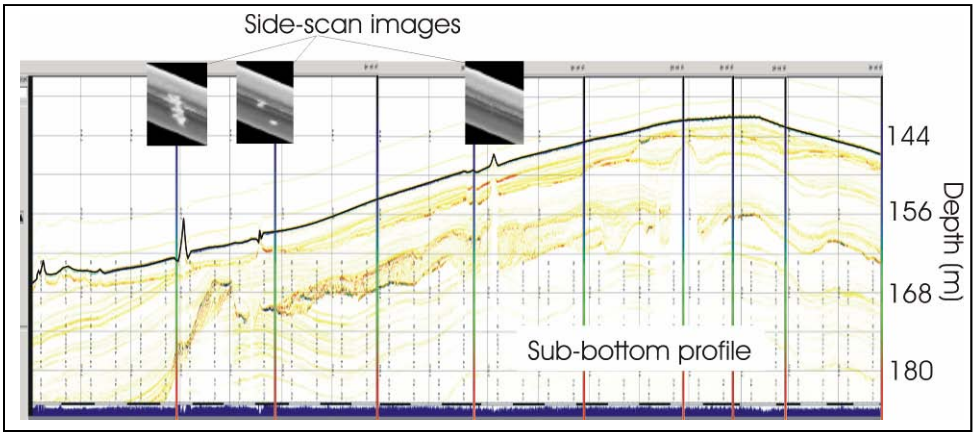


Figure 3. Sub-bottom profile acquired along the red track indicated in Fig. 2 (b) by RV Planet. Inserts of side-scan images show bathymetric features at locations consistent with the sub-bottom profiles and Atlas swath. The bathymetry in the sub-bottom profiles is highlighted by thick black line clearly showing obstacles on the bottom.

Through-the-sensor inversion techniques were also applied in-situ while operating the LFAS system along specified tracks during the BABO '06 experiment. The inversion algorithm provided seabed geoacoustic models along the tracks from sequential received acoustic signals, within tactically relevant time frames (5 to 10 minutes per inversion) (see Figures 4 and 5). A qualitative evaluation of the inversion results was performed before updates of seabed properties were delivered to the general sonar performance model SUPREMO.

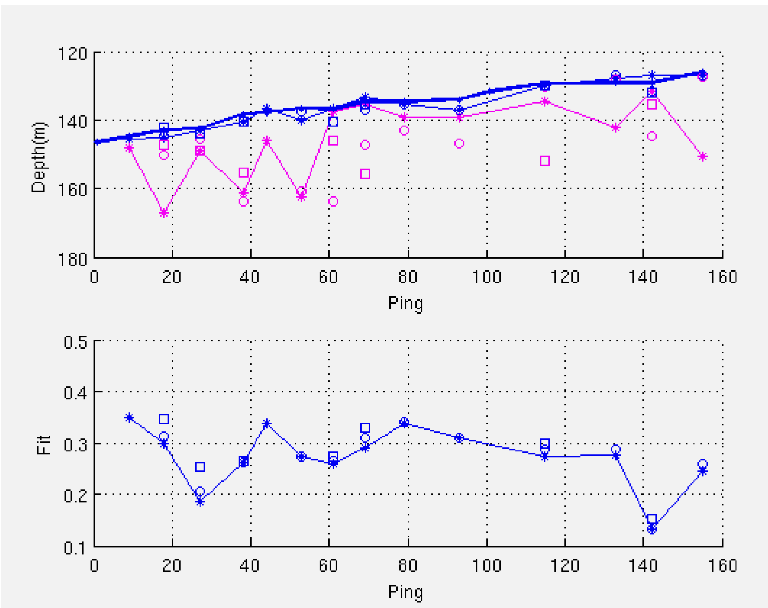
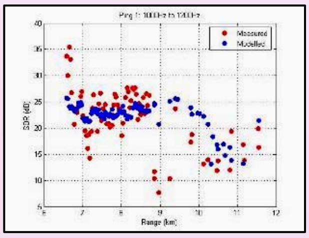


Figure 4. Example of Ping-to-Ping inversion along a track. Top: The inverted model is looked for as an upper sediment layer above a basement. In blue, the inverted bathymetry (thin) compared to the measured bathymetry with a classical vertical echo sounder. In magenta the position of the inverted basement. Bottom: One indicator of the quality of the inversion consists in comparing the spatial structure of the measured and the predicted acoustical pressure field along the towed HLA with the inverted seabed model. A perfect fit between prediction and measurements would be zero.

Reconnaisssance, Surviellance and Networks (RSN)



Output screen from SUPREMO, a sonar modelling tool

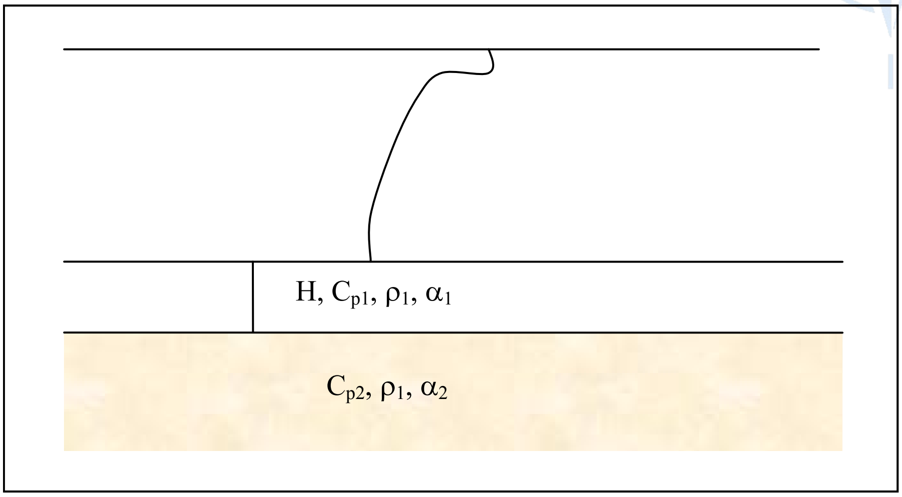


Figure 5. Typical representation of the seabed geoacoustic model was described by 6 geoacoustic parameters. For the upper sediment: thickness of the layer H, compressional speed Cp1, attenuation ˜ $_1$ and density ˜ $_1$. Idem for the basement with infinite height. Note that due to lack of sensitivity to the density parameter, density of the sediment layer and the basement were imposed to be equal.

With regard to modelling capabilities, it must be noted that the environmentally adaptive sonar concept being developed under project 4C3 uses a sonar performance model to:

1. predict received intensity on the sonar array so that this can be compared to the measured data and any mismatch can be quantified to give an assessment of the quality of the current environmental description data,
2. predict settings for pulse band and processing scheme that will optimize target detection.

SUPREMO, the model that will fulfill these roles, is being developed under project 4C4 (SUPREMO Multistatic Sonar Model). During BABO '06, SUPREMO successfully performed the first task listed above, within short enough timescales for the model to be applicable within the environmentally adaptive sonar concept. The model was run on a standard PC and predicted received intensity in run times around 20s, a time which is, crucially, shorter than the one-minute ping acquisition time of the LFAS sonar. Thus, the model was shown to be capable of predicting received intensity fast enough for one comparison to be made for each ping transmitted. The model used environmental description data provided by TTS methods developed under 4C2. These data were themselves deduced from the sonar data. The disagreement between model predictions and measurements was generally good. An example of the data is shown in Figure 6, along with a histogram of the decibel difference between predictions and measurements. The figure shows that the most frequently occurring model-measured difference was about 1dB and that the majority of absolute differences were less than 5dB.

The operation of SUPREMO at sea and the associated good model-measured agreement was a significant milestone in the process of producing a sonar performance model for integration within an environmentally adaptive sonar.

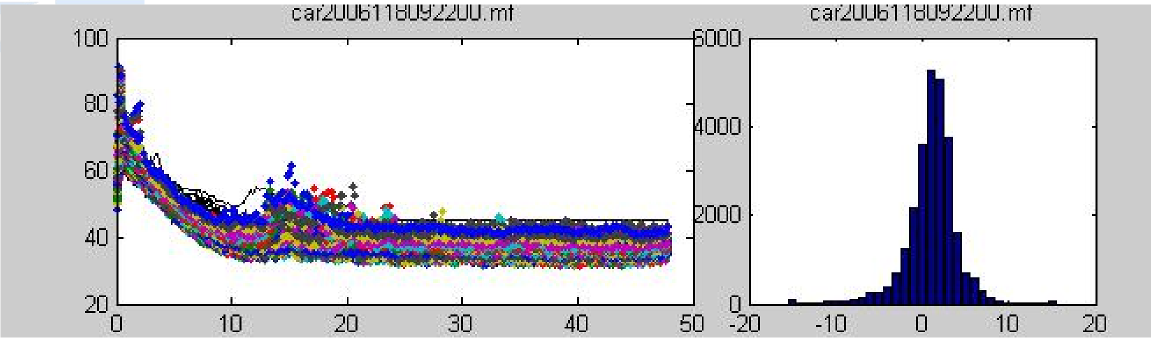


Figure 6: Screenshot taken during at-sea operation showing calibrated, measured sonar data (in dB re 1 micropascal) as coloured dots in left-hand pane, plotted as a function of time in seconds. Also shown in the same pane are model predictions, shown by black lines in the same axes. Right-hand pane shows a histogram of the decibel difference between model predictions and calibrated measurements.

Sirena '06 / Zifio '06 sea trials

From 17 July – 8 August 2006, NURC along with 16 partner organizations with over 60 scientists and technicians from 6 nations onboard 5 vessels conducted the Sirena '06 & Zifio '06 sea trials in the Ligurian Sea and the Sea of Corsica. The partner organisations represented were: SPAWAR; Acquario di Genova; ICRAM (Istituto Centrale per la Ricerca Applicata al Mare); Museo Storia Naturale Milano; Politecnico Milano; Aquastudio; GREC- France; Marine Defense – France; Istituto Idrografico – Spain; CETUS; Universita Degli Studi di Genova; BLUWEST; WHOI (Woods Hole Oceanographic Institution); Naval Oceanographic Office (USA); ISMAR CNR (Consiglio Nazionale delle Ricerche); BLUEFIN.

The Ligurian Sea and Sea of Corsica are important habitats of marine mammals and particularly the Genoa canyon for *Ziphius cavirostris* (*Zc*), Cuvier's Beaked Whale. They have been observed during all seasons in this area and, being strongly suspected to be extremely sensitive to active sonar transmissions during certain oceanographic conditions and geometries, are the primary subjects for Project 4F1 (Marine Mammal Risk Mitigation). The project has dedicated several sea trials over the years to the collection of animal sighting data as well as both physical and biological oceanographic data in this region. The compiled data set provides the basis for a detailed habitat model which will be further developed in 2007, to be tested/verified in other parts of the Mediterranean in 2008 & 2009.

