NURC

PARTNERING FOR MARITIME INNOVATION

2009 Research & Technology Highlights

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NATO OTAN

Contents

Message from the Director

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Fifty years ago when NURC was formed, WWII had just finished and we were in the midst of the Cold War. Research at the Centre naturally focused on undersea, or antisubmarine, warfare. At the end of the Cold War, most research labs closed down (except in the United States) as programmes were cut. Although industry filled in some of the gaps, national undersea warfare capabilities dwindled. The current economic crisis has further dampened countries' interest and ability to fund basic undersea research, despite the fact that many conflicts after the Cold War have played out on our oceans: the naval forces used in the Falkland Island conflict, the mines that were laid during the first Gulf War, the torpedo that was likely used to sink the South Korean warship. In addition, other new threats have emerged and demanded our attention: suicide bombers attacking the USS Cole, Somali pirates hijacking cargo ships, and the Mumbai attackers entering the city undetected by boat.

The Centre is addressing these new and traditional threats. Our 2009 programme reflected the shift to research and technology for policing our shorelines and waterways and developing appropriate responses to multiple, low-intensity threats. For 2009, greater emphasis was placed on port and harbour protection, maritime surveillance, and mine countermeasures. Antisubmarine warfare research continues to be an essential part of NURC's programme, because there is a need to prepare for the next generation of submarines that non-NATO nations are purchasing. However, emphasis is no longer on tracking submarines in deep ocean water, but in tracking smaller, stealthier subs in the shallow water near our shores.

Underlying all of these research projects at the Centre is the recent development of autonomous underwater networks that will monitor crucial marine areas for intruders, whether a poacher, a submarine, or a suicide bomber in SCUBA gear. These networks allow continuous, remote surveillance using a combination of inexpensive mobile sensors onboard autonomous underwater vehicles and fixed sensors moored or adrift in the water column. Data from land-based sensors, such as high-frequency radar, and air-based sensors, such as synthetic aperture radar from satellites, is also being integrated into these networks.

The scientists and engineers at NURC understand that the Cold War is long over. The challenges we face have changed and, more importantly, will continue to change at an ever–increasing pace. Although NATO funding is becoming harder to secure, the threats that face NATO nations in the maritime environment aren't going away. Protecting NATO nations' navy assets, ports and harbours, and commercial shipping fleets is essential to the political and economic stability of all NATO nations. In this environment, the staff at the Centre redoubles its efforts to scrutinize old business assumptions and to stay in front of the rapidly changing needs of a modern NATO military.

About the Centre—50 Years

With a history almost as long as that of the North Atlantic Treaty Organization (NATO), the Centre celebrated its 50th anniversary year in 2009. It has been a time to look back at accomplishments but also a time to look forward to ensure that the Centre's work continues to be relevant, is of the highest quality, and is shared with our partners.

Maritime research and technology

One of three research and technology organizations in NATO, the NATO Undersea Research Centre (NURC) conducts research and develops products to support NATO maritime operations and to support the continuous improvement, or transformation, of NATO military capabilities.

If science and technology for maritime innovation is the body of our work, collaboration is the heart and soul.

Originally a research centre for antisubmarine warfare, NURC's role has expanded and evolved over the years to meet the needs of a modern military. In addition to antisubmarine warfare, current research areas include port protection, mine countermeasures, maritime situational awareness, marine mammal risk mitigation, and environmental knowledge and operational assessment. Each of these research areas relies on the expertise of scientist in underwater acoustics, sensors and signal processing, ocean prediction, remote sensing and adaptive sampling, autonomy and collective intelligence, communication engineering, and operations research. Their work is supported by an engineering team with expertise in unmanned vehicles, sonar arrays, oceanographic instrumentation, and calibration.

Located in the port town of La Spezia, Italy, the Centre's scientists and engineers are able to spend a great deal of time at-sea testing and proving concepts and technologies aboard either the NRV *Alliance* or the CRV *Leonardo*, two research vessels specifically built for the Centre's research and the research of our partners.

Collaboration and sharing

If science and technology for maritime innovation is the body of our work at the Centre, collaboration is the heart and soul. As a NATO agency, comprised of a scientific and technical staff from 14 countries, NURC is truly a centre for multinational collaboration like no other in the world.

In addition to collaboration within the Centre, NURC has a commitment to share information with NATO nation militaries and research institutes. Through joint research projects, the visiting researcher programme, published articles, conferences, newsletters, and our website (www.nurc.nato.int), the Centre is continually sharing our knowledge and research findings. In 2010, the Centre is launching a

Quick Facts about NURC

Years since inception: 50

Location: La Spezia, Italy

Staffing: Approximately 40 scientists and 150 engineers, programmers, technicians, and administrative staff

