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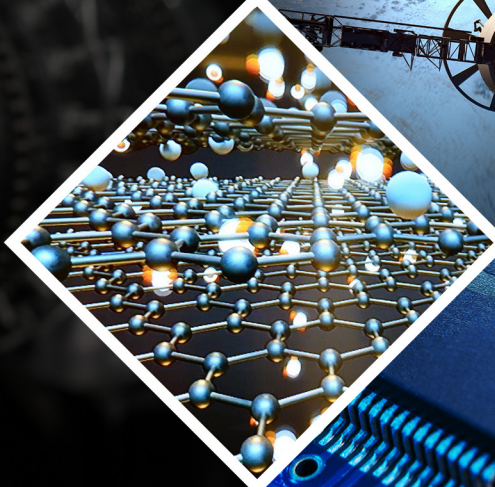
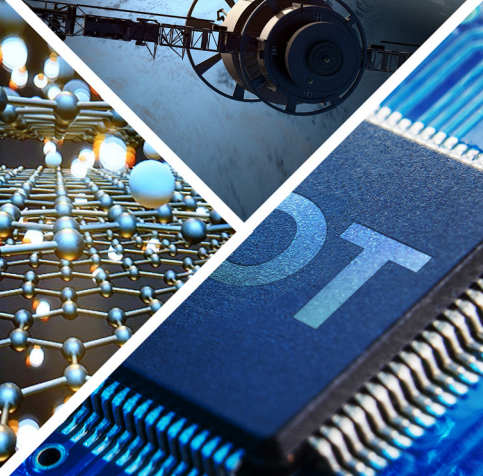
2020 HIGHLIGHTS

SCIENCE AND TECHNOLOGY ORGANIZATION





EMPOWERING THE ALLIANCE'S TECHNOLOGICAL EDGE

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FOREWORD

THE NATO SCIENCE AND TECHNOLOGY ORGANIZATION "EMPOWERING THE ALLIANCE'S TECHNOLOGICAL EDGE"

Figure 1: Dr Bryan Wells, NATO Chief Scientist.

2020 has been an extremely busy and successful year for the NATO Science and Technology Organization (STO). Despite the difficulties of COVID-19, the network of over 6,000 scientists, engineers and analysts who are part of the STO have remained focused on delivering excellence for the Nations and NATO.

The threats that existed before the pandemic have not diminished, and therefore the STO's commitment has further intensified. NATO has to stay at the forefront of technological innovation to ensure the defence and security of its Allies and the success of its operations. The STO supports the Alliance in maintaining its advantage in this area by generating, sharing and utilizing advanced scientific knowledge, technological developments and innovation.

Supporting National and NATO priorities on delivering **innovation for the Alliance** has been a particular focus of the work of the STO in 2020. Although the STO had been researching Emerging and Disruptive Technologies (EDTs) for many years, it has redoubled its efforts. Currently, almost half of the Centre for Maritime Research and Experimentation and Collaborative Programmes of Work are related to these technologies. These new and emerging technologies: artificial intelligence, autonomy, big data, biotechnology, hypersonics, novel materials, quantum and space, are changing modern military operations. The majority of new technologies are readily available to all and are different from those used in the past. The huge scale of the change is as important as its rapid pace. Thanks to the scientific expertise in the STO network, NATO starts from a position of strength when addressing these challenges.

The **COVID-19** pandemic was a priority that emerged rapidly in the first months of 2020. The network of scientists, engineers and analysts responded with speed and imagination to this new challenge. Specific work focused on solutions for virus detection, improved situational awareness, resilience and the post-COVID-19 future. The STO also provided NATO itself with real-time advice, particularly on misinformation. There has been a tremendous response from the STO network, showing how they can bring their expertise to bear on this vital task.

The STO is responding to the policy initiatives of NATO in its provision of **advice to leadership**. This year, the STO held a workshop on the science that underpins the verification of nuclear dismantlement, bringing together experts who research this topic with experts from the STO network. The Centre for Maritime Research and Experimentation (CMRE) has also been undertaking maritime environmental monitoring in the context of climate change.

The STO network is at the forefront of innovative thinking, but it remains conscious of the need to seek out new ideas and to ensure that the network has a strong representation from **young scientists** – the next generation of scientific leaders. A number of initiatives have therefore been developed to welcome early career scientists into the network and to encourage their participation in the Programmes of Work. These initiatives give them the opportunity to learn more about each other's work and how they can contribute to maintaining NATO's scientific and technological edge.

The statistics on our two Programmes of Work (CMRE and Collaborative) demonstrate the scale of our efforts. We now have over 340 activities currently underway, ranging from major research programmes to horizon scanning and lecture series, as well as cooperative demonstration of technologies.

In addition to the scientists from the Nations, NATO supports an Office of the Chief Scientist in the NATO HQ in Brussels, to give scientific advice direct to NATO political and military leadership, a Collaboration Support Office in Paris, to administer the Collaborative Programme of Work, and the Centre for Maritime Research and Experimentation at La Spezia, a world-class laboratory in its area of expertise. We retain close links with the institutions of the European Union.

This booklet demonstrates the very high quality of work that is being done within NATO S&T, and it also points the way in which we are working to enhance our work, its importance for the Alliance and how STO prepares NATO for the new technological environment.

Dr Bryan Wells

NATO Chief Scientist (CS)
STB Chairman

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"Today, NATO is driving innovation across the Alliance. For instance, the NATO Science and Technology Organization has a network of more than 6,000 scientists and engineers. Dedicated to integrating the latest technologies – including Artificial Intelligence, Big Data and quantum computing – into NATO and Allied platforms. Such as our next generation early warning aircraft. And maritime autonomous vehicles for mine sweeping."

NATO Secretary General Jens Stoltenberg, Global Security 2020 (GLOBSEC) Bratislava Forum, 7 October 2020

"NATO has tapped into its very important resource of defence scientists – the largest such network in the world – to support the COVID-19 response."

Chairman of the NATO Military Committee Air Chief Marshal Sir Stuart Peach, Military Committee in Chiefs of Defence Session, 14 May 2020

"This report is a glimpse into the future of defence. It will guide research at NATO and our Allies, to ensure that we maintain our cutting-edge technology in the years ahead".

NATO Deputy Secretary General Mircea Geoană, launching "Science & Technology Trends: 2020 – 2040", 4 May 2020

INNOVATION FOR THE ALLIANCE

INNOVATION FOR THE ALLIANCE

The evolution of Science and Technology (S&T) has historically been a critical driver of military innovation. This has been especially true for NATO and its partner nations throughout the history of the Alliance, providing the Alliance with a "technological edge." As noted by the NATO Secretary General Jens Stoltenberg, *"Today, emerging and disruptive technologies are having a profound impact on how the Alliance carries out its core tasks. How we understand, adopt and implement those technologies will largely determine our future security, and NATO will play a key role in driving this change."*

Responding to this challenge, beginning in 2019 and continuing into 2020, the Alliance initiated the development of an ambitious innovation agenda spanning three areas:

- **Capability development and delivery**, where military capability needs are to be fielded more rapidly, through gradual maturation as well as the exploitation of the disruptive effects of novel and convergent technologies;
- **Policy-making and decision-making**, where new technologies may enable a more extensive range of options for future actions, and where operational decisions may be required in highly compressed timescales; and
- **Management**, where the Alliance may need to adapt the processes and cultures that underpin its political, military, and administrative functions.

To meet these obectives NATO is developing an Emerging and Disruptive Technology (EDT) roadmap, linked to a new NATO warfare capstone concept. Such a renewed focus on "innovation", "technology," and "disruption" is essential if NATO is to adapt to changing military, socio-technical and geopolitical realities. Ultimately, the Alliance seeks to explore, exploit and lead in the military use of the following EDTs: space, big data, artificial intelligence, autonomy, hypersonics, quantum technologies, and biotechnologies.

Over 2020, the STO contributed to the understanding and development of the EDT implementation roadmap, as well as the broader challenges of EDT development and defence innovation. It has done so through a variety of mechanisms such as:

- The STO's Collaborative Programme of Work (CPoW) and the STO's Centre for Maritime Research and Experimentation Programme of Work (CMRE PoW), which provide an underlying knowledge base for targeted, evidence-based advice to inform policy and capability decisions, including those related to EDTs;
- Through its Technology Watch programme built upon von Kármán Horizon Scans, Technology Watch Cards and technology trend analysis;
- The publication of Science and Technology Trends 2020 – 2040, a major analysis of EDT development over the next 20 years, and its military implications;
- The Chief Scientist's challenge in response to COVID-19;
- Exploratory research or scoping activities in quantum technologies, maritime autonomy, biotechnology, nuclear verification, environmental change and AI;
- Initialization of a strategic roadmap for S&T development supporting Space as a force enabler;
- Alignment of activities in the CPoW and CMRE PoW to better identify and support EDT development, essential synergies and integration into NATO operational capabilities (see the following charts highlighting proposed, planned or active activities, with some activities aligned to more than one EDT).

Over the entirety of 2020, the STO has proactively shaped the discussion around EDTs and defence innovation. It has done so through the dissemination of a variety of innovation oriented "food for thought papers", focused EDT seminars and presentations, technical reviews, EDT focused workshops such as the NATO OR&A conference, participation in major committees such as the Innovation Board and the Data Exploitation Working Group, and active collaboration with other NATO elements in the development of the EDT implementation roadmap and associated military concepts and policy development activities.

In the spring of 2020, the STO delivered the "S&T Trends: 2020 – 2040" report, a comprehensive assessment of EDTs (including the state and rate of technological maturity, current developments, potential applications and military impact). The report seeks to inform and provide context for planners, policy development and decision

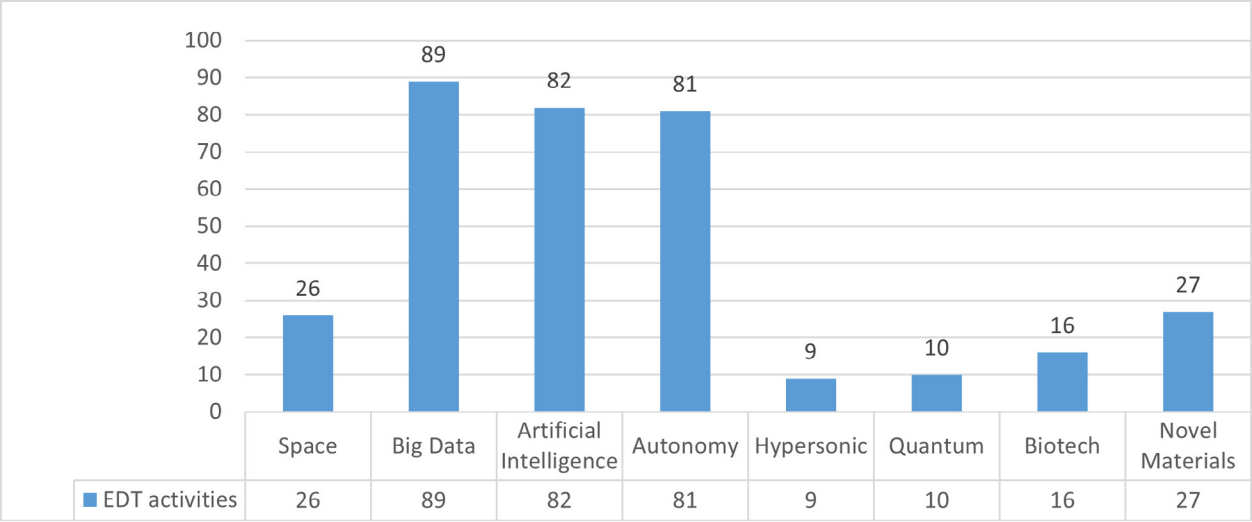

Figure 2: Alignment of EDTs with STO CPoW and STO-CMRE PoW Activities (7 December 2020). [Please note that a STO PoW Activity can be aligned to more than one EDT (in particular for Big Data, AI and Autonomy)].

