NATO STO-CMRE

2018 - 2019

BIENNIAL REPORT

Science and Technology Organization

Centre for Maritime Research and Experimentation

S&T organization

Centre for Maritime Research & Experimentation

CMRE staff service the Deployable Multistatic Sonar System source buoy during the Littoral Continuous Active Sonar (LCAS) 2018 sea trial.

MISSION

The mission of the Centre for Maritime Research and Experimentation (CMRE) is to organize and conduct scientific research and technology development, centred on the maritime domain, delivering innovative and field tested Science & Technology (S&T) solutions to address defence and security needs of the Alliance.

STRUCTURE

CMRE is an executive body of NATO's Science and Technology Organization (STO), which operates under North Atlantic Council (NAC) authority through the Military Committee (MC) and the Conference of National Armaments Directors (CNAD).

ABOUT

The Centre for Maritime Research and Experimentation, originally known as SACLANT ASW Research Centre or SACLANTCEN and subsequently as NATO Undersea Research Centre (NURC), was commissioned on 02 May 1959.

With over 60 years of accumulated knowledge and experience in undersea research, CMRE is a recognized centre of world-class expertise in the maritime domain. The Centre is a collaboration hub for scientists from all NATO Nations to work together to maintain NATO's maritime technological edge.

Today, the Centre's scope encompasses the fields of artificial intelligence, big data analytics, underwater acoustics, oceanography and autonomous systems. Underpinning CMRE's success in maritime research over the years is its sea-going capability.

CMRE provides an outstanding at-sea research environment where internationally recognized scientists and engineers from NATO Nations share their knowledge while delivering results more effectively than would be possible by individual nations. The Centre conducts cutting-edge maritime experimentation and demonstration in extremely challenging conditions from the Mediterranean Sea to the Arctic Ocean.

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FOREWORD

The maritime domain has been of strategic importance to NATO since its founding in 1949. The security environment has changed significantly over the past few years, and NATO is now in an era of great power competition. NATO must not lose its technological edge. During the past decade, the Centre for Maritime Research and Experimentation has established itself as a global leader and well-recognized reference for research in key areas such as military oceanography, artificial intelligence and the development of autonomous underwater vehicles conducting mine countermeasure missions, support to anti-submarine warfare, and the use of big data analytics for decision support. With the ability to carry out research at sea and demonstrate technological solutions in operational settings, CMRE will continue to play a central role as a hub for maritime innovation, research, and development, for the benefit of the Alliance and its partners.

At the 2018 Brussels Summit, Allied leaders agreed to reinforce the Alliance's maritime posture. Leaders reaffirmed the strategic importance of the maritime domain and the need to reinvigorate core maritime warfighting competencies, addressing capability shortfalls accrued over two decades of declining investment. The resulting communique highlighted a number of areas in the maritime domain where CMRE could contribute effectively to the strategic challenges ahead. At the NATO military strategic level, SACT leads in the area of S&T. SACT fully supports the collective need for the Alliance to address priority S&T problems and opportunities through the ability to conduct scientific research, technology development and systems engineering, prototyping and demonstration in areas relevant to NATO defence planning priorities in the maritime domain. ACT funding currently accounts for more than two thirds of CMRE's revenue, and SACT has indicated support for CMRE capital investment in refreshing the S&T infrastructure, facilities, and modernization of IT for research and experimentation. At the end of 2019, HQ SACT staff drafted an Operational Requirements Statement for Maritime S&T, which was submitted to governance in early 2020.

The Centre is leveraging its expertise by contributing to the acceleration of capability development via participation in NATO exercises, operational experimentation, and technical demonstrations at sea. In particular, CMRE has developed Maritime Unmanned Systems (MUS) for performing multistatic anti-submarine warfare demonstrated in Dynamic Mongoose 2017 and Dynamic Manta 2020, in addition to working with the submarine squadrons of seven NATO allies. Our Autonomous Naval Mine Countermeasures programme deployed on the SNMCMG2 Flagship HMS *Enterprise* in 2018 to participate in both the Spanish and Italian Mine Exercises. The Centre also demonstrated MUS potential as Maritime Intelligence Surveillance and Reconnaissance gathering systems as they as they are covert and persistent. While the Centre developed the first ever digital underwater communications protocol, JANUS, in 2017, the relevance to distressed submarine rescue operations became more fully developed at the REP-Atlantic 2018 trials in collaboration with the Portuguese Navy and the University of Porto.

The Centre's Environmental Knowledge and Operational Effectiveness team participated in the NARVAL19 sea trial conducted by the Service Hydrographique et Océanographique de la Marine in collaboration with the Direction Générale de l'Armament and the Norwegian Defence Research Establishment. A large suite of CMRE oceanographic and acoustic assets were deployed to characterize the underwater environment on the Svalbard shelf/slope and across the Polar Front in the western Barents Sea. And finally, during the International Maritime Exercise 2019, the Centre's Data Knowledge and Operational Effectiveness team successfully integrated output from its Maritime Pattern of Life System with SeaVision, a web-based maritime situational analysis tool operated by the US Department of Transportation that enables users to view and share maritime information.

Between January and March of 2018, NRV *Alliance* returned to the polar regions in the winter months for the first time in 20 years. The upgrade of the ship's systems to meet the latest polar codes and her annual visits to the High North since 2016, have reinforced the knowledge that she can operate in any ocean of strategic interest to NATO. Unfortunately, in July 2018, NRV *Alliance* suffered a catastrophic engine failure to one of her two diesel main propulsion generators (MPG). The rebuild of the MPG began in January 2019 and took almost nine months to complete, due in part to lack of spare parts and knowledgeable craftsmen. In October 2019, NRV *Alliance* returned to the open seas, first to participate in NATO's Dynamic Mariner and then transited to the High North on behalf of the Italian Navy.

Internal to CMRE, many changes occurred during 2018-2019. The Centre completed efficiency measures and transitioned to a new organizational structure, as requested by the Science and Technology Board at the end of 2017. The new structure includes leaner administrative overhead, which has allowed us to reduce our burden labor rates from 73.5% in 2013 to 60.1 % in 2020. Additionally, a new Information Technology Branch was created within the Engineering Division including specific computing and software sections. This move is in-line with CMRE's vision to become the maritime data and software hub for NATO and Nations.

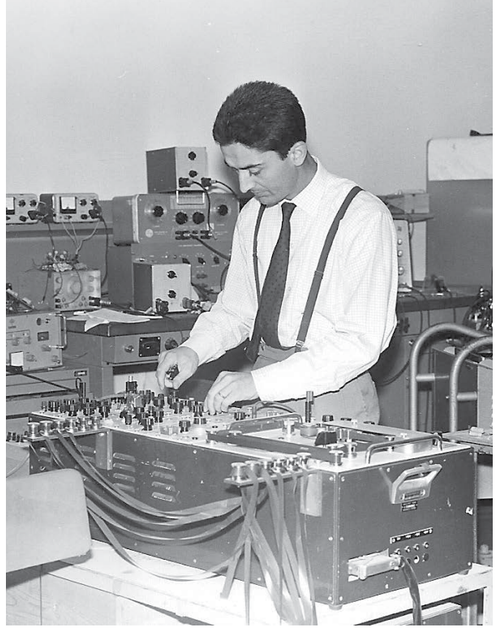
Notwithstanding the difficult financial situation caused by the unavailability of NRV *Alliance* during 2019, the Centre's business prospects remain very promising. Growth is being achieved by securing additional funding from NATO Nations to support national programmes for maritime research, capability development and demonstration, and training efforts. NATO and the Nations are increasing their exploitation of the Centre's knowledge and experience in experimentation at sea and CMRE revenue is forecast to remain firm; there is still a strong demand signal from NATO Nations for CMRE's products and services. The Centre also maintains a strong relationship with the European Commission Horizon 2020 programme and is also part of the winning consortium for the Ocean 2020 project.

In 2019, the Centre celebrated its 60th Anniversary, a testament to the continuing requirement for NATO to have a research centre dedicated to the maritime domain. The Centre and NATO express their gratitude for our Host Nation Italy for providing our home in this beautiful part of the world for the past 60 years. And especially for the Italian Navy who have crewed our two research ships, NRV *Alliance* and CRV *Leonardo,* since 2016.

With pleasure, I submit this report summarizing the scientific, engineering, and business support activities accomplished in 2018-2019.

Dr Catherine Warner
Director, CMRE



CELEBRATING 60 YEARS OF EXCELLENCE

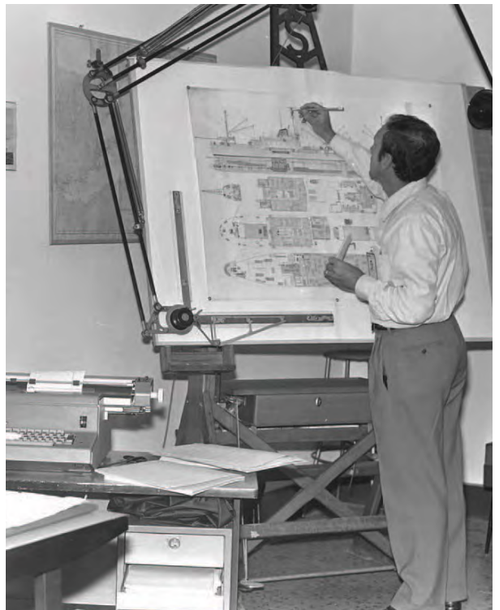
Recognizing the link between technology and sea power in the Atlantic, a research collaboration hub was established in La Spezia, Italy, in 1959, where the Nations could pool their collective knowledge and resources to address maritime warfighting challenges with science and technology. By 1960, nine Nations' flags flew over the SACLANT ASW Centre. It was later renamed the NATO Undersea Research Centre, and today, six decades later, 30 Nations' flags fly in front of the NATO Centre for Maritime Research and Experimentation.










CMRE'S 60TH ANNIVERSARY

CMRE CELEBRATED ITS 60TH ANNIVERSARY ON THE 03 – 04 OCTOBER 2019

Today the maritime environment is more important than ever — 90 percent of international trade is by sea, and 99 percent of the world's transcontinental communications and internet traffic travels on undersea cables.

After the collapse of the Soviet Union and the more recent expeditionary land-focused counterterrorism campaigns, the Alliance has fallen behind in key maritime warfare areas, just as Russia is increasing its capabilities and operations. Today, CMRE's mission reflects the importance of a multidisciplinary approach to multi-domain maritime challenges.

Throughout its history, the Centre has operated coastal and ocean-going research vessels to take science to sea. Building upon its reputation for world-class acoustics research, CMRE is now also a world leader in maritime unmanned systems; all-domain data analytics and fusion; modelling and simulation; and artificial intelligence and autonomy. Over the course of two days, 03 and 04 October 2019, CMRE welcomed more than 400 guests to honour its 60th anniversary.

The Official Commemoration Day on 03 October included the participation of NATO and Italian dignitaries, civil and military authorities, previous Directors and Deputy Directors, as well as current staff of the Centre. Guests enjoyed a live performance by the Banda Musicale della Marina Militare, who played throughout the ceremony. The celebration began with welcome speeches by Dr Catherine Warner, Director CMRE; Dr Bryan Wells, NATO Chief Scientist; Rear Admiral Giorgio Lazio on behalf of the Italian Navy Chief of Staff; and General Paolo Ruggiero, Deputy Supreme Allied Command Transformation.

CMRE staff, alumni and their families came together for the CMRE Open Day on 04 October. Guests were invited to visit the Coastal Research Vessel (CRV) *Leonardo* and engaged in live demonstrations by the CMRE Modelling & Simulation team. In addition, a walk-through exhibition of the technology used for maritime research and experimentation throughout the history of the Centre was on display.

As the Centre celebrates its 60th Anniversary, the threat of adverse naval powers with growing capabilities has thrust the work of the Centre's scientists, engineers and technicians into international prominence again. Along with its ever-widening network of international partners, CMRE will continue to meet the Alliance's maritime challenges of the future.

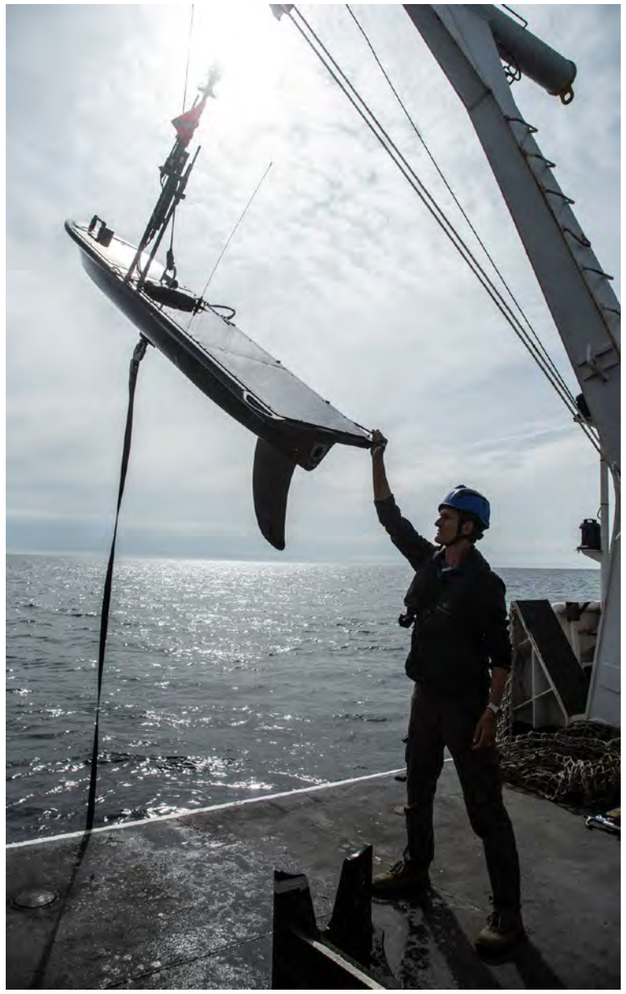
Left Page: Dr Warner stands with VIP guests in front of CRV *Leonardo* during the Official Commemoration Day.
Right Page, Top: Dr Warner delivers the 60th Anniversary Welcome Address.
Below: Guests enjoy the Centre's historical exhibit during Open Day.

Drone image of CMRE captured during the 60th Anniversary celebration.

"The maritime domain is of vital strategic importance to NATO. CMRE has consistently used science, technology and engineering expertise to meet the challenge of advances in adversary capability and to maintain our technological edge. . . . The research conducted by CMRE is to the benefit of all Member Nations – not just those with a Navy."

– Dr Catherine Warner, CMRE Director,
60th Anniversary Welcome Address

RESEARCH HIGHLIGHTS



MINE COUNTERMEASURES

“Our plan is to be able to send a fleet – or a squad – of autonomous, intelligent vehicles over the horizon where they can understand the environment on their own, and how best to plan and execute missions as a team. . . . We want to take the human completely out of the minefield.”