Nations represented: Staff from 14 of the 28 member NATO nations

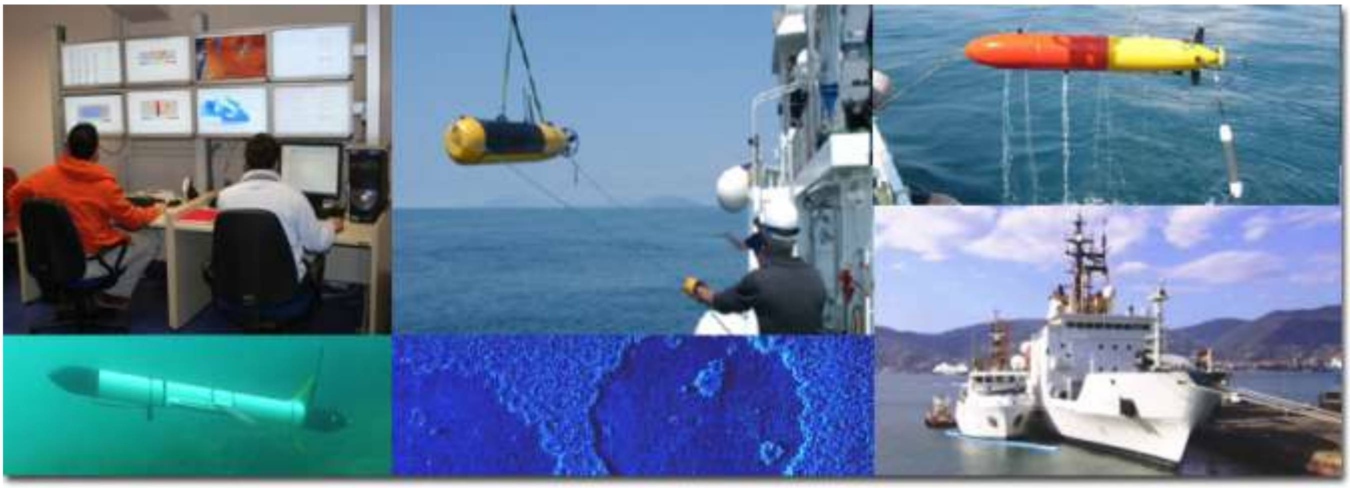
# of Maritime Innovation

new short-course series that will allow people from around the world to come to La Spezia and learn from the wealth of experience and expertise that the Centre can offer to the oceanographic community.

The next 50 years

As it has been for the past 50 years, NURC's primary objective will be to continue supporting NATO's military mission, but in 2009 NURC has formally expanded its services to entities outside NATO (see "The Centre is Officially Open for Business"). Although this new business model is being driven by economics and smaller NATO budgets, it will expose scientists to new projects and stimulate new collaboration. Lessons learned and knowledge gained from projects outside of NATO can be applied to NATO-funded projects. It is with this new business model and with a continued emphasis on serving NATO that NURC starts its next 50 years.

The Centre then...



and now

The Centre is Officially

In 2009, the Centre formally introduced a new business model that opened the doors wide to customers outside of NATO. Although offering services to customers is not entirely new, it is now part of the Centre's charter, and the Centre is putting the finishing touches on processes and plans for formally and efficiently expanding these services. Customers will likely include universities, agencies, or corporations from NATO nations who are interested in tapping into the scientific and engineering expertise as well as the world-class equipment and facilities available at the Centre. The advantage of this new business model is that some of the severe budget cuts that have plagued NATO funding will be offset. Another advantage is that work performed for a variety of customers on diverse projects will result in new skills and knowledge that can be applied to the Centre's core work for NATO.

Given the customer projects that the Centre undertook in 2009, there is clearly a demand for the services and expertise that the Centre offers, including its world-class acoustic calibration facilities, at-sea capabilities, and scientific and engineering expertise. For example, the Centre's expertise in ocean monitoring systems as part of the NATO anti-submarine warfare program helped obtain European Commission funding for the ARGOMARINE project, a marine monitoring system capable of detecting and monitoring oil spills (read "Sniffing the sea for oil spills").

The Centre offers customers a revolving staff of 40 scientists, a top-notch engineering department of 40 engineers and technicians, advanced laboratories and facilities, and two world-class research ships. The scientific staff offers core competencies in underwater acoustics, sensors and signal processing, ocean prediction, remote sensing and adaptive sampling, autonomy and collective intelligence, communication engineering, and operations research. The engineering facilities at the Centre include oceanographic calibration facilities, pressure test facilities (up to 6000 meters), acoustic calibration facilities, a suite of oceanographic equipment and instruments, and a fleet of underwater and surface vehicles. The 93-meter, 3000-tonne NRV *Alliance*, built in 1988, is still one of the quietest ships of its class. With a crew of 24, the *Alliance* can take up to 25 scientific staff and offer state-of-the-art facilities on and below deck. The 28-meter CRV *Leonardo* is also an excellent at-sea research platform for smaller teams of up to 7 scientific staff.

With the expertise and resources it has available, the Centre anticipates that the new customer business model will continue to grow in the coming years. New customers will benefit from the Centre's 50-years of experience, and NATO will benefit from the new knowledge gained by Centre staff.

Sample of 2009 Customer Projects

- Design and calibration of hydrophones for neutrino telescope
- Calibration of deepwater hydrophones
- Survey of Puglia ports for WWII ordnance
- Gliders for near real-time METOC
- Estimating winds with SAR under typhoon conditions
- Optical physical and ecosystem regional assessment (OPERA) workshop
- Calibration and validation of the visible infrared imager radiometer suite
- Logistic support for test of underwater network
- Use of MUSCLE AUV to measure seafloor subsidence
- Automatic oil-spill recognition and geo-positioning (ARGOMARINE)
- MED09 marine mammal cruise
- Algorithms for marine mammal detection and identification

Open for Business

Sniffing the sea for oil spills

As the world's attention is focused on the recent catastrophic oil spill in the Gulf of Mexico, it is easy to lose sight of the smaller spills that occur (intentionally and unintentionally) in waterways around the world. According to the National Park of the Tuscany Archipelago, about 60 major accidents occur in the Mediterranean basin each year. Of those, approximately 15 will result in oil spills. Ships in transit also discharge oily wastewater, intentionally and unintentionally. This type of spill is difficult to quantify and monitor.

Although ship discharges of oil are small scale compared to the BP oil spill or a tanker spill, their cumulative effects on the marine environment can be detrimental, particularly in sensitive areas. The European Commission through its Seventh Framework Programme (FP7) is looking for ways to protect the environment and has subsequently funded a consortium of universities, businesses, and research centres, including NURC, to develop an oil-spill marine monitoring network. Called ARGOMARINE (automatic oil-spill recognition and geo-positioning integrated in a marine monitoring network), the project's goal is to develop and test a marine information system to monitor the water for oil spills so that immediate action can be taken. This work is being overseen by the National Park of the Tuscany Archipelago, and the system will be tested within the park.

ARGOMARINE will rely on traditional tools for remotely monitoring oil spills, such as satellite imagery, sensors on aircraft, and sensors onboard ships. ARGOMARINE will also use state-of-the-art technologies developed as part of the Centre's anti-submarine warfare program to monitor conditions below the surface. Monitoring for oil spills underwater gives a more accurate picture of the extent of an oil spill, and it eliminates problems associated with above-sea monitoring, such as cloudy weather obscuring aerial imagery or winds making it difficult to see oil spill conditions on the surface.