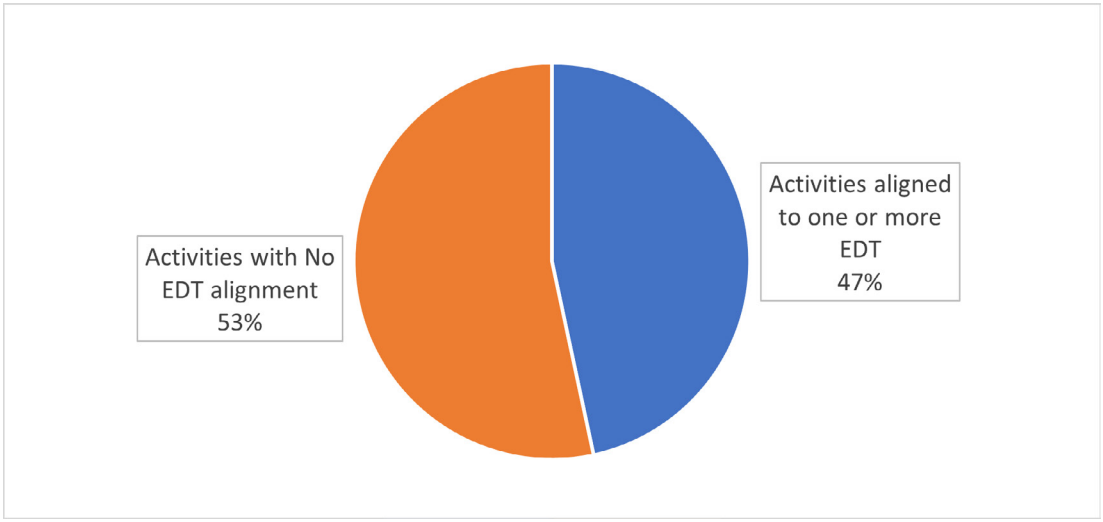

Figure 3: The Percentage of the STO CPoW and STO-CMRE PoW Activities Aligned to EDTs shows the broad portfolio of the STO addressed in support of the Nations' and NATO's objectives and needs (status 7 December 2020).

makers in NATO and the Alliance around EDTs. A supporting handout was launched by the Deputy Secretary General. Building upon this report and under the guidance of the NATO Science and Technology Board, the STO shaped its programmes to focus on the identified EDTs and their integration into fielded military capabilities.

Naturally, STO S&T activities extend beyond the current set of EDTs to cover the broad range of S&T essential to NATO and Alliance nations. The Nations' funded Collaborative Programme of Work (CPoW) and the customer funded research programme undertaken by the Centre for Maritime Research and Experimentation (CMRE PoW) provided a wealth of innovative technological developments essential for new defence and enterprise capabilities. The STO, as the original innovation engine for the Alliance, is committed to delivering value and impact, through a balanced and militarily relevant S&T portfolio that responds to current requirements and seeks to anticipate operational and enterprise needs, including identification of the next generation of emerging and disruptive technologies.

ACCELERATING AND ACHIEVING CAPABILITY DEVELOPMENT AND DELIVERY (A2CD2)

The Alliance finds itself in a new and dynamic reality, marked by growing uncertainty, instability, risks (including pandemics and climate change), and rapid scientific and technological changes, which all have the potential to disrupt the global strategic balance. For the Alliance to fulfil its core strategic objectives and meet its level of ambition, it is fundamental to have cutting-edge military capabilities for collective deterrence and defence, to which NATO's Science and Technology (S&T) edge is the lifeblood.

Against this backdrop, the NATO Science and Technology Board (STB) launched a Strategic Initiative on Accelerating and Achieving Capability Development and Delivery (A2CD2), aiming to seize collaborative opportunities and combine resources to support Allied Nations and NATO to develop and deliver capabilities critical for collective deterrence and defence, as quickly as possible. The STB Strategic Initiative was built on and is in full compliance with the Council approved 2018 NATO S&T Strategy, the 2019 Political Guidance, the NATO Defence Planning Process, and the 2019 Emerging and Disruptive Technologies (EDTs) roadmap.

In 2020, the STB endorsed a Multi-Year Effort for implementing this Strategic Initiative through major cross-domain Alliance-wide A2CD2 Workshops for selected Critical Capabilities. Workshops are planned on Surface Based Air and Missile Defence (SBAMD) and Joint Mission Training by Distributed Simulation (JMTDS) will take place.

RESPONSE TO COVID 19

COVID-19

The STO has been heavily involved in supporting NATO and the Nations in their response to the COVID-19 pandemic.

RESPONSE

NATO Foreign Ministers said in April that they would *"... harness our medical, scientific, and technological knowledge and resources to help deliver innovative responses"* to the COVID-19 pandemic. As part of these efforts, the STO leveraged the power of its network of over 6,000 scientists and researchers, including medical experts, supporting multiple lines of effort such as:

- **Sharing**: To better understand national actions, and to help improve NATO's response to national requests, the STO set up a password-protected collaborative web platform where medical researchers and scientists from Allied and partner nations shared ideas, research materials and other information of relevance to the crisis response. This exchange was facilitated by the NATO Collaboration Support Office in Paris. It covered such topics as virtual reality scenarios for emergency medical care, reducing the lifespan of viruses by treating surfaces and fabrics with polymer coatings, laser testing of saliva samples, countering misinformation, and the application of big data analytics and modelling and simulation to support decision making.

Figure 4: Director of CMRE, Dr Catherine Warner, checks on staff during the COVID-19 crisis.

- **Innovation**: To support a rapid and agile response, the Chief Scientist launched the "NATO Chief Scientist Challenge", calling upon the network to develop solutions to specific issues where National defence S&T leaders saw opportunities to reinforce or complement ongoing national efforts in response to the COVID-19 pandemic. Areas of interest included: Stand-off detection (in particular, of infected people or groups); Improved Situational Awareness (of both government and the general public); Decontamination; Resilience (including working practices, logistics supply chains, info-ops); and Understanding the post-COVID-19 future (geopolitical, military, economic). A subset of project submissions was selected to be taken forward.

- **Advice**: In addition to contributing to the NATO Crisis Management Task Force (CMTF), the STO shared research from the Human Factors and Medicine (HFM) Panel on countering disinformation and misleading narratives, as well as relevant advice drawn from many years of research on Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) countermeasures. NATO's laboratory, the Centre for Maritime Research and Experimentation (CMRE), based in La Spezia, Italy, assisted the US State of Connecticut in its handling of the COVID-19 lockdown. This collaboration used CMRE's models for anomalous ship movements to forecast the spread of COVID-19. The STO network of scientists also responded in real-time to medical and scientific questions raised (for example) by Committee of the Chiefs of Military Medical Services (COMEDS) and other NATO bodies. Lessons learned from these activities have been captured and actions have been taken to ensure that the STO is better integrated and prepared to assist a future NATO crisis response.

- **Anticipating**: The System Analysis and Studies Panel (SAS) assessed the post-COVID-19 military, economic and geopolitical environment and their implications for NATO, the Alliance and Partners. Preliminary results of this study were delivered in early December.

RESILIENCE

Demonstrating resilience and agility, the STO looked for new ways and means of collaboration in order to maintain programmatic momentum. A Crisis Oversight Board (COB) was stood up via the Strategy Sub-Group of the STB to guide the STO response and associated initiatives. Following the lead of the STB, all Panels and the Group opted for virtual meetings in both the Spring and Fall, developing new processes and approaches to maintain the momentum of the CPoW. Significant events such as the launch of the S&T trends report

or the NATO OR&A conference were turned into virtual events, with feedback highlighting their effectiveness and ability to reach a broader audience.

CMRE was able to continue its vital operations in full compliance with local policies. Crucial work required a physical presence at the Centre and onboard the NRV Alliance and CRV Leonardo.

All this work was planned and executed in close consultation with medical advisors from the Host Nation and from NATO to ensure the health, safety, and well-being of all staff involved.

The process of adapting to the impact of COVID-19 was an evolutionary one: the creativity, agility and focus on our core mission and people exemplified the STO's responses to the virus.

ADVICE TO LEADERSHIP

ADVICE

The conduct of science, the development of new technologies and the generation of advice are intimately linked. In 2020, a large number of collaborative activities and reports were generated building upon the collective knowledge base of the STO network. Many of these have provided essential advice to decision makers, as well as reflecting the results of the research activities themselves. A small sample of major advisory activities of note for 2020 is included below:

1. **S&T Trends 2020 – 2040**: In April 2020, the STO published "*S&T Trends 2020 – 2040: Exploring the S&T Edge*", a major report looking at defence technology trends over the next 20 years and their impact on our collective security. The report targeted leaders and opinion-makers in the defence and security sector, as well as experts seeking insights into specific technologies. As noted by the NATO Deputy Secretary General Mircea Geoană: *"This report is a glimpse into the future of defence. It will guide research at NATO and our Allies, to ensure that we maintain our cutting-edge technology in the years ahead"*. The report draws upon S&T insights and foresight activities of the STO's network of scientists, engineers and analysts. It provides an assessment of the emerging and disruptive technologies endorsed by NATO Heads of State and Government at their meeting in London last December. These include such technology areas as big data, artificial intelligence, quantum, autonomous systems, space, biotechnologies and hypersonic weapons. The report explains why these technologies are essential to the Alliance and how they may develop over the next 20 years. In addition to the report, the Deputy Secretary General launched a handout summarizing its results. Multiple workshops and seminars were conducted to highlight the implications of the report, as well as supporting NATO's response to Ministerial taskings on emerging and disruptive technologies and the development of an EDT roadmap.

2. **Innovation**: Over the year, the Chief Scientist produced a series of well-received "food for thought" papers around the themes of innovation and technological disruption. These food for thought papers covered a wide range of topics, including outlining the current technological landscape, exploring EDT synergies, outlining NATO's S&T challenges and strengths, as well as exploring technological uncertainty and the consequences of technology decisions on the nature of the Alliance.

3. **Misinformation**: Disinformation and misinformation contributed significantly to the COVID-19 challenges faced by the Alliance and the Nations. Countering disinformation, especially from actors who were using the crisis for geopolitical advantage, became an essential aspect of NATO's COVID-19 response. The HFM Panel conducted a series of workshops around the topic and provided necessary advice to NATO HQ on mitigation strategies and the importance of developing counter-narratives.

4. **Climate Change**: Environmental change is an existential crisis for humanity. NATO has a role to play in adapting to environmental change driven operational and geopolitical challenges. Further, it must seek out new ways of conducting its operations to reflect environmental concerns and regulations. Among other activities undertaken by the STO within the CPoW, the CMRE continues to provide world-class advice on the implications for maritime operation, especially as to how these changes may impact AntiSubmarine Warfare (ASW) activities in the Arctic or near-Arctic waters.

5. **Data Policy**: NATO is exploiting the advice provided by SAS-111 ("Data Collection and Management (DC&M) For Analysis Support to Operations") in the development of a NATO Data Exploitation Policy.

6. **Nuclear Verification**: Verification regimes and the associated technologies which underlie them are essential elements of arms control efforts. The STO developed a nuclear verification primer and held a workshop to explore the current state of verification technologies and explore potential S&T areas for development under the STO. The results of this workshop have contributed to advice to NATO leadership on how NATO may be able to support such verification efforts.