Spray glider being deployed from the Leonardo during its acceptance test.

The Sirena '06 / Zifio '06 sea trials focused on adding to this data base by doing extensive visual and acoustic sighting surveys as well as correlated oceanographic measurements.

In addition, work was undertaken to do a sea acceptance test of the Spray Glider. While the glider did not pass its acceptance test, there was a substantial amount of acoustic sighting worked done with the V-Fin tow body, the EARS Buoys and the Pop-Up Buoy.

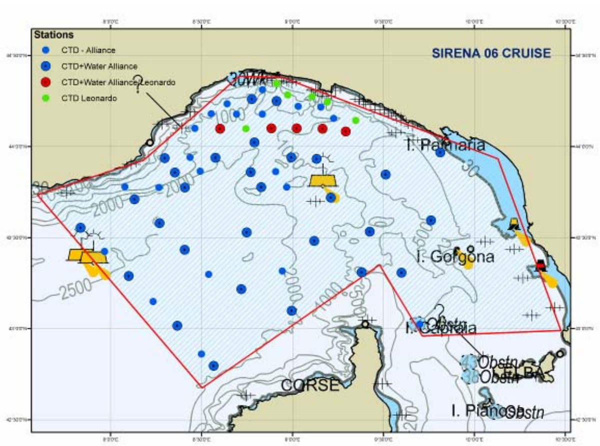
Some of the sea trial data includes a total of 65 oceanographic stations, 54 on Alliance including 34 with water sampling, 11 on Leonardo including 4 with water sampling, a total of 138 animal sightings including 1170 individual animals: 122 sightings of 1048 animals including 4 Ziphius on the Alliance and 16 sightings of 122 animals on the Leonardo. The BLUWEST & WHOI team were able to tag a total of 3 Beaked whales with the WHOI D-Tag.

One of the most interesting discoveries of this sea trial was the low numbers of beaked whales sighted in what is normally a fairly high abundance area. The beaked whales that were sighted were more to the Southwestern portion of the operation area and the most obvious correlate for this was the higher than normal water temperatures for this time of year. Unfortunately there is no way to verify this or to determine if it is a direct function on the animals or a function to the food source and thus an indirect function on the animals.

Reconnaisssance, Surviellance and Networks (RSN)

Engineering staff getting ready to deploy the topas acoustic source tower at the FAF 06 sea trial

All of the data gathered on this sea trial and the previous ones will be used to develop a robust habitat model for beaked whales in the Ligurian Sea area. This information will be used as one of the predictive tools for Centre scientists and fleet commanders to assess the potential for a given area of the sea or ocean to contain beaked whales and other marine mammals that may impede research sea trials or normal naval training. In addition, the passive acoustic work that was done on this and other sea trials brings us one step closer to having easily fieldable hardware to determine, in a tactically relevant timeframe, the presence or absence of whales in an operation area. Finally the tagging work that was done is vital to determining the normal behavior pattern of these animals. When we are able to conduct behavioral response studies to active sources, we know what the baseline is, to compare with this important data.



Area surveyed during the Sirena'06/Zifio'06 sea trial

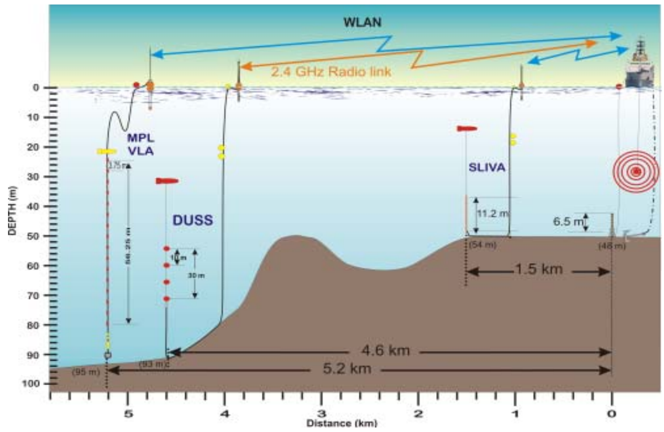
Focused Acoustic Fields (FAF) '06

The application of digital communications theory has substantially advanced the underwater acoustic telemetry state of the art. This includes the development of increasingly sophisticated receivers designed to realize the potential channel capacity of the undersea acoustic medium. Even so, sound propagation through the ocean suffers distortion and dispersion— from multi-path, scattering, Doppler spread, and short coherence times—that can confound these receivers, especially in shallow littoral waters. Moreover, frequency-dependent attenuation increasingly restricts spectral bandwidth with transmission range. Non-white ambient noise further impairs the acoustic communications medium, especially in littoral oceans where noise variations can be extreme. Spectrally efficient techniques are required to increase throughput. MIMO (Multiple-Input-Multiple-Output) techniques may help solve these problems.

The FAF '06 sea trial addressed environmentally adaptive digital underwater communications research that could eventually facilitate the implementation of an operational underwater surveillance system that includes distributed off-board sensors. The envisioned concept would allow an autonomous sensor system to covertly transmit signals via digital acoustic modem within an undersea network. The technique could also be applied to a mine detonation messaging. The motivation for this is that success of the network-centric warfare concept applied to undersea warfare depends upon distributed, autonomous sensors. This in turn requires new development of deployable detection-resistant acoustic communications.

Deployment of the Marine Physical Laboratory, Scripps Institution of Oceanography's surface and radio communication buoy

The FAF '06 sea trial addressed research issues at Technology Readiness Level 2, building upon a foundation groundbreaking experimental work in underwater acoustic time-reversal acoustics conducted at NURC since 1996. Analysis suggests applications of this technique to undersea communications whereby time reversal provides an opportunity to implement space-time multiplexing in complex environments. Our experiments indicate that vertical aperture provides a capability for implementing MIMO communications, which may increase data throughput without increasing power or bandwidth. Eventually, this work will be extended to mobile communications nodes in mid-water column.



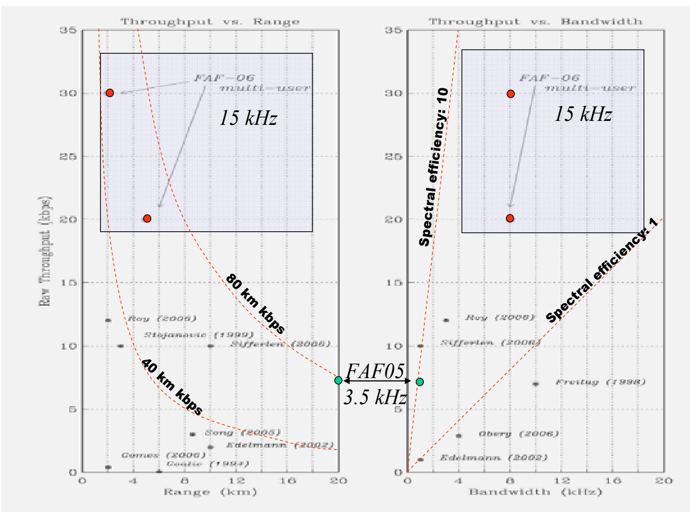
The FAF '06 transmit and receive array configuration provided a range of opportunities to test the spatial diversity provided by acoustic time reversal methods. An array of 12 transmitters deployed in the bottom 10 m of the water column sent digital communications sequences to three receive arrays deployed in deeper water

Since 1996, a series of sea trials were conducted to experimentally test acoustic time reversal methods in the sea. Through a progression of experiments, the concept of underwater, acoustic time-reversal (TR) focusing in the sea developed from an unverified hypothesis to reality. When the experiments began, it was completely unknown whether the time-varying nature of the oceanic environment would support sufficient temporal stability for the method to succeed, even at long (λ>3 m) acoustic wavelengths. A 10-year progression of experiments showed that not only was this possible, but that various applications could be implemented using higher frequency sound (up to 18 kHz), including phase coherent digital communications. These sea trials have always been a cooperative effort between the scientific, engineering and ship staffs of NURC and its predecessor organizations, and scientists and engineers of the Marine Physical Laboratory (MPL) at the Scripps Institution of Oceanography (SIO).

The FAF '06 experiments built upon knowledge acquired during experimental work dating as far back as the 1960s, some of which was classified. For example, Antares Parvulescu and Clarence Clay were awarded a classified patent in 1962 based on a point-to-point experiment that established a basis for the technique that they then called matched-signal processing whereby the ocean was considered as a time-varying correlation processor. Extending this theory, we investigated multiuser applications for passive TR communications using progressively complex array geometries with small transmit and receive arrays. The theory behind this is described in D. Rouseff, D.R. Jackson, W.L.J. Fox, C.D. Jones, J.A. Ritcey, and D.R. Dowling, "Underwater acoustic communication by passive phase conjugation: Theory and experimental results," IEEE J. Ocean. Eng., 26(4), 821-831 (2001).

During FAF '06, data rates of 10-20 kbps for single user communication were demonstrated between a single element of the Topas source array and the 16-element MPL vertical receiver array at ranges of 2 and 5 km in a shallow-water propagation channel where the transfer function had an ISI span of several hundred symbols. Using 16-QAM at 2 km range resulted in a data rate of Rb=20 kbps (R=5000 symbols/s) and using 8-QAM at 5 km range resulted in Rb=15 kbps (R=5000 symbols/s). Both cases use a bandwidth of W=7500 Hz (11250-18750 Hz) around the center frequency of fc=15000 Hz. This compares favorably with the state of the art, as depicted in the following figure.

Some Communications Comparison Metrics



Following the performance metric comparison in Kilfoyle and Baggeroer, "The State of the Art in Underwater Acoustic Telemetry", IEEE JOE 25, 4-27, 2000, some recent results are plotted to provide a general basis for measuring progress in the six years since that publication was released

RSN publications and presentations

Peer reviewed journal papers (submitted)

Coraluppi, S., Carthel, C., Grimmett, D., Gérard, O. Multistatic sonar tracking: algorithmic advances and sea trial evaluation. *U.S. Navy Journal of Underwater Acoustics*.

Zimmer, W.M.X., Tyack, P. Beaked whales and decompression sickness. *Marine Mammal Science*.

Reports

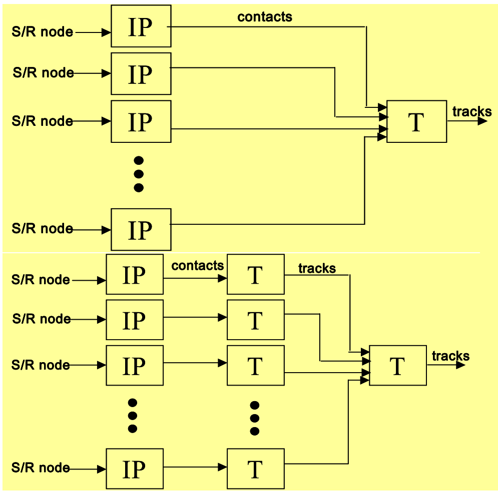
Coraluppi, S., Baldacci, A., Carthel, C., Willett, P., Lynch, R., Marano, S., Farina, A. The Ninth International Conference on Information Fusion (Fusion 2006): Final Conference Report. NURC-SP-2006-005.