For underwater monitoring, the Centre is designing and developing two prototype buoy systems that will be linked to shore. Using passive acoustic technologies, these systems will monitor, classify, and track vessels as they move through a specific area. The Centre is also outfitting the Folaga autonomous underwater vehicle (AUV) with a hydrocarbon sensitive electronic sensor designed by a partner firm. This sensor, which is mounted in the nose of the Folaga, will be able to "smell" oil in the water and provide its location and extent. The Folaga is a hybrid of a traditional AUV and an energy-efficient glider, making it a useful tool for long-term monitoring.

The eFolaga hybrid AUV will be outfitted with a sensor that detects oily water.

Finally, NURC researchers are looking at how to integrate all of these different technologies and sources of information (satellite data, airborne sensors, ship-based sensors, passive acoustic systems, AUVs) in an optimal marine information system for monitoring and tracking oil spills. The results from this work can help protect our marine environment and can help protect the commercial fishing and tourism economies that rely on this natural resource.

Harbour Security: Matching

A small boat enters a busy harbour at high speed: a terror attack or boaters who are unaware of the restricted area they have innocently entered? A boat approaches a cruise ship: an act of piracy or someone simply interested in a closer look? Divers emerge from the water at a ferry terminal: saboteurs or just lost? The Centre has been looking at these scenarios as part of its port and harbour security programme. Begun in 2004, the programme investigates port surveillance technologies to help NATO nations protect against acts of terrorism. This year the emphasis was on analyzing the types of responses that security forces can use when the threat is uncertain and when the appropriate response is non-lethal.

Assessing the need

Researchers at the Centre began their work by hosting a specialist workshop on non-lethal capabilities in port protection. Over seventy participants attended, representing a broad cross-section of stakeholders, including national labs (28% of attendees), port and harbour employees (27%), industry (32%), and NATO organizations (13%). This workshop made it clear that there is great interest in the emerging field of non-lethal response in the maritime sector.

The project team had the goal in 2009 of surveying candidate non-lethal technologies. A 90-page report produced by the team outlines the concepts of non-lethal response in the maritime environment, provides a review of eight selected maritime non-lethal response technologies, and makes recommendations. The technologies reviewed included underwater air gun and sparker, above and underwater loud hailing devices, dazzlers, boat entanglement barriers, projected energy, and marine mammals (see "Novel solution to port protection"). The review emphasized technology readiness and gaps.

In addition to the primary goal of evaluating non-lethal weapons, the team has also looked at other related topics, such as sonar and radar sensor detection systems, the use of unmanned surface vessels for surface threats (speed boats) and subsurface threats (divers), and automated systems for first-detection and first-response.

Testing it in the field

Exercises throughout 2009 contributed to the findings in the report on non-lethal weapons in a maritime environment. One of the biggest exercises took place in December 2009 in La Spezia harbour. This research exercise, known as PROVEx09 (PRactices, Operations, & Validation Experiment in Port Protection 2009), provided an opportunity for the Centre and industry partners to test the coordinated use of detection and response technologies. The exercise involved sonar sensors, radar sensors, unmanned surface vehicles, and response technologies. The

NURC's USV Gemellina autonomously patrolling La Spezia harbour.

the Response to the Threat

Italian Navy hosted the demonstrations, which included divers and small boats that were used to simulate an intrusion into an area of surveillance.

Industrial partners deployed wide-area sonar sensors and radar, which were used to detect and track small vessels, divers, and underwater vehicles. Such sensors are an important first step in constructing a harbour protection system. These sensors were integrated into a larger detection system that NURC had developed for this exercise.

Two unmanned surface vehicles, developed at the Centre, were tested for their ability to cooperatively respond to a potential threat. Specifically, the researchers wanted to know how well two USVs working together with input from a shore-based operator can deter or intercept a small boat or diver. Researchers also tested the ability of sensors to keep the USV in close-quarters to the small boat or diver during the exercise. One of the USVs was equipped with forward-looking and side-scan sonar, which can be used to find objects on the shallow sea floor or SCUBA divers in the water.

PROVEx09 also focused on portable commercial off-the-shelf (COTS) technology that can be used to deliver a rapid, unambiguous warning to the operators of a small, fast-moving boat. The first-response technologies included cameras and a laser range-finder to assess the situation and a loud-hailer (bullhorn) and spotlight to deliver the warning.

Automating the first response

In addition to assessing the technologies available for non-lethal response in a maritime environment, researchers are looking at automating the first response. The concept is to use radar or other sensors to detect and track a small boat that is entering an exclusion zone, to warn the operator of the boat by using a non-lethal technology, and then to determine whether the boat complies with the warning or has hostile intent and requires an increased level of force. First response is a good candidate for automation because it eliminates the need to have humans monitoring for a small likelihood event that is critically important to detect.

Novel solution to port protection

As part of the harbour security program, the Centre investigated using sea lions as a surveillance option and as a non-lethal response to an underwater intruder, for example a SCUBA diver who has entered a secured area. Trainers and sea lions from the MK5 Marine Mammal Group came from the Space and Naval Warfare Systems Center Pacific in San Diego, California, to participate in joint exercises off Elba Island where NURC was comparing different means of identifying objects on the seafloor. The sea lions have extraordinary agility and vision, and they are able to dive to great depths. With extensive training, they can perform the valuable function of retrieving expensive equipment off the ocean floor or shackling an underwater SCUBA diver who has intruded into a secured area, as was shown at a demo in La Spezia. The sea lions are amazingly accurate at their job, but they come with a unique set of requirements, such as a full-time staff and loads of fresh fish!

Making it Harder to

The Centre's Cooperative Anti-Submarine Warfare Concept is a group of multidisciplinary projects aimed at defining the next generation of anti-submarine warfare (ASW). The researchers have an overall goal to demonstrate the ability of NATO navies to track submarines using an underwater network of stationary and mobile autonomous sensors.

The Centre has studied active sonar for decades, particularly the use of multi-static sonar, using multiple sources and receivers to identify and track submarines. Historically, multi-static sonar systems are based on ships and on tethered or free-swimming buoys, but the introduction of autonomous underwater vehicles (AUVs) in the last decade offers new opportunities for inexpensive, portable, risk-free mobile platforms. The use of AUVs was a big part of the Centre's ASW effort in 2009, along with advancements in sonar modelling and data processing and improvements to underwater communication and networking.