– Dr Samantha Dugelay, ANMCM Programme Manager

Looking for underwater mines is an essential naval mission, but it is a difficult, dangerous and time-consuming process. CMRE is helping warfighters get a clearer picture of what lies in the murky depths below, thanks to a cooperative fleet of unmanned vehicles. The Centre’s Autonomous Naval Mine Countermeasures (ANMCM) programme addresses technological shortfalls in minehunting capability through the use of collaborative autonomous underwater systems, thus helping to position NATO Nations to counter the naval mine threat with interoperable intelligent unmanned systems of systems.

At CMRE, much of the hardware used for experimentation, such as unmanned underwater vehicles (UUVs) and unmanned surface vehicles (USVs), are customized for the ANMCM programme. “We take systems created by Nations’ industries, and add on new capabilities,” states CMRE scientist Thomas Furfaro, “In particular, we want to show how, with software and algorithms, we can take assets that are already operational in the fleet and make them perform like next-generation systems.”

The ANMCM team is using high-frequency synthetic aperture sonar mounted on UUVs. “We design algorithms and implement them in software that runs on-board the vehicles during missions to be able to perceive their environment in real time. For minehunting, this means that operators can receive immediate feedback about what the vehicle thinks it sees, and make decisions in fast-time about how to respond,” says Furfaro.

“At CMRE, we marry the laws of physics with human ingenuity to produce advanced technologies that enable NATO to better achieve its mission goals. Within the ANMCM programme, this often means creating custom hardware solutions, like novel autonomous underwater vehicles equipped with state-of-the-art sonar sensors,” states scientist Dr David Williams, “We then enhance these systems by developing sophisticated software algorithms that give the assets the powers of perception – in essence, a ‘brain’–and the ability to react to tactical and environmental conditions in real time. We also undertake extensive at-sea experimentation to verify the robustness of our techniques and to ensure that they can handle the unique challenges presented by real-world operations.”

Programme Manager for ANMCM, Dr Samantha Dugelay, leads three separate but tightly integrated projects: Collaborative Autonomous MCM (CAMCM); Planning and Evaluation for MCM (PE-MCM) and High-Resolution Low-Frequency Synthetic Aperture Sonar (HRLFSAS).

CMRE has already designed, built and demonstrated a prototype HRLFSAS for minehunting, which is at the cutting edge of underwater sonar technology. The system leverages modern electroacoustic technologies coupled with heavy-hitting processing capabilities to ‘get more for

Technicians work on an autonomous underwater vehicle during Dynamic Mariner 2019.

MINE COUNTERMEASURES

less', providing a powerful new way to view underwater objects and the seabed environment.

The Collaborative Autonomous MCM project focuses on the science of autonomy, which enables machines to make decisions independently and in real time about how to perform specific missions. This includes scenarios with multiple vehicles interacting, thanks to CMRE's Distributed and Decoupled Collaborative Autonomy Framework (D2CAF), which allows federations of autonomous systems to communicate about mission goals, combining efforts to perform MCM missions better and faster.

When conducting MCM operations, NATO doctrine requires a determination of risk. CMRE uses a pair of specially configured General Dynamics Mission Systems Bluefin-21 UUVs. One has been adapted as the Minehunting UUV for Shallow Water Covert Littoral Expeditions (MUSCLE) experimentation platform, and the other is the BlackCAT (Collaborative Autonomy Testbed). The MUSCLE is equipped with a high frequency synthetic aperture sonar to cover large areas of the seabed quickly with high spatial resolution and a digital library of objects to help it conduct automatic target recognition. BlackCAT has a forward looking sonar, optical camera, and multi-beam 3D sonar. The two vehicles, which both host D2CAF, work together: the MUSCLE processes information such as quality of data and complexity of the seabed in real time on-board the vehicle to plan and execute wide-area survey missions, and works with BlackCAT, which then determines the best way to reacquire targets and to increase the classification confidence.

According to Dr Dugelay, the standard on exchanging information between MCM platforms today is based on old technology and old sensors. "There's a lot more information that we could give when we report targets that could be useful. As we improve the standardization of reporting targets and performance, this information actually feeds back into the collaborative autonomy, and how we can conduct planning and evaluation."

Dr Dugelay continues, "Our plan is to be able to send a fleet–or a squad–of autonomous, intelligent vehicles, over the horizon, where they can understand the environment on their own and how best to plan and execute missions as a team. We believe that these vehicles can accelerate the MCM timeline and, ultimately, take the human completely out of the minefield."

CMRE staff pose for a team photo during Dynamic Mariner 2019.

The MUSCLE vehicle is deployed from NRV *Alliance* during Dynamic Mariner 2019.

MINE COUNTERMEASURES

2018-2019 AT A GLANCE

Topics in CMRE MCM research include machine-driven decision-making, adaptive behaviours to improve data quality, architectures for autonomy at the single- and multi-vehicle levels, standardization of autonomy architectures and data modelling for unmanned minehunting.

MCM Autonomy

In 2018, the main achievement was the on-board implementation and software release of D2CAF, a framework for the development and deployment of multi-agent task allocation taking into account operational constraints for unmanned maritime systems. The tool was demonstrated during the Italian MINEX sea exercise on-board the Standing NATO MCM Group 2 (SNMCMG2) flagship HMS *Enterprise*, where it was deployed on the BlackCat and MUSCLE, and linked to an Italian Navy REMUS100 autonomous underwater vehicle (AUV) via a smart gateway buoy.

CMRE has been helping to lead a standardization initiative by co-chairing the STO Collaborative Support Office's research task group SCI-288-RTG "Autonomy in Communications-Limited Environments," which aims to develop a prototype messaging layer to promote interoperability between squads of unmanned systems.

Starting in 2018, a new platform, BIONDo (SPARUS II AUV), with a hovering capability has been under development. This system is equipped with an ARIS Explorer 3000s ultra-high-resolution imaging sonar. The combination of a hovering platform with a high-resolution, short range sonar will produce a system that is suited for MCM reacquisition and identification tasks. In 2019, the vehicle was tested at sea during the Dynamic Mariner exercise on-board the NRV *Alliance*.

The main focus of 2019 was the redevelopment of a coverage path planning solution for the MUSCLE survey vehicle. This approach allows for mission areas of complex geometry to be covered, while adaptively adjusting track orientation and track spacing depending on changes to the characteristics of the observed area. Crucially, the novelty resides in the integration of the on-board evaluation to drive the vehicle autonomy.

Standing NATO MCM Group 2 crews and CMRE scientists during Italian Minex 2018 on-board the flagship HMS *Enterprise*.

Planning and Evaluation

This project seeks to develop new methods for the planning and evaluation (P&E) of MCM operations employing autonomous platforms with side-looking sonars. The evaluation of performance following minehunting efforts is particularly important since it provides military planners with a measure of the risk to any traffic transiting through the mined area.

CMRE employs a 'gridded through- the-sensor' approach, which seeks to estimate the probability of detection and classification throughout each sonar image. In 2018 the P&E project deployed on-board HMS *Enterprise* during the Spanish MINEX exercise. The algorithms were tested on real data and the resulting output provided to military personnel. This allowed for valuable feedback about the utility of the product. In 2019, the algorithms were employed on-board CMRE's MUSCLE platform where they ran in real time. Maps depicting the estimated detection performance and bottom type were generated in real time and were available for further analysis immediately at the end of each mission.

MINE COUNTERMEASURES

Experimentation at sea is an important part of CMRE's research in MCM, which results in the validation of theoretical work, as well as the demonstration of new capabilities to NATO Nations.

2018-2019 AT A GLANCE

High-resolution Low-frequency Synthetic Aperture Sonar

Staffed with an entirely new scientific team, the HRLFSAS project achieved great progress both in research and experimentation activities in 2018/2019.

CMRE TORHEX'19 team.

For the past two years, CMRE's Engineering Branch was engaged in the development and construction of the HRLFSAS prototype for low-frequency sea floor mapping and target recognition. This new modality enables imaging of structural resonances and buried objects, which is not possible with commercial high-frequency systems.

Numerical tools based on finite difference and finite element methods were adapted to model the wave propagation in 2D and 3D underwater environments. The accuracy of the resulting simulations provides not only insight into the physics of low-frequency backscattering from man-made objects but also a source of realistic synthetic data for training Automatic target Recognition (ATR) algorithms.

A new SAS imaging method was developed that exploits the sparsity of strong scatterers to provide high-resolution object reconstruction even with narrowband or limited-view data. Experimentation activities included:

- Two system calibration trials (SAS3A for the transmit system and CALISA for the receive system), which provided necessary information on the prototype system response; and
- Two rail-based SAS trials (TORHEX'18 and TORHEX'19 with the partial and full system respectively), which provided data for the HRLFSAS proof of concept.

The encouraging results and international interest in CMRE's HRLFSAS system capability inspire future efforts such as deploying the system on underwater platforms and integration of the SAS signal processing with ATR algorithms.

Deep Learning for MCM

CMRE's automatic target recognition approach employs convolutional neural network (CNN) classifiers, a state-of-the-art technique that leverages multiple data representations simultaneously. Over the last two years, CMRE has made great strides in advancing this methodology for underwater mines in synthetic aperture sonar (SAS) imagery. Findings include:

- Alternative data representations contain additional discriminative information that can be exploited for mine classification;
- Adapted and optimized CNN architectures can alleviate some of the problems of very large training datasets;
- The original, smaller deep-learning classifiers can match, and even surpass, the performance achievable by a human subject matter expert; and
- Extensive experimental results on challenging real-world SAS image datasets collected under diverse conditions illustrate that the CNNs possess strong generalization ability.

The CNNs developed at CMRE provide a blueprint for achieving excellent classification performance even with limited computing power or limited data. At the same time, they increase the level of automation, helping to remove the man from the minefield, and provide a sound way to accelerate time-critical MCM missions. In 2019, a version of the CMRE deep-learning software was officially released and it is now available to the Nations for exploitation.

ANTI-SUBMARINE WARFARE

"We're integrating experimentation as part of the regular routine of our ASW capability development and operational practicing. CMRE brings an extra, added tool to the undersea fight."

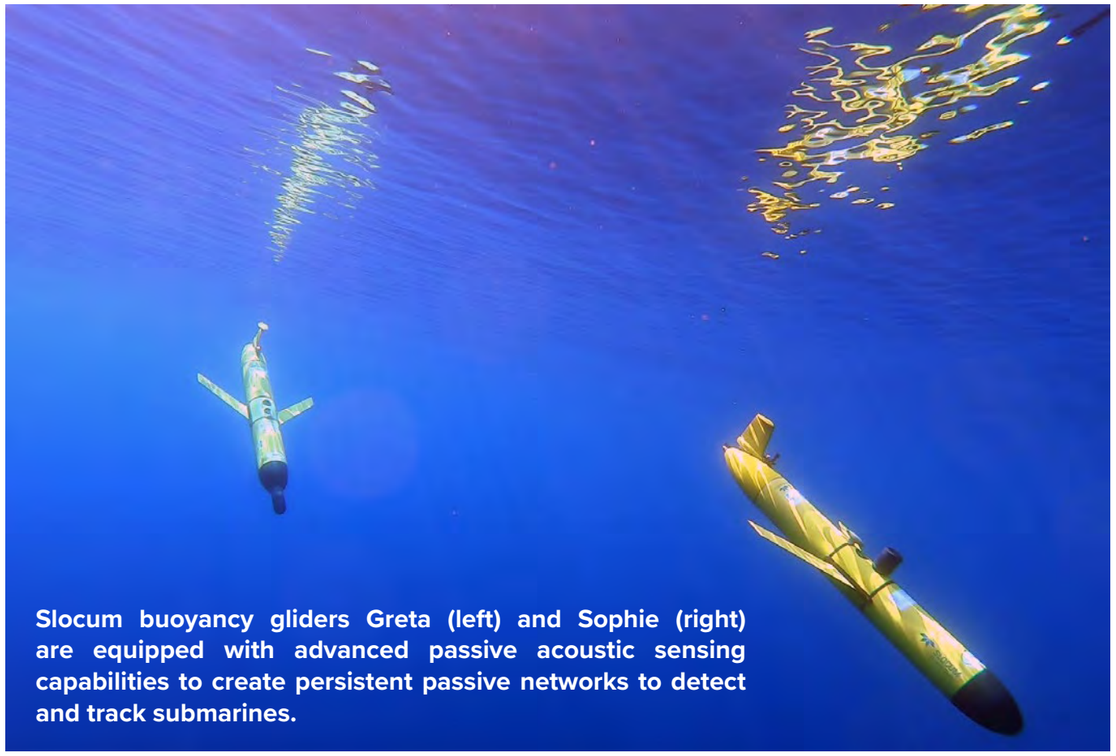
– Admiral James G. Foggo III, Commander of the US Naval Forces Europe and NATO Joint Force Command Naples

NATO is facing a growing and increasingly sophisticated international submarine threat. As the threat becomes more acute, NATO is seeing its anti-submarine warfare (ASW) capabilities challenged at levels not seen since the end of the Cold War. As knowledge and understanding of the ocean environment becomes more important to warfighters, global climate change is making much of what is known about the ocean environment outdated. As a core, 60-year activity at NATO's world-class maritime science and technology institution, CMRE's ASW programme is in the unique position to undertake scientific research and experimentation to validate and de-risk advanced concepts for operational solutions supporting NATO's ability to counter the submarine threat and control the seas.

With its long history of conducting research and experimentation to improve the ASW capabilities of the Alliance, CMRE is once again at the forefront of both blue water and littoral ASW to stay ahead of the submarine threat. The Centre is leading the way with advances in Maritime Unmanned Systems (MUS) for ASW applications, in particular demonstrating the potential of MUS for stand-off operations and the management and exploitation of long-endurance unmanned system networks, all enabled and controlled through underwater digital communications using JANUS, the CMRE-developed NATO standard protocol.

One major thrust area for ASW sensing, pursued by CMRE since 2000, has been based on the concept of multistatic active sonar using unmanned systems. Recently, a new, complementary, effort has been initiated to investigate the utility of passive ASW sensing networks composed of low-power, long-endurance and covert mobile autonomous platforms. In this new work, CMRE is using buoyancy and wave-powered gliders equipped with advanced passive acoustic sensing capabilities such as acoustic vector sensors, to create persistent passive networks to detect and track submarines. In order to ensure operational effectiveness, CMRE is building upon its extensive knowledge of the underwater environment to maximize network performance.

CMRE has been evaluating the potential of autonomous networked systems for ASW through a programme of operations research and analysis validated by an ambitious at-sea experimentation programme and demonstrations during NATO ASW exercises. Funded by ACT, CMRE has developed a fast and easy-to-use decision support tool called the Rapid Acoustic Prediction Service, which leverages acoustic models developed at the Centre to provide operators a picture of the sonar coverage of ASW assets, both manned and unmanned.