Coraluppi, S., Grimmett, D. Benchmark and sea-trial performance of nearest-neighbour multistatic sonar tracker. NURC-FR-2006-018, NATO Confidential.

Crowe, D.V. Present and future in-buoy processing for the DEMUS system. NURC-MR-2006-003, NATO Unclassified.

Erdinc, O., Coraluppi, S., Willett, P., Grimmett, D. Sonobuoy placement for optimal multistatic detection and localization. NURC-FR-2006-020 / SR-440, NATO Unclassified.

Gérard, O., Coraluppi, S., Grimmett, D., Carthel, C. Performance of centralized and distributed tracking for multistatic ASW scenarios. NURC-FR-2006-001. NATO Confidential.



Methods for performance comparison between different fusion/tracking architectures are described in several RSN publications.

Grimmett, D., Coraluppi, S. Multistatic active sonar system interoperability, data fusion, and measures of performance. NURC-FR-2006-004, NATO Unclassified.

Grimmett, D., Coraluppi, S., Laterveer, R., Bongi, S., Baldacci, A.,Fox, W. Performance of a distributed multistatic surveillance network during the DEMUS'04 sea trial. NURC-FR-2006-015, NATO Confidential.

Grimmett, D., Wathelet, R. Proceedings of the NATO Workshop on Multistatic Operations Research, 15-17 November 2005. NURC-CP-2006-001, NATO Restricted.

Haralabus, G., Baldacci, A. Active detection performance sensitivity to target depth and aspect changes in a shallow water environment. NURC-FR-2006-006, NATO Confidential.

Marine Mammal Risk Mitigation Project. NATO Undersea Research Centre Human Diver and Marine Mammal Risk Mitigation Rules and Procedures. NURC-SP-2006-008.

Nielsen, P. L. Simultaneous inversion of propagation and reverberation data. NURC-FR-2006-023, NATO Unclassified.

Preparation for the deployment of the EARs (Environmental Acoustic Recording System) buoy which were to be positioned at 1000 m depth for continuous sound recording during Sirena06

van Velzen, M., Haralabus, G., Baldacci, A. Calibration of cardioid beamforming algorithms. NURC-FR-2006-003, NATO Unclassified.

Conference presentations

Baldacci, A., Haralabus, G., van Velzen, M. Cardioid receive array calibration for active systems. UDT Europe 2006, June 2006.

Baldacci, A., Grimmett, D. The DEMUS distributed multistatic underwater surveillance network: description, signal. RTO-SET-95 Specialists Meeting on Bistatic-Multistatic Radar and Sonar Systems, June 2006.

Baldacci, A., Haralabus, G. Signal processing for an active sonar system suitable for advanced sensor technology applications and environmental adaptation schemes. 14th European

Signal Processing Conference (EUSPCO06), September 2006.

Blanding, W., Willett, P., Bar-Shalom, Y., Coraluppi, S. Track Management in a Multi-Sensor MHT for Targets with Aspect-Dependent SNR. In: *Proceedings of the 2006 SPIE Conference on Signal and Data Processing of Small Targets*, April 2006, Orlando FL, USA.

Coraluppi, S. Advances in active sonar tracking. 14th European Signal Processing Conference (EUSIPCO06), September 2006.

Coraluppi, S. Advances in multisensor tracker modelling. 2006 SPIE Conference on Signal and Data Processing of Small Targets, April 2006.

Coraluppi, S., Grimmett, D., de Theije, P. Benchmark evaluation of multistatic sonar trackers. 9th International Conference on Information Fusion, July 2006.

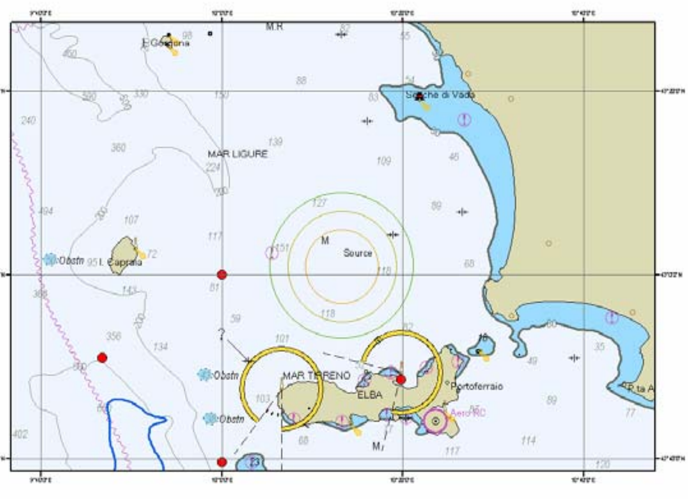


Chart showing sightings of marine mammals during the Environmental Scoping Study at the PreDemus '06 cruise

Coraluppi, S. Integrated detection and tracking in multistatic sonar. RTO-SET-95 Specialists Meeting on Bistatic-Multistatic Radar and Sonar Systems, June 2006.

Gérard, O., Coraluppi, S. Carthel, C., Grimmett, D. Benchmark analysis of NURC multistatic tracking capability. 9th International Conference on Information Fusion, July 2006.

Gérard, O., Coraluppi, S., Zimmer, W., Willett, P. A chorus of whales: evaluation of sequential and batch approaches to time-series tracking. OCEANS'06, September 2006.

Grimmett, D., Coraluppi, S. Contact-level multistatic sonar data simulator for tracker performance assessment. 9th International Conference on Information Fusion, July 2006.

Haralabus, G., Baldacci, A. Impact of bottom properties on low frequency active sonar performance for littoral anti submarine warfare. UDT Europe 2006, June 2006.

Haralabus, G., Baldacci, A. Impact of seafloor and water column parameter variations on signal-to-background ratio estimates - a sensitivity analysis based on sonar performance modelling. 8th European Conference on Underwater Acoustics (ECUA 2006), June 2006.

Haralabus, G., Baldacci, A. Unambiguous triplet array beamforming and calibration algorithms to facilitate the implementation of an environmentally adaptive active sonar concept. OCEANS'06, September 2006.

Prior, M.K. Long-range, low-frequency measurements of seabed scattering strength and inferences of scattering rule validity. 8th European Conference on Underwater Acoustics (ECUA 2006), June 2006.

Prior, M.K. The physical causes of clutter and its suppression via sub-band processing. OCEANS'06, September 2006.

Willett, P. Coraluppi, S. MLPDA and MLPMHT Applied to Some MSTWG Data. In: *Proceedings of the 9th International Conference on Information Fusion*, July 2006, Florence, Italy.

Willett, P. Coraluppi, S., Blanding, W. Comparison of Soft and Hard Assignment ML Trackers on Multistatic Data. In: *Proceedings of the 2006 IEEE Aerospace Conference*, March 2006, Big Sky MT, USA.

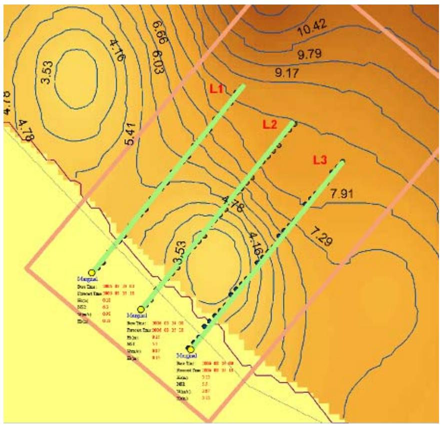
Balaenoptera physalus (Fin Whale) sighted in the middle of the Ligurian Sea during the Sirena06 / Zifio06 Sea Trial

Expeditionary Operations Support (EOS)

The EOS thrust area maintained a primary focus on the development of innovative approaches for implementation of the Recognized Environmental Picture (REP) to support NATO expeditionary operations. The main areas of research are characterization and forecasting of the battlespace environment, data assessment and sensitivity, and the generation, maintenance and delivery of the REP.

EOS conducts research in support of NATO expeditionary operations by developing and demonstrating methods for timely collection, analysis, and dissemination of meteorology and oceanography information and products

Research efforts on air-sea interaction and small scale effects in the littoral environment have increased to address this difficult domain. Geospatial data fusion technologies have become increasingly important in the thrust area's efforts as the difficulty becomes more apparent in employing high resolution METOC to support Expeditionary Operations. Efforts continue across the thrust area to use space based remote sensing, autonomous vehicles, and in situ sensors to measure METOC parameters and combine them using robust data assimilation methods to provide advanced battlespace characterization.



Example of geospatial data fusion to support an amphibious landing

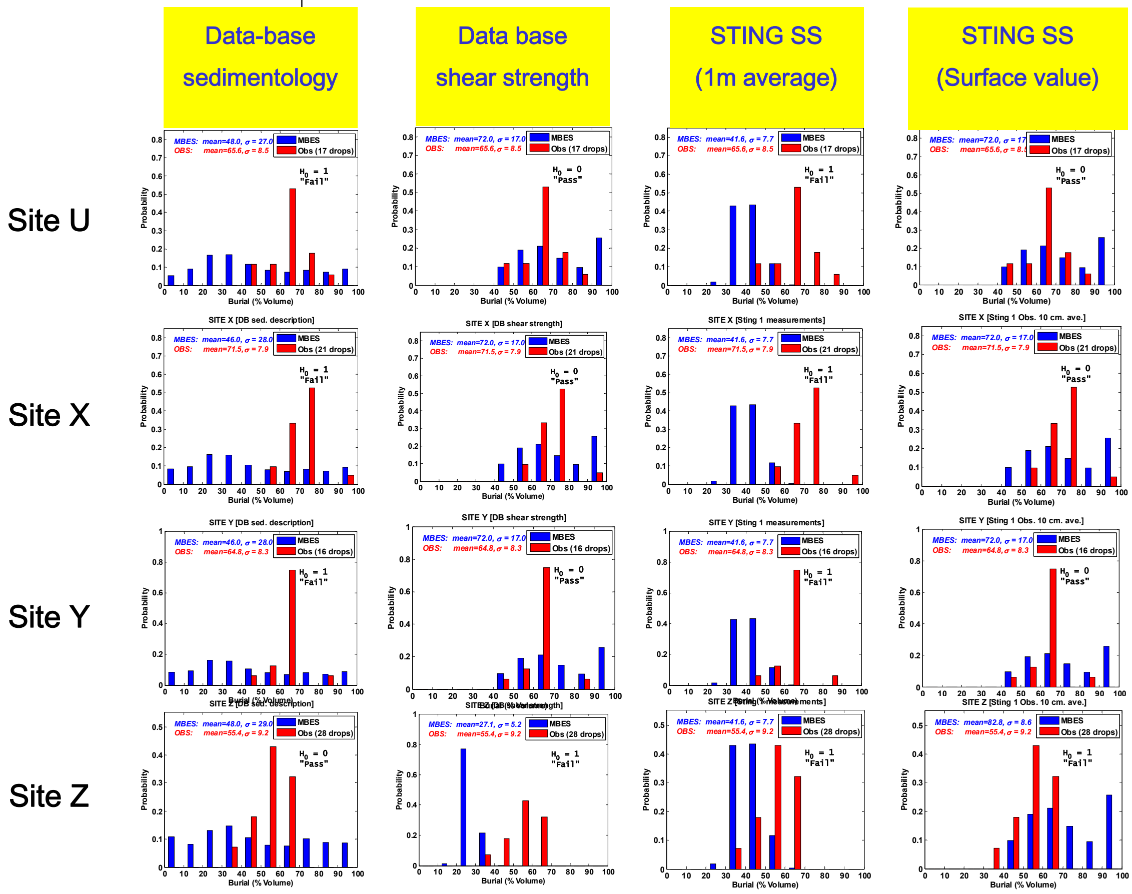
In 2006, two special issues of the Journal of Marine Systems on 'Marine Environmental Monitoring and Prediction' and 'Maritime Rapid Environmental Assessment' were published under NURC editorship. The issues summarized the work on the REA concept conducted since 1995 and are the culmination of the efforts of partners from many nations that have worked collaboratively on numerous sea trials to develop and implement REA as