AUVs: Toward true autonomy

AUV technology is a young technology. Although AUVs have shown excellent results as data gathering platforms that can be left at-sea for long periods of time with minimal input from a land-based "pilot", the Centre is just starting to push the envelope of what it means for an AUV to be truly autonomous and for a group of AUVs to work cooperatively. In 2009, emphasis was on setting up an infrastructure that allowed AUVs to be used in a completely self-sustained configuration. For this to happen, signal processing must be carried out onboard the AUV, and the AUV must adapt its behaviour in ways that are relevant to tracking submarines. To accomplish this, a simulation environment was created so that software could be developed and downloaded to the AUV. The simulator needed to cover everything from hydrophone behaviour to the physical behaviour of the vehicle, which required dynamic models of AUV movement. All of this modelling was done in the first half of 2009 and then field tested during the GLINT09 experiment in July near Elba Island.

During GLINT09, the team was able to demonstrate that an AUV towing a source and an array could coordinate with a bottom-tethered source. The AUV used was the Ocean Explorer (OEX) and the fixed source is a platform developed at NURC called DEMUS. The OEX AUV was able to make contact with a target and then adapt its behaviour to the target. In this case, the AUV following a pre-programmed track until it "decided", based on pre-set criteria, that a target was nearby, at which point it followed the target keeping it at broadside. GLINT09 showed, among other things, that an AUV can be used to autonomously track a target. The next step will be to show that teams of AUVs can coordinate their efforts and provide persistent surveillance.

The complexity of shallow water

One of the challenges of modern day submarine hunting is working in the littoral zone of the ocean, the shallow water between the shore and the continental shelf (up to approximately 200 metres deep). Most Cold War-era submarine tracking occurred in the deep ocean, which is a simpler environment for using sonar because there is less noise and little clutter (echoes from objects in the environment that are not of interest). Tracking submarines in the littoral zone requires better models of clutter because of all the natural and manmade features in shallow water. Efforts are ongoing at the Centre to characterize clutter for the benefits it provides to anti-submarine warfare as well as other major research interests at NURC, such as mine hunting.

In May 2009, NURC, in conjunction with partners, conducted the CLUTTER09 sea trial on the Malta Plateau in the Strait of Sicily. The team collected environmental and acoustic data to develop and validate models and survey tools for clutter characterization using broadband, low-frequency active sonar.

Hide a Submarine

Using these models and tools, NURC is working on improving prediction capabilities, reducing the false alarm rate of active sonar systems against submerged mobile and stationary targets, and characterizing natural and man-made clutter features. In a novel application, the OEX AUV was used to tow both a source and an array to gather geo-acoustic data of the seabed, perhaps the first time an AUV has been used as a mono-static sonar platform. This gave the researchers a chance to gather data within 10 metres of the seafloor, a task that is impractical from a surface ship.

Can you hear me now?

Transmitting data underwater is challenging. Unlike radio signals in air, which travel at 300,000 km/s, underwater acoustic signals travel at speeds of only 1.5 km/s. The slow speed means the amount of data that can be transmitted and the distances it can travel are limited and data can be corrupted or missing. The other challenge with undersea communication is that there is no shared protocol. Most current solutions are specially made for a given instrument or system, which means there is no interoperability between systems. Interoperability is essential for a NATO surveillance network.

The Centre is tackling the communication issue on two fronts. First of all, moving more of the "decision-making" onboard the AUV minimizes the amount of data that needs to be transmitted, but data still needs to be transferred as quickly and accurately as possible for networked surveillance to work. Investments are being made in micro-modems capable of transmitting larger data packets at higher data rates than are currently available. Second, researchers at the Centre have been working for several years to develop a common underwater communications protocol, called JANUS that enables communication between platforms using diverse hardware and software. In March 2009, the Centre hosted a JANUS workshop to further refine the protocols. And in May, the Centre conducted the SubNet 2009 sea trials. Several kilometres of fibre-optic cable were deployed around Pianosa Island. The cables supplied a shore-based lab with real-time acoustic communications and environmental data, and a satellite link allowed scientists from around the world to perform underwater experiments remotely over the internet.

The next steps

The Centre will continue to push forward in all areas of research needed to prove the concept of a cooperative anti-submarine warfare system. More processing will be moved to the AUVs and other platforms. Continued efforts on communication and networking will focus on a robust system with a strong emphasis on interoperability. Finally, researchers will develop decision support tools, which will include the design and rapid prototyping of collaborative behaviour with the objective of improving target detection, classification, localization, and tracking.

The OEX AUV set up to tow a sound source and an array, the first time an AUV has been used as a multi-static sonar platform.

Sound Matters: Understanding

For 10 years, the Centre has been working to understand the relationship between sound in the ocean and marine mammal behaviour. A series of whale strandings in the 1990s and early 2000s highlighted the need to understand this relationship. Although navies throughout the world use sonar during tests and training exercises, little was known about the relationship between active sonar and marine mammal strandings. The Centre took a proactive approach to this issue and began a decade of research in and around the Mediterranean starting in 1999.

Answering basic questions

The Marine Mammal Risk Mitigation (MMRM) project is a comprehensive, multi-national effort to shed light on some basic questions: What animals are most at-risk? What are their habitats? Can we understand their behaviour (dive patterns, sounds, etc.)? What causes mass strandings? What can we do to minimize the risk of sonar operations? The goal of this project is to make it possible for NATO navies and researchers to use sonar during exercises and experiments while minimizing the risk to marine mammals. This is being accomplished by a multi-pronged approach, including the development of:

- A database of sightings and habitat models that predict the distribution of marine mammals in the Mediterranean
- Hardware and software tools that can help ensure areas are safe for sonar operations
- Policies, protocols, and guidelines for NURC researchers and recommendations for NATO personnel in charge of active sonar operations

10 years of research and data

MED09 was the tenth marine mammal survey conducted by the Centre and its partners over the past decade. Each survey is a source of large quantities of data that are added to the marine mammal database and analyzed to help develop habitat models. During MED09, which was conducted in the Balearic Sea, Alboran Sea, and Tyrrhenian Sea, more than 172 hours of visual surveys were conducted, which resulted in 6,412 marine mammal sightings. In addition to the visual surveys, 550 hours of acoustic surveys were conducted using five different methods of passive sonar monitoring technologies.