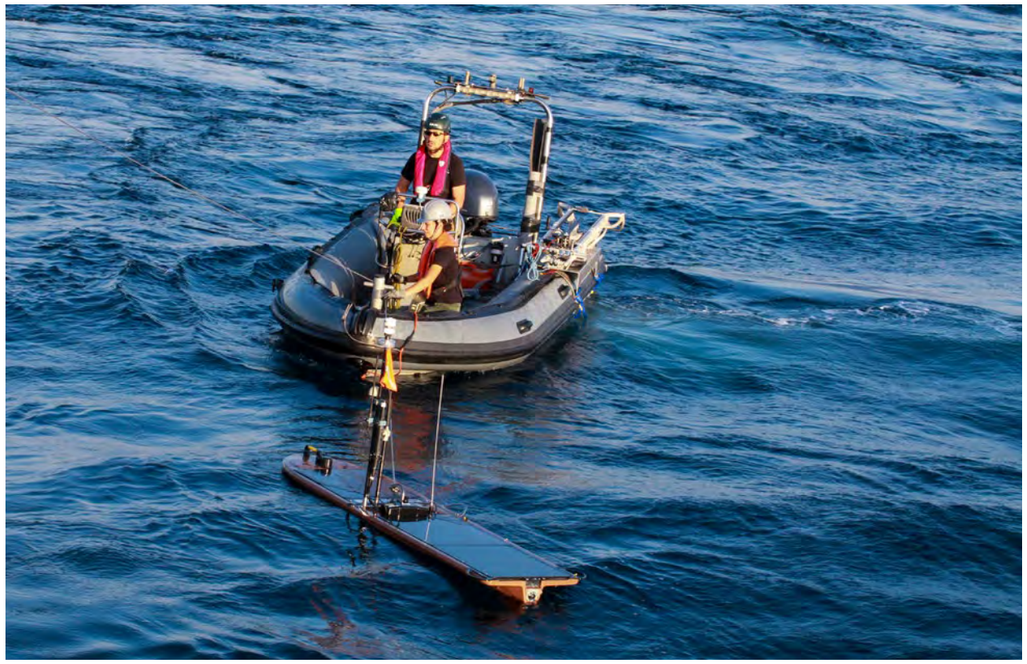


Slocum buoyancy gliders Greta (left) and Sophie (right) are equipped with advanced passive acoustic sensing capabilities to create persistent passive networks to detect and track submarines.

ANTI-SUBMARINE WARFARE

"Anti-submarine warfare is a team sport," states Rear Admiral E. Andrew Burcher, Commander, Submarines NATO, "It requires surface, air and submarine assets to locate another submarine. When we work together in an exercise, we are practicing that team sport on the equivalent of the pitch out here at sea and we are improving our skill sets as a team." In NATO ASW exercises such as Dynamic Manta in the Mediterranean and Dynamic Mongoose in the North Atlantic, CMRE is part of that team, and not just to conduct scientific experiments, CMRE is a player. CMRE's unmanned vehicles are often used for testing new sensors or concepts, and to inform a state-of-the-art assessment of the current environmental picture with measurements collected in situ by the unmanned systems. "Dynamic Mongoose and Dynamic Manta are ASW exercises that move us forward each year and make us better," says RADM Burcher, "and the fact that we have CMRE as part of our exercise is a positive development."

As CMRE Director, Dr Catherine Warner, explains, "The importance of participating in exercises is that it allows us to bring science to the operator in his or her environment, and for the operator to be able to understand what these unmanned systems can do." Dr Warner continues, "Our new sensors are so much better with automatic target recognition. We want to have that conversation with the operators to see what science can do for them. It's a two-way street – we want our scientists to understand what the operator needs. This is important to go to the next step in systems development."



CMRE staff recover a wave glider during the Recognized Environmental Picture, Atlantic 2018 (REP18-Atlantic) exercise.

CMRE underwater networks team and a Portuguese naval officer stand on-board the NRP *Arpao* during the execution of the REP18-Atlantic exercise.

ANTI-SUBMARINE WARFARE

2018-2019 AT A GLANCE

The CMRE Maritime Unmanned Systems for ASW project has a significant component of experimentation at sea. In 2018-2019, three sea trials were successfully conducted: Littoral Continuous Active Sonar 2018 (LCAS18), Recognized Environmental Picture Mediterranean 2018 (REP-MED'18) and Distributed Autonomous Networked Systems 2019 (DANS19).

During 2018 and 2019, ASW research focused on the areas of:

- Advanced signal processing for both passive and active networks;
- Collaborative autonomy for heterogeneous unmanned sensor networks;
- Sea trials of CMRE unmanned systems and performance evaluation of autonomous ASW concepts;
- Development and integration of unique sensors onto low-power, long-endurance unmanned platforms such as buoyancy and wave-powered gliders;
- Development of cognitive sonar techniques for autonomous sensors to learn about and best exploit the sensing environment;
- Training and testing of automatic classification techniques that exploit recent breakthroughs in deep learning and CMRE's large ASW datasets; and
- Operations Research and Analysis, including exploiting modelling and simulation, to better explore the trade space of networked heterogeneous unmanned ASW concepts.

CMRE staff use a Rigid Hull Inflatable Boat (RHIB) to recover equipment during the REP-MED'18 exercise.

Littoral Continuous Active Sonar 2018

CMRE, in conjunction with seven partner Nations, conducted the LCAS18 trial in November 2018 from the NRV *Alliance* along with the support vessels CRV *Leonardo* and the Istituto Superiore per la Protezione e Ricerca Ambientale's N/O *Anteo*, in the shallow waters north of Elba, Italy. The purpose of the trial was to evaluate the utility of high duty cycle active sonar in littoral environments, which are characterized by strong boundary interactions, dynamic oceanography and high ambient noise. Testing during this trial allowed real-time visualization of sonar results obtained over a variety of target and environmental conditions. In addition, several experiments were conducted to explore the effects of sea surface roughness on high duty cycle waveforms. Significant advances in multi-robot collaborative autonomy were demonstrated for track initiation and hold.

Recognized Environmental Picture Mediterranean 2018

REP-MED'18 was conducted near La Spezia, Italy in September from CRV *Leonardo*, where the following advances were made:

- CMRE's new SLICTA towed array, composed of 64 directional triplet acoustic sensors, was deployed for the first time from one of the Centre's Ocean Explorer AUVs;
- The new STANAG 4748 (JANUS) digital underwater communications protocol, developed at CMRE, was used to broadcast the positions of the Centre's ASW AUVs in real time to provide situational awareness for water space management of a Blue Force underwater asset, a joint activity with the underwater communications and network project discussed further on page 47; and
- The first at-sea test with a Teledyne Webb Research Slocum buoyancy glider equipped with a 3D acoustic vector sensor and an integrated underwater modem.

Distributed Autonomous Networked Systems 2019

In December 2019, the inaugural DANS experiment was conducted from the NRV *Alliance* near La Spezia. DANS19 was dedicated to passive acoustic ASW and was conducted in cooperation with the Italian Naval Experimentation and Support Centre (CSSN). The experiment was successful, with both multistatic active and passive ASW sensing concepts being deployed and tested. In particular the following accomplishments were noted:

- The development and testing at sea of a new acoustic payload for the OEX-C AUVs that allows them to play the role of an artificial target for passive ASW missions. This will be extended to also provide an echo-repeating capability in 2020.
- The development, testing at sea and analysis of data collected from a new linear array of eight 3D acoustic vector sensors. This array, including the vector sensor elements themselves, was entirely designed and built at CMRE. This array will allow the WaveGlider to become a passive acoustic sensor platform in addition to being a gateway buoy within ASW networks; and
- The first testing and demonstration at sea of the real-time version of the signal processing chain for passive target detection, direction-of-arrival estimation and clustering on two Slocum buoyancy gliders. Initial work on passive tracking combining information from two gliders was also performed.

The CMRE Anti-submarine Warfare team on the CRV *Leonardo* during REP-MED'18.

DATA KNOWLEDGE AND OPERATIONAL EFFECTIVENESS

“Data is the core of everything we do. We collect and analyse data with different tools and make our analysis available to stakeholders. This has not changed much in 60 years—What has changed is the way we do it; the tools we use to do it; the speed with which we do it; and the relevance and impact we can deliver.”

– Alessandro Berni, CMRE’s Chief Information Officer

The CMRE Data Knowledge and Operational Effectiveness (DKOE) programme addresses NATO capability gaps and interoperability requirements in the maritime data and information domain. Through information processing, big data analysis and prediction tools, DKOE contributes to NATO Maritime Situational Awareness and information exchange between NATO Nations. DKOE research draws upon an extensive network of collaboration with experts both within the NATO maritime community and at institutions and universities in the US, Canada, France, Italy and Germany. Through these partnerships, and its own in-house research, CMRE’s DKOE team is contributing to the future of NATO’s Maritime Command and Control capability.

The goal of DKOE is to improve Maritime Situational Awareness (MSA) for NATO through the interpretation and fusion of data. This results in a comprehensive understanding of activities in the maritime theatre and the ability to detect and mitigate threats at sea. To achieve this DKOE develops techniques to quickly extract and process relevant data from numerous and diverse sources.

CMRE’s DKOE researchers are tackling MSA challenges on multiple fronts including improving understanding of shipping patterns of life, anomaly detection and better target identification. According to scientist, Dr Anne-Laure Jousselme, “DKOE research and tools provide NATO and Nations the most advanced solutions to support the future development of NATO’s Maritime Command and Control Information Systems.”

One of the challenges of MSA is identifying vessel intent. Whether from faulty equipment, poor weather conditions or malicious motives, data from ship’s Automatic Identification Systems (AIS) often has gaps that make intent difficult to determine. This is a notable concern of the maritime defence and law enforcement communities. CMRE’s DKOE team have developed algorithms to analyse AIS and other data to show authorities what ‘normal’ looks like at a given time and area of the ocean. Anomaly detection techniques developed by DKOE can help operators identify abnormalities in the vast data available, resulting in more comprehensive maritime intelligence.

According to US Navy LT Kathryn Ransom, stationed at CMRE and working with the DKOE team, the immense amount of data poses challenges. “There are two parts to the challenge, the first is how we handle the volume of AIS data and satellite tracks and the second is the reasoning behind how we process the data.”

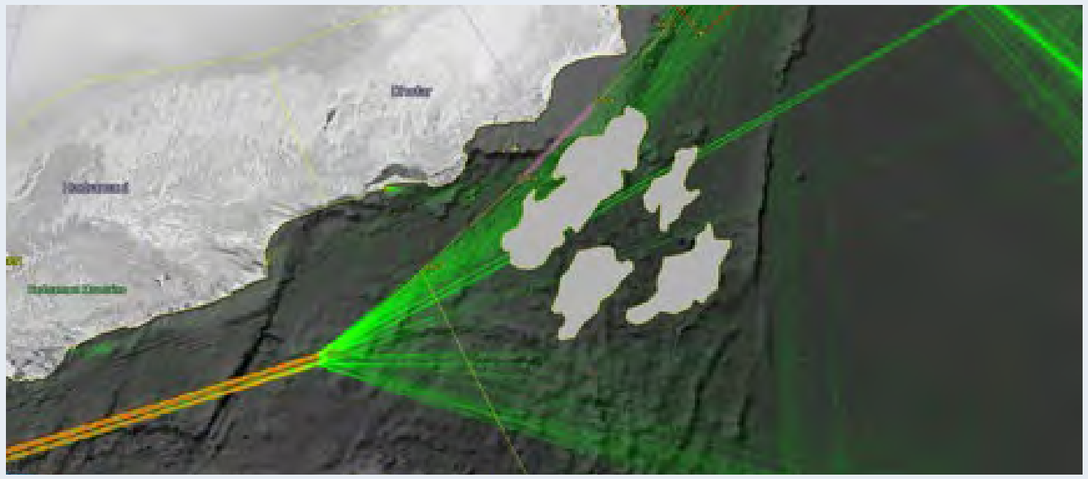
During the International Maritime Exercise 2019 (IMX19), a US Navy led event in the Middle East involving 50 nations, DKOE successfully integrated output from its Maritime Pattern of Life System (MPoLIS) with SeaVision, a web-based MSA tool operated by the US Department of Transportation that enables users to view and share maritime information. CMRE has also contributed patterns of life, vessel position prediction and vessel behavior analysis software to the EU-funded Maritime Integrated Surveillance Awareness (MARISA) Project. These contributions allow the MARISA prototype to determine the probability of vessels conducting illegal activities such as human trafficking or unlicensed fishing.

The DKOE team has used its expertise in the cognitive processes of perception, comprehension and projection to solve a range of MSA problems. According to Dr Paolo Braca, “The technology DKOE provides is aimed at improving the recognized maritime picture with fewer false alarms and increased time-on-target. We are establishing the baseline for maritime traffic analysis and the ability for early detection and management of abnormalities. By helping relieve the cognitive workload of operators, NATO Nations will be able to better utilize their personnel to conduct efficient and effective operations.”

DKOE

2018-2019 AT A GLANCE

The DKOE programme advanced artificial intelligence, machine learning and information fusion techniques, while addressing the big data challenges of volume, velocity, variety and veracity. DKOE demonstrated enhancements to Maritime Situation Awareness through improved cognition processes of perception, comprehension and projection.



This AIS density map shows 110 million ship positions from March - September 2019 in the Gulf of Aden. Four fictitious Islands were superimposed as part of the IMX19 training scenario.

CMRE DKOE team members at the Maritime Situational Awareness Workshop 2019 held in Lerici, Italy in October 2019.

DKOE achievements in 2018 and 2019 for improved MSA include:

- Perception: A new solution to the multi-target tracking problem and a new model of maritime traffic patterns of life, the maritime traffic graph;
- Comprehension: New multi-source automated reasoning techniques with conflict-handling and a method for original expert knowledge elicitation; and
- Projection: New long-term ship position and destination prediction techniques.

In 2018 and 2019 the DKOE team's research resulted in more than 70 peer-reviewed publications including one in the prestigious *Proceedings of the IEEE*. Additionally, the team has been recognized by NATO for delivering operationally relevant capabilities. For example, DKOE provided the prototype MPoLIS to NATO's Maritime Command (MARCOM) Shipping Centre. MPoLIS allows operators to understand normal maritime traffic patterns making it easier for them to identify anomalies. MARCOM assessed MPoLIS as essential to operations and requested that it be implemented in the NATO Maritime Command and Control Information System TRITON. With funding from NATO Allied Command Operations, the DKOE team are now assisting with the operationalization of the MPoLIS computer code for incorporation into TRITON.