Tactical prediction for the Recognized Environmental Picture

The goal of this programme area is to develop the capability to provide a timely, highly resolved 4-D picture of oceanographic and meteorological conditions of the battlespace. Areas of activity include air-sea interaction effects, ensemble and stochastic modelling including model uncertainty and reliability and assimilation of remote sensing data, nearshore wave and sediment modelling including mine burial prediction.

Surf zone and nearshore circulation

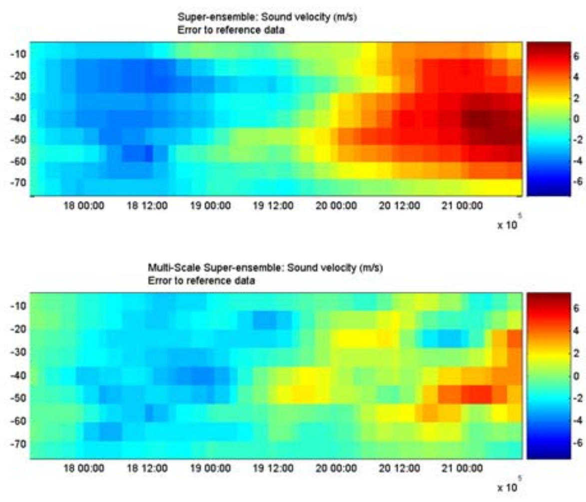
The hybrid surf model final report was completed and ISSM model software delivered for operational use to the United States, Spain, Turkey, Greece, and Germany. Two Centre reports and two external publications were published. Two experiments were conducted for the validation of the Sea Mine Burial Expert System (SMBES) under sponsorship of MCG3. The model evaluation demonstrated that the model had significant improvements over current doctrine in the prediction of sea mine burial and that the most critical environmental parameter for successful predictions was some estimate of bottom shear strength. The SMBES is now available for use within NATO and member nations in support to MCM operations. NURC is the repository for distribution within NATO.



Results of the NATO Sea Mine Burial Expert System validation trial. The red bars indicate the distribution of observed burial and the blue bars represent the predicted distribution. The four rows represent different sites (U, X, Y, Z) and the four columns give predictions using four different sources for sediment shear strength characterization. Predictions based on the optimal input values, measured surface values, are quite good but all predictions based on shear strength values far outperform predictions based on grain size distributions.

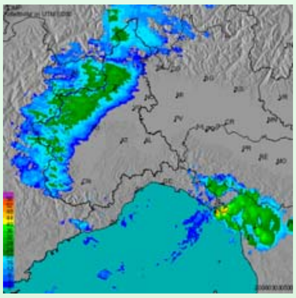
Real time high resolution prediction

Two highly complex sea trials in the Adriatic Sea, DART '06 A and B (Dynamics of the Adriatic in Real-Time) were conducted to test and demonstrate the ability to provide real-time high resolution forecast of shallow water and coastal meteorological conditions. The trials involved participants from over 30 partners representing 15 NATO member nations and 2 PFP nations. The two DART inter-disciplinary field experiments successfully addressed the monitoring and prediction capabilities of small-scale insta-bilities in a highly dynamic environment. A new multi-scale multi-model superensemble data-model fusion method has been developed and validated operationally in the framework of the DART experiments.



Comparison of 72hrs forecast errors on sound velocity derived from optimal combinations of SEPTR data and operational ocean models predictions during DART06A (top) standard multi-model (bottom) multi-scale multi-model.

Expeditionary Operations Support (EOS)



Screen display of a local storm that was successfully forecasted using COAMPS-OS

Air-Sea interaction

The Coupled Ocean-Atmosphere Mesoscale Prediciton System, On-Scene (COAMPS-OS) was installed at NURC and is now used for real-time high-resolution weather prediction in support of sea trials and exercises. (e.g. in the Adriatic, Black Sea, Cabo Verde). Methods were developed and are being tested for the utilization of SAR high-resolution wind data to validate and estimate COAMPS-OS model uncertainty. Development of stochastic parameterizations and implementation into the US Navy weather prediction system was initiated.

The capability of the Ocean Explorer AUV (OEX) was expanded by adding the WISE (Wideband Scientific Echosounder) payload to allow multispectral, multi-aspect analysis of acoustic response of sea floor for battlespace preparation. The first test at sea was conducted in November 2006

Geospatial decision support for the Recognized Environmental Picture

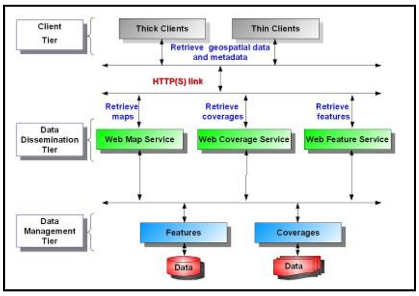
The goal of this programme area is to provide methods for more efficient and timely geospatial decision support. This includes activity in geospatial decision support tools, end-to-end data services (collection to military user), network-enabled, object-oriented, geographic information systems using Open Source/ Open Architecture systems and efficient REA/REP communications.

End-to-end data services

EOS continued development of an end-to-end process for collecting remote sensing data, combining it with data from in-situ sensors and computer models to characterize and predict the environment to provide decision support for operational commanders. These services were tested in DART 06A and DART 06B.

Open Source/Open Architecture GIS

The development and testing of the first working prototype of a web server was completed. The prototype is based on a data fusion engine which allows configuration of processing nodes into networks implementing a data-to-product data fusion flow that can be automatically triggered by the delivery of the input data sets. It is based on Open GIS standards (OGC) software architecture for geospatial tactical decision support and was tested at Steadfast Jaguar ‘06 and DART 06B.



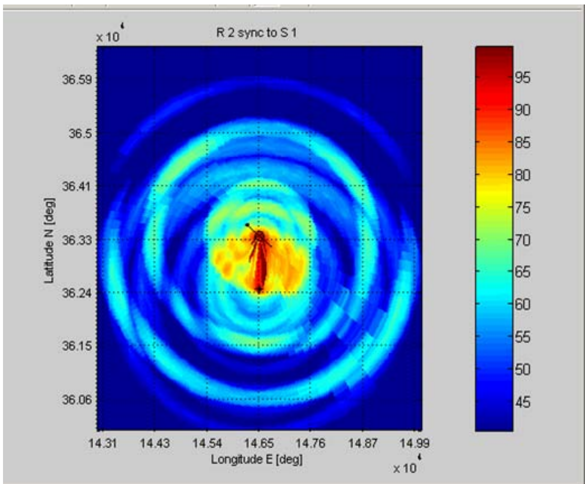
Architecture of the NURC Geoserver built on open source tools

Shallow water acoustic propagation

The goal of this programme area is to improve shallow water acoustic propagation models to improve detection and classification of sensors, and operation of acoustic communication systems. Current activities include modelling and applications of high frequency (5-50Khz) underwater acoustics to support environmental effects on propagation at communications frequencies, and geoacoustic inversion of ambient noise and direct use of seabed properties in propagation models.

Geoacoustic inversion

The development and testing of a prototype autonomous vertical array for real-time, geoacoustic inversion of ambient noise was completed. This included two separate engineering tests of the Slim Line Vertical Array (Sliva), its buoy, processor, and radio links. Preliminary checks of the acoustic data show that it is of high quality. The design and development of algorithms for real-time sub-bottom profiling in shallow water made significant progress. New techniques for long range reverberation inversion were developed that show the remote bottom reflection properties can be derived from reverberation. Testing of multipath pulse shapes in shallow water shows that the spreading of the pulse is predictable and depends only on the water depth and bottom reflection properties (surprisingly, not travel time) and can be used to measure the reflection properties. This combination provides the capability to perform real-time sonar performance prediction using in-situ bottom conditions.



Geoacoustic parameters derived from new inversion methods

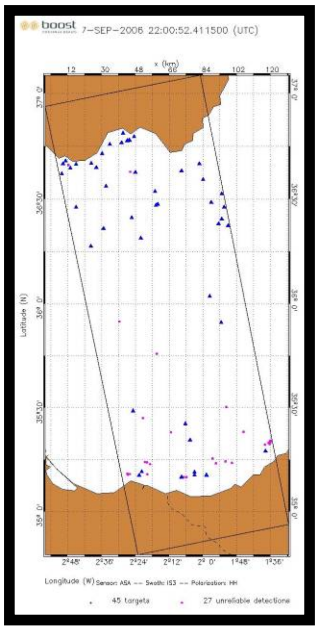
High frequency acoustic propagation

This programme proved that acoustic signals (from the Makai '05 data) in the 8-12 kHz frequency band could be used over long time periods (over 12 hours) to track the environmental changes in the water column. This result is the early beginning of HF tomography. A new robust algorithm was invented, and tested on numerical and experimental data (from Barrier '04) which images multiple targets crossing an HF acoustic trip wire (10-20 kHz). A proof of concept was developed for the acoustic barrier to detect and localize multiple targets, using multipath propagation as an advantage. Since the concept is not sensitive to environmental changes and is compatible with ship surface traffic, possible areas of application include harbour protection and environmental monitoring of harbours.