What are active and passive sonar?

Sonar is a technique for determining the location, range, and identity of objects in the water. The simplest way to think of active and passive sonar is that active sonar sends out a sound signal, also commonly referred to as a "ping," and listens for the returning sound waves as they bounce off objects in the water. Passive sonar just listens for noise in the water. Many marine mammals, particularly certain types of whales and dolphins, rely on "biological sonar", called echolocation, for navigating, communicating, and hunting prey. Sounds of a certain frequency, such as the kind associated with active sonar, can disrupt the behaviour of echolocating species.

MED09 was also an opportunity to test new hardware developed at NURC. The Compact Passive Acoustic Monitor (CPAM) was designed to detect Cuvier's beaked whales (*Ziphius cavirostris*) by "listening" for their unique vocalizations. Using a unique tetrahedral configuration of hydrophones and sophisticated algorithms, the CPAM is able to detect Cuvier's beaked whales and pinpoint their location. Beaked whales are of particular interest because this species, along with sperm whales (*Physeter macrocephalus*), are most sensitive to sound in the marine environment. Research conducted by the Centre, in conjunction with Woods Hole Oceanographic Institute, has allowed us to understand the dive and feeding patterns of both of

Sonar's Effect on Whales

these deep diving species and helped us with the development of hypotheses concerning the impacts of naval sonar on their behaviour.

New policies to help lead the way

In 2009, the MMRM Policy, which guides operations at the Centre, was significantly revised to reflect new research in the field. The Centre also contributed to the development of the principles and operating guidelines that will be used during NATO maritime active sonar exercises.

The Centre continued to influence research and policy beyond NATO by hosting the 3rd Intergovernmental Conference on the Effects of Sound in the Ocean on Marine Mammals. This conference, which was held near the Centre in September 2009, facilitated the open exchange of current research and policies in this field. Approximately 75 scientists and government personnel from 10 countries attended.

The towed CPAM array uses a unique tetrahedral arrangement of sensors to find marine mammals.

A commitment to protect the environment

Going into its final year, the MMRM project will conduct a survey off the coast of Portugal and continue to test passive acoustic monitoring technologies, such as CPAM. Data from this survey will contribute to the continued development of distribution and habitat models. These models along with environmental data and policy data will be incorporated into the Integrated Decision Aid, a software planning tool that will help experts make recommendations on ways to further minimize risk to marine mammals. With a decade of research behind the Centre, interest in this work continues to be strong, as NATO navies commit to protecting the environment.

A whale is tagged during the MED09 cruise. (Photo courtesy of Woods Hole Oceanographic Institute.)

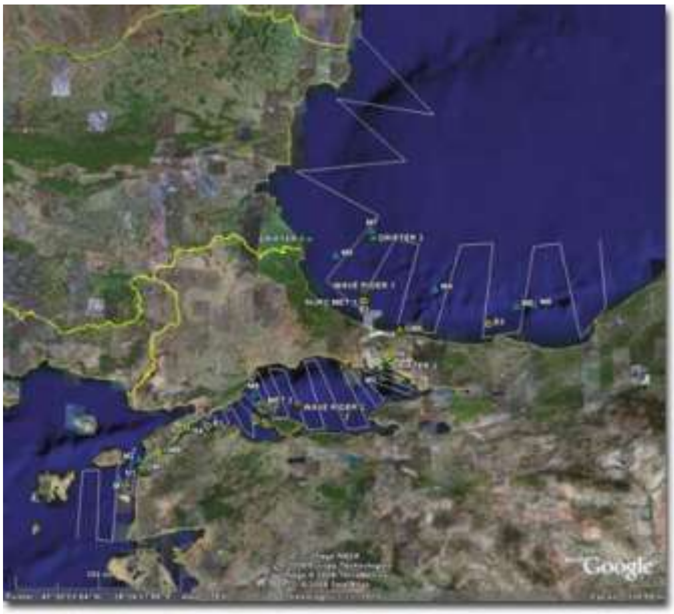
MED09 Partners

- Woods Hole Oceanographic Institute
- U.S. Chief of Naval Operations Environmental Readiness Division
- U.S. Navy Office of Naval Research
- SPAWAR Pacific
- University of Pavia
- Alnitak
- U.S. Department of Defense Strategic Environmental Research and Development Program
- U.S. National Oceanographic and Atmospheric Administration

Helping NATO Maritime Forces

The success of NATO forces depends on understanding the environment in which they operate and using that knowledge to make accurate decisions. Information that navies need before they start an operation includes current meteorological and oceanographic data, such as winds, waves, currents, and water visibility, but more importantly predictions for these factors during the course of an operation. Because most military operations occur in restricted territory, this data must be gathered remotely. The challenge of gathering remote data and building an accurate model is further complicated when the operation is in shallow water, which is strongly influenced by the coastline and topography of the seafloor.

In 2009, the Centre continued with a broad-based effort to gather data remotely, develop models that can provide accurate meteorological and oceanographic forecasts, and to create tools that NATO navy commanders can use to aid in and simplify the decision-making process before and during an operation. Two research operations were conducted early in 2009 to move forward on these goals.



Location of moorings and station network in TSS09.

Data from the moorings are invaluable in modelling complex oceanographic processes.

Understanding shallow water

The first operation (TSS09) was conducted in February in the Marmara Sea (the sea that connects the Black Sea and the Aegean Sea). The goal of this research cruise was to gather large amounts of data to help better understand the complex processes of shallow water, particularly as it moves through a restricted straight. This small area offered researchers an opportunity to study complex processes, such as two-way exchange flows, hydraulic controls, dense water overflows and jets, turbulent mixing and entrainment, and locally and remotely driven motions reflecting ocean-atmosphere interactions. Conducting the cruise in February meant that atmospheric conditions would be variable, giving the scientists more opportunities to gather data over a wide range of meteorological conditions.