Between 08-10 October 2019, CMRE organized the Maritime Situational Awareness Workshop (MSAW'19) held near CMRE, in Lerici, Italy. The purpose of the workshop was to discuss emerging scientific challenges of the MSA needs of the operational community. Under the theme Science and Technology Meets Operational Needs, MSAW'19 covered topics including signal processing and fusion, artificial intelligence, anomaly detection, and big data analytics. The workshop brought together about 170 participants from 23 countries, 18 NATO Nations, 14 EU nations, scientists, engineers, national and international authorities, operators, and industry. MSAW'19 was sponsored by NATO Allied Command Transformation through the CMRE DKOE project, and the EU Horizon 2020 RANGER project. As a result of the overwhelming success of MSAW'19, CMRE hopes to hold a MSAW workshop again in 2021.

CMRE scientist Leonardo Millefiori and USN LCDR Tom Miller discuss logistics with officers for an upcoming exercise during the final planning conference of the IMX19.

"IMX was about promoting interoperability. The nations are interested in finding new, more effective, affordable and less risky ways to create maritime situational awareness, and CMRE was able to show some new situational awareness solutions that the U.S. Navy and other nations didn't possess."

– Dr Eric Pouliquen, Head, Innovation Branch at NATO ACT

ENVIRONMENTAL KNOWLEDGE AND OPERATIONAL EFFECTIVENESS

“We need to have an understanding of the environmental conditions of the water column to make sure we have that operational advantage.”

– Royal Canadian Navy Rear Admiral Steve Waddell, Vice Commander of the US Second Fleet

CMRE’s Environmental Knowledge and Operational Effectiveness (EKOE) programme helps NATO forces maintain superiority in maritime environmental awareness. This is critical in underwater warfare where accurate knowledge and predictions of the ocean structure allows you to find the adversary before he finds you.

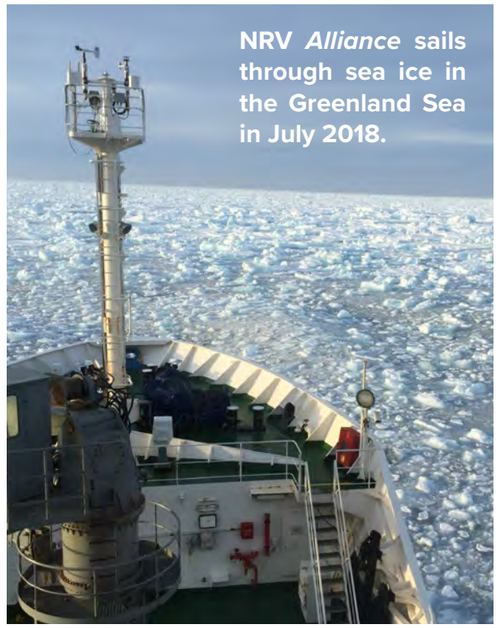
Understanding the physical environment of the ocean is key to maritime situational awareness. But a shared understanding of the theatre of operations among allied forces is difficult to achieve. Efforts to collect, assimilate, analyse and disseminate information and predictions of the naval battle space environment, have long been the focus of military meteorology and oceanography.

The CMRE EKOE programme focuses on observing, understanding, describing and forecasting the marine environment for NATO Nations. Armed with vital maritime environmental information, NATO forces can prepare for potential threats from littoral waters to the open ocean. This requires knowing the ocean environment better than the adversary as well as employing science-based decision-making and tools to select appropriate tactics and combat systems.

Environmental knowledge and operational effectiveness requires remote sensing and ocean observing networks that are able to cover huge ocean areas. EKOE’s approach focuses on networking. “We are looking at networking capabilities to sample vast areas in order to help forecast the oceans and environmental conditions. The more data we have, the more accurate the forecast becomes,” states Dr Alberto Alvarez, programme manager for EKOE.

CMRE strives to improve its numerical models, but the ocean is under-sampled. “We need to improve the ocean forecast by improving the quantity and quality of the data as well as our ability to make observations. We have the ability to sample using networks of unmanned sensors. Robotics allows us to gather in situ data over vast areas,” explains Dr Alvarez.

Dr Alvarez says that his team is conducting its research in naval choke points, such as between the Faroe Islands and Iceland, and further north beyond the Arctic Circle. “We are testing and evaluating the performance of our ocean modelling and observing technologies, using a variety of sensors, to predict aspects related to acoustic transmission behaviour and sonar performance. We will be deploying our systems from the NRV *Alliance* and working with international partners.” Alvarez continues, “Complex experiments require a higher degree of international collaboration.”



NRV *Alliance* sails through sea ice in the Greenland Sea in July 2018.

Achieving EKOE is vital to warfighters. According to Royal Canadian Navy Rear Admiral Steve Waddell, Vice Commander of the US Second Fleet, “There are different ways to exploit the maritime battle space, which is austere, remote and vast. We will never be able to generate and build the infrastructure and deploy the number of ships necessary to be able to do that in that environment, so better use of domain awareness enablers through autonomous vehicles and others is going to be key.”

EKOE

2018-2019 AT A GLANCE

The vision of CMRE's EKOE programme is to establish Maritime Environmental Information Dominance for NATO forces through observing, understanding, describing and forecasting the ocean environment and enabling information exploitation.

The CMRE EKOE research team deploys an AUV during a 2018 exercise in the High North.

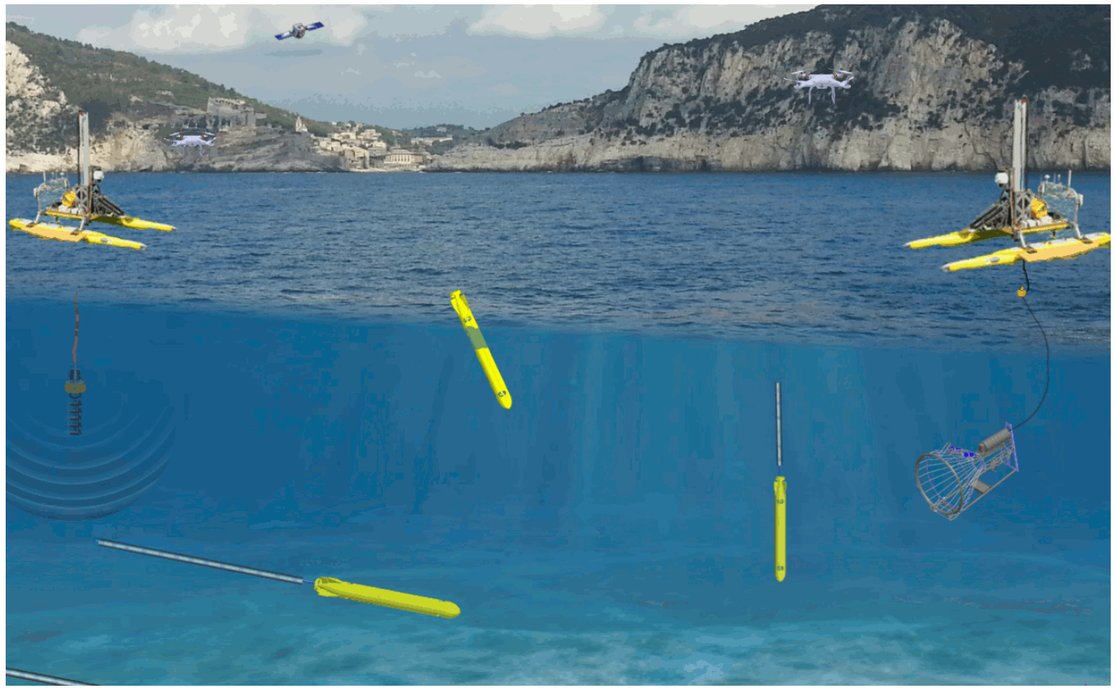
During 2018-2019, the EKOE programme developed improvements to existing data assimilation techniques to increase the accuracy of acoustic and underwater noise predictions. Significant improvements in the ability to predict acoustic transmission loss were obtained by assimilating ocean observations in a coupled ocean-acoustic modelling framework. The accuracy of ocean predictions can be increased by assimilating observations of transmission loss. This is done by using a Canonical Correlation Analysis to extract the modes of co-variability that maximize the oceanic-acoustic correlations, upon which the acoustic inversion is based.

A new state-of-the-art pan-Arctic Ocean Model was developed by EKOE with the aim to support NATO naval operations at high latitudes. Specifically, the Nucleus for the European Modelling of the Ocean (NEMO) coupled with the Louvain-la-Neuve sea ice model (LIM), was implemented in a pan-Arctic domain with a resolution ranging from 7 to 20 km. The model has 91 unevenly spaced vertical levels, with more levels near the surface. Two nested children models with a higher resolution of 2 km increment the spatio-temporal resolution of the forecasts in the Iceland Faroe Front and Svalbard regions. Both regions are considered naval choke points. The model uses an assimilation scheme to incorporate observations from different ocean observing platforms (ships, satellites, gliders, and drifting profilers). The pan-Arctic ice-ocean model forecasts the time evolution of ice coverage and water column temperature, salinity and current to feed naval decision support and risk assessment engines.

In September-October 2019 the EKOE team participated in the NARVAL19 sea trial conducted by the Service hydrographique et océanographique de la Marine (SHOM) in collaboration with the Direction Générale de l'Armament (DGA) and the Norwegian Defence Research Establishment (FFI). A large suite of CMRE oceanographic and acoustic assets (moorings, gliders, a wirewalker and drifters) were deployed to characterize the underwater environment on the Svalbard shelf/slope and across the Polar Front in the western Barents. EKOE supported the acoustical experiment, led by DGA, by operating a horizontal hydrophone array towed behind the ship. The deployments of the wirewalker, a new sensing technology, adequately resolved the high-frequency variability of the water mass properties and sound speed, mostly due to internal tide signals.

The EKOE programme is expected to increase its research activities at high latitudes in the coming years. This is in response to the CMRE Arctic Science and Technology Strategy to support Anti-Submarine Warfare operations in an Arctic Ocean that is in rapid transformation.

View from aft deck of research vessel *Pourquoi Pas ?* during the international trial NARVAL19 with CMRE's EKOE team in October 2019.



MARITIME UNMANNED SYSTEMS ENABLERS

We're addressing the science and technology needed to increase communication interoperability, scalability and security of maritime unmanned systems, providing a synthetic but realistic environment to test their applications within and across the sea domain.

– Dr Sandro Carniel, Head, Research Division

Maritime Unmanned Systems Enablers (MUSE) is a programme that brings together cross-cutting capabilities for maritime security, standardization and underwater communications to respond to the need to develop unmanned systems-of-systems with a high level of interoperability for autonomous operations. Throughout 2018-2019, the programme was known as PARC (Persistent Autonomous Reconfigurable Capability) with a mission to assist NATO in preparing for the unmanned and autonomous systems future in the maritime domain.

Interoperability, security and persistence are key enablers for current and future NATO operations using autonomous unmanned systems across all domains. CMRE's MUSE programme exploits these enablers to address NATO ACT's long-term objective to transform NATO forces by delivering an interoperable operational capability based on autonomous systems-of-systems in the maritime domain. The MUSE programme seeks to design the architectural framework in which future autonomous underwater systems will be cast, establishing standards for control, data flow, information security, performance and interfaces, to provide NATO future forces with interoperable systems that are scalable and that reduce risk and cost. The MUSE programme addresses systems architecture; underwater communications; interoperability, security and standards; and modelling and simulation (M&S).

Interoperability, Standards and Security for Maritime Unmanned Systems

The aim of the Interoperability, Standards and Security for Maritime Unmanned Systems (MUS-ISS) project is to address the technology and engineering requirements for future unmanned maritime system-of-systems, across maritime warfare areas such as MCM, ASW, intelligence preparation of the battlefield and Maritime Situational Awareness (MSA). This project focuses on increasing systems-of-systems capabilities including communications, interoperability and scalability, while addressing standardization and information assurance aspects of assets.

The technical approach builds on the experience that CMRE has gained in the last two decades in specification, procurement, modification, design, prototyping and fielding maritime unmanned systems.

Moving forward, MUS-ISS will continue leveraging CMRE's extensive partner network, with the objective of both reducing S&T overlap across NATO and optimizing ACT's investment in the project. MUS-ISS will be addressing topics, such as potential standards for information assurance and unmanned maritime system software payloads, emphasizing the use of open-architectures with a service-oriented-architecture approach. In this regard, CMRE will continue its effort to take part in and to be aligned with the NATO Multi-Domain Control Stations STANAG working group.

Modelling and Simulation

M&S is a critical capability that allows CMRE scientists and NATO Nations to analyse existing or proposed systems and concepts under a range of conditions. M&S techniques and methodologies facilitate or enable experiments that are otherwise too costly, dangerous, and, sometimes even impossible to enact in the physical world.

As Dr Pilar Caamaño, a scientist on the CMRE M&S team describes, "We are developing a modeling and simulation capability to support the other teams of the Centre so they can have a synthetic environment to test concepts, algorithms, systems and assets before going to sea. Our work is to recreate the conditions they might find and conduct pre-testing of systems and concepts."

M&S allows frequent, cost-effective iterations of system design and testing, exploring new ideas and performing complex multi-variable experiments to inform the design phase. Similarly, M&S can provide tools and data to aid in each phase of a system life cycle, from conception to testing to deployment and training of algorithms and operators.

CMRE adheres to international standards for connectivity, data formats and exchange of information with simulations–such as high-level architecture and distributed simulation engineering and evaluation process, the NATO standard for the development of federations of simulations and simulation environments. This way CMRE can share

MARITIME UNMANNED SYSTEMS ENABLERS

data between their simulations and a variety of sources and connect to other models, algorithms and Command and Control components.

“By adhering to these international standards, we should be able to plug-and-play different pieces of the federation and create a federation that represents or recreates the environment where we want to test our system, concept or asset, and provide the customer or the user the results that they aimed to get from the simulation,” states Dr Caamaño.

In addition to supporting the various programmes of the Centre, CMRE is able to offer its M&S capability to external partners to support concept development and experimentation; verification and validation; and to train and educate operators. CMRE participates in national, European, and NATO projects, linking public and private sectors. In this way, M&S is positioned to bridge the gap between the theoretical and the practical.

By participating in projects both within and outside of NATO, CMRE M&S helps to build a community of scientists, engineers, analysts and military personnel across Nations. In turn, these communities foster dialogue and connections, ensuring that new and innovative technologies address real needs and make it from the lab into everyday use.

The CMRE M&S team testing simulation technology.

Underwater Communications and Networks

The Littoral Ocean Observatory Network (LOON) facilitates experimentation of mission-based teams of marine robots by creating a monitoring acoustic network, accessible by users across the world via the internet. “LOON is a network of underwater acoustic nodes mounted on tripods here in La Spezia Harbour that is used for testing,” describes CMRE Director Dr Catherine Warner. “Researchers can access that network from their office anywhere. They can send waveforms and run them on the LOON and see how they perform in an undersea environment.” The LOON facility is being used to develop and evaluate new ways to ensure the security of the exchange of underwater data.