Surveillance of maritime vessels using commercial remote sensing systems

The aim of this experiment was to demonstrate the use of commercial satellite imagery to support near real time surveillance, identification and tracking of maritime shipping. This would greatly enhance the maritime traffic awareness efforts of Operation Active Endeavour at CC MAR (Allied Maritime Component Command) Naples and will directly support other NATO ACT efforts on Maritime Situational Awareness (MSA).

The demonstration involved the CSTARS facility in Miami, Eagle Eyes, a USAF mobile satellite station and the NURC Remote Sensing System Ground Station (RSSGS) to monitor maritime vessel traffic by combining satellite imagery with the Automated Information System (AIS). The coverage area in this three station demonstration included the entire Mediterranean Sea and the main shipping lanes in the North Atlantic Ocean. This allowed tracking of vessels of interest from the Suez Canal to the east coast of the United States. The experiment was designed to test our ability to use commercial remote sensing to detect, classify, identify and track vessels at sea. In twelve days, the three ground stations (NURC, Azores and Miami) collected over 1500 images, covering more than 14 million square km and had over 1100 ship detections. The primary sensor was space borne Synthetic Aperture Radar (SAR) from the RADARSAT1 and Envisat satellites. Other optical systems were also used. The network and data flow to combine remote sensing collection from three ground stations and provide ship detections in a timely manner to a central site was satisfactorily tested.



Space-based ship detection in the Straits of Gibraltar

Expeditionary Operations Support (EOS)

The strategy of using civil sensors for maritime surveillance was proven feasible. The process to conduct timely ship detection and classification identification was proven and progress on ship identification and tracking was made. This approach would quickly provide a comprehensive picture of transiting vessels and allow the verification of known vessels with AIS and other intelligence information, singling out those targets that may show anomalous behaviour or suspicious travel patterns.

The major operational problem identified was the tasking to the satellite operators to achieve timely scheduling of commercial satellites. Satellite operators normally require a lead time of 3 days (for RADARSAT) and 14 days (for Envisat). Ship tracking may require rescheduling a satellite on as little as six hours notice. The European Space Agency (ESA) was very cooperative in reprogramming Envisat in response to the needs of the experiment.

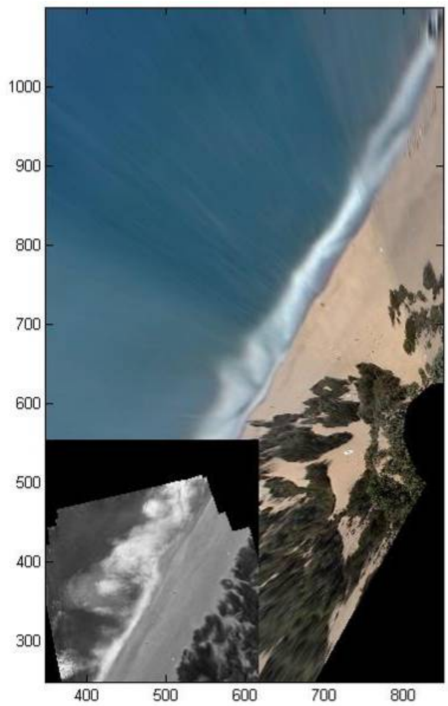
The technical problem is the need for improved temporal coverage. The planned launch of several new satellites in the next few years may help to alleviate this shortfall. The other technical area to be developed is in multi-sensor fusion, combing satellite detections with other sensors to provide the most efficient methods for MSA. Some correlation with AIS data was attempted but this area needs to be more fully exploited.

COTS small unmanned aerial vehicle (SUAV) selected for use in the Airborne Forward Eyes EPOW project. The vehicle which carries two cameras, has a 1.4 m wingspan, 0.9 m length, weighs less than 1 kg. and is widely disseminated among NATO forces.

Airborne Forward Eyes

Previous work under the EPOW (Experimental Programme of Work) has shown the value of time exposed surf zone imagery collected by terrestrial based camera systems in the planning and execution of amphibious and other land-sea operations. The goal of Airborne Forward Eyes was to investigate the feasibility of utilizing commonly operated small unmanned aerial vehicles (SUAV) to collect similar information in denied areas. This activity is considered a first pass at developing methodologies to permit Rapid Environmental Assessment (REA) of littoral regions from non-stationary aerial platforms.

The immediate goals of the project were to acquire medium duration video imagery (~10 minutes) of a beach and surf-zone, geo-rectify, merge and time-average the images in order to create time-averaged surf zone imagery, and then use the resulting time exposures to evaluate the conditions in the surf-zone. However, much of the methodology developed has relevance to any application that involves geo-referencing and mosaicing of images collected from an SUAV. Other potential applications include mapping as well as higher order REA activities such as the estimation of wave frequency and direction information and or measurement of long shore currents.



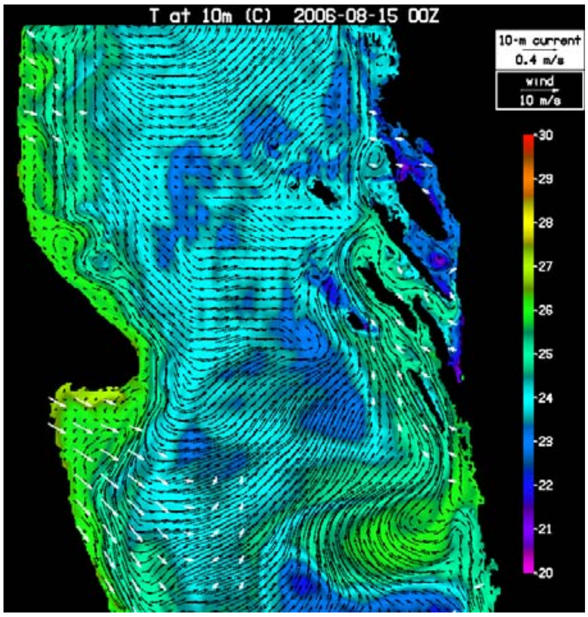
Right: Comparison of time averaged surf zone images collected from land based camera (color image) and from SUAV (black and white insert). Notice how SUAV collected image leads to a significant reduction in image projection errors.

During 2006 two field experiments were performed in which SUAVs were successfully flown in both coastal locations and over 18 hours of imagery were collected. During these exercises, extensive testing was performed to characterize the SUAV geometry, meta-data reliability and video camera properties. Activities included lens calibrations, ground assessments of camera mounting relative to the airframe, static calibrations of attitude sensors, and in-flight acquisition of imagery of a dense “target farm” of ground reference points for use in various post experiment activities. These activities led to the development of methods which utilize system characterization and calibrations to automatically navigate the collected images. Positioning errors in images stabilized through this methodology were reduced by half in comparison to vendor provided information. Manually produced time-exposed surf imagery for the surf zone was created which was superior in quality to that collected by land based camera systems and positioning errors were reduced by a further factor of 10. Further work is planned to utilize satellite acquired base imagery for geo-referencing and standard image processing algorithms for mosaicing and time-averaging in order to remove the need for operator intervention in the development of nearshore imagery.

Dynamics of the Adriatic in Real-Time (DART)

The main thrust of the EOS thrust area is to provide support to expeditionary operations. A paradigm to meet these requirements is to provide scientific research excellence in Rapid Environment Assessment (REA) and Recognized Environment Picture (REP) to be delivered to the end-users.

The DART effort, which is part of a Joint Research Project (JRP) between NURC and the Naval Research Laboratory, Stennis Space Center (NRL-SSC) USA, is a multi-institutional field programme in the Adriatic Sea which aimed at addressing monitoring and prediction capabilities on small-scale instabilities in a controlled environment, under winter and summer conditions with the same scientific sound approach. Two field experiments onboard the NRV ALLIANCE have been conducted respectively in March and August 2006, complemented with other 7 partner support trials. From winter 2006 and to summer 2006, 33 different institutions have contributed to gather a broad suite of environmental measurements and models, including 6 ocean, 4 wave and 7 atmospheric models.



Example of high resolution NCOM sea surface temperature output during DART06B

The Adriatic was an ideal natural laboratory to conduct this research because it is a highly dynamic area which exhibits a wide range of processes to explore, due to the complex bathymetry and coastline, wind forcing, water masses and currents, river outflows and plumes, sea floors, etc. In addition, there was already a critical mass of expertise and operational models running in the area.

Using the Adriatic as a test bed, we evaluated, combined and improved existing observational and modelling capabilities. During the trial, operational meteorological, wave and ocean models with different resolutions were compared with local observations (buoy, drifters, moorings, ship and satellite based) in the mid-Adriatic and more specifically, around the Gargano peninsula and in the Gulf of Manfredonia on the East coast of Italy, adopting a general nested domain approach to reach the scales relevant to NATO operations. A multi-scale approach was adopted to assess monitoring and prediction skills over a wide range of processes and to obtain robust statistical estimations. Dedicated satellite links were used to mirror the GEOS web/ftp server onboard the ALLIANCE, in order to provide seamless access to the wide range of data collected onboard the different ships and the models running in the different places. A critical aspect of the DART effort was to build a comprehensive multi-disciplinary set of *in-situ* and remotely sensed data and atmospheric, oceanic and wave models. The newly developed suite of SEPTR moorings provided real-time water column information which would have been impossible to obtain otherwise, in this heavily fished area. These models and data were used in multi-scale super-ensemble techniques - aimed at finding optimal combinations of available models – and have been successfully demonstrated through the prediction of surface drift and sound velocity profiles during the experiment. Real-time tactical decision aids were also produced to support water-borne assault scenarios in the Gulf of Manfredonia.

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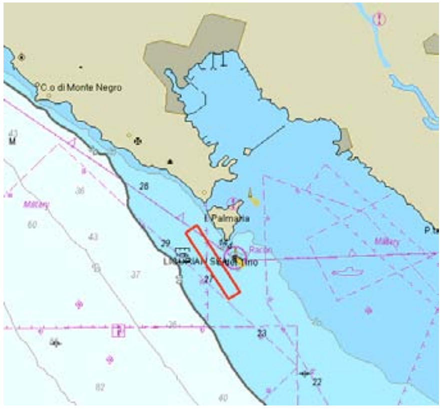
Command & Operational Support (COS)

Two new projects and one exploratory activity have started in the Command and Operational Support Thrust Area in 2006 that will help provide answers to Defence Against Terrorism issues. Military Experimentation also was an active area, with two mine countermeasures experiments conducted in cooperation with recent NATO nations, in Bulgaria and Estonia. Finally, operational support has been provided to NATO Response Force exercises ITMINEX 06 and BRILLIANT MIDAS 06.