The primary activities of the cruise were the recovery and redeployment of 29 oceanographic moorings deployed in the region in September 2008 to study the inflows and outflows from the Strait of Istanbul and the Strait of Canakkale and to study the interaction between the straights and the basin. Large amounts of oceanographic data were also recorded using a variety of instrumentation. Data from the cruise and from the long-term moorings are invaluable for understanding and modelling complex oceanographic processes.

This research cruise was a highly collaborative operation with a total of 16 scientists from Italy, USA, Turkey, Bulgaria, and Romania and 14 scientific personnel from the Centre participating in the cruise. The Centre's NRV *Alliance* was joined by Bulgarian, Romanian, and Turkish research vessels to gather the

Prepare for Operations

data in Marmara Sea, Aegean Sea, Western Black Sea, Strait of Istanbul, and Strait of Canakkale.

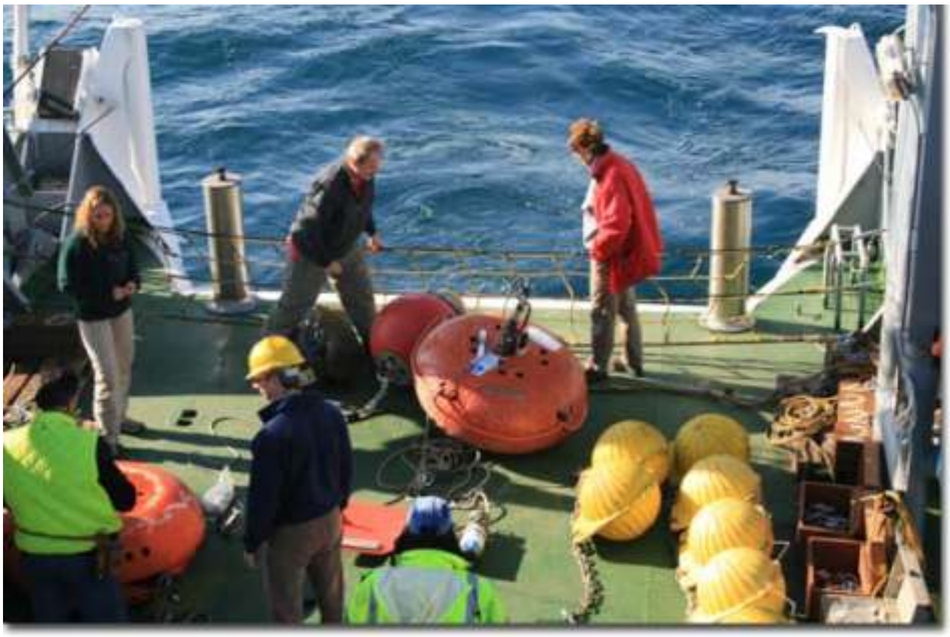
Remotely gathering data

The goal of the second research cruise (BP09), conducted in March 2009, was to evaluate uncertainties in a variety of optical instrumentation. Optical data and modelling can contribute to ocean prediction systems and can be used by military personnel to determine relevant operational information, such as water visibility for divers. Prior to this research cruise, gliders were used to map out the distribution of bio-optical and physical properties to help initiate the physical model and to provide vertical distributions of geophysical parameters. In conjunction with the optical data gathered from the gliders, satellite data and high frequency radar data were collected.

One of the goals of this sea trial was to demonstrate that gliders, deployed off vessels in coastal areas, can improve rapid environmental assessment, leading to better meteorological and oceanographic forecast models. Gliders, a type of autonomous underwater vehicle (AUV), use shifts in mass to steer and changes in buoyancy to dive and surface. Gliders are easy for two people to deploy (most weigh less than 50 kg), and because they operate at low speeds (1 - 2 km/h), they have low energy requirements, so they can remain at sea for long periods.

Building a unified picture

Gathering quality data remotely is an important part of preparing for a maritime operation, but the data must be interpreted using a variety of models and then fused into an overall picture of the environment. Work at the Centre continued throughout 2009 on developing robust data fusion techniques and graphic user interfaces that allow researchers, and ultimately NATO military operators, to see the environmental picture, including risk analysis and decision support for operations. Advanced techniques, such as the Kalman-filter-based superensemble algorithm, resulted in significant improvements to modelling efforts. Likewise, complex algorithms are being developed to help operators understand the uncertainties and risks associated with the models and to make decisions on the operations of AUVs.



Preparing moorings for deployment from the NRV Alliance.

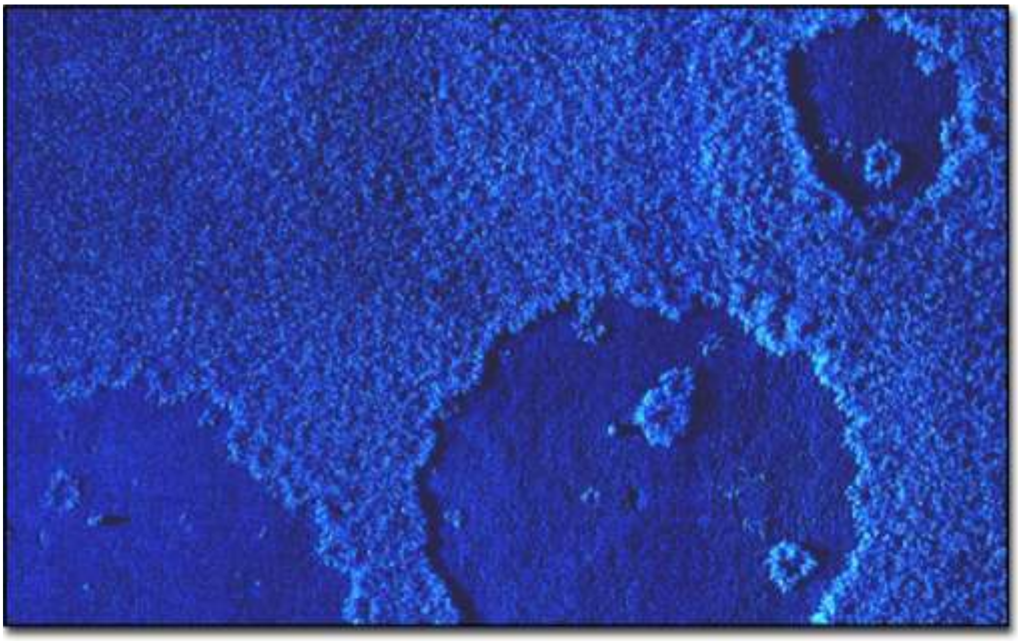
Work in 2010 is pushing forward on all areas of this multi-faceted research effort. A research cruise in the summer (REP10) will demonstrate a prototype environmental decision support system, which will include data from a coordinated fleet of gliders. This research cruise will be held in the Ligurian Sea, an area with strong current and heavy maritime traffic, offering a dynamic environment for data gathering and modelling.