A new effort being introduced in the Underwater Communications and Networks (UWNET) project is related to quantum-based security. The era of quantum computing brings the necessity of quantum-secure cryptography schemes. Based on the laws of physics rather than mathematical complexity, quantum cryptography promises unconditional security. In the last decade, significant advances have been made in the area of quantum key distribution (QKD) and successful experimental demonstrations have been performed for various transmission ranges and data rates. QKD systems are also commercially available in the market. These are however mainly limited for use over fiber optic links and not directly applicable to underwater environments where QKD remains almost unexplored. In an effort to address this, UWNET aims to develop a proof-of-concept for underwater QKD.

“This may change the way warfighters conduct their business such as submarine rescue operations or by enabling capabilities like cooperative autonomy and providing a secure network infrastructure for undersea autonomous vehicles,” states João Alves, MUSE Programme Manager.

Meanwhile, the demand for JANUS-related activities continues to increase. JANUS is the digital underwater coding standard aimed at providing a common baseline for underwater acoustic communications. It was developed with the collaboration of academia, industry and government with the intention that it should be freely distributed and available to all. JANUS has been adopted as an official NATO standard called STANAG 4748, and will be implemented on NATO vessels and underwater vehicles. “With JANUS we demonstrated the benefits of digital wireless underwater communications for submarine operations,” explains Alves.

In 2018 and again in 2019, JANUS was demonstrated in an operational setting during the international Rapid Environmental Picture exercises hosted by the Portuguese Navy. The CMRE team participated in submarine rescue scenarios by employing AUVs to relay information between the surface rescue ship and the distressed submarine using JANUS-based underwater communications. According to Dr Warner, “Instead of trying to understand the typically garbled underwater telephone, we used a chat application we call ‘WetsApp,’ which is sort of an underwater WhatsApp. We’re participating in other exercises to look at how to incorporate digital underwater communications into doctrine and tactics.”

“We support the national industries – that’s what we’re for,” continues Dr Warner, “We develop the concept and then we let the industries build it. And with JANUS, the different modem manufacturers can talk to each other without having to change anything, or give up anything proprietary.”

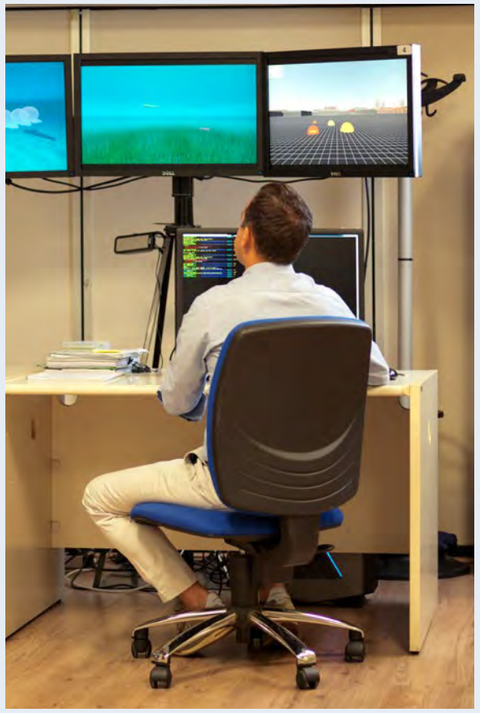
MUSE - M&S

2018-2019 AT A GLANCE

The work delivered in 2018 and 2019 supports all phases of the life cycle of systems and system-of-systems for CMRE and external partners, made possible by multinational funding initiatives. CMRE is in the position to be an actor in the evolution and growth of M&S in NATO, supporting innovation and the adoption of emerging technologies by the operational community.

In 2018, NATO set the foundations for future growth for Modelling and Simulation, opening lines of investigation on the use of M&S in areas such as decision making; operations and defence planning; Concept Development and Experimentation; and Verification and Validation.

Behind the support of M&S lies the success of the Anti-Area/Access Denial (A2AD) Simulation Study. The first simulation study in NATO since 1989 in which an M&S-based methodology was used to support a study to inform military decision-making and advise NATO advance planning. In this study, the CMRE M&S team played an important role observing and collecting best practices to elicit lessons learned and recommendations on the use of M&S to be applied in future simulation studies.



A staff member works in the M&S lab.

In 2018 the M&S team was awarded two European Commission (EC) projects. The first was ARESIBO (Augmented Reality Enriched Situation Awareness for Border Security), which aims at improving situational awareness for border security. CMRE is providing its expertise on the development of synthetic environments for the use of serious gaming for training operators.

COMPASS 2020 was the second EC project. Its goal is to demonstrate the integration of aerial, underwater and ground systems to enhance operational maritime border surveillance. CMRE is supporting the project by providing its expertise on the use of M&S as a methodology for concept development and experimentation in safe-to-fail environments.

ARESIBO and COMPASS 2020 were awarded in addition to European Commission projects ROBORDER and Ocean 2020, which were already under way by the M&S team.

In order to manage a large number of activities, in 2019 the M&S team undertook a cross-project review to identify synergies and to understand where value could be enhanced. Guided by standards-based processes (IEEE 1730 - DSEEP and IEEE 15288) and supported by the latest NATO toolsets (The NATO Architectural Framework), the team was able to maximize efficiencies, which resulted in the timely delivery of higher quality products on multiple projects–an achievement this small team is proud of.

This methodology was successfully applied to the upgrade of the environmental federate of the CMRE High Level Architecture federation. The M&S team designed, developed and tested a major upgrade of the federate, significantly improving its content, scalability and usability. Specifically, the improved model includes an expanded range of water column, surface and seabed properties, as well as the addition of an air column. Input data can now be downloaded in standardized formats and loaded directly into the model. These improvements provide a valuable resource for many future M&S activities at the Centre, including underwater, on the surface and in the air.

In the area of M&S for decision-making, in 2019 the team was involved in the Dual Capable Aircraft Simulation Study, an add-on to the A2/AD Simulation Study. Also, continuing with activities carried out since 2016 in the area of logistics, the CMRE M&S team developed a prototype simulator for the elicitation of requirements and the development of recommendations for logistics, based on human-in-the-loop and analytical simulation. The prototype was presented to the operational community in venues such as STEADFAST FLOW (a NATO exercise on logistics) and the NATO Movement and Transportation Forum.

Also in 2019, through a grant from the NATO Science for Peace and Security Programme, the M&S team supported the Tunisian Navy in their effort to enhance and modernize their M&S capabilities to NATO standards and architectures in order to improve their competencies and interoperability with NATO. The work included a technical assessment of their simulation capabilities and two training sessions.

At the end of 2019 CMRE started a collaboration with the Innovation Lab at the ACT Innovation Hub for the enhancement of the Disruptive Technology Assessment Game and for the development of a synthetic testing environment, based on M&S, for the Lab's products.

MUSE - UWNET

UWNET continued the development of a physical security technique to protect underwater acoustic communication links. The approach utilizes physical characteristics of the wireless channel to ensure that two nodes can exchange secret messages in the presence of an eavesdropper.

2018-2019 AT A GLANCE

Recognized Environmental Picture - Atlantic 2018

In 2018, the REP18-Atlantic sea trial in Portugal was a focal activity of the year. CMRE successfully conducted extensive data acquisition and experimentation with new concepts of operations supported by underwater communications, such as new methods to automate submarine emergency messages employing JANUS. REP18-Atlantic coincided with the conference on interoperability for Maritime Unmanned Systems, an initiative of the NATO Naval Armaments Group and the Submarine Commanders Conference.

Underwater Communications Workshops

In May 2018, CMRE organized the second secure underwater communications workshop with the participation of DEU, FRA, POL, PRT, CAN, NLD and ITA. In this meeting Nations conducted a joint review of national initiatives to find commonalities and better define CMRE's future programme of work. The group committed to develop common reference documents to introduce new NATO-wide definitions for the security of underwater communications.

In 2019, CMRE's series of secure underwater communications workshops resulted in a NATO Industrial Advisory Group (NIAG) Study Group 243 and a STO Information Systems Technology (IST) panel Research Task Group (IST RTG 174). In parallel, CMRE, in collaboration with the NATO Centre of Excellence for Operations in Confined and Shallow Waters, kicked off a NIAG Study Group (SG243) on industrial perspectives on secure underwater communications.

JANUS Interoperability Fest

After the promulgation of JANUS as a NATO standard (STANAG 4748) in 2017, CMRE began to engage industrial players to push the underwater digital communication protocol towards becoming a true capability, delivered by industry to end-users. 2018 and 2019 marked the first two JANUS Interoperability Fests, an event that brings manufacturers together to test their JANUS-capable technology in real time. Over five days of experimentation, 25 companies successfully used JANUS to exchange data among the different industrial platforms with novel applications, such as underwater Automatic Identification Systems to increase sub-surface situational awareness and the underwater chat application, WetsApp. The success of JANUS Fest is a major step towards an interoperable wide-scale underwater communications capability.

Recognized Environmental Picture - Maritime Unmanned Systems

For the first time, in 2019 the REP exercise series hosted the Maritime Unmanned Systems (MUS) initiative. This new activity generated an unprecedented level of interest from the Nations, which gave CMRE the opportunity for increased experimentation and collaboration. REP-MUS'19 was a extremely successful sea trial through which CMRE received additional valuable datasets, increased the visibility of the Centre and expanded on a series of important topics in the fields of interoperability and C2 for maritime unmanned systems.

CMRE technicians deploy a wave glider during the REP-MUS'19 exercise in Portugal as part of underwater communications and networking experiments.

ENGINEERING & IT HIGHLIGHTS

ENGINEERING AND INFORMATION TECHNOLOGY

"Our Engineering and Information Technology Division is amazing, they are able to take concepts and turn them into real experiments that can get meaningful data for the scientists. They can make anything—and will make it work."

– Dr Catherine Warner, CMRE Director

The Engineering and Information Technology Division (EITD) is a group of about 60 engineers, technicians and IT specialists organized in two branches; Engineering and IT. Together, EITD staff apply their knowledge and experience to design, develop, test, operate and maintain the broad range of systems that support CMRE's sea and field activities. The Centre's science activities generate vast quantities of data that must be curated, managed and stored in a secure and accredited environment in accordance with NATO policies. The EITD bridges the gap between providing at-sea experimentation capability and ensuring that the acquired data is safeguarded and available for exploitation.

As the name implies, the Centre for Maritime Research and Experimentation tests and validates scientific concepts at sea. That science requires carefully engineered experiments to capture the right data. Then the data must be organized and made accessible to scientists both at the Centre and internationally.

The Centre has a long legacy of world class ocean engineering and information technology. But the IT capability was spread across several divisions. In 2019 the Director consolidated engineering and IT resources in a single division, EITD, with two branches, Engineering and IT. According to Dr Alain Maguer, Head of EITD, the merger will help with the implementation of standards, which will allow data from multiple experiments to be more easily compared and allow the nations better access to it. States Dr Maguer, "We will be able to use the proper tools and processes so that data can be captured in the same way, in the same format and with the same metadata — this way you know where and when it was collected and can compare it with other datasets."

Quality data relies upon quality measurements. To ensure accurate measurements, CMRE has world-class facilities for acoustic, oceanographic and optical calibration. "Each time we go to sea, we have to calibrate our equipment," says Stefano Biagini, Deputy Head of Engineering, "and we have the capability to do that here."

EITD has a warehouse full of equipment that can be used or modified for experimentation, including unmanned vehicles to operate on and under the water. These systems are constantly being repurposed for different experiments. According to Biagini, no system is used at sea twice the same way. "Industry doesn't always make what we want, but we adapt and modify off-the-shelf equipment to suit our needs. They often come back to us to see how we use their products and get ideas they can use themselves", says Biagini.

"We work for the NATO Nations," says Dr Maguer, "We invite their researchers, and the companies that make things for the nations, to come and work with us. Our work is never the same, it's changing every day."

CMRE engineers support a sea trial in a portable lab.

ENGINEERING

Over the past 60 years, the Engineering Branch at CMRE has been working to accomplish one mission: to support researchers from all NATO Nations to validate their theories through experimentation at-sea.

2018-2019 AT A GLANCE

In 2018-2019 Engineering continued its mission to enable CMRE to do at-sea science and experimentation. Applying its extensive experience and expertise in multiple complementary domains, the achievements Engineering are most proud of in the past two years were:

- For the first time, CMRE's OEX-C-class AUV was deployed and operated with CMRE's new generation SLICTA towed-array. The data from the device's 192 hydrophones, assembled in triplet-configuration, and 11 attitude sensors were acquired and processed autonomously. This new fully directional sensing system significantly enhances the research capability of the Anti-submarine Warfare Programme;

- A Slocum buoyancy glider was fitted with a 3D Acoustic Vector Sensor (3D AVS) for the first time and successfully acquired and processed the collected data on-board, in real time. The Electronics Section contributed with the development of an innovative, compact and low power data acquisition system, specifically developed for long-endurance platforms;
- The in-house design and development of the 3D AVS, the integration of eight such sensor modules into the Vector Sensor Prototype Array (VESPA), and its first full-scale operation at sea, under tow of a WaveGlider Unmanned Surface Vehicle (USV), as part of the new passive acoustic sensing network of the ASW programme;
- The first pier-side test of the High Resolution Low Frequency Synthetic Aperture Sonar, comprising 192 transmitting transducers driven by custom designed amplifiers, and processing data from 320 receiving hydrophones, to provide high resolution images that exploit the material-penetration properties of low-frequency sound for the Autonomous Naval Mine Counter Measures programme (ANMCM);
- The support to the ANMCM programme, demonstrating the multidisciplinary capability of Engineering to deploy a full suite of different unmanned systems with different payloads, working cooperatively to perform autonomous on-board detection, classification and identification of mine-like objects. In 2018, AUVs used in the ANMCM project were deployed for the first time from the HMS *Enterprise*—at that time the flagship of the Standing NATO MCM Group 2, led by Commander Justin Hains. With excellent help from the crew, CMRE's Command and Control (C2) system was integrated with the ship's systems and operated together with other MCM vessels, during the SPMINEX off the coast of Spain and the ITMINEX trial off the coast of Sicily; and
- Supported several major oceanographic campaigns in the hostile environment of the Arctic seas including a 60-day cruise off the coast of Greenland in February/March 2018. Additionally, Engineering has supported more than 50 Slocum buoyancy glider deployments, including CMRE's longest glider at sea endurance of 70 days; the first glider under ice; the first glider with an Acoustic Doppler Current Profiler (ADCP) installed; and a glider able to transmit real time ambient noise data. Furthermore, the integration of a CMRE-designed Compact Volumetric Sensor Array on a glider and the implementation of science payloads on several Slocum buoyancy gliders provided acoustic capabilities, including recording and real time on-board processing.

INFORMATION TECHNOLOGY

2018-2019 AT A GLANCE

The Information Technology Branch supports the CMRE Programme of Work through the conception, design, development, and delivery of state-of-the-art technologies in software and data services, and computing and networking, while ensuring interoperability, security, and compliance with relevant NATO policies and regulations.