7. **Post-COVID-19 Futures Assessment**: The long-term implications of COVID-19 are of significant concern to NATO and the Alliance nations. SAS launched SAS-169 to develop a framework for and report on the future impacts of COVID-19 on NATO.

8. **CBR Multi-National Experiment**: In January, HFM-273 conducted a Multi-national Exercise (MNE) on Chemical, Biological and Radiological (CBR) Defence. The MNE was the culmination of a Long-Term Scientific Study (LTSS) on CBR defensive measures. During the MNE, the LTSS results were presented, discussed and validated through peer review by CBR defence experts, as well as decision and policy makers. CBR vignettes were used to showcase the impact of the LTSS on NATO's CBR defensive capabilities. The advice provided identified existing and emerging CBR threats and supported an understanding of how advances in S&T may be used to strengthen CBR defence, as well as informing decision makers, capability developers and scientists.

FIFTH GENERATION (5G) MOBILE TELECOMMUNICATIONS AND BEYOND

Fifth Generation (5G) mobile telecommunications systems will be made available at large scale in the years to come. It is the next technology standard for wireless (telephone) communications which started in the late 1970s and early 1980s as 1G. Even the Sixth Generation (6G) is already emerging in specific applications in space this year.

The NATO Science and Technology Organization (STO) has addressed mobile telecommunications and related applications of the electromagnetic spectrum from many different perspectives, including Distributed Electronic Warfare Operations in the Modern Congested Radiofrequency Environment; High-Throughput Satellite Communications; Military Secure Wireless (Long-Range) Communications; Software Defined Architectures for Federated Mission Networks; Military Applications of Internet of Things; and Efficient Group and Information-Centric Communications in Mobile Military Heterogeneous Networks.

In 2020, the STO looked into "5G and Beyond Technologies" and the progress in confluent technologies, including Artificial Intelligence and Edge (Internet of Things Enabled) Computing leading to notions on Enhanced Mobile Communications, Massive Machine-Type Communications, and Ultra-Reliable Low-Latency Communications. Envisaged potential military applications include Smart (additive) manufacturing; Next-generation drones and communications/imagery satellites; Robotic surgery; Smart C2 centres/posts; Augmented reality/virtual reality remote presence; Robotics enabled logistics; Collaborative (distributed) wargaming; Smart headquarters; Cyber; Precision navigation and timing; and Autonomous military vehicles.

YOUNG SCIENTISTS

THE FUTURE OF DEFENCE SCIENCE AND TECHNOLOGY FOR THE ALLIANCE

The STO remains committed to encouraging the next generation of defence S&T scientists, technicians, and engineers. As NATO looks towards its future through the reflective exercise of NATO 2030, it is vital for the STO to nurture the young scientists already in its international network as well as encourage young scientists who may be contemplating a career in defence S&T. By cultivating this demographic, the STO aims to engage the next generation of defence S&T specialists whose research will ensure the NATO Alliance remains ready to face tomorrow's challenges.

NURTURING YOUNG SCIENTISTS IN THE STO NETWORK

The STO network of defence scientists who work on the annual "Collaborative Programme of Work" (CPoW) is composed of 13% of young scientists (those aged under 35 years old). In 2020, efforts continued to encourage and nurture this demographic.

The Early Career Scientist Event offers young scientists nominated by representatives of the NATO Nations the opportunity to showcase their work while providing a venue for networking with the S&T community and their peers from across the Alliance. It is usually held during the week of the Fall Science and Technology Board (STB) meeting and includes a three-minute oral presentation and a display poster networking session. Although the physical 2020 Early Career Scientist Event was postponed, the STO launched a thread of video-posts in Fall 2020 on STO social media accounts from the Early Career Scientists to allow them to share their research with the STO network and show how they contribute to maintaining NATO's scientific and technological edge.

Each year the STO Panels and Group individually recognize the exceptional contributions of their young scientists to the technical activities under

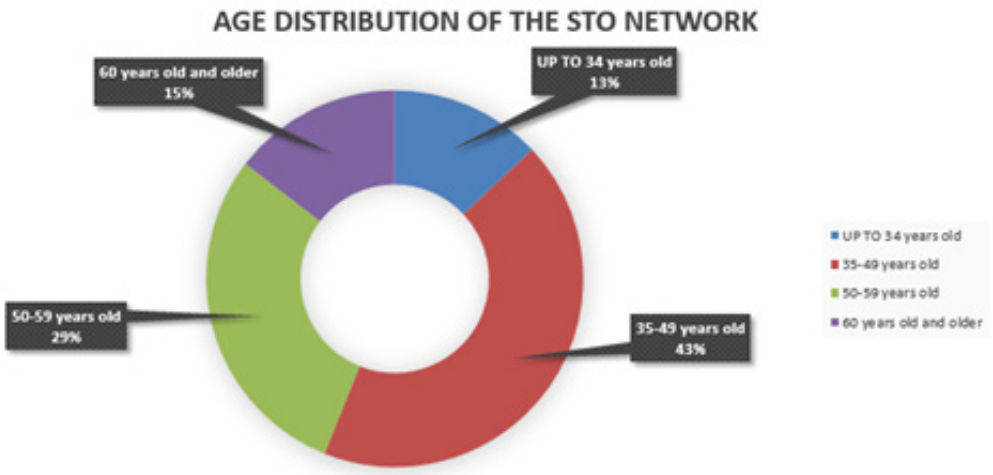

Figure 5: Age distribution of the STO Network in 2020.

Figure 6: Excerpts from the Early Career Scientist Event videos.

Figure 7: Panels and Group Young Scientist Awards 2020.

the STO CPoW through the Young Scientist Awards. This programme is designed to encourage participation and networking for promising and talented young researchers in the STO community. In 2020, there were seven recipients of the award: João Caetano and Gino Rubino (Applied Vehicle Technology Panel); Alexander Charlish and Jason Zeibel (Sensors and Electronics Technology Panel); Matthew Cook (Systems Concepts and Integration Panel); Helen Pettitt (Systems Analysis and Studies); and Manas Pradhan (Information Systems Technology Panel). The award winners' areas of research include the military applications of the Internet of Things; intelligence exploitation of social media; future multi-sensor threat defeat concepts; cognitive radar; hyperspectral and polarization sensing; and the physical analysis of the flow-field in the core of the vortices and computational fluid dynamics.

ENGAGING YOUNG SCIENTISTS

NATO's in-house research laboratory the Centre for Maritime Research and Experimentation (CMRE) in La Spezia, Italy, has a vibrant outreach effort to encourage young people to get involved with Science, Technology, Engineering and Mathematics (STEM) today so that they will become the scientists, engineers and technicians of tomorrow. The Centre's research department has nearly 30 percent of scientists under the age of 35 (60 percent under the age of 40), who along with their counterparts in the engineering department, are excellent mentors for the students and interns who participate in research projects.

YOUNG SCIENTIST INTERNSHIP PROGRAMME

In 2020, CMRE launched the Young Scientist Internship Programme in order to create a more diverse workforce of young scientists and to expand the reputation of CMRE in NATO Nations, universities and research institutions. This programme will provide aspiring scientists and engineers with the opportunity to gain hands-on experience through working with CMRE researchers.

150 applications were received in the summer of 2020. CMRE is currently assessing the applicants and the first interns are expected to begin work at the Centre in September 2021. The young scientists will be researching physical oceanography and environmental acoustics; engineering; applied mathematics; and computer science. They will undertake all aspects of scientific investigation from the formulation of hypotheses to the experiment design, data collection and analysis.

GIONA PROJECT

The GIONA Project, involving several research institutions in the area of La Spezia, Italy, promotes awareness, understanding, and the safeguarding of the marine environment among local high school students. In 2020, a group of 13 students from two local technical high schools continued their work on the "Bio-Acoustic Research to Learn About the Marine Environment" (BARLAMARE) experiment, which began in 2019. Under the guidance of CMRE scientists, the students attended talks by subject matter experts. They visited the CMRE workshop to see the scientific instrumentation that is used during sea trials.

The BARLAMARE experiment was to culminate in the deployment of three moorings in the nearby Parco delle Cinque Terre, a national protected marine area. However, the COVID-19 lockdown forced an interruption of all external school activities, and therefore, the final phase of the experiment was cancelled. Nevertheless, with

Figure 8: CMRE Director Dr Catherine Warner, Italian Naval officers and CMRE staff work with local high school students onboard the CRV Leonardo for the 2019 GIONA Project's at-sea activity.

Figure 9: Students prepare to launch an autonomous underwater vehicle at the 2019 European Robotics League Tournament hosted by the Centre for Maritime Research and Experimentation, in La Spezia, Italy.

school activities restarting in May, the project resumed with an online lecture and discussion by Dr Gabriele Ferri for 18 local informatics and robotics students who are constructing their underwater robot prototype for the next European Robotics League competition to be held at STO-CMRE in 2021.

EUROPEAN ROBOTICS LEAGUE COMPETITION

The European Robotics League (ERL) Emergency is a friendly annual robotics competition held at the Centre that attracts student robotics teams from around the world. The team's robots compete outdoors and underwater to carry out tasks in realistic emergency response scenarios, promoting collaboration and the 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 do not have to.

Due to COVID-19 safety precautions, the 2020 ERL physical event was cancelled. However, ERL has joined efforts with the "Metrological Evaluation and Testing of Robots in International Competitions" (METRICS) EU project. Under this new structure, CMRE is organizing its first virtual challenges to be held alongside physical meetings in 2021 and 2022.

MSTC EARLY CAREER AWARD

In 2019, the Maritime Science and Technology Experts Committee (MSTC) launched the Early Career Award to recognize the outstanding achievements of early career researchers working with CMRE in delivering high quality S&T to the Alliance.

Each year, four finalists present their work at the MSTC Fall meeting and member nations select the award winners. The selection criteria include experience in the field of S&T, innovation, the relevance of the work to NATO, and the quality of oral presentation. The 2020 Early Career Award was presented to Dr Jeffrey Bates for his work on CMRE's "Littoral Continuous Active Sonar Multi National Joint Research Project", which investigated the performance of continuous active sonar for anti-submarine warfare in littoral environments, using conventional pulsed active sonar as a benchmark.

NATO STO PROGRAMME OF WORK

NATO STO Programme of Work

INNOVATION FOR THE ALLIANCE

ACOUSTICS SENSORS DETECT AND LOCATE WEAPON SIGNATURES IN REFLECTIVE ENVIRONMENTS (SET-233 RTG)

Research showed that acoustic sensors, algorithms and distributed processing overcome signature and timing distortions caused by the influences of reflective structures in complex propagation channels. Multiple field experiments characterized open and reflective channels and created a signature database to accelerate algorithm development.

Mr. Michael V. SCANLON, USA, and Dr. William C. K. ALBERTS, USA, Combat Capabilities Development Command, Army Research Laboratory.

BACKGROUND AND MILITARY RELEVANCE

There is a need for robust acoustic threat awareness and reporting throughout the battlefield. Acoustic systems have been fielded to detect transients from gunshots, mortars, rockets artillery, and broadband vehicles. Acoustic systems perform better in open areas than in urban ones. Given increasing operations in urban areas, the need exists to improve acoustic system performance.

SET-233 improved the understanding of propagation channel effects and performance in diverse environments, and its findings are applicable to soldier-worn, unattended ground sensors, and vehicle systems.

OBJECTIVES

The main objectives of SET-233 were to improve the foundational understanding of factors that influence the acoustic detection and localization accuracy for impulsive weapon signatures and to develop sensors and algorithms including characterizing their performance in realistic environments and capturing their signatures for future R&D.