COS performs operational analysis of maritime components of NATO exercises, designs and analyzes percentage clearance trials and develops decision aids/tools to improve operational effectiveness of NATO forces



Map showing area (red rectangle) of PC trials during the NATO MCM Group 2 exercise in La Spezia, March 2006

The first project that started in 2006 is entitled "Threat behaviour modelling using Intelligent Agents". This is an exploratory research activity, aimed at solving problems in various and complex environments such as countering Improvised Explosive Devices (C-IED), maritime surveillance and networked multi-sensor underwater warfare. Because of the nature of these areas, and the strong impact of threat behaviour on system performance, it becomes more and more difficult to assess system performance and develop effective tactical decision aids without adequate threat behaviour models and simulation techniques. To assess the performance and the potential of these techniques, an underwater barrier operation has been simulated and the first results are very encouraging. Very good performance of the neural network driven threat has been achieved and the process was found to be adaptive and robust to most situations not encountered in the training phase.

The second new project addresses port protection issues. The objective is to define system requirements to achieve a given level of effectiveness to counter a terrorist attack on a vessel in a harbour scenario. This includes intruder initial detection, relocalisation, classification and neutralization. In 2006, the study has been focused on underwater intruders. The Specialist Team Harbour Protection Trials conducted in La Spezia in April 2006 have been analyzed and key system parameters identified. A defense and reaction simulation was developed, results analyzed in a number of situations. The study provided answers for optimizing integrated defense efficiency and effectiveness. The project will address surface attack issues in 2007.

In response to a requirement from Component Commander Maritime (CC MAR) Naples to support Operation Active Endeavour, exploratory activities started in 2006 on maritime surveillance issues. This limited effort was part of a larger ACT lead initiative designed to improve maritime awareness effectiveness based on collection and analysis of Automatic Identification System (AIS) messages. An AIS receiver has been installed in the La Spezia area and AIS data are made available to CC MAR Naples. Key technical issues are being addressed by adapting underwater tracking and fusion algorithms to AIS and radar data. Statistical analysis of AIS messages provides the foundation for some aspects of anomaly detection algorithms that are currently being developed. Future activity will address multi sensor multi asset capabilities and will focus on adaptive techniques for multi sensor anomaly detection.

Operational support

Exercise support and analysis

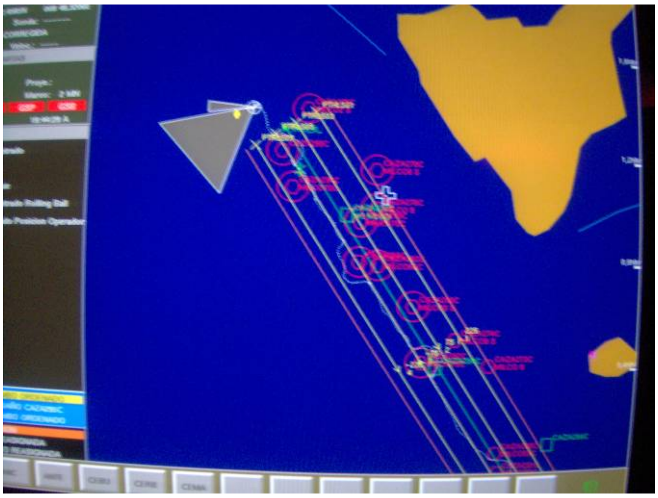
Minehunting Percentage Clearance Trials

The Centre has continued to support the planning, execution and operational analysis of challenging minehunting 'Percentage Clearance' (PC) trials in 2006. These trials are used by the Standing NATO MCM Groups 1 and 2 to practice MCM planning and evaluation in challenging minehunting scenarios. Accurate evaluation of MCM operation is necessary for the assessment of risk to follow-on shipping traffic. Participating minehunting teams normally receive an analysis of their performance immediately after the trial. The timeliness of this analysis feedback is an essential part of the trial because it provides the best opportunity for each minehunting team to review their performance with the independent analysis provided the Centre. These trials maintain and improve the force readiness of NATO's Standing MCM Readiness Groups.

In March 2006, four NATO MCM Vessels and one FRA MCM Vessel participated in a PC Trial organized within the ITALIAN MINEX 06. Four out of five MCM Vessels reported PC that were higher than their achieved PC against the lower target-strength targets. Future trials will focus on improving that situation.

Notional Minefields in Brilliant Midas 06

In the fall of 2006, notional minefields were used to simulate an asymmetric threat from opposing forces in NATO Exercise Brilliant Midas 06, which was conducted in the territorial waters of southern France. The goals of this activity were to gather operational data to develop effective algorithms representing low-density notional minefields, to provide NATO Commands with an assessment of the risk posed by asymmetric threats and to allow non-MCM units to practice damage control in the event of a mine actuation. The initial analysis of the data was conducted in 2006. No mine actuation occurred from the units that provided their data. The initial analysis and lessons learned for implementing notional minefields into future exercise were documented in the Brilliant Midas First Exercise Report 06. Additional analysis to provide an evaluation of the actual risk to participating units has been completed and the final report will be delivered in the second quarter of 2007.



Tactical display on a NATO MCMV (mine counter measure vehicle) during the PC (percentage clearance) trial in the Italian Mine Exercise 2006.

Support to the Defence Requirements Review

The Center provides support to the Defence Requirement Review. In 2006 this activity developed a methodology to determine the required operational time for an Autonomous Underwater Vehicles to detect and classify naval ground mines in various DRR 07 planning situations. This work was used by NC3A, who is the lead agency for the maritime element of the DRR 07, to determine the required number of generic AUVs for the corresponding capabilities.

Outputs

1. Report NURC-MR-2006-002 "Defence Requirement Review 07, requirements for large AUV in rapid MCM". NATO Restricted.
2. Rapid analysis feedback to NATO MCM Forces, ITN MINEX HWU, ITN Academy, Livorno, 25 March 2006
3. Notional Minefield Implementation & Ship statistics in notional minefields, Brilliant Midas First Exercise Report, ANNEX E, Appendix 5, 31 Dec, 2006

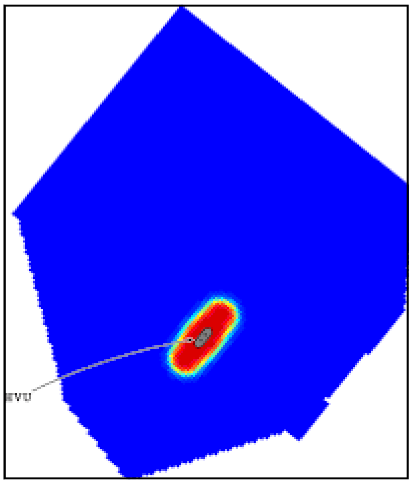
Command and Operational Support (COS)

Requirement Study for Countering Intruders in Ports & Harbours

In 2006, this project developed a methodology to model the integrated effectiveness of a defence system to counter underwater terrorist attacks on a vessel in a harbour scenario. Threat analysis, observations of the performance of existing systems during the Specialist Team Harbour Protection Trials in La Spezia 2006, target-strength measurements and tracking systems (both from NURC project 3J1) were key activities and inputs relevant to the model development.

A harbour scenario for countering underwater intruders

The modelled integrated defense system is comprised of an active-sonar with a tracking system, underwater barrier, and a response craft equipped with a weapon system. This defence system was evaluated against two threat platforms with explosives attacking a high-value vessel in a specific harbour scenario. A sensitivity analysis of the modelling parameters provided the required launch-times for the response craft to counter the underwater terrorist attacks. The utility of the active sonar system depends on the launch-times of the response craft. The underwater barrier system is required against the faster underwater threat in the harbour scenario considered herein. These requirements are dependent on the chosen harbour scenario. The methodology developed during 2006 is applicable to other harbour scenarios.



Map of the system effectiveness against a diver attacking a vessel in the harbour. The red colour represents low system effectiveness against an intruder attacking from any position within the red area.

Output:
Modelling & Analysis for harbour protection against underwater attacks, Draft V1.1, H. Yip, B. Nguyen, P. Grignan, and A. Vermeij.

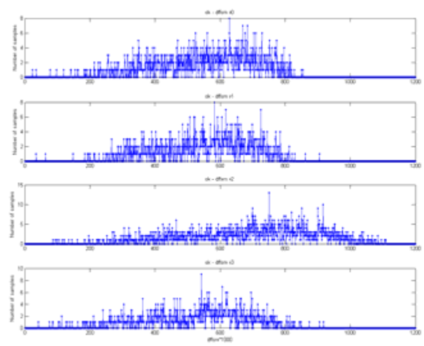
Threat behaviour modelling using Intelligent Agents (IA)

The project started mid 2006 as an exploratory research of the SPOW with the objective of developing a model of threat behaviour using machine learning and IA techniques. The idea is to apply these techniques to military simulations and Tactical Decision Aids of complex systems such as C-IED and Maritime Surveillance.

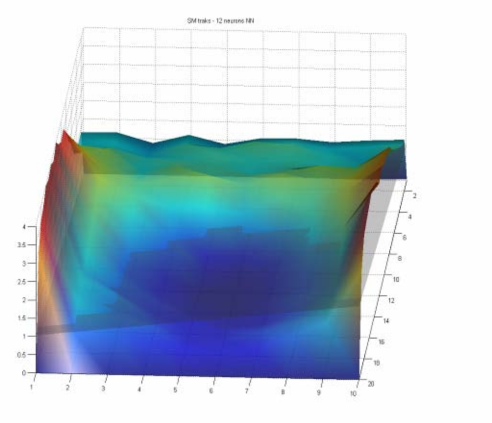
The first step was to define a representative scenario of military operation with known threat/searcher performance as a baseline for assessing the performance of neural network driven threats. An underwater barrier operation was selected because the Centre has expertise in this field, has analysis tools readily available and could concentrate on the threat model rather than on simulation and analysis issues. A simplified simulation of a barrier operation has been developed that includes all the basic characteristics of environment, system and threat necessary for a realistic assessment of mission analysis and threat behaviour model performance.

Initial conclusions are that this technique can be applied successfully to such a simulation, with Measure of Effectiveness of the Neural Network driven threat shown to be consistently well above 90%. A sensitivity study also concluded that neural network sensitivity, scalability, suitability and adaptability to this application were very encouraging.

Future activity will add optimizing and supervising modules to the simulation and address more complex scenarios such as multistatic operations. It is also planned to integrate this threat model into NURC tactical decision aids such as Area Search Tactical Planning Aid and/or MultiStatic Tactical Planning Aid and assess the performance of this technique against rule based solutions.



Analysis of training data distribution



SM track distribution in barrier operation with neural network driven threat. 93% success rate

Outputs:

- Draft Report on "Applicability of Neural Network techniques to underwater barrier operations" end of 2006, to be published in 07.
- Scientific grade threat behaviour software module.

Black Sea port & harbour protection with autonomous underwater vehicles

This operational experimentation was funded by Allied Command Transformation (ACT) to demonstrate and to assess the effectiveness of Commercial-Off-The-Shelf (COTS) Autonomous Underwater Vehicles with computer-aided-detection and network enabled technologies to counter terrorist placement of underwater Improvised Explosive Devices (UW IED) in ports and harbours. The experiment was conducted in the harbours of Varna and Burgas, Bulgaria, 19-22 June 2006. The Bulgarian Navy was a key partner in this experiment. The experiment was designed to determine if high-frequency target acquisition with multiple-look analysis of targets would increase the efficiency in countering UW IED in the summer harbour environments of Varna and Burgas. A Commercial-Off-The-SHELF change-detection system for detecting UW IED was demonstrated with the surveyed data from the harbours of Varna and Burgas.