The IT Branch is now responsible for the Centre's software development, data management and scientific Computer and Information Systems (CIS). In 2019, a major upgrade and improvement of the reliability of CMRE's unclassified data centre was accomplished by implementing state-of-the-art data backup and archive systems at both CMRE and on-board the NRV *Alliance*. The two systems are interoperable and integrated, to provide backup to the virtualization environments used to provide Infrastructure as a Service (IaaS) to CMRE scientists and engineers. Moreover, the system provides backup services to the Scientific Data Storage, a high-performance network-attached storage system composed of seven RAID nodes, recently upgraded to a total of 360 TB of space.

Also, the Enterprise version of GitLab™ was introduced at CMRE. GitLab, a collaboration tool for software production, is a single application to manage the life cycles of both software development and operations. The application can be used to manage, plan, create, verify, package, version control, configure and secure applications. The industrial version has extended features to assist the Centre in its integrated software effort.

Other activities in 2018 and 2019 included:

- Trials preparation, including security aspects, both for CMRE experimentation and participation in NATO exercises;
- Support to European Commission projects: virtual sea trials over the internet;
- Definition of a multi-year data management project;
- NATO STO activities on unmanned system security;
- A symposium on data management; and the
- Organization of an Artificial Intelligence (AI) workshop.

Data Management

Looking towards the future, CMRE intends to expand on previous efforts to catalogue and exploit its existing datasets, augmented with a clear process for collecting and exploiting new datasets. This capability will allow the Centre to be more effective at advertising the vast amount of data it has collected. This effort will also help with identifying datasets that are useful to the stakeholder community. The resulting capability should present both the datasets and services that allow users to access data in a convenient way by type, location and date.

Infrastructure, Scientific Computing and Information Systems

Centre work requires the exchange of information in a multitude of ways; this requires the creation and sustainment of a single, interoperable information environment that can be interfaced, at both unclassified and classified levels, with the NATO Enterprise and external partners such as the Nations and industry.

Many research and engineering activities still rely on legacy and non-centralized IT systems. The Centre has recently invested in hardware to mitigate the obsolescence of critical systems and support the migration from legacy operating systems to more recent ones; upgrading these systems (especially the classified CIS supporting the ASW and MCM programmes) will require further effort, particularly upgrading the CIS environment needed for research in Big Data and Artificial Intelligence.

An additional challenge for the IT Branch is that changes have to be introduced at the same time the CMRE Programme of Work is being executed. This requires a continuous risk management approach to balance and de-conflict support activities with the on-going modernization activities, minimizing the impact that changes of the CIS environment and policies will have on the delivery of the programme.

Software Development

To improve the delivery of services and software, CMRE intends to progressively move away from waterfall type development. The Centre aims to develop an agile approach with integrated configuration management (GitLab), continuous testing, continuous deployment and operations practices. A new Head of Software Development has been hired to lead this initiative beginning in 2020.

CMRE Internal Services Catalogue

CMRE is adopting a service-based model for IT to move away from the current asset-based, highly personalized way of working. This will result in more structured processes, supported by an Enterprise architecture and managed environment which is more efficient and secure. One of the objectives of the IT Branch is to define and provide the current CIS capabilities as services, adopting the Information Technology Infrastructure Library (ITIL) as a service management framework, complemented by other industry best practices.

RESEARCH VESSELS

"As you can imagine, taking science to sea is really hard and it's really expensive. . . . Without resources like the NRV *Alliance*, Nations couldn't afford to go to the Arctic just to run an individual test, making what we do at CMRE extremely efficient and valuable to the Alliance."

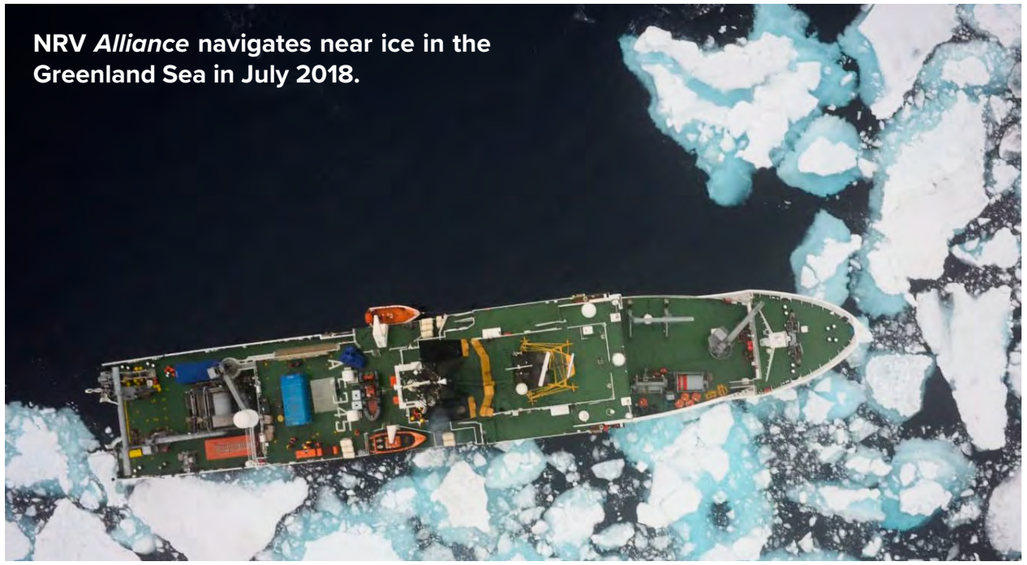
– *Dr Catherine Warner, CMRE Director*

NATO Research Vessel (NRV) *Alliance* and Coastal Research Vessel (CRV) *Leonardo*, allow CMRE to conduct research and demonstrate science and technology at sea. Owned by NATO, both ships have operated under the Italian Navy flag since 2016 and are manned by Italian Navy crews. The vessels are critical to demonstrating the potential of Maritime Unmanned Systems at sea, and in operational settings, as solutions to future naval capability requirements.

The NRV *Alliance* is a 93-metre, 3,100-ton, global-class ship, designed and built to minimize the noise it radiates into the water, making it the ideal platform for research in underwater acoustics and sonar sensing. Able to sustain speeds over 16 knots, the NRV *Alliance* can cruise economically at 11.5 knots for 7,200 nautical miles, with an endurance of 26 days, enabling scientists and engineers the opportunity to perform extended research at sea in remote waters.

With 400 square metres of laboratory space, which includes state-of-the-art wet labs, computers and connectivity, the NRV *Alliance* is equipped with a precision navigation system and hull-mounted sensor suite, along with powerful winches, cranes and deck handling equipment to deploy, tow, and recover a variety of sensor systems, unmanned vehicles, and oceanographic instrumentation in the most severe ocean conditions. The NRV *Alliance* is a highly versatile ship that has been employed in a wide range of ocean research from deployment and control of multiple autonomous underwater vehicles; to deep ocean anti-submarine warfare experiments; to oceanographic and bathymetric surveys in the High North.

The NRV *Alliance* features a hull mounted multi-beam echo sounder for detailed surveys of the ocean bottom, especially useful in mine countermeasures and anti-submarine warfare research. The ship can also collect core samples from the seabed as well as water samples from various depths that can be processed and analyzed in the oceanographic wet lab. The NRV *Alliance* can deploy acoustic and oceanographic sensors such as vertical and horizontal towed acoustic arrays; towed or moored oceanographic instruments; and a range of autonomous surface and underwater



NRV *Alliance* navigates near ice in the Greenland Sea in July 2018.

platforms, all with precision navigation and timing to support multiple experiments simultaneously.

NATO's second research vessel, the CRV *Leonardo*, is a 29-metre, 393-ton coastal ship designed to accommodate an array of scientific instrumentation and, like the NRV *Alliance*, radiates minimal noise to facilitate underwater acoustic research. The CRV *Leonardo* is equipped with a dynamic positioning system capable of station-keeping to within 1-metre and can sail in quiet state at speeds up to five knots. CRV *Leonardo* can host up to 15 persons for day cruises and has 10 berths. The vessel can accommodate a six-metre laboratory container that augments the 35 square metre on-board laboratory space.

The science and engineering demonstrated on NRV *Alliance* and CRV *Leonardo* delivers the knowledge to enable better strategy and tactics for warfighters, and there's no harder place to make decisions than the ocean environment. Dr Dan Hutt, CMRE's Acting Head of Marine Operations, highlights that the Centre invites partners to join them at sea. "NRV *Alliance* and CRV *Leonardo* are available for charter to military, government, or defense organizations within the NATO Nations, and we work with a wide range of academic institutions." Dr Hutt continues, "We're open for business. Our ships are ideal platforms for defence science and engineering at sea, and for oceanography. With NRV *Alliance* we have global reach."

With NATO's renewed interest in the High North, growing commercial potential in the Arctic, and studies on climate change by the scientific community, there is high demand for underway time on the ice-capable NRV *Alliance* that can get up to the Arctic, stay there and operate in extreme conditions.

"As you can imagine, taking science to sea is really hard and it's really expensive. Not many nations can do that," states CMRE Director Dr Catherine Warner. "When we go out on NRV *Alliance* with whatever mission packages or trials we're going to do, we will have several different Nations participating. Without resources like the NRV *Alliance*, Nations couldn't afford to go to the Arctic just to run an individual test, making what we do at CMRE extremely efficient and valuable to the Alliance."

CRV *Leonardo* at sea during the Recognized Environmental Picture Mediterranean 2018 (REP-MED'18) sea trial.

CRV *Leonardo* during the REP-MED'18 sea trial in La Spezia Bay.

Researchers deploy an AUV from CRV *Leonardo* into the Mediterranean Sea during REP-MED'18.

CMRE's MUSCLE AUV operates near NRV *Alliance* in October 2019 during Dynamic Mariner'19 off Almeria, Spain.

COMMUNITY OUTREACH

“This is close to my heart because we want to encourage young people, and young women especially, to get into STEM. When we look at maintaining our technological edge, one of the things we need are qualified people, and that starts with getting people educated in STEM.”

– Dr Catherine Warner, CMRE Director

A student tests an AUV at the 2019 European Robotics League Tournament hosted by CMRE.

COMMUNITY OUTREACH

The next generation of CMRE scientists, engineers and technicians are in school today.

CMRE Director Dr Catherine Warner, Italian Naval officers and CMRE staff with local high school students on-board the CRV *Leonardo* for the Giona Project's at-sea activity.

CMRE has a vibrant outreach effort to encourage young people to get involved with science, technology, engineering and mathematics (STEM) today so they will become the scientists, engineers and technicians of tomorrow.

CMRE's relationship with high schools in and around La Spezia, as well as colleges and universities that come to the Centre to participate in international robotics competitions, has successfully attracted people who are obtaining STEM degrees and work in relevant fields to become involved with the Centre, including joining CMRE as research interns.

CMRE Director Dr Catherine Warner is particularly proud of the Centre's engagement with local schools. "This is close to my heart because we want to encourage young people, and young women especially, to get into STEM. When we look at maintaining our technological edge, one of the things we need are qualified people, and that starts with getting people educated in STEM," states Dr Warner.

Dr Warner continues, "In La Spezia, students who attend the technical high school do internships in their junior and senior year. We've provided opportunities for some of them to come here to CMRE. You wouldn't believe how technically advanced they are."

One recent success story is the collaboration with the Giona Project, an ongoing initiative that involves several institutions in the area of La Spezia aimed at promoting awareness, understanding, and the safeguarding of the marine environment among students. Through a cooperation agreement with three local high schools, students and their teachers, tutored and assisted by CMRE scientists and engineers, had the chance to embark on-board CRV *Leonardo* to conduct a real bio-acoustic research project.

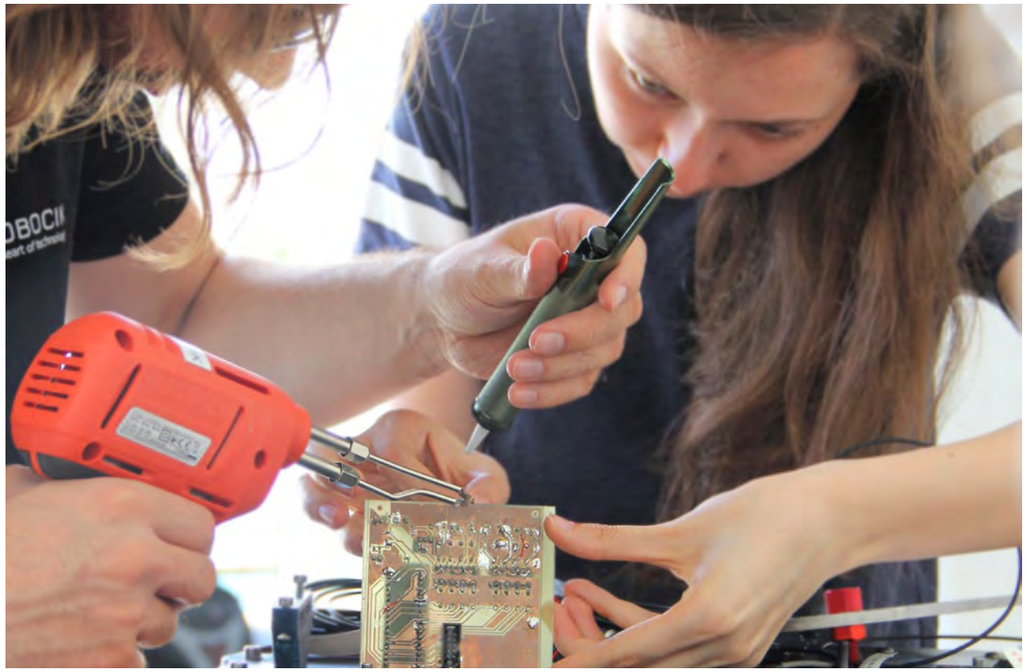
In the spring of 2019, after three weeks of planning and preparation, the Giona Project's at-sea activity was carried out. The experiment was called BARLAMARE (Bio-Acoustic Research to Learn About Marine Environment) and consisted of the deployment of three moorings in the nearby Parco delle Cinque Terre, a national marine protected area. Each mooring was equipped with a self-recording broadband digital hydrophone used to record the underwater soundscape. Of particular interest were the many marine mammal vocalizations obtained. The moorings were deployed for about one month.

The students were involved in the design and planning of the experiment, and in the operations at sea, within the appropriate boundaries of safety, and, most notably, in the pre-deployment deck preparations and tests of the moorings. Additionally, they were charged with keeping a detailed log-book of all events. Thanks to the generous availability of CRV *Leonardo's* Commanding Officer, LT (ITA N) Loreta Cipro and all the Italian Navy crew, the students had the unique opportunity to learn about NATO's premier coastal research vessel and take part in the type of operations it often does with institutions from all over the NATO Alliance.

"The students demonstrated a high degree of enthusiasm and willingness to participate in all phases of the activity. I believe I speak for everyone involved in the project when I say that it was a real pleasure working for and with them," says Dr Alessandra Tesei, scientist in charge of the BARLAMARE sea trial.