S&T ACHIEVEMENTS

SET-233 showed: 1) Improved acoustic accuracy by overcoming signature and timing distortions; 2) A 3D in situ array derived the channel's Green's function for improved bearings; 3) Distributed arrays mitigated multipath; 4) Six wearable Android smartphone nodes produced accurate solutions; 5) Proved localization accuracy depends more on array geometry and range than on gun calibre; and 6) Showed acoustic particle velocity sensors reduce the size of traditional arrays. Members produced more than 70 publications and journal articles relating to research, experiments, and algorithms.

SYNERGIES AND COMPLEMENTARITIES

Three joint field experiments in France and the United States leveraged participants' sensor hardware and shared all data collected during the joint field trial. Participants took advantage of the host's planning, logistical support and execution of complex field trials. Value was greatly increased by numbers, diversity, and maximum coverage with increased sensor density for highest interest areas.

EXPLOITATION AND IMPACT

Three-dimensional localization of snipers was demonstrated in reflective environments, and applied to soldier-worn, unattended ground systems and vehicle-based sensing. Acoustics can cue collocated sensors, and distributed systems can monitor the larger battlespace. Research facilitated a DEA A 2015-AT-0661 "Advanced Aero-Acoustic Surveillance Systems," Cooperative Agreement W911NF-15-2-5225 "Atmosphere-induced fluctuations of propagating impulses" and SET-286 RTG "Acoustic and Seismic Sensing of Threats in Urban Environments."

CONCLUSIONS

Acoustic sensor systems provided continuous, omnidirectional, and non-line-of-sight threat detection and localization capabilities. Research improved understanding, mitigated propagation channel effects and characterized system performance in open and urban environments.

Figure 10: Acoustic sensing of threats can augment heterogeneous sensing and fusion for multi-domain operations dominance.

Figure 11: Bullet's trajectory through sensor field with upright reflective structures simulating complex urban propagation and collapsed for freefield propagation.

ALLIED FUTURE SURVEILLANCE AND CONTROL (AFSC) HIGH LEVEL TECHNICAL CONCEPTS (HLTCs) TECHNOLOGY READINESS LEVEL (TRL) ASSESSMENTS (SCI-339)

The Alliance Future Surveillance and Control (AFSC) initiative was established to provide NATO with the capability to effectively monitor the skies over Allied territory when its current fleet of Airborne Warning and Control System (AWACS) aircraft are retired in 2035. In March 2020, six Allied companies' consortia delivered concept studies, providing initial views on how NATO could meet the AFSC Project Ofice system of system requirements by 2035.[1] SCI-339 was conducted to assess the current and future technical maturity of the critical technical elements and assess concept technical risk.

Colonel Daniel Gallton, USA, NATO STO and Lt Col (GS) Manfred Hoffmann-Singer, DEU, Bundeswehr Office for Defence Planning.

BACKGROUND AND MILITARY RELEVANCE

In 2014, the North Atlantic Council (NAC) tasked the Conference of the National Armament Directors (CNAD) to reflect on the delivery of the follow-on to the E-3 Airborne Early Warning and Control System (AWACS) in view of its retirement in 2035. The AFSC project was then launched to perform this evaluation.

The successor of the AWACS is not envisioned to be a single flying platform with a stand-alone on board system, but more likely a Command and Control system of systems with large cross domain capabilities, connected to other system architectures.

By assessing the TRLs of the technologies that industry included in the HLTCs, the SCI-339 STO Specialist Team contributed to the down-selection of the most relevant HLTCs and associated technologies, reducing programme technical risk and paving the way to the delivery of the future AFSC Capability.

OBJECTIVES

SCI-339 aimed to provide the AFSC Project Office and the Steering Committee (SPC) with valuable and documented TRLs assessments on the technologies contained in the proposed HLTCs.

S&T ACHIEVEMENTS

SCI-339 delivered a TRL assessment technical report to inform Phase 3 of the AFSC project. The Technical Readiness Assessment generated by the activity assessed current and future technical programmatic risk of the high level technical concepts and identified areas of future assessment for each proposal.

SYNERGIES AND COMPLEMENTARITIES

The AFSC project was managed by a Project Office, hosted by the NATO Support and Procurement Agency (NSPA) and steered by the SPC, a body which reports to the CNAD. In addition, ACT, ACO, the NCIA and the STO contributed to the project.

EXPLOITATION AND IMPACT

The SCI-339 TRL assessment was part of the overall assessment of the different HLTCs and contributed to the down-selection process to converge towards the preferred Technical Concept. In order to take account of future threats and emerging technologies, NATO is working with experts from academia, industry and the military fields to encourage innovative solutions.

CONCLUSIONS

The SCI-339 team performed a first of a kind technical evaluation and as a result well positioned the AFSC initiative to reduce the technology risk to the next phase of the project.

Figure 12: The NATO E-3A AWACS aircraft fleet one of the few military assets that is actually owned and operated by NATO.

[1] https://www.nato.int/nato_static_fl2014/assets/pdf/2020/7/pdf/200701-Factsheet_Alliance_Future_Surveil-1.pdf.

ASSESSMENT OF ANTI-ICING AND DE-ICING TECHNOLOGIES FOR AIR AND SEA VEHICLES (AVT-299)

AVT-299 conducted a critical assessment of existing and emerging ice protection technologies that are required to protect military air and sea vehicles against the threat of icing. By providing the state-of-the-art of ice protection systems, NATO Nations could improve the mitigation of icing risks for their military aircraft and ships for safe and efficient operations in cold and humid environments.

Dr. Ali Benmeddour, CAN, National Research Council Canada (NRC) and Dr. Ki-Han Kim, USA , Office of Naval Research (ONR).

BACKGROUND AND MILITARY RELEVANCE

Mitigating icing risks for air and sea vehicles is critical for their safe and efficient operations in icing environments. Passive and active ice protection solutions have been developed to reduce the risk of icing. Electro-thermal systems using nanomaterials and super-hydrophobic and icephobic surfaces hold a promising potential for application to military air and sea vehicles. However, accurate evaluation of these emerging anti-icing and de-icing technologies, along with the existing ice protection technologies, is required to establish their performance and suitability for aircraft and ships.

Critical assessment of Ice Protection Systems (IPS) will help identify the most effective technologies to protect military air and sea vehicles of NATO Nations when operating in icing environments.

OBJECTIVES

The main goals of the AVT-299 activity were: a) Establish the state-of-the-art of passive and active ice protection systems for application to military air and sea vehicles through critical evaluation of existing and emerging technologies; b) Identify technology gaps in the field of IPS; and c) Identify and establish the state-of-the-art of the tools that are required for effective evaluation of IPS.

S&T ACHIEVEMENTS

AVT-299 reviewed, evaluated and established the state-of-the-art of existing and emerging ice protection technologies based on publicly available scientific data. It also identified technology gaps in the field of IPS to guide future developments of novel and effective ice protection systems and initiated a Cooperative Demonstration of Technology (CDT) (AVT-332) for in-flight demonstration of ice detection sensor and icephobic coating technologies

SYNERGIES AND COMPLEMENTARITIES

Ten nations participated in this research task group. This diverse group contributed to the success of the activity and the high quality of the work.

> *Mitigating icing risks for air and sea vehicles is critical for their safe and efficient operations in icing environments.*

EXPLOITATION AND IMPACT

The outcomes of the AVT-299 will help improve existing ice protection systems and develop novel and effective ones. This will maximize the utilization of NATO current and future fleets of military aircraft and ships and make the fleets remain at first degree of readiness in all weather conditions.

CONCLUSIONS

Military aircraft and ships operating in cold and humid environments are exposed to the dangerous hazard of icing. To operate in these environments, the vehicles need to be equipped with an effective IPS. The AVT-299 final report will provide recommendations to help identify adequate experimental and computational simulation methods for accurate evaluation of ice protection systems and better protect NATO air and sea vehicles operating in icing weather.

Figure 13: Ice-build up on the nacelle inlet lip of the Convair 580 research aircraft of the National Research Council (NRC) Canada. (Courtesy of the NRC Canada, Flight Research Laboratory.)

AUTONOMOUS NAVAL MINE COUNTERMEASURES (ANMCM) (CMRE)

The CMRE ANMCM programme strengthens NATO's ability to counter naval mines through networks of securely communicating autonomous systems. ANMCM is helping warfighters get a clearer picture of what lies on the seabed, thanks to a fleet of heterogeneous unmanned vehicles that can communicate and cooperate with each other, validated through NATO exercises.

Dr. Samantha Dugelay, GBR, NATO STO Centre for Maritime Research and Experimentation (CMRE).

BACKGROUND

The ANMCM programme of work focuses on delivering methods, algorithms and data that will enable CMRE and Allied Navies to test a network of securely communicating autonomous vehicles under realistic operational conditions for the localization, detection, identification and neutralization of underwater mines.

OBJECTIVES

Objectives this year included: extracting actionable information from vehicle sensor data by developing advanced signal processing methods such as deep learning algorithms for automatic target recognition; automating seabed characterization; low frequency "x-ray" type vision to see internal acoustic resonances and buried targets; Bayesian inference for vehicle self-awareness on mission progression and the elaboration of autonomy; and collaborative autonomy to optimize mission performance.

S&T ACHIEVEMENTS

In 2020, work began on task allocation for multi-vehicle autonomy that focused on defining a strategy for simultaneous survey and reacquisition. A new cost function for defining task priority was developed, taking into account the probability of a contact being a mine, contact locations vis à vis transit costs and preferential zones of the survey area.

CMRE's MCM scientists continued to improve vehicle self-awareness through on-board evaluation of minehunting performance. CMRE is developing novel techniques, based on machine learning to estimate sonar performance from actual sensor information, such as quality of data and complexity of an area. This "through the sensor" approach allows for continually updating assessments, taking into account sonar system measurements. Further input to the performance assessment may be made by estimating the real-world conditions directly, such as the complexity or type of seabed. Machine learning techniques are further employed to derive this information from the sonar images themselves – adding granularity to the assessment of sonar performance.

EXPLOITATION AND IMPACT

The CMRE MCM Team participated in NATO Exercise DYNAMIC MARINER 2020 on-board NRV ALLIANCE off the coast of Toulon, France. Several research and testing activities were successfully conducted with a focus on new methods and technologies, related to the employment of a squad of different minehunting autonomous vehicles, such as on-board seabed characterization and Planning and Evaluation products, adaptive survey, and on-board Automatic Target Recognition.

CMRE also hosted on-board NRV ALLIANCE a US Navy MCM team from the 6th Fleet detachment in Rota Spain, with their three MK18 Mod II vehicles. The CMRE and US vehicles have been deployed together to demonstrate collaborative autonomous behaviours.

Daily reporting to NATO's Maritime Command (MARCOM) was effectively carried out, together with a comparison between legacy MCM systems and new autonomous concepts.

SYNERGIES AND COMPLEMENTARITIES

The ANMCM programme multi-disciplinary approach is founded on basic principles of physics, underwater acoustics and mathematics. ANMCM research is tested in simulation and on historical data, and demonstrated and validated live during national and NATO exercises.

CONCLUSIONS

CMRE has steadily advanced the technology of Unmanned Underwater Vehicles (UUVs) for warfighting missions like MCM and ASW. Now CMRE is helping warfighters get a clearer picture of what lies in the murky depths below, thanks to a fleet of unmanned vehicles with advanced sensors that can communicate and cooperate with each other.