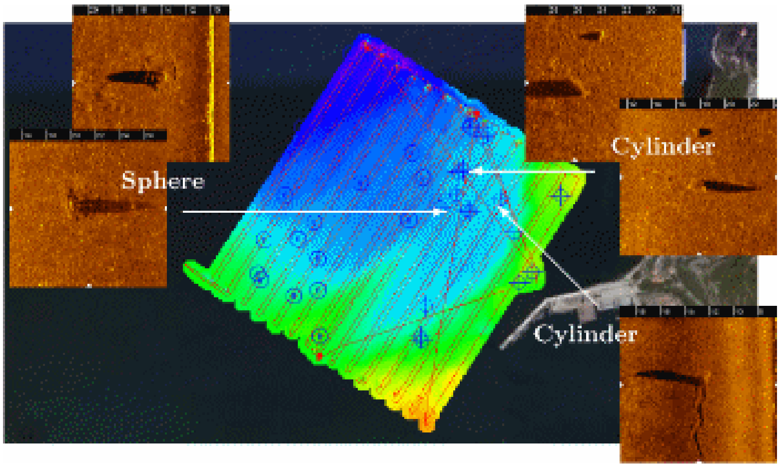
UW IED were deployed in an area of size .30 nm^2 in the harbour of Varna, and in two areas (each area-size is approximately 0.23 nm^2) in the military harbour of Burgas. In one of the Burgas areas a very high probability of correctly classifying a false target using single-look analysis was measured. No comprehensive data collection (Target Acquisition using multiple aspect survey using 1800 kHz side-scan sonar) for multiple-look analysis was conducted because of the very high performance already achieved from the single-look analysis. A COTS change-detection solution based on meta-data extracted from side-scan images (using a priori target information) was demonstrated to detect two out of the three UW IED deployed in Varna Harbour, and two out of two UW IED in Burgas Harbour.

Command and Operational Support (COS)

An underwater improvised explosive device used for change-detection.

A lawn-mower survey pattern with single-look analysis was shown to be very efficient in detecting and classifying the UW IED in the harbour of Burgas. The change detection method was demonstrated during post analysis, and it is an improvement over manually comparing a large number (405) of side-scan files to detect changes.

Future experimentation with fully automated change-detection solutions in real ports and harbours is recommended. The use of planning tools to plan optimal missions for multiple AUV in ports & harbours is recommended. The temporal variation in the clutter density within ports and harbours needs to be assessed to determine the required time-interval for change-detection surveys.



Side-scan images of the Underwater IED in a harbour area in Burgas

Output:
MX04 Trial Report: Black Sea Port & Harbour Protection with Autonomous Underwater Vehicles, Draft V1.1, H. Yip, F. Baralli, E. Bovio, F. Cernich, and B. Rehr.

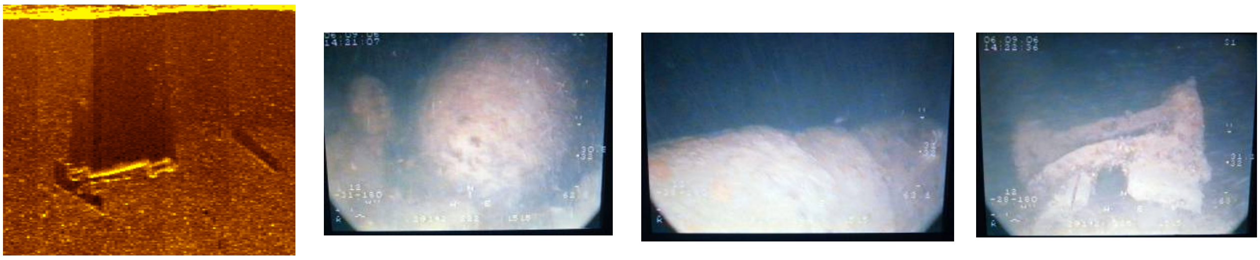
MCM with autonomous underwater vehicles & Standing MCM Readiness Group 1 in Open Spirit '06

This operational experimentation was funded by Allied Command Transformation (ACT) to assess the effectiveness of Commercial-Off-The-Shelf (COTS) Autonomous Underwater Vehicles (AUV) and network enabled technologies with today's mine countermeasures vessels (MCMV) in an MCM environment with historic ordnance. The experimentation was conducted in Estonian territorial waters near the island of Naissaar, 3-13 September 2006. Standing MCM Readiness Group 1, the Estonian Navy and ACT were partners in this experimentation. AUV operations were conducted onboard four NATO MCMV; HMS MIDDLETON (GBR), ORP FLAMING (POL), BNS NARCIS (BEL), and HNLMS HAARLEM (NLD).

Two lightweight AUV surveyed a total area-size of 1.8 nm^2 during this experimentation. The surveys provided mine-like contacts that were subsequently acquired and identified by NATO MCMV. Data from the experiment showed that contact classification performance from using lawn-mower survey patterns with single-look contact analysis was the same as that using contact acquisition with multiple-look contact analysis in the environment of Open Spirit where the ordnances are large and well preserved. This result was conditional on the operator acquiring sufficient experience in classifying contacts in the same MCM environment prior to the evaluation of the sample contacts. Thirty-eight mine-like contacts from the

AUV were successfully acquired and identified by the Remotely Operated Vehicles (ROV) of the MCMV. Two Russian AMD 1000 ground mines and two Russian M12 moored mines were identified by NATO MCMV, thus demonstrating further that COTS AUV can be used effectively in conjunction with MCMV to reduce the risk to shipping.

Three recommendations follow from the activities of this experimentation. The use of AUV for MCM in future operations in Open Spirit should be conducted with an inertial navigation system instead of an acoustic baseline system. An AUV planning & evaluation system is highly recommended for such MCM operations where the long-term goal is to eliminate the shipping risk from live ordnances in the Baltic area. Finally, the next step is to exploit the AUV technology in utilizing the vehicles from non-MCM units in an operational military environment. Further experimentation using AUV to provide stand-off organic MCM/REA/FP capabilities for NATO Naval Force Commanders is recommended.



Side-scan image of a Russian AMD 1000 Naval Ground Mine with the corresponding photos (from a Remotely Operated Vehicle) of the mine from different aspects

Output:
MX05 Trial Report: MCM with Autonomous Underwater Vehicles & Standing MCM Readiness Group 1 in Open Spirit 06, Draft V1.1, H. Yip, F. Baralli, E. Bovio, F. Cernich, and B. Rehr

COS publications and presentations

Reports

Bryan, K. Algorithms for Decision Aid for Risk Evaluation (DARE) version 2.1. NURC-FR-2006-002, NATO Unclassified.

Bryan, K., Signell, E.P., Arsenault, N. Decision Aid for Risk Evaluation (DARE) Version 2.1 User Guide. NURC-SP-2006-001, NATO Unclassified.

Bryan, K. Modern minehunting techniques and the MCM EXPERT software. NURC-FR-2006-011, NATO Restricted.

Davies, G.L., Signell, E.P. Espresso — Scientific User Guide. NURC-SP-2006-003, NATO Unclassified

Davies, G.L., Signell, E.P. Expresso(m) - User Guide. NURC-SP-2006-002, NATO Unclassified

Strode, C. Analysis of Free Play Serial conducted during Noble Marlin 05. NURC-MR-2006-001. NATO Confidential.

Strode, C. ASTPA User Guide. NURC-SP-2006-006, NATO Unclassified.

Strode, C. ASTPA Wizard User Guide. NURC-SP-2006-007, NATO Unclassified.

Strode, C. Defence Requirements Review 07, requirements for large AUVs in rapid MCM. NURC-MR-2006-002, NATO Confidential.

Wathelet, A., Strode, C., Vermeij, A. Advances in Multistatic Tactical Planning Aid. NURC-FR-2006-022, NATO Restricted

Conference presentations

Bryan, K., Carthel, C. A Bayesian approach to predicting an unknown number of targets based on sensor performance. 9th International Conference on Information Fusion, July 2006.

Report from the Ship Management Office

NRV Alliance

After completion of the grounding repairs at the end of 2005, NRV ALLIANCE had a full scientific schedule planned for 2006 with all work due to take place in the Mediterranean area. The first three months of the year consisted of scientific projects that had been carried forward from 2005 and included a cruise in the Adriatic Sea in support of MILOC and further development of the DEMUS system. On return from these activities the vessel was berthed in the Italian Navy Base in order to prepare for a major harbour defence demonstration.

As part of this demonstration a VIP Day was held which included a visit from the North Atlantic Council and Military Committee. The group enjoyed a tour of the ship and lunch on board whilst viewing live demonstrations of harbour and port defence technology. This visit was followed a few days later by the SCNR and NG3 group who were treated to the same demonstration.

ALLIANCE continued with the scientific programme throughout the summer months and included the BABO'06 (Malta Plateau), FAF06 (Pianosa Island), cruises in June and July, SIRENA06 (Ligurian Sea) in July and August and Dart 06 (Adriatic Sea) in August . The planned DEMUS 06 trial was cancelled due to equipment problems with the DEMUS system.

The break in the scientific schedule caused by the cancellation of the DEMUS cruise allowed some valuable preparation work to be undertaken for the installation of the new integrated navigation, engine monitoring and power management system.

The vessel left for the final cruise of the year, COACH 06, on the 14^{th} October, but a major engine failure resulted in the cruise being cancelled and the ALLIANCE had to return to La Spezia. COACH 06 was to be conducted in very restricted waters, close inshore and the loss of the propulsion generator engine made it unsafe to continue with the cruise in this location. On return to La Spezia, the engine was removed from the vessel and taken to the manufacturer's workshop in Genoa for inspection and repair. This engine is being repaired under an insurance claim and is not expected to be returned to the vessel until early January 2007. The unfortunate cancellation of the cruise gave rise to the opportunity to commence the installation of the new Integrated Bridge, Navigation, Machinery Data Monitoring and Power Management Systems earlier than expected. These new systems will greatly enhance the capabilities of ALLIANCE and the ship is expected to be fully operational by February

Alliance's makeover, from left: Bridge before the new IBNS (Integrated Bridge Navigation System) was installed, removal of old bridge system, preparing for the new units, new units in the process of installation.

CRV Leonardo

During 2006 CRV LEONARDO continued to provide a very capable platform for coastal research activities and as a working companion alongside ALLIANCE when required. The versatility of LEONARDO was continually demonstrated throughout the year and with the support of the dedicated and experienced ships staff the vessel achieved full availability for all planned operations.