Dr Warner adds, "Over the course of our research we have accumulated a lot of data on marine mammals. We provided this acoustics data to the students and they

COMMUNITY OUTREACH

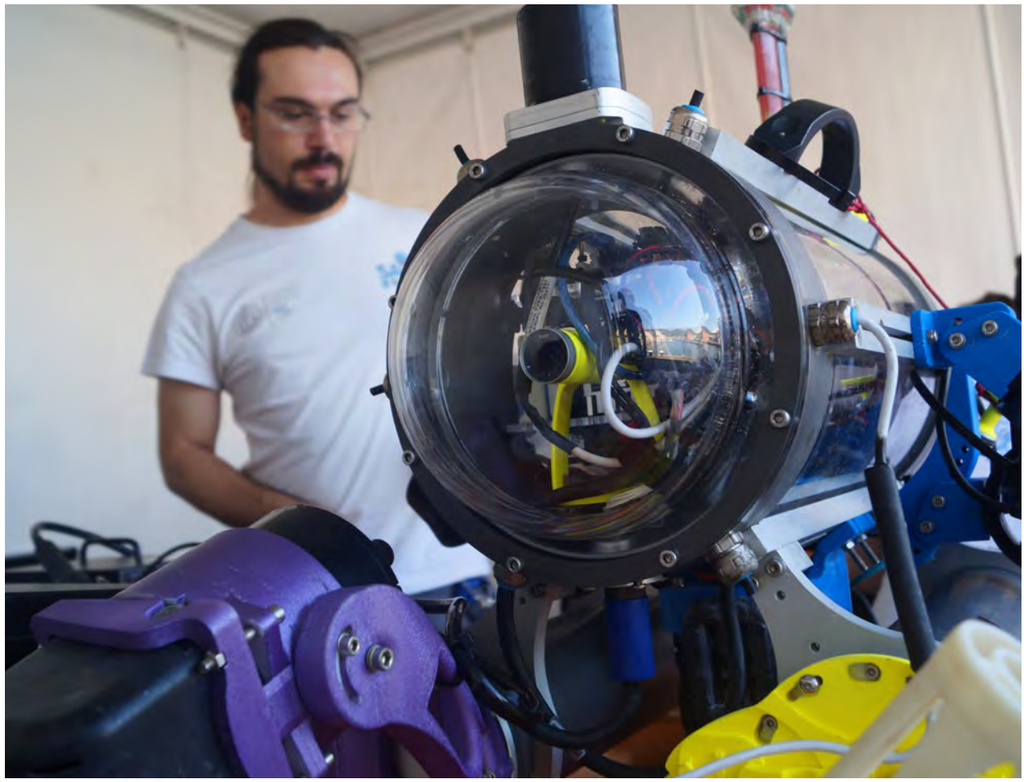


Students work at the 2019 European Robotics League Tournament.

conducted an analysis of it as a science project. The students were then able to present their findings at a very large and prestigious conference here in May with the European Cetacean Society. It was a huge success and we hope to continue that relationship."

In addition to the BARLAMARE sea trial, the Giona project students participated in another major event at CMRE, the European Robotics League (ERL) Emergency robotic competition held at the Centre in 2018 and 2019. Now part of the SciRoc EU project and sponsored by IEEE Oceanic Engineering Society (OES) and Blue Robotics, and with the help of the Italian Naval Support and Experimentation Center (CSSN) next door to CMRE, the ERL Emergency competitions attract student robotics teams from around the world. The team's robots compete outdoors and underwater to carry out tasks in realistic emergency response scenarios. One task is for the robot to autonomously find a mannequin underwater that represents a casualty. Although ERL Emergency is a competition, it's a friendly one that promotes collaboration and exchange of ideas between international teams of science and engineering students with a common interest in robotics. These young people will be building the robots of tomorrow who will do more "dull, dirty and dangerous work" so that humans don't have to.

In 2019 the ERL Emergency was held 14-19 July, and included 60 participants from ten universities, high schools and companies from seven European countries. In parallel to the competition, demonstrations were held and



A student shows his AUV at the 2019 European Robotics League Tournament.

talks were given by Prof Shinji Kawatsuma, the engineer who led the robotics intervention at the Fukushima nuclear power plant after the tsunami in 2011, Mr David McKay, manager of the Eelume project that is developing a snake-like underwater robot; Dr William Kirkwood from the Monterey Bay Aquarium Research Institute (USA) and representatives of IEEE OES. Approximately 100 guests attended the competition, including judges from Singapore, Japan, the United States and Europe representing the most prestigious robotics institutions in the world.

"We want young people to champion ERL Emergency Robots," says Dr Gabriele Ferri, CMRE roboticist and Technical Director of the event, "The high school teams that won the Olimpiadi di Robotica, a project funded by the Italian Ministry of Education, University and Research (MIUR), also attended to show their robots and see the more experienced students competing. Moreover, young students from La Spezia high schools saw the robots in action during the competition, and had the opportunity to help the organization and interact with the international judging team."

Today, CMRE continues to organize competitions of the European Robotics League and are renowned for this in the world-wide robotics community. Dr Ferri continues, "At CMRE we firmly believe that robotics competitions are the perfect way to form the engineers of tomorrow, to push the state of the art in robotics and at the same time they are an effective means for disseminating knowledge of robotics and new technologies among the general public."

CMRE AT A GLANCE

2018-2019 FINANCIAL OVERVIEW

CMRE has successfully adapted to the challenges of the move to the customer-funded business model and has now hit its stride in bringing in new business from the Nation's defence S&T sector including many European Commission (EC) funded projects to augment the revenue from the main customer, NATO Allied Command Transformation (ACT).

2018-2019 was a period of sustainment for CMRE. The Centre improved business practices to tap in to various funding opportunities from the Nation's defence S&T sector, including many European Commission (EC) projects, to augment the revenue from the main customer, NATO Allied Command Transformation (ACT).

CMRE's two ships CRV *Leonardo* and NRV *Alliance* contribute revenue to the Centre by providing at-sea experimentation and demonstration services. CMRE owns the ships on behalf of NATO. Since 2016 the vessels are crewed by the Italian Navy with operations shared between CMRE and the navy.

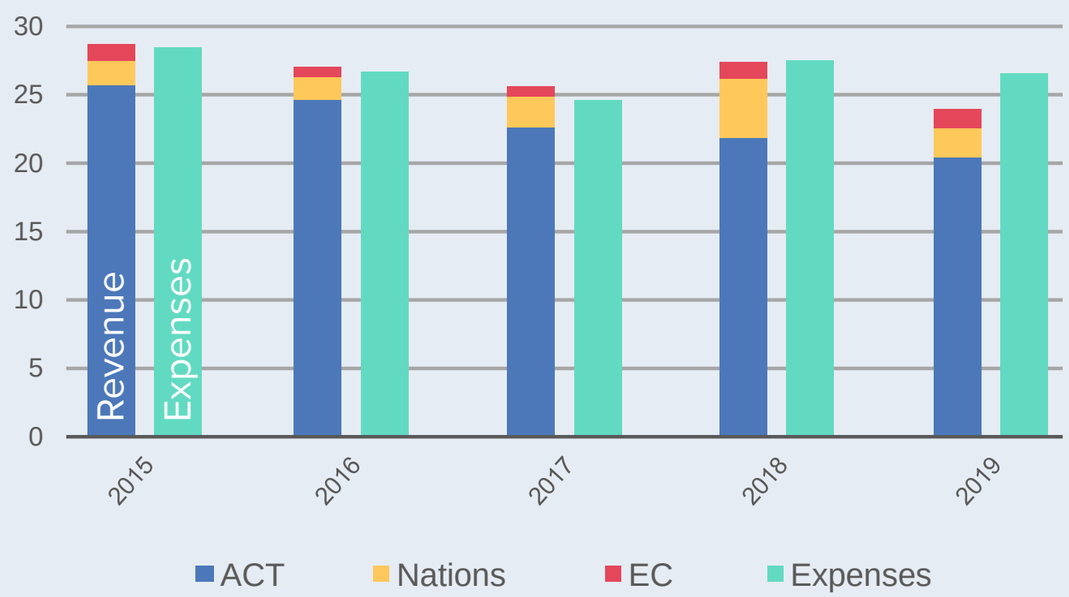
Due to extensive maintenance and a primary engine re-build, the Alliance was not available for sea trials for most of 2019. Because the vessel was not available to generate revenue, yet fixed costs of maintenance and insurance remained, the Centre had an overall operating loss in 2019. Fortunately, due in part to a major charter in early 2018, the Centre was able to absorb the loss within its general reserves. Today CMRE is financially stable but must identify resources to modernize its S&T infrastructure. An overhaul of facilities and infrastructure, including engineering and IT assets, is critical in order to remain at the leading edge of maritime research and experimentation.

Five-Year Trend

The five-year trend of CMRE's revenue declined somewhat, going from 28.6 MEUR in 2015 to 24.2 MEUR in 2019, partially due to the unavailability of NRV *Alliance* in 2019. Additionally between 2016 – 2020, the Centre's main customer, ACT, decreased their annual Maritime S&T Programme of Work (POW) approximately 30% landing at 19.8 MEUR in 2019. As the glideslope was pre-planned and gradual over five years, the Centre was able to compensate by expanding its customer base within NATO Allies and EC projects.

ACT's Maritime S&T POW is expected to remain stable at 18.5 MEUR for NATO's five-year medium term resource plan horizon. The Centre's business prospects look favourable in the coming years based on the knowledge and experience CMRE has acquired in recent years in selling its unique capabilities and facilities. In 2019 the Centre established the Integrated Business Support Unit to support the development of business opportunities.

Figure 1: Five-year trend of revenue and expenses in MEURO



CMRE AT A GLANCE

2018-2019 FINANCIAL OVERVIEW

CMRE's work for the Nations has seen a general upward trend since 2013 led by the United States and the host nation, Italy. In 2018 total revenue from the Nations was 4.3 MEURO but declined to 2.0 MEURO in 2019. The forecast for 2020 is again in-line with 2018.

Work for the European Commission and NATO Nations

CMRE's work for the Nations has seen a general upward trend since 2013 led by the United States and the host nation, Italy. In 2018 total revenue from the Nations was 4.3 MEURO but declined to 2.0 MEURO in 2019, largely due to the unavailability of NRV *Alliance,* which resulted from a major engine repair. The forecast for 2020 is again in-line with 2018.

Revenue from European Commission (EC) Consortia projects has also been trending upward becoming an established component of the Centre's programme. In 2018 revenue from EC projects was 1.2 MEURO and it was 1.4 MEURO in 2019. EC-funded activities complement and reinforce the core work of the Centre. For instance, Modelling and Simulation work for EC projects helps the Centre maintain a critical mass of expertise that benefits the M&S programme of CMRE's main customer, ACT.

Figure 2: Two year summary of revenue from European Commission projects

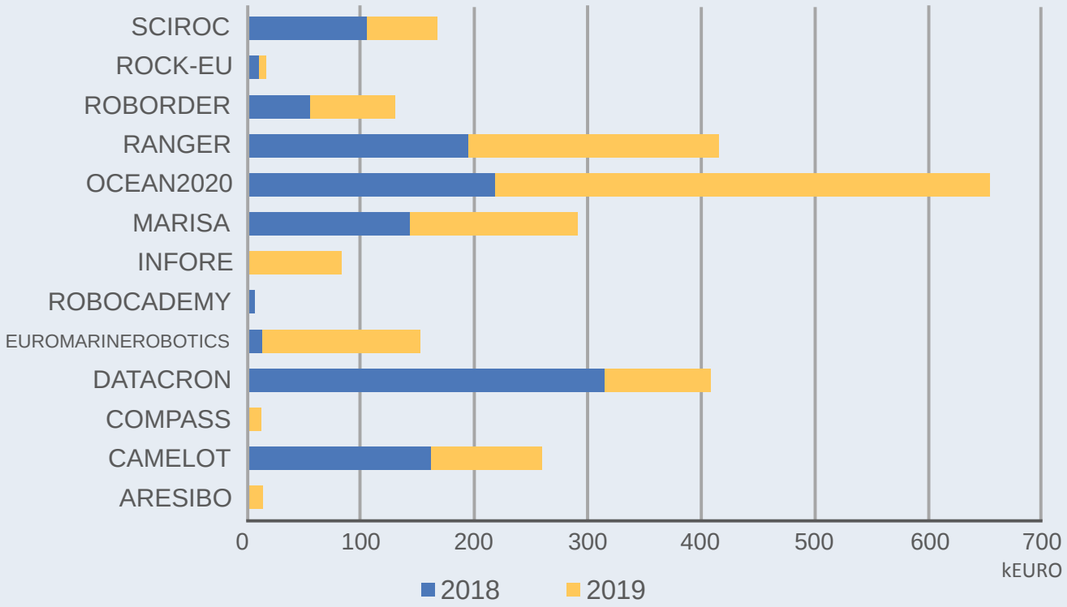
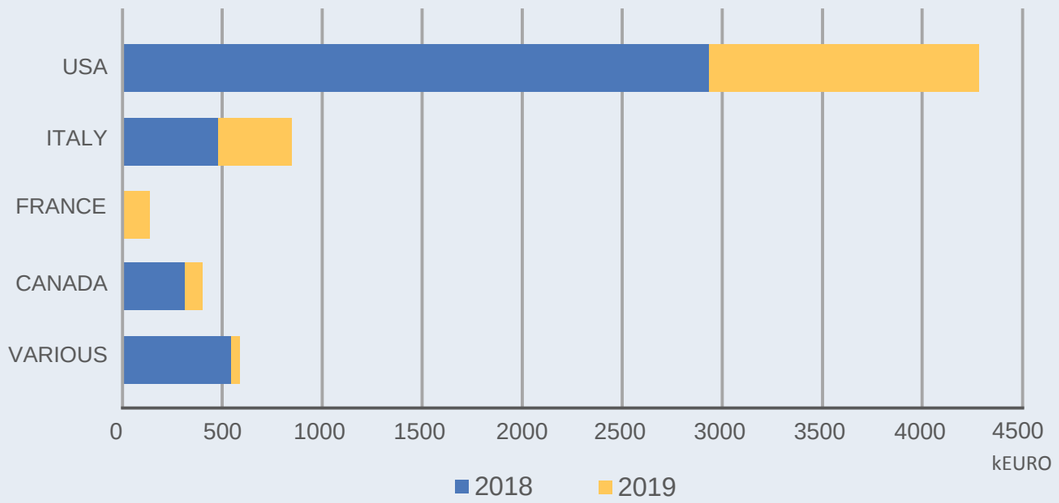
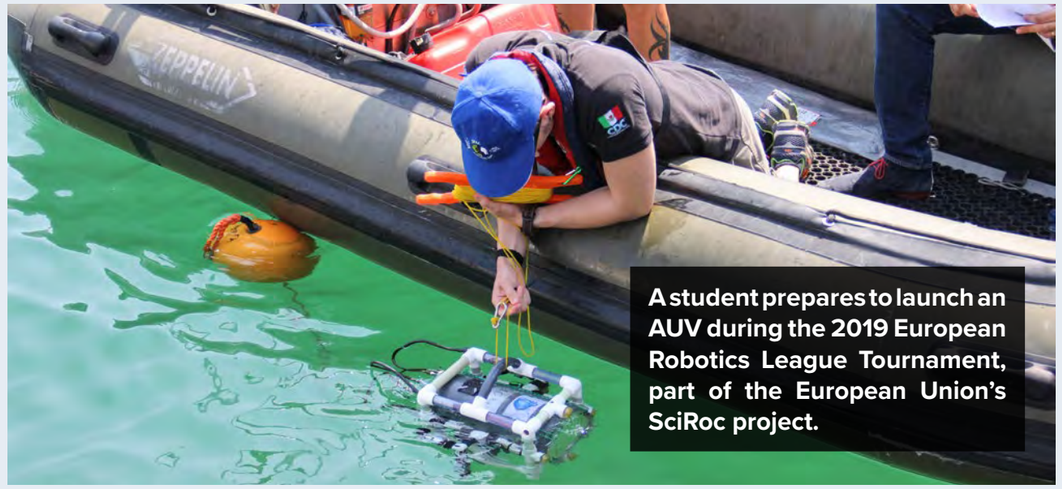


Figure 3: Two year summary of revenue for NATO Nations





A student prepares to launch an AUV during the 2019 European Robotics League Tournament, part of the European Union's SciRoc project.