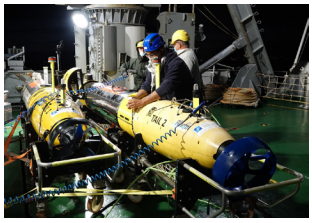

Figure 14: CMRE engineers work on the Minehunting UUV for Shallow Water Covert Littoral Expeditions (MUSCLE) on-board NRV ALLIANCE during NATO Exercise DYNAMIC MARINER 2020.

AUTONOMY FOR ANTI-SUBMARINE WARFARE (ASW) (CMRE)

The CMRE ASW programme is improving the Alliance's ability to counter submarine threats through networks of securely communicating autonomous systems. 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 long endurance unmanned system networks.

Dr. Kevin Lepage, USA, NATO STO Centre for Maritime Research and Experimentation (CMRE).

BACKGROUND

As a core, 60-year activity at NATO's world-class maritime science and technology institution, CMRE's ASW programme is in a unique position to undertake scientific research and experimentation to validate and de-risk advanced concepts for operational solutions that support NATO Nations in controlling the seas and countering submarine threats.

OBJECTIVES

The Autonomy for Anti-Submarine Warfare programme pursues the development, testing and validation of advanced concepts for unmanned ASW. The two main projects of the programme are Maritime Unmanned Systems (MUS) for ASW and ASW Decision Support.

S&T ACHIEVEMENTS

In the MUS for ASW project, scientists have been working to test a number of novel sensor and algorithmic advances for the detection of submarines. For active ASW, work in 2020 has centred on the development of multi-static active concepts built around 21" Unmanned Underwater Vehicles (UUVs) with towed arrays. Work has included: the testing of high-gain arrays deployed from UUVs; the implementation of cognitive sonar concepts; and the development of automatic target classification and data fusion algorithms. In the passive ASW domain, the emphasis has been on the development and testing of Acoustic Vector Sensors for the deployment of low-power, long endurance platforms such as buoyancy gliders and wave gliders as well as bottom nodes. At the collaborative autonomy level, CMRE researchers have developed a depth-adaptive behaviour optimizing communications throughput. Finally, an Exploring Future Science and Technology project on quantum magnetometry was launched in 2020. Novel quantum effect magnetometers have been evaluated for their suitability to add a magnetic anomaly detection capability to MUS for ASW.

EXPLOITATION AND IMPACT

The technologies and concepts developed within the MUS for ASW programme have been tested at sea, in representative ASW environments, often against actual submarine targets. The ASW Decision Support project includes significant elements in doctrine development, operations research for unmanned ASW, advanced ASW Decision Support, and operations analysis of data collected in sea trials and ASW exercises. This work explores the real-world performance of future unmanned ASW deployments and allows for a more complete cost benefit analysis of deployments consisting of a heterogeneous mix of platforms as may be available during future ASW missions.

SYNERGIES AND COMPLEMENTARITIES

The seagoing element of the programme includes participation in multi-national projects for the development and testing of advanced ASW concepts in a collaborative environment as well as participation in NATO ASW exercises and ad hoc Passaging Exercise (PASSEX) opportunities. In 2020, the multi-static UUVs were used alongside manned systems for hunting submarines during the NATO DYNAMIC MANTA ASW exercise in Sicily. Also, during the exercise, the ASW team performed the first Technical Demonstration of the passive detection capabilities of unmanned underwater gliders. Seperately, the programme provided support to operators on how to effectively employ their sensors through a sonar performance prediction tool fed by environmental data from CMRE ocean gliders.

In March 2020, an entirely multi-nationally funded experiment for the Littoral Continuous Active Sonar (LCAS) partners was conducted in the Bay of Taranto in southern Italy. This was the fourth LCAS experiment conducted since 2015 and only the second with a submarine target. Although partners were unable to join LCAS20 due to the imposition of COVID-19 related travel restrictions, the experiment was conducted according to the partners plans and specification via remote planning augmented by daily teleconferences. Operations were conducted on a 24 hr basis for four days, yielding an extremely rich data set for a variety of standard and National high duty cycle waveforms, measured over a great diversity of target aspects and geometries. Both the NRV Alliance and the submarine were able to closely follow the extremely involved run plan, with the result that all experimental objectives were met to the partner's satisfaction.

The final sea going activity was the Distributed Autonomous Networked Systems (DANS) sea trial conducted in local waters near La Spezia. The DANS trials are designed for CMRE to test low-power, long endurance platforms for passive ASW. In the 2020 edition, a new eight-element Acoustic Vector Sensor (AVS) array for the wave gliders was tested, along with improvements to AVSs installed on underwater buoyancy gliders.

CONCLUSIONS

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 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.

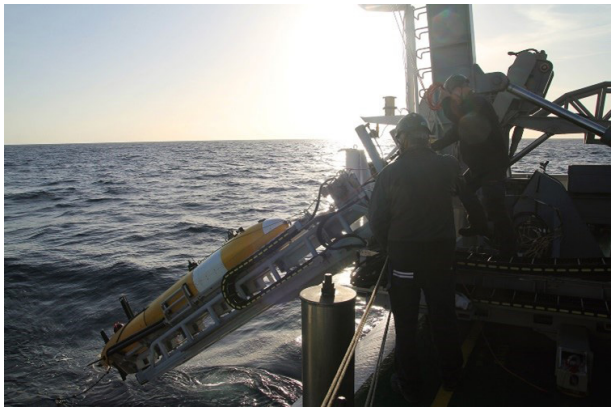

Figure 15: ASW Ocean Explorer OEX-C Unmanned Underwater Vehicle, called Harpo, is deployed from the NATO Research Vessel (NRV) ALLIANCE during the NATO Exercise DYNAMIC MANTA 2020, off the coast of Sicily.

CAPABILITY CONCEPT DEMONSTRATOR FOR INTEROPERABILITY WITHIN UNMANNED GROUND SYSTEMS AND C2 (IST-149)

Unmanned Ground Vehicles (UGVs) are becoming increasingly relevant in the modern battlespace. The goal of the RTG was to test the standards JAUS/IOP and ROS for controlling several heterogeneous UGVs from different Operator Control Units (OCUs) in a real-world multi-national scenario. The trials on a Norwegian proving ground showed that it is possible to extend the systems quite easily and achieve compliance with parts of the standard in a relatively short time.

Dr. Frank .E. Schneider, DEU, Fraunhofer Institute and Dr. Kim Mathiassen, NOR, Norwegian Defence Research Establishment (FFI).

BACKGROUND AND MILITARY RELEVANCE

Multi-national operations often reveal that seamless interoperability does not work in practice. Most systems use proprietary or national information systems or information exchange protocols. This group has been investigating how to close this gap for NATO by using existing standards for information sharing.

To be effective, unmanned systems in general need to be capable of interoperability, coordination, and collaboration with other manned and unmanned systems with Joint, Interagency, Intergovernmental, and Multi-National (JIIM) forces. Interoperability standards will enable this and will serve to reduce procurement, logistics, and training costs across the NATO UGV community.

> *The standards identified can lead to interoperability of unmanned systems and sub-systems that will accelerate NATO countries development of UGVs.*

OBJECTIVES

The main objective of the group was to plan and implement a Capability Concept Demonstrator (CCD) that would test interoperability standards for UGVs and C2 system. An additional goal was to identify additional related groups and other potential collaborators such as to achieve a synergy in the area of UGS and C2.

S&T ACHIEVEMENTS

The RTG has implemented and tested a subset of STANAG 4818 in the field. The group assessed how much effort it takes to implement the standard on existing platforms and to identify possible shortcomings of the standard. A comprehensive field experiment was successfully conducted in Rena, Norway in 2018. Seven organizations participated with four robotic systems, and three different Operator's Control Units. The group wrote a NATO STO report about the experiment and has also submitted a scientific journal paper in collaboration with NATO LCG LE UGV Team of Experts (ToE) about the experiment.

SYNERGIES AND COMPLEMENTARITIES

The group has worked closely with the NATO LCG LE UGV ToE, in preparations, conducting the experiment, as well as developing and enhancing the STANAG 4818. The group promoted the usage of the standards to a wider community through the robotic competitions ELROB and EnRicH. ELROB was in collaboration with the military community, while EnRicH was a CIMIC collaboration with the ERNCIP thematic group. There were also some interactions with the EU project ICARUS.

EXPLOITATION AND IMPACT

The standards identified can lead to interoperability of unmanned systems and sub-systems that will accelerate NATO countries development of UGVs. Matured and evaluated sub-systems can be used to create more complex and autonomous UGVs. The robotics community provides an open source Robot Operating System (ROS), and it is important that the military also leverage this. The groups have developed software components that bridge ROS with the standard, making it easier to access and use the functionalities provided by ROS.

CONCLUSIONS

The necessary standards were identified and are in cooperation with the UGV ToE under constant improvement (e.g., STANAG 4818). A successful CCD was held on a Norwegian proving ground where several real UGVs as well as OCUs were in operation. In addition, the group had many synergetic and complementary activities. It has proven that with the appropriate set of standards interoperability can be achieved even in a multi-heterogeneous environment.

Figure 16: The robots used in the field trial in Norway.

CORRELATED DYNAMIC ENVIRONMENTS IN DISTRIBUTED SIMULATION (MSG-156)

To better prepare coalition forces for the challenges of operational environments, distributed simulation systems need to represent the environment and, in particular, its dynamic changes more realistically. MSG-156 demonstrated a solution concept that supports correlated synthetic dynamic environments distributed across heterogenous simulation systems.

Mr. Arno Gerretsen, NLD, Netherlands Aerospace Centre (NLR), Dr. Ing. Ruben Smelik, NLD, Netherlands Organisation for Applied Scientific Research (TNO) and Mr. Neil Smith GBR, Defence Science and Technology Laboratory (Dstl).

BACKGROUND AND MILITARY RELEVANCE

Have you ever been surprised by a sudden heavy rain shower? Most likely you have. The dynamic nature of operational environments is an important factor that can influence mission outcomes. Examples of this are reduced trafficability due to bad weather or structural damage to buildings and infrastructure due to force engagement affecting the operational plan. Therefore, it is important that these dynamic environmental effects are represented consistently in the simulation systems we use to prepare our missions.

OBJECTIVES

The goals of MSG-156 were: 1) Research the technologies, methodologies, and best practices needed to be able to represent a dynamic synthetic environment in NATO's future distributed simulations; and 2) To evaluate these through concept demonstration.

S&T ACHIEVEMENTS

A solution architecture based on Modelling and Simulation as a Service (MSaaS) technologies was developed to make a consistent dynamic synthetic environment possible. This architecture was evaluated in a demonstration that included simulation systems and services from various nations. A terrain server, weather service and various query and modification services were combined with simulation systems to simulate a convoy protection scenario in a dynamic and challenging environment. This demonstration proved that it is possible to provide terrain and weather data from a common repository and that modification services can be used to enable dynamic changes to the environment.

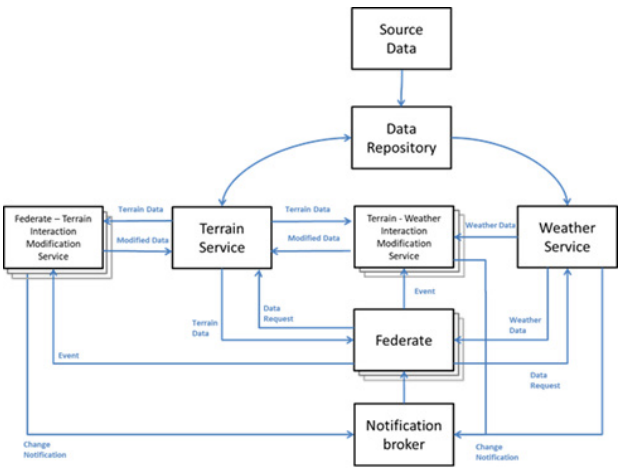

Figure 17: Solution architecture for correlated dynamic synthetic environments.