Advancements in Finding

Mine hunting and disposal have been dangerous and unbalanced propositions: The effort to safely find and eliminate a mine vastly outweighs the effort to build and place the mine. The Centre is trying to rebalance the discrepancy so that mines can be quickly and safely found, identified, and detonated in a cost-effective way. Advancements in sonar, autonomous vehicles, and software development are all contributing to new end-to-end approaches to mine hunting, identification, and disposal.

Synthetic aperture sonar matures

Since 1996, the Centre has been working on synthetic aperture sonar (SAS), a technique for taking the data from multiple sonar pings and processing it into a higher resolution image. The Centre has played a significant scientific role in the leap forward in mine hunting sonar capability using SAS. Results from NURC research have led to the design and development of high-resolution sonar systems throughout the NATO nations. With high-resolution sonar images now in a mature state, the Centre is focused on using autonomous vehicles as a platform for SAS.



SAS image collected with the MUSCLE AUV in an area with seaweed and open patches of sandy sea bottom. Two target shapes can be seen in the open patches.

Autonomy equals safety

The primary benefit of using autonomous vehicles in mine countermeasures is the safety that unmanned equipment offers NATO forces. In the same way that land mines are being identified and disposed of by robots, autonomous vehicles now have the potential to safely identify and dispose of mines placed on the seafloor or attached to a buoy. Autonomous vehicles include both autonomous underwater vehicles (AUVs) and autonomous surface vehicles (ASVs). Recent advances in autonomous vehicle navigation, control, and sensor processing have increased the speed, risk reduction, and capability of mine countermeasure missions.

Autonomous vehicles now have the potential to safely identify and dispose of mines.

This year during the CATHARSIS sea trials, the Centre compared its MUSCLE AUV with other mine countermeasure platforms in mine hunting and classification. Using processing software previously developed at NURC, the capabilities of synthetic aperture sonar and automated target detection were successfully demonstrated at-sea. The MUSCLE AUV was able to hunt mines more accurately and quickly than alternative platforms, even in challenging situations such as shallow water, sand ripples, sea grass, or areas

and Disposing of Mines

with a large amount of clutter (for example, rocky bottoms).

Finding and identifying the mine is only half the battle. The other component of mine countermeasures is mine destruction. The first step typically involves locating the mine again with the detonation equipment. The Center has made progress in relocating mines by using advanced navigation techniques that rely on the autonomous vehicles' built-in navigation and a set of GPS-positioned surface buoys. The high level of accuracy that the researchers saw during the sea trials using these combined techniques will allow the Centre to explore improvements in electronic neutralization of mines, an inherently safe, non-explosive method that could replace the current costly method of using ROVs.

CATHARSIS 2 Trial tested two AUVs, equipped with different high-resolution SAS systems: HUGIN AUV (top) and MUSCLE AUV (bottom).

Software to improve autonomy

During 2009 sea trials, researchers successfully tested a set of programmed behaviours that they wanted AUVs to take depending on the situation, for example having an AUV survey an area in a zig-zag motion or circle a target. Researchers also made great improvements in getting the communication chain, from the autonomous vehicles to the shore-based operations, working smoothly.

Efforts moving forward will focus on putting more of the processing tasks onto the autonomous vehicles so that less time is needed to transmit data to and from a shore-based processing system. With onboard processing, autonomous vehicles will start to make decisions based on their environment. For example, an AUV might gather additional data because the sonar data it gathered isn't sufficient. Or an AUV might adopt a circling behaviour when it detects a mine. AUVs will also rely on onboard software to communicate with other autonomous vehicles, including sharing data and coordinating operations.

The Centre is working toward a scenario where multiple surface and underwater vehicles can work collaboratively with greater and greater autonomy and less reliance on shore-based analysis and processing. In this scenario, the safety, efficiency, and cost effectiveness of mine hunting has the potential to dramatically improve.

Tackling Threats on the High

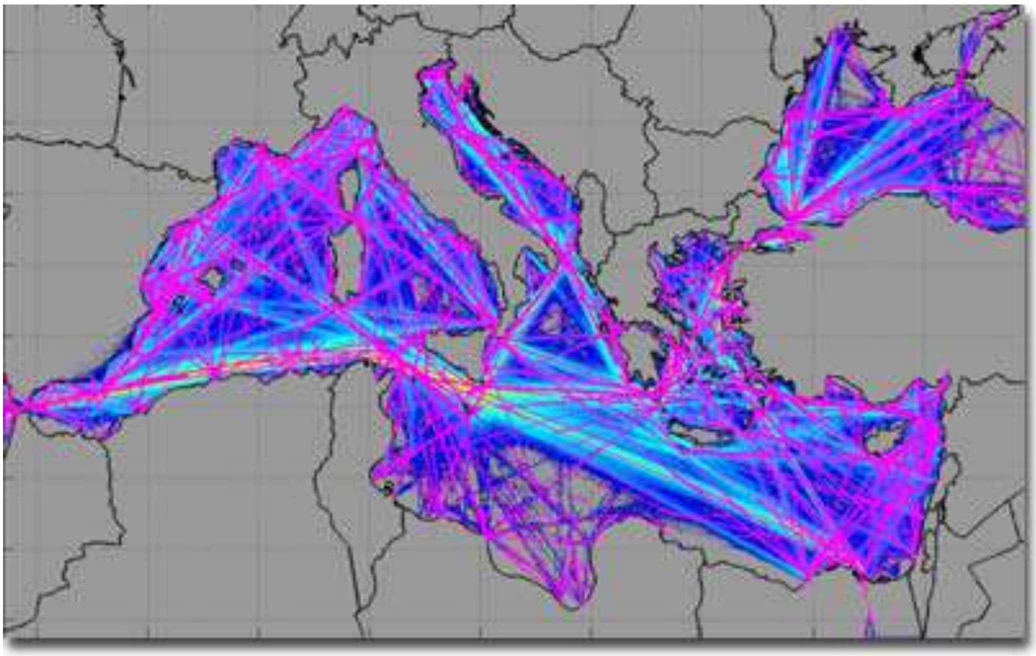
Historically, the Centre has focused on science and technology to explore the sub-surface ocean, primarily using sonar to create a map of the underwater environment and to find submarines and mines. However, over the years, interest has grown in monitoring maritime traffic on the ocean's surface to guard against threats of piracy, hijacking, smuggling, or terrorism. Disruption to maritime commerce is a concern of NATO nations who know that our growing global markets rely on oceanic transport of goods. Maintaining safe transit for our shipping industry is essential to economic stability, which in turn is essential to political stability.