CMRE AT A GLANCE

2018-2019 FINANCIAL OVERVIEW

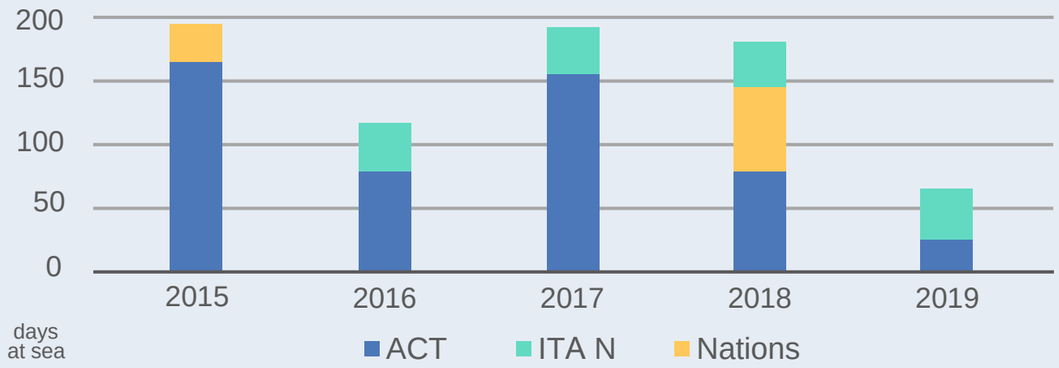
NATO's two research vessels CRV *Leonardo* and NRV *Alliance* are exceptional assets for CMRE's at-sea research and experimentation for and with NATO Nations. In addition, the vessels can bring significant revenue for the Centre when fully employed throughout the year.

Research Vessels

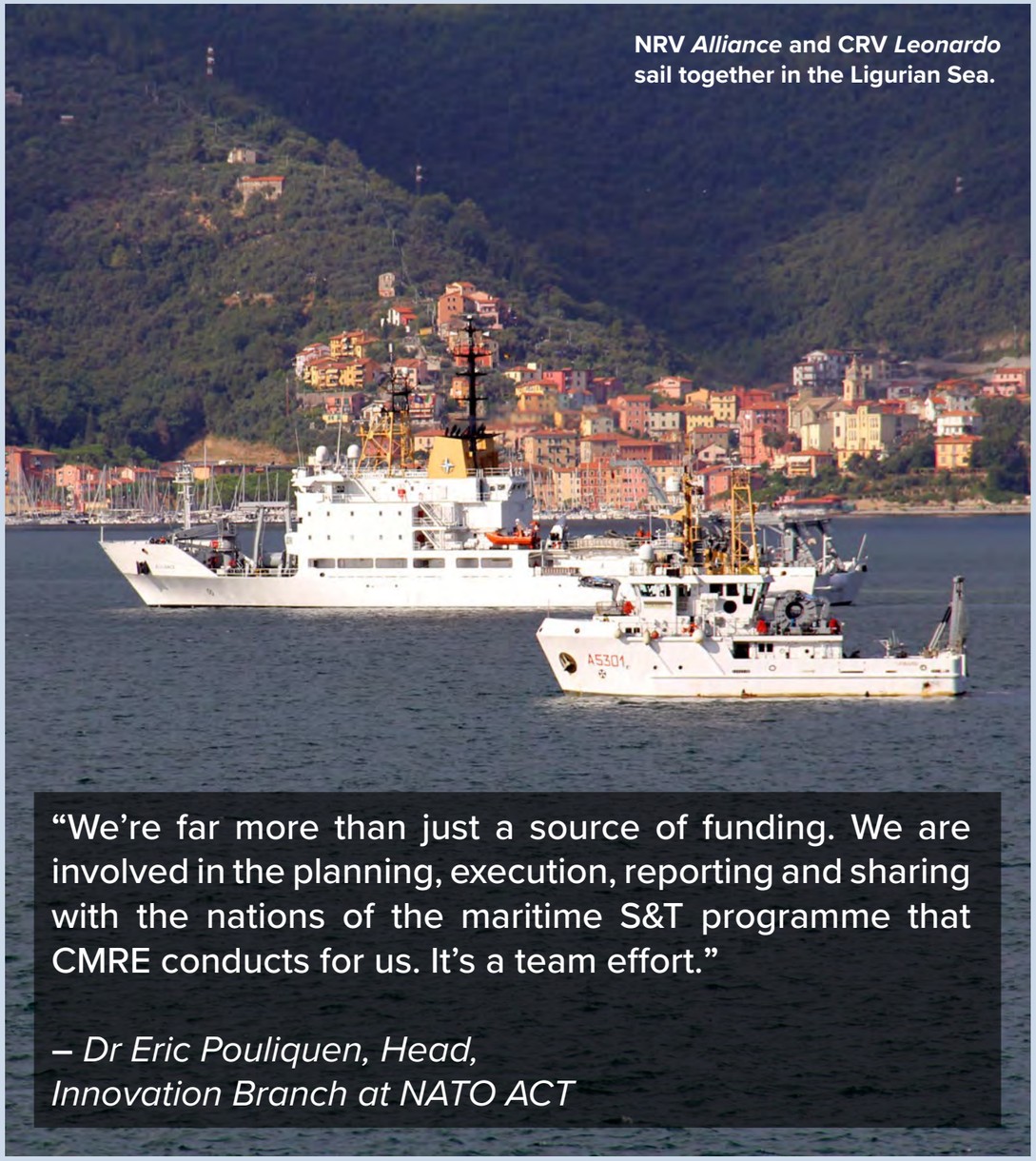
For NRV *Alliance*, 80 funded sea days is the target for sustainable operation. The five-year trend of seas days for NRV *Alliance* is shown in Figure 4. In 2016 extensive changes were made to the configuration of the ship to accommodate a larger crew for the Italian Navy, but the vessel still accomplished 79 days of work for CMRE in addition to 38 days for the navy.

2018 was the first year of a significant number of sea days funded by external partners since the flagging by Italy. The single biggest contribution came from the United States National Science Foundation who funded a major cruise to Greenland. However, in July 2018 one of NRV *Alliance's* two main propulsion generators (MPG) failed. The re-build of the MPG began in January 2019 and took almost nine months to complete, due in part to lack of spare parts and knowledgeable craftsmen. This delay required significant modifications to planned sea trials; therefore, a continuous risk analysis including a tight alignment with our customers was required to reposition the S&T programme of work. This is reflected in the number of days at sea for 2019 shown in Figure 4. By October 2019 the main engine repair was complete and other improvements to the vessel were also made, such as replacement of the gas turbine propulsion engine used for low-noise operations. NRV *Alliance* is now in excellent operating condition.

Figure 4: Five-year trend for NRV *Alliance* days at sea with major users indicated



Note: 2016 was the first year of operation by ITA N. ITA N days do not generate revenue.



NRV *Alliance* and CRV *Leonardo* sail together in the Ligurian Sea.

"We're far more than just a source of funding. We are involved in the planning, execution, reporting and sharing with the nations of the maritime S&T programme that CMRE conducts for us. It's a team effort."

– Dr Eric Pouliquen, Head, Innovation Branch at NATO ACT

CMRE AT A GLANCE

2018-2019 HUMAN RESOURCES

While NATO civilian employees make up the majority of the workforce, it is augmented by a significant and growing number of visiting researchers. The Centre also relies on consultants and contractors to deliver specialized expertise and services and to help absorb surge workload.

2018 and 2019 continued the trend of gradually increasing workforce at CMRE. While NATO civilian employees make up the majority of the workforce, it is augmented by a significant and growing number of visiting researchers. Many of the visiting researchers are young scientists recently graduated from university or are still students. Some are doing graduate theses based on their work at CMRE with Centre scientists as co-supervisors. Some visiting researchers are university professors on sabbatical from their home institution.

Military staff are contributed by various nations for specific roles. For example, most scientific programmes have a dedicated military coordination officer, which is extremely helpful for embedding CMRE's scientific activities in military events and exercises as well as maintaining a link between CMRE technical staff and the military organizations of the Nations. Furthermore, the Host Nation, Italy contributes two Security officers and, although not counted as Centre staff, also contributes 14 Carabinieri for physical security and 53 members of the Italian navy to crew CMRE's research vessels. The Centre also relies on consultants and contractors to deliver specialized expertise and services and to help absorb surge workload.

CMRE's Human Resources Branch provides the recruitment, retention and training of the best qualified staff to fulfil the Centre's mission as well as support to Centre staff and their families. In 2019 CMRE hired 24 NATO civilians with an average time to hire of 6 months. The average time to fill the positions was 11 months. Much of the time to fill positions is due to the time required for new staff to obtain a security clearance from their national government. At the end of 2019 CMRE had 145 NATO civilian employees and a total workforce of 213 including military personnel, visiting scientists, contractors and consultants. Of the CMRE workforce, 23% of employees are female and the average age is 47 years. The average length of service is 9.5 years. CMRE strives for a diverse workforce representing all NATO countries and has a programme to attract young scientists. More information about job opportunities can be found at: www.cmre.nato.int.

Figure 5: Five-year workforce trend

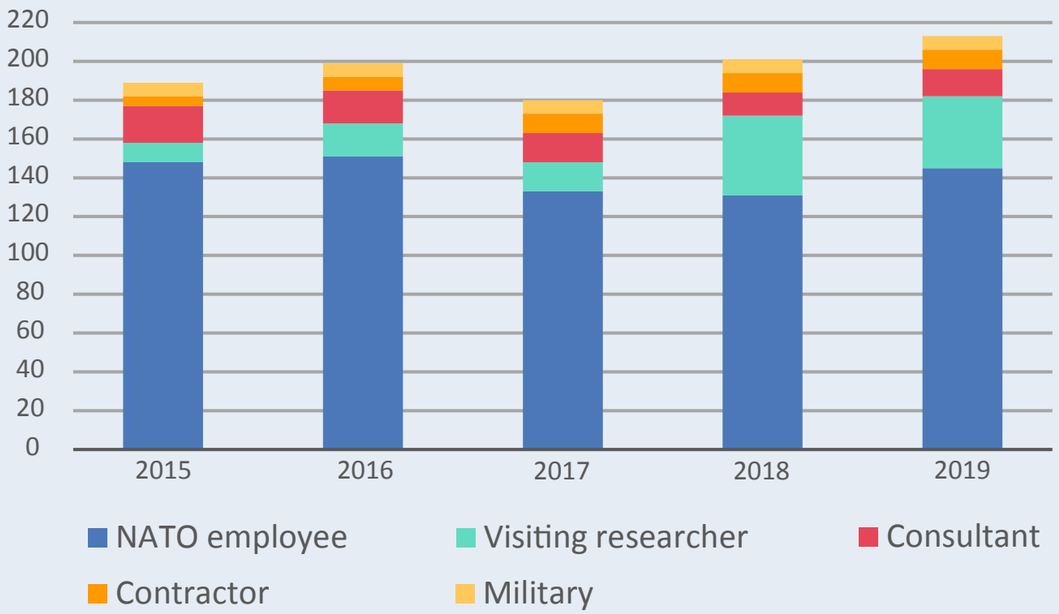
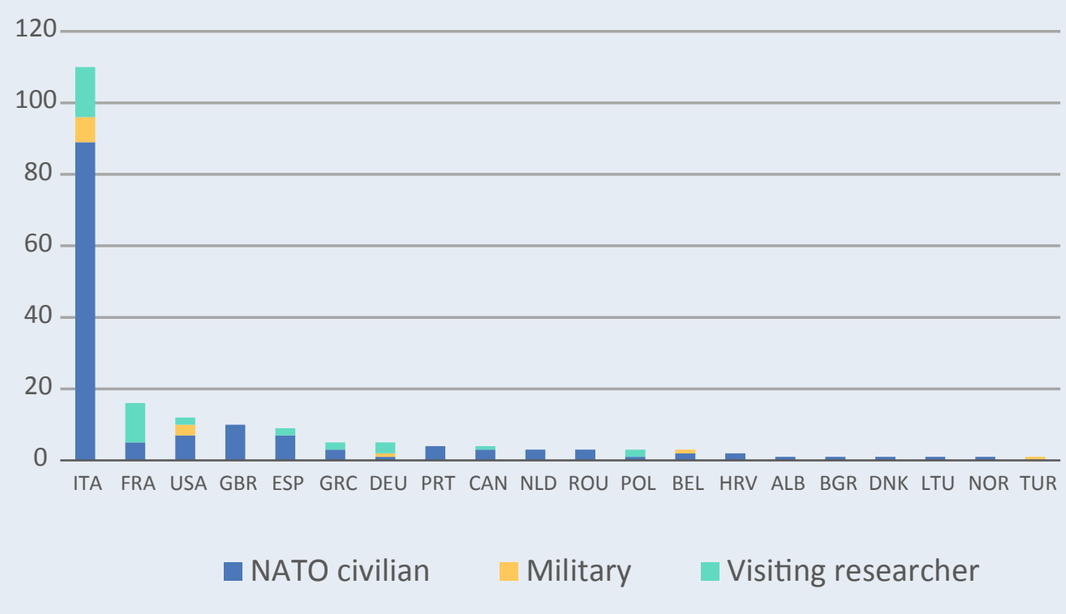


Figure 6: CMRE staff by nationality in 2019



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