SYNERGIES AND COMPLEMENTARITIES

MSG-156 collaborated with MSG-164 relevant to MSaaS technologies, while the Federation Object Model (FOM) used to distribute weather information in the simulation was defined together with MSG-163. Various member nations also brought results of related national projects to the task group. COVID-19 restrictions threatened to hinder the concept demonstration, but the task group successfully finalized the work remotely.

> *Coalition troops must be able to train anytime and anywhere in an ever-changing complex environment.*

EXPLOITATION AND IMPACT

The lessons learned from the demonstration will inform refinements to the architecture and recommendations for standards based interfaces as a blueprint for future simulation systems used by NATO and partner nations. This will allow NATO to improve the realism of distributed simulations for concept evaluation, training and mission preparation, as the dynamic and challenging nature of the environment can be represented more realistically and consistently.

CONCLUSIONS

The results of MSG-156 show it is possible to create a more realistic representation of operational environments in future distributed simulation systems. This will allow coalition troops to better prepare for future missions in ever-changing and complex environments.

Figure 18: Craters made by a terrain modification service shown in a vehicle simulator.

EMERGING BIOTECHNOLOGY AND HUMAN ENHANCEMENT TECHNOLOGIES FOR THE FUTURE FORCE (HFM-335)

Following endorsement of the Emerging and Disruptive Technologies (EDT) roadmap, a Research Specialist Team (RST) – comprised of experts from HFM, COMEDS, and ACT (Innovation Branch), amongst others – was set up to perform a horizon scan of the most promising biotechnologies and capabilities for human augmentation and enhancement. To date, the RST have developed and agreed on the definition of the terminology used and have set in place a framework through which to discuss the most promising S&T.

Dr. Rajesh Naik, USA, US Air Force Research Laboratory.

BACKGROUND AND MILITARY RELEVANCE

The global growth and proliferation of biotechnology and human enhancement technologies has resulted in more rapid, innovative, and disruptive applications than we can currently recognize or envision. These technological advancements have both innovative and threat implications for the military. In line with NATO capability areas, the following sub-areas have been agreed on: Warfighter Performance, Military Medicine, Force Protection, Warfighter Systems, and Security and Compliance.

OBJECTIVES

The RST team will identify technologies that are relevant to the military community and will undertake the following objectives:

- Identify the most promising S&T efforts in the context of the identified sub-areas and their military relevance through a horizon scan.
- Produce a short, high level overview of the key applications of biotechnologies and human enhancement / augmentation.
- Identify future research areas and activities for STO Panels.

> *In line with NATO capability areas, the following sub-areas are main pillars for the Human Enhancement Technologies and Emerging Biotechnology: Warfighter Performance, Military Medicine, Force Protection, Warfighter Systems, and Security and Compliance.*

S&T ACHIEVEMENTS

The team has developed working definitions for biotechnology and human enhancement / augmentation. Biotechnology is a broad discipline in which biological processes, cells, or cellular components are exploited to develop products and new technologies. Human enhancement is the process of impacting physical, cognitive, physiological, sensory, or social functions beyond normal performance. In addition, emphasis on compliance and security is going to be a critical area for developing policies as well as guidance for the use and implementation of biotechnology and human enhancement technologies to enable future interoperability across NATO and its members.

Figure 19: Key areas/pillars of military importance as identified by HFM-335 RST.

SYNERGIES AND COMPLEMENTARITIES

The HFM-335 technical team is collaborating with ACT as they are planning to conduct a horizon scan but at a higher level of classification. NATO Economics and Security Committee (ESC) will be running a virtual workshop in biotechnologies late 2020, and an expert from the ST is expected to join this initiative. Members from RST are participating in other STO Panels related to the biotechnology and human enhancement technical areas.

EXPLOITATION AND IMPACT

In additional to identifying topics that are worthy of further investigation within the HFM Panel, the output from the RST will inform and provide direction to other STO Panels, and other NATO bodies (e.g., ACT, COMEDS, MilMeD COE) as well as the political decision makers within the NATO HQ.

EXPLOITATION METHODOLOGIES FOR LONGWAVE INFRARED AIRBORNE HYPERSPECTRAL DATA (SET-240)

Airborne hyperspectral sensing technology enables the detection, identification and location of targets with a high degree of confidence. SET-240 research focused on identifying the factors influencing target detection in the reflective and longwave infrared.

Dr. Alexandre Jouan, CAN, Defence Research and Development Canada (DRDC).

BACKGROUND AND MILITARY RELEVANCE

NATO Nations have been active in developing the hyperspectral technology over the last twenty years. This technology has demonstrated superior capabilities at detecting, locating, and identifying targets. More research needs to be conducted in the longwave infrared to provide a full spectrum night and day electro-optical ISR capability.

OBJECTIVES

SET-240 aimed to determine the conditions (collection geometry, sensor characteristics, flight altitude) and maximize the performance of detection and identification for various targets (materials, chemical spills, buried IEDs) under challenging conditions (day-time and night-time collections, effect of neighbouring infrastructures, weathering).

S&T ACHIEVEMENTS

SET-240 main findings are:

- Material identification is sensitive to the geometry of data collection and atmospheric compensation. How much of this information can be encoded into a detection algorithm remains to be explored.
- Hyperspectral polarization seems to improve the detection performance of surface contaminants under specific conditions.
- UXO can be best detected if data collection is performed after sunset.
- Studies of indirect illumination and adjacency effects have demonstrated that neighbouring structures significantly influence target signatures and affect the performance of hyperspectral target detection algorithms.
- Vehicle rediscovery using airborne hyperspectral data showed superior results in the reflective part of the spectrum.
- Identifying materials involved in mixed signatures continues to be challenging.
- Deep learning strategies (Auto-Encoders, Generative Adversarial Networks) have been applied successfully for atmospheric compensation and anomaly detection in terrain textures.

SYNERGIES AND COMPLEMENTARITIES

SET-240 research complements studies made by other NATO groups (SET-190, SET-232, SCI-286, SCI-287, SCI-295, and SET-277) and was monitored by the NATO ACT/JCBRN Def COE.

EXPLOITATION AND IMPACT

SET-240 results are contributing to the maturation of the hyperspectral technology as an advanced day-time and night-time electro-optical ISR capability for CBRNE and C-IED units in Defence and Homeland Security.

CONCLUSIONS

International cooperation has been key in the success of this research. No individual country would have been able to mobilize such a broad range of skills, expertise and resources to reach the level of knowledge we garnered collectively. Significant progress has been made in identifying the many factors influencing reflective and thermal hyperspectral target detection in specific contexts. The question of how far we should go in modelling the variability of signatures is still the subject of active research and new approaches have been recently introduced (such as deep learning) which can make a significant contribution in addressing this issue.

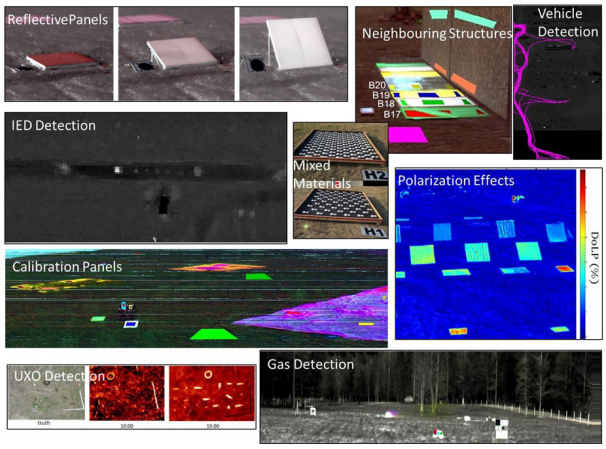

Figure 20: Some results obtained from the exploitation of the SET-240 dataset.

MARITIME UNMANNED SYSTEMS ENABLERS (MUSE) (CMRE)

The CMRE MUSE programme provides capabilities for the development of unmanned system of systems with a high level of interoperability, security and persistence. MUSE aims to establish standards to provide NATO future forces with secure, interoperable and scalable systems that increase effectiveness while reducing risk and cost.

Mr. João Alves, PRT, NATO STO Centre for Maritime Research and Experimentation (CMRE).

BACKGROUND

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 Allied Command Transformation's (ACT) 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 is organized in three projects addressing specific thematic areas: Interoperability and security for Maritime Unmanned Systems (MUS); Modelling and Simulation for MUS; and Underwater Communications and Networks.

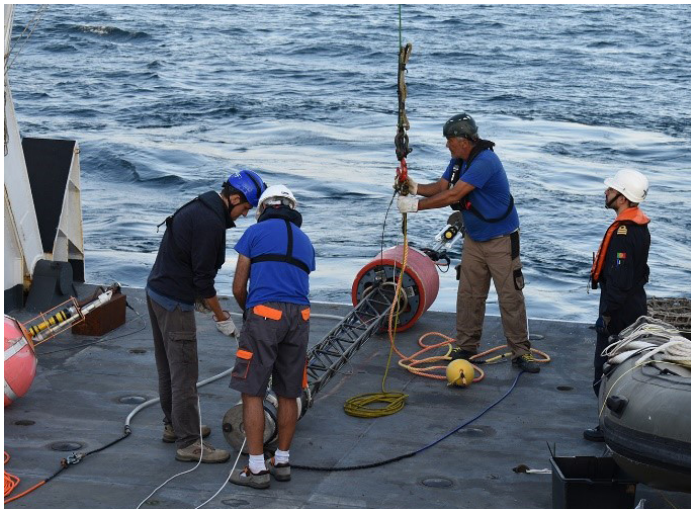

Figure 21: CMRE crews deploy a Gateway Buoy, part of the Underwater Communications network.

OBJECTIVES

MUSE focuses on three broad themes based on the Alliance's key tenets of interoperability: maritime C2 support and development from a system-level to maritime picture aggregation; mission assurance and security aspects of MUS; and digital twins for concept development, testing, and validation of autonomous maritime systems and missions.

S&T ACHIEVEMENTS

Interoperability and standards applied to LVC (Live-Virtual-Constructive) simulation provide enabling concepts for serious gaming and augmented/mixed reality. Such capabilities were employed by the Modelling and Simulation project in support of concept development for cooperative and autonomous ASW to provide ways to experiment with and validate new tactics and algorithms.

The Underwater Communications team is pursuing two specific lines of work for the generation and distribution of cryptographic keys: one based on the intrinsic properties of the acoustic channel; and another based on quantum properties. This work will allow CMRE and NATO to establish ways forward on achieving underwater quantum-based security and underwater post-quantum cryptography.

Another important line of research is cognitive underwater communications. CMRE developed and implemented a software architecture to support cognitive communications and is now testing and validating real-time underwater cognitive techniques based on machine learning. This allows a system to automatically change its communications parameters to better face the challenges of specific environments.

SYNERGIES AND COMPLEMENTARITIES

The Interoperability and Security for MUS project continued its work with research on the International Regulation for Preventing Collisions at Sea (COLREGs) and issued a proposal for its adaptation to include Autonomous Surface Vessels (ASVs). Further work has been carried out towards achieving cyber security and mission assurance of autonomous systems.

EXPLOITATION AND IMPACT

The Underwater Communications project participated in the NATO Exercise DYNAMIC MANTA 2020, conducted in the south of Italy in February. The objective was to demonstrate the usage of standardized digital underwater communications in support of submarine operations. CMRE worked with the crew of the Hellenic Navy submarine HS Katsonis that operated the JANUS system on board, using a CMRE-developed NATO-standard protocol for communicating between underwater modems.