LEONARDO was dry docked for a two week period at the end of November and beginning of December. The hull was cleaned and painted and annual ABS class inspections were carried out along with the 1st special 5 year survey. This docking, as with previous ones, utilized a local shipyard to lift the vessel out of the water by a synchrolift.

Left: CRV Leonardo being lifted out and placed on dry dock

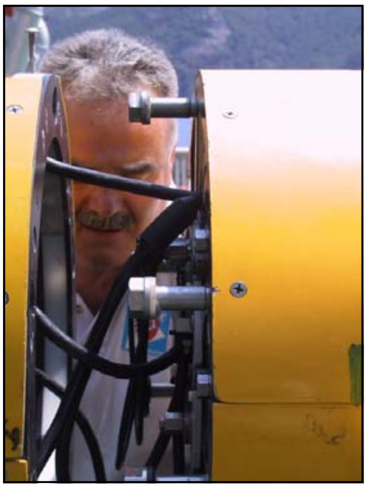
In summary 2006 has proved to be a year of mixed fortunes for ALLIANCE, with the failure of the Starboard GMT engine casting a shadow over what had been until then a particularly successful period after the grounding of 2005. The core capability of the Centre to provide 2 ship availability for scientific research from the deep ocean to the shoreline remains, and during 2006 both ships demonstrated this in the combined work they carried out.

With the new upgrades to the ALLIANCE navigation and machinery systems the vessel capabilities have been greatly increased and will improve the attractiveness of the ship for outside institutions and prospective charterers.

Progress in Engineering and Technology

The role of ETD at NURC is to:-

- Support the execution of the Scientific Programme of Work (SPOW) by designing, procuring and operating state-of-the-art measurement systems.
- To transition experimental concepts arising form the SPOW into the more directly applicable arena of military experimentation.
- To support the overall Supplementary Work programme (SWP) as required.
- To initiate and coordinate programmes of collaboration with the host countries research community.
- To maintain a "technology watch" identifying future trends in technology that could assist the implementation of the SPOW.



ETD engineering staff working on an AUV before a sea trial

2006 highlights

- Preparation and operation of measurement systems in support more than 10 separate experiments, involving 233 days at sea with NRV ALLIANCE and CRV LEONARDO plus other days onboard vessels from collaborative Nations.
- Completion of the backlog of trials from the 2005 programme. i.e. DEMUS 05 and DART 05.
- Deployment of the DEMUS system demonstrating improved reliability due to the cable and connector rework programme.
- Initiation of the final DEMUS reliability programme in readiness for 2007
- Production of a proven set of SEPTR units with enhanced capability. These units were deployed in support of the Centre's SPOW in 2006 in programmes being conducted by EOS.
- Under the coordination of the STO (Science and Technology supporting initiatives Office) several programmes of collaboration with the host country research community have been activated, continued or extended. Such cooperation builds up synergies and sharing of resources in support of the SPOW.
- Provide a calibration facility for oceanographic instrumentation in support of several NATO navies and research establishments.

Technical accomplishments

SEPTR (Shallow-water Environmental Profiler in Trawl-safe Real-time configuration)

Between May 2003 and the end of 2005 NURC collaborated with NRL to enhance early versions of a system, known as SEPTR, which had been designed to monitor the littoral ocean environment. This new system was to have the ability to monitor in quasi real time a number of ocean parameters which could be assimilated into numerical models that traditionally require boundary condition information to be effective.

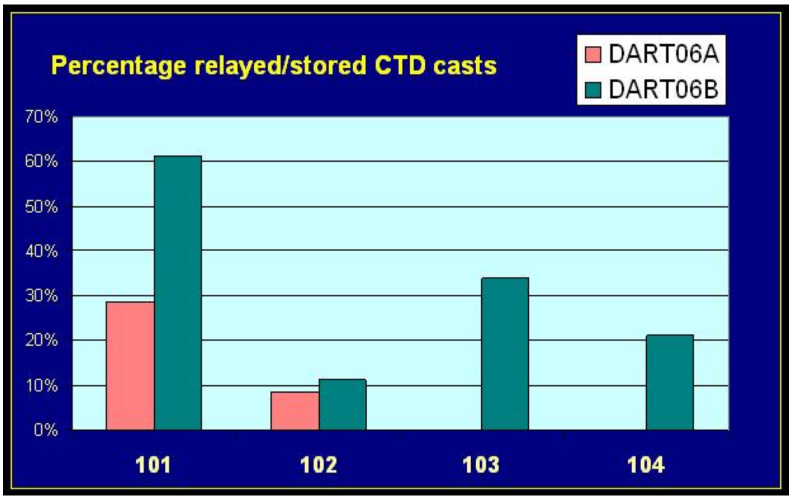
Final production unit of the SEPTR, developed under the NURC-NRL Cooperative Agreement

This work builds on previous development of the BARNY trawl-resistant system which is placed on the sea-bed, is resistant to trawler activity, and collects Acoustic Doppler Current Profiler (ADCP) data over a long period of time. The enhanced concept is to augment a "BARNY like" system with a profiler buoy. This buoy periodically rises to the surface where it transmits via satellite communications the ADCP data and additional water column data it collects en route to the surface. The buoy then returns to the seabed where it is docked within the trawl safe body providing it with a long term survival capability. This complete concept is known as a Shallow water Environmental Profiler in Trawl-safe Real-time configuration (SEPTR).

By the end of 2005 this programme had reached the point where the first prototype had been built, tested, modified and re tested and the design approved for production. The joint programme called for a total of 5 units to be manufactured. Four for delivery to NRL and one for future use by NURC.

The 5 units were successfully produced, assembled and tested in time for a first deployment in the Spring of 2006 during DART 06A. This trial, performed under arduous conditions highlighted a number of minor changes that were required to provide a high level of system availability. In addition one unit was lost at sea, presumably removed by heavy local fishing activity. The necessary improvements were carried out during the summer of 2006 prior to deployment on the DART 06B trial in August 2006 in support of Project 1A5. During this trial 4 units were deployed. All units performed with a high level of reliability and operated throughout the trial. (It should be noted that the lost unit was eventually recovered in May 2007).

One of the new SEPTR systems being deployed for testing



shows the improvement in data availability between the initial deployments (DART 06A) and the final deployment in August 2006 (DART 06B)

ETD publications and presentations

Peer reviewed journal papers

Bortolotti, V., Gombia, M., Cernich, F. A study to apply nuclear magnetic resonance porosity measurements to seabed sediments. *Marine Geology*, 2006, Vol. 230, pp. 21-27.

Gualdesi, L. An auto-focusing heuristic model to increase reliability of scientific mission. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 2006, Vol. 567, pp. 505-507.

Stevenson, M., etc. An acoustic tripwire based on forward scattering in a time reversal mirror. *U.S. Navy Journal of Underwater Acoustics*, 2006

Reports

Bassetti, M., Grandi, V., Carta, A., Rixen, M., de Strobel, F., Gualdesi, L., Fioravanti, S. The ADCP as a proxy for suspended concentration: calibration and comparison against optical data during an extended test in the Marine Protected Area of Portofino. NURC-FR-2006-013, NATO Unclassified.

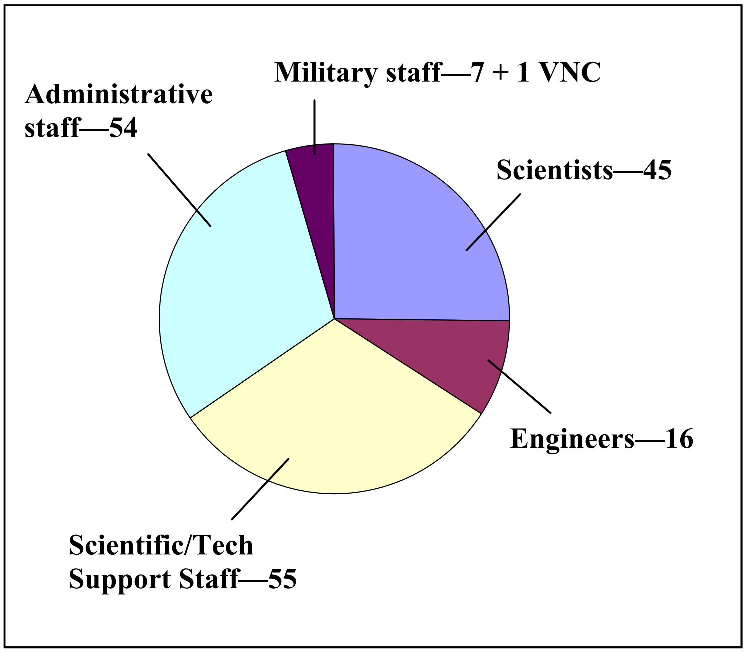
Conference presentations

Akal, T., Koprulu, K., Guerrini, P., Roux, P. Surveillance and protection of underwater archeological sites "SeaGuard" IEEE International Conference on Technologies for Homeland Security and Safety 2006 (TEHOSS 2006).

Cecchi, D., Fioravanti, S. SAMPLE: Simulation Aided Mission Planning Environment. 7th IFAC Conference on Manoeuvering and Control of Marine Craft MCMC'2006, September 2006.

Gualdesi, L. An auto-focusing heuristic model to increase reliability of scientific mission. II International Workshop on Very Large Volume Neutrino Telescopes VLVnT2.

Personnel & Staffing



Approved PE seats: 180 civilians + 9 military staff.
Above: Personnel onboard by categories, as of December 2006
(Note: VNC=Voluntary National Contribution)
Left: Personnel strength by national citizenship.

Country	Total
Belgium	5
Canada	3
Denmark	4
France	6
Germany	4
Greece	1
Italy	109
Netherlands	4
Norway	1
Portugal	2
Spain	1
Turkey	1
United Kingdom	16
United States	20
TOTAL	177

The MARE Award

In 2006, the Centre established an award recognizing serving and departed scientific staff who have made significant and lasting contributions in one or more of the following areas:

- The Centre's scientific and technical reputation
- The Centre's Scientific Programme of work
- NATO Operating Forces

The first 6 recipients of the MARE (Maritime Advanced Research Excellence) award below were selected after many months of discussions and review of contributions of current and departed staff members over the past 10 years. A permanent display will be made in a prominent location to record the names of these awardees and the names of future recipients. Nominations for future recipients are accepted from members of the Centre's Scientific Committee of National Representatives.

Tuncay AKAL
Edoardo BOVIO
John FAWCETT
Douglas GRIMMETT
Finn JENSEN
John REDMAYNE

Viale S. Bartolomeo 400
19126 La Spezia, Italy

From USA / Canada:
CMR 426 APO AE 09613-5000

Tel: (+39) 0187 527 1
Fax: (+39) 0187 527 700
Email: pio@nurc.nato.int

Website: http://www.nurc.nato.int