The Centre is applying its knowledge in tracking submarines to tracking surface ships. This field, which is known as maritime situational awareness, involves merging data from multiple sources and showing a real-time image to a trained operator at a remote, land-based observation centre. Because surveillance resources are constrained and because most ships are operating legally, the goal is to develop a maritime surveillance system that monitors everything but only flags abnormal ship behaviour, or anomalies, which might need to be investigated further.

Interest has grown in monitoring maritime traffic to guard against threats of piracy, hijacking, smuggling, or terrorism.

Technologies for monitoring traffic

One of the main technologies used to track ships around the world is the Automatic Identification System (AIS), a tracking system that is required on all ships over 300 tonnes and all passenger ships. Each ship has a unique AIS identification code and its location, speed, and course can be monitored by operators at a shore-based facility and by other nearby ships to prevent collisions and to assist in emergencies. AIS offers useful information for monitoring maritime traffic, but transmitters can be turned off to avoid detection. To supplement AIS information, the Centre is using other traditional resources, such coastal radar, as well as some non-traditional sources, such as high-frequency (HF) radar and spaced-based synthetic aperture radar (SAR).



Sea lanes (shown in purple) superimposed on one year of AIS data for the Mediterranean and Black Seas.

Seas with Technology

Fusing data from multiple sources

AIS, satellite imagery, coastal- and ship-based radar offer additional information, but it is only useful if it can be merged to form a more detailed picture of the maritime environment and if it can be interpreted for the surveillance operator. It is the fusion and interpretation of data that the Centre is contributing to the field of maritime situational awareness. The Centre has been working on data fusion in the area of anti-submarine warfare for the last decade. As part of this effort, a sophisticated software program—a data fusion engine—was developed to merge information from a variety of sonar sources. The Centre has now taken the software, known as the Distributed Multi-Hypothesis Tracker (DMHT), and applied it to maritime situational awareness. The DMHT can use input from a variety of sensors and fill in gaps in temporal or spatial data. The program can also find anomalies in ship behaviour. This is particularly important because surveillance operators are only interested in behaviours that could be a result of suspicious activity, for example, two ships without AIS that rendezvous or a ship with AIS that radically alters its course.

Because of the large number of sea-going vessels, operators only monitor anomalies at any given time, such as those shown in this image.

Testing a surveillance system

As part of NATO's counter-terrorism program, Active Endeavour, a 5-day research cruise was held in October 2009 to test the Centre-developed maritime surveillance system. This prototype system has the ability to fuse maritime data from multiple resources, highlight anomalies, and provide that data to shore-based operators in real-time. For this operation, the NRV *Alliance* was used to gather AIS and HF radar data onboard, and coastal radar data was provided by Greece and Turkey. Greece contributed two navy vessels that followed preplanned manoeuvres designed to test the limits of data fusion and anomaly detection. Real-time data was fused using the DMHT and then transmitted to the Centre in La Spezia and to the Maritime Operations Center at Maritime Component Command in Naples, where operators could see the fused data results with detected abnormalities in real-time. Satellite SAR images were collected during the research cruise and information on detected ships was provided to the operators on a near real-time basis. SAR allowed the operators another way to see ships that were not transmitting AIS.

This test showed the viability of gathering data at-sea, fusing it, and providing the fused data with anomaly detection to operators in a remote location. In 2010, emphasis is on incorporating additional data sources, improving the speed of ship detections using SAR, and integrating the Centre's software with other systems under development by NATO.

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2009 Sea Trials and Engineering Tests

PROBA Survey	25 January—2 February	Puglia Harbours
TSS09	29 January – 9 March	Marmara Sea and Black Sea
CATHARSIS	9 March – 6 April	La Spezia
BP09	13 March – 27 March	Ligurian Sea
CASW09	31 March – 9 April	La Spezia
Marine Surveillance HF-Radar	6 April – 30 June	Ligurian Sea
TANGLEX	6 – 7 April	La Spezia
CLUTTER09	29 April – 31 May	Malta Plateau
Ghost Buster	18 May	Malta Plateau
SubNet 2009	18 May – 30 September	Isola di Pianosa/Elba
GLINT09	29 June – 21 July	South of Elba
MED09	27 July – 7 September	Tyrrhenian Sea
CPAM Engineering Test	21 – 25 September	La Spezia
Sea Acceptance of Web Gliders	17 – 18 September	La Spezia
MUSCLE Engineering Test	28 September – 2 October	La Spezia
CATHARSIS 2	5 – 20 October	Elba
LionEx	22 – 26 October	La Spezia
MS09	15 – 22 October	Aegean Sea – East Mediterranean
TSS09A	7 – 15 October	Aegean Sea, Marmara Sea
CPAM Engineering Test	2 – 4 November	La Spezia
MUSCLE Engineering Test	2 – 6 November	La Spezia
Glider Fleet Engineering Test	24 – 27 November	La Spezia
PROVEx09	30 November – 11 December	La Spezia
LASEREX09	15 December	La Spezia

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