CONCLUSIONS

The MUSE programme seeks to design the architectural framework in which future autonomous underwater systems and missions will be cast. MUSE aims to establish standards for control, data flow, information security, performance and interfaces, to provide NATO future forces with secure, interoperable and scalable systems that increase effectiveness while reducing risk and cost.

RANGE DESIGN AND MANAGEMENT FOR REDUCED ENVIRONMENTAL IMPACTS (AVT-291)

AVT-291 produced a technical guidance document on best available technology/management practices to avoid/minimize contamination from training activities. Current and emerging technologies can be used to limit impacts of training activities. Altering range practices may also lead to reductions in range contamination and provide tools for range sustainability within the NATO Nations.

Prof. Richard Martel, CAN, National Institute of Scientific Research (INRS) and Mr. Rolf Keiser, CHE, The Federal Department of Defence, Civil Protection and Sport (DDPS)

BACKGROUND AND MILITARY RELEVANCE

The ability to realistically train for combat on military live-fire training ranges is critical to NATO Nations. The alliance structure of NATO's forces requires large scale intensive training to replicate combat conditions, and the increased size and tempo of live-fire training is environmentally stressful. Losing one of these precious assets would strongly weaken the readiness of NATO's military forces. If not managed properly, live-fire training can have considerable impacts on human health and the environment, which can jeopardize the existence of these ranges. By taking a technical approach to range design and maintenance, the increased size and tempo of NATO training in the Connected Forces Initiative can be safely implemented.

Figure 22: A Canadian small arm range with bullet catchers covered by a self-healing membrane to minimize the contact of water infiltration with the bullet residues.

Military readiness and live-fire training range sustainability are critical for NATO. The Connected Forces Initiative will require larger, more intensive use of training ranges. There is a real concern that this increased tempo of training will adversely affect live-fire training ranges. AVT-291 focused on innovative technology and design practices that will ensure munitions constituents do not negatively affect the environment. Topics included are the minimization and mitigation of energetics and metals contamination in soils; noise impacts and noise reduction; prevention of surface and groundwater contamination; and the monitoring and prevention of migration of contaminants off range.

OBJECTIVES

The objectives of AVT-291 were to: a) Exchange information on range design and management; b) Establish an international network of experts; c) Learn through site visits; and d) Produce a NATO STO Technical Report on findings.

S&T ACHIEVEMENTS

AVT-291 identified the potential problem areas on ranges for soil and water quality and the technology available to reduce contamination of those media; reviewed the use and maintenance of active ranges; and proposed sustainable range design. Several field and laboratory tests were made by the participating members, enabling the team to make specific recommendations for NATO.

SYNERGIES AND COMPLEMENTARITIES

In total, eleven nations participated in this research activity. All together 20 members contributed to the production of the NATO STO Technical Report. AVT-291 is closely related with: AVT-249, AVT 277, AVT-293, AVT-322, AVT-335, NATO EPWG, MSIAC AC/236, and NSPA.

EXPLOITATION AND IMPACT

AVT-291 developed a compendium of recommendations for sustainable range design and operations and produced a NATO STO Technical Report. It also developed a community of subject matter experts. The sustainability of military live-fire training ranges can be achieved by protecting the environment from munition's residues. Following AVT-291, a RSM (AVT-335) was proposed to widen the influence. A new RTG on water sampling, monitoring, and control/remediation for live-fire military ranges was proposed and accepted at the Fall 2020 PBM.

> *AVT-291 has demonstrated that implementing innovative monitoring, mitigation, and remediation technologies will lead to more sustainable ranges for all countries.*

CONCLUSIONS

The implementation of best available practices and techniques on shooting ranges for live-fire training is a key element. This must be based on evidence from laboratory and field tests. Therefore, the whole chain of command must be involved in the process. Together with technical improvements, adverse effects on the environment can be minimized, and the loss of ranges can be avoided.

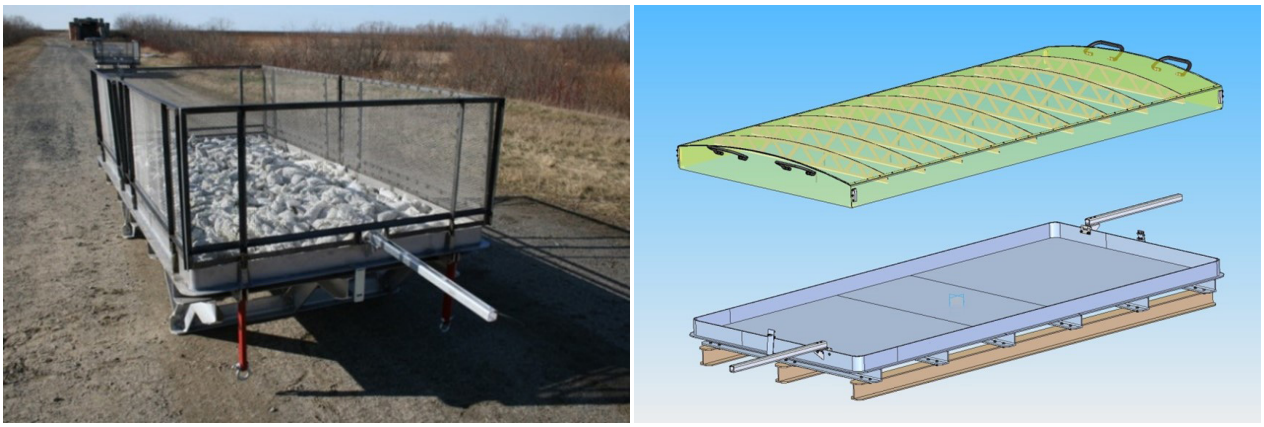

Figure 23: Two types of burning tables for the destruction of remaining propellant bags from artillery exercises.

SEARCHING FOR ~~WALDO~~* UAV: RADAR BASED NON COOPERATIVE TARGET RECOGNITION (NCTR) IN THE LOW AIRSPACE AND COMPLEX SURFACE ENVIRONMENTS (SET-245)

The SET-245 Task Group (TG) aimed to improve counter UAV radar system performances thanks to NCTR techniques. To this end, the design of NCTR algorithms has relied on a unique data set collected during several live trials organized by the TG. Likewise, live trials in realistic scenarios have been carried out for testing new or updated counter UAV radar capabilities.

Mr. Philippe Brouard, FRA, Office National d 'Etudes et de Recherches Aérospatiales (ONERA).

BACKGROUND AND MILITARY RELEVANCE

To date, preliminary promising results were obtained in UAV identification by SET-180 TG from simulated electromagnetic signatures and real UAV radar signatures collected during measurement campaigns (e.g., Spain CEDEA 2013: UNDINE). However, those results relied mainly on techniques developed for fighter a/c recognition.

When UAVs are within complex cluttered environments, radar detection, and tracking tasks are very challenging. As a consequence, lower detection thresholds are implemented leading to higher false alarm rates. Therefore, the development of various techniques for false alarm regulation becomes mandatory and recognition techniques could be one of them.

OBJECTIVES

SET-245 TG considered the problems of detecting, classifying, and identifying Class I UAVs that could appear at any location in cluttered radar scenes and their impacts on radar architectures.

S&T ACHIEVEMENTS

SET-245 TG explored Neural Networks (NN) / Deep Learning based UAV recognition algorithms and tested them against datasets collected during several measurement campaigns. Radar design was the second topic addressed by the TG. It included NCTR algorithms implementation into radar systems and investigations of new concepts. This phase was also supported by several experimentations e.g., Black Dart 2018 (DB18) which took place in the Muscatatuck Urban Training Complex (MUTC) in Butlerville, USA from 8 – 21 September 2018.

SYNERGIES AND COMPLEMENTARITIES

In total, 12 organizations coming from industry, military, Research and Technology Organizations (RTOs), and NCIA participated in this research activity. The diversity of this group and the close collaboration with SET-260 contributed to the high quality of the work as illustrated by the organization of seven live trials and to the preparation of a follow-on activity which should address swarms of UAVs and focus on threat/intent assessment techniques.

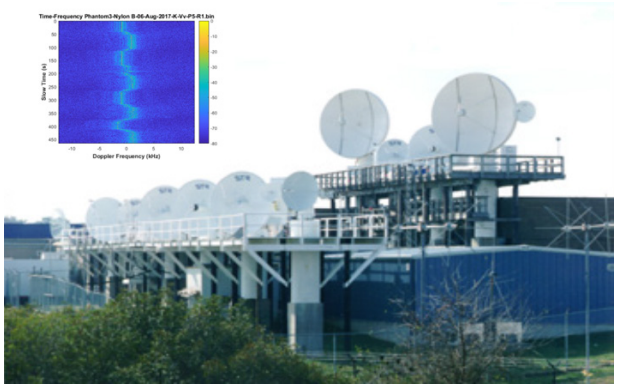

Figure 24: ATR Instrumentation Radar System. (Courtesy of AFRL.)

EXPLOITATION AND IMPACT

The results of the Task Group can be used to adapt or to rethink UAV detection/classification/identification by radars, taking into account the specificity of that potential threat (especially its capacity to behave as endo clutter target) in order to get higher score of correct identification and to reduce false alarm rate.

CONCLUSIONS

The SET-245 TG organized several measurement campaigns to build up a common Class I UAV reference radar signature database. Based upon this database, most suitable counter UAV radar parameters have been investigated and Non-Cooperative Target Recognition algorithms designed, tested and compared. The SET-245 TG also evaluated counter UAV radar systems and prototypes in realistic scenarios, in particular during the Black Dart exercise (USA – 2018) and initiated works within the field of threat/intent assessment.

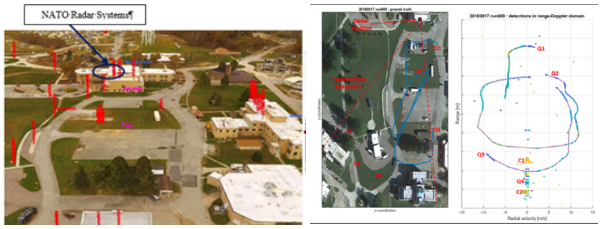

Figure 25: Black Dart 18 experimental setup / preliminary results. (Courtesy of TNO.)

* The strikethrough in the title is intentional

SKILLS AND CHILL PILLS: NAVIGATING THE CYBER-SOCIAL INFORMATION ENVIRONMENT (HFM-ET-193)

In the last few years, the use of social media by adversaries who seek to influence events related to NATO and NATO countries have increased steadily. This is done both to try to achieve specific aims counter to NATO interests and to spread general distrust and chaos to destabilize Western democracies. Techniques include amplification of misinformation, spread of disinformation, and the automated manipulation of the popularity of certain views.

Dr. Arild Bergh, NOR, Norwegian Defence Research Establishment (FFI) and Dr. Ritu Gill, CAN, Defence Research and Development (DRDC).

BACKGROUND AND MILITARY RELEVANCE

The use of social media to exert influence and spread disinformation has become an "everyday" strategy for some actors. It is thus vital that the skills to navigate a confusing and rapidly changing information environment is also developed among warfighters who are not part of the domain expert groups for social media. Through this RTG, NATO and national defence organizations will obtain tools to create tailor-made training programmes to develop such skills. Just as all soldiers learn basic emergency medical skills, despite the existence of trained doctors, there is a need for basic skills to relate to the cyber-social information environment. Given the ubiquity and instant, worldwide reach of social media, adversaries are likely to try to attack different parts of the military chain of command. NATO therefore requires new ways of training warfighters that provide relevant training tools based on concepts tested through research and practical workshops. The research in this ET will incorporate an operational perspective to develop a pragmatic training approach that can be adapted for different roles in the armed forces during peacetime, exercises and operations abroad.

OBJECTIVES

In spring and summer 2020, many researchers, partly under the STO umbrella, have provided valuable knowledge and insights related to social media-based influence efforts related to COVID-19. This ET will build on these efforts and undertake additional, workshop based socio-technical research and development together with relevant military staff. The main scientific purpose will be to identify knowledge gaps in relation to the cyber-social information environment among military staff who are not communications or PSYOPS specialists.

S&T ACHIEVEMENTS

Through a multi-disciplinary approach, sociology, anthropology, and psychology will be combined with political science and technological insights to identify the skills required to handle the needs that have been identified. These skills should allow non-experts to interpret and contextualise current cyber-social information environment activities, such as the spread of dis- and misinformation on a relevant topic, in relation to their everyday tasks.

> *What I believe is that the best way to counter propaganda and disinformation are to provide facts, the truth". NATO Secretary General, Jens Stoltenberg – On Launching #NATO2030 – Strengthening the Alliance in an Increasingly Competitive World, 9 June 2020.*

The aim is to provide clear guidance to trainers who need to provide instructions to military non-experts in how to navigate and relate to the cyber-social information environment, and how to evaluate possible solutions such as purchasing commercial analysis on a specific phenomenon.

SYNERGIES AND COMPLEMENTARITIES

IST-177 and HFM-293 will provide valuable input from their soon to be concluded activities. Norway will provide an online training environment that extends work done by NATO's JWC. The NATO CoE in Riga will provide insights to technical and analytical solutions.

EXPLOITATION AND IMPACT

Improve the effectiveness of military operations: Enable military operations planners to better understand all three dimensions of the information environment (physical, virtual and cognitive) and the impact of cyber-social influence in order to more effectively identify own, opponents' and other stakeholders' Center-of-Gravity (CoG), risks and opportunities in operations planning and execution on all levels (strategic, operational and tactical).

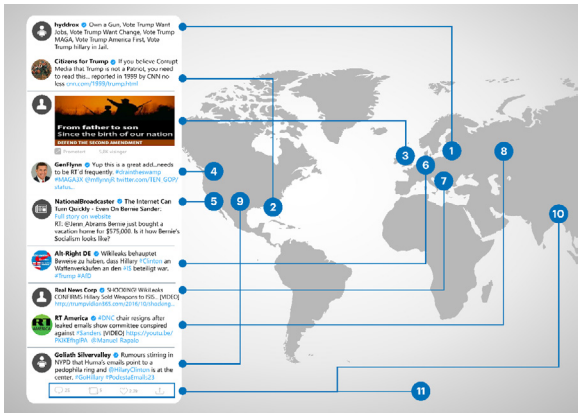

Figure 26: The map shows how input from very different actors end up in one convincing stream. (Graphic created by the activity Chair, Arild Bergh.)

STATUS AND CHALLENGES POSED BY HYPERSONIC OPERATIONAL THREATS (AVT-ST-008)

The Specialists Team AVT-ST-008 analyzed the military threat and technical challenges of hypersonic weapon systems. The team compiled a core report for military operators and decision makers that summarized key military and technical issues and gave recommendations for action for NATO and NATO Nations. Part of the threat analysis is a classified (NATO-SECRET) Annex to the core report. A comprehensive Science and Technology Annex report provides a deep dive into the related system and platform technologies.

Dipl. Ing. Hans-Ludwig Besser, DEU, Bayern-Chemie GmbH and Mr. Michael Huggins, USA, US Air Force Research Laboratory.

BACKGROUND AND MILITARY RELEVANCE

NATO adversaries are ahead of the Alliance on the fielding of disruptive hypersonic capabilities. Different hypersonic weapon systems were claimed to be operational by Russia (Avangard and Zirkon) and China (DF-17) within the last two years. The NATO Alliance and the Nations have to consider how this impacts NATO's deterrence posture, and what measures need to be taken to catch up with their own hypersonic strike capabilities as well as their ability to defend against an adversary hypersonic threat.

> *Gen. (ret) David H. Petraeus (Chairman of the KKR Global Institute and former CIA Director)"Well, the development and fielding of hypersonic weapons is going to have a revolutionary effect, I think, on the strategic security situation...There is some similarity between the introduction of nuclear weapons and the potential introduction of hypersonic weapon systems. Each pose a very significant new threat."*

OBJECTIVES

The AVT Specialists Team ST-008 aimed at:

- Compiling information about the capabilities and limitations of hypersonic weapon systems.
- Assessing potential threat from adversary systems.
- Providing a survey of technical challenges posed by hypersonic vehicle design.
- Pointing to current capability gaps within the NATO Alliance.
- Offering conclusions and recommendations to military planners and decision makers in NATO.

S&T ACHIEVEMENTS

ST-008 experts have collected, assessed, and appraised information and data to provide military operators, planners, and decision makers with a reflected picture of opportunities, threat, and technical challenges arising from hypersonic weapons within one concise document. The Science and Technology Annex provides the expert reader with a unique comprehensive compilation of technical information regarding hypersonic platforms, system architectures, and enabling technologies. The results of ST-008 are being promulgated in NATO and NATO Nations by tailored briefings of different depth. Presentations derived from ST-008 work were already given at ACT and at various conferences.

SYNERGIES AND COMPLEMENTARITIES

The Specialists Team leveraged knowledge from high ranking technical experts and military operators from eight countries and two NATO related bodies (Joint Air Power Competence Centre (JAPCC) and Competence Centre Surface Based Air Missile Defence (CC SBAMD)). Additional valuable information was drawn from discussion with other STO Panels, which have also led to follow-on inter-panel activities.

EXPLOITATION AND IMPACT

Hypersonic weapon systems have a potential to be a game changer for strike actions and Integrated Air and Ballistic Missile Defense (IABMD). ST-008 findings and recommendations are offered to support planning and decisions to maintain NATO's deterrence posture.

CONCLUSIONS

NATO needs to react on the disruptive potential of hypersonic weapon systems, both by building own capabilities and by upgrading IABMD to cope with the late detection, difficult tracking, speed, and manoeuvrability of hypersonic weapons. ST-008 has provided a sound contribution to the decision basis for this urgent issue.

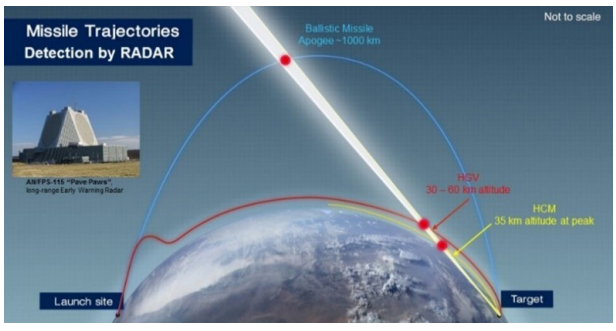

Figure 27: Late detection of hypersonic weapons by RADAR.

UNDERSTANDING THE COST RELATED IMPLICATIONS OF AUTONOMY – A SYSTEM OF SYSTEMS PERSPECTIVE (SAS-146)

SAS-146 focused on the cost related implications of autonomy using a System Of Systems (SoS) approach. The methodology that SAS-146 developed allows for the comparison of existing systems with autonomous alternatives.

Prof. Martin Parr, GBR, Defence Science and Technology Laboratory (Dstl) and Ms. Georgia Court, GBR, Defence Science and Technology Laboratory (Dstl).

BACKGROUND AND MILITARY RELEVANCE

The application of well-proven mechanization, automation and/or autonomy in well understood domains can yield significant budget savings and efficiency improvements. The SoS view and associated analytical approach will enable military decision makers to better understand the effects of introducing autonomy and will provide input for new methodologies to analyze in detail cost mission effectiveness-risk trade-offs. Moreover, in terms of costs, there is a general belief that autonomy will reduce costs. Therefore, it is important to develop a better understanding of the cost related implications of autonomy in the military environment.

> *In considering autonomous systems to meet a capability need, nations will benefit from understanding the cost and performance related implications of autonomy.*

OBJECTIVES

SAS-146 aimed to provide a structure through which nations can compare the cost and effectiveness of current approaches with those expected for potential autonomous systems and to populate this structure with illustrative cost data and insights.

S&T ACHIEVEMENTS

A select group of autonomy applications in the context of a generic military scenario were used as a starting point to facilitate the development of a SoS approach. This led to more focus on the cost of autonomous systems and a fuller understanding of the cost implications of autonomy which can be gained over time.

SYNERGIES AND COMPLEMENTARITIES

The SAS-146 efforts provide an opportunity to establish joint research activities in areas of common interest, which will be considered by the STO Autonomy Leadership Team (reference SCI-335).

EXPLOITATION AND IMPACT

The SAS-146 report describes the SoS perspective of the cost related impact of the introduction of autonomy as well as a SoS analysis approach to create awareness of the possible cost related effects of the introduction of autonomy for different contexts. It is recommended that nations adopt the standardized approach of comparing systems in this report with their own data and share the results, where possible. This will lead to more focus on the cost of autonomous systems and a fuller understanding of the cost implications of autonomy can then be gained over time.

CONCLUSION(S)

This area of work is maturing rapidly so it is necessary to watch key areas of technology that might enhance the ability of NATO to deliver efficiency savings from their military capability using technology push. There is a need to draw together a view of what the roadmap towards autonomy might look like and identify the critical areas for NATO and Partner Nations. The SAS-146 methodology supports these efforts.

Figure 28: The implementation of autonomous systems in NATO and National operations is maturing rapidly.

NATO STO Programme of Work

RESPONSE TO COVID 19

COVID-19 LEADERSHIP IN VOLATILE, UNCERTAIN, COMPLEX AND AMBIGOUS WORLD (HFM-337 ST)

The COVID-19 global pandemic has changed the way the world operates and interacts, at the tactical, operational and strategic level. This has required adaptive leadership, with leaders at all levels having to think, decide, and behave differently. This Specialist Team will therefore focus on leadership in Volatile, Uncertain, Complex, and Ambiguous (VUCA) environments, drawing on previous STO activities while expanding current leadership research.

Dr. Yvonne R. Masakowski, USA, US Naval War College Research Fellow and Colonel Matt Petersen, GBR, Defence Academy of the United Kingdom.

BACKGROUND AND MILITARY RELEVANCE

For several years now, the term "VUCA" has gained popularity and acceptance as a term that encompasses the differing dimensions of a "complex" environment or situation, with myriad reports and articles framing the "VUCA World" as:

- **Volatile** – Volatility refers to the rate of change in an industry, market or the world in general. It is associated with fluctuations in demand, turbulence and short "time to market" and is well documented in the industry dynamics literature.
- **Uncertain** – Uncertainty refers to the degree to which we can predict the future with confidence. Part of the uncertainty is associated with people's inability to understand what's going on.
- **Complex** – Complexity refers to the number of factors we have to take into account, their variety and the mutual relationships. The more factors, the greater their variety and the more they are linked together, the more complex an environment is.
- **Ambiguous** – Ambiguity refers to a lack of clarity on how to interpret something. A situation is ambiguous, for example when information is incomplete, contradictory, or too inaccurate to draw clear conclusions. More generally, it refers to blur and vagueness in ideas and terminology.

The 21st century global security environment has led to an increase in the number of NATO multinational military operations – the COVID-19 pandemic is but another layer of complexity. There is a strategic need to undertake cooperative and collaborative research to address the leadership challenges presented by VUCA environments, while informing leader development in support of NATO multinational operations.

> *"NATO's main task during the pandemic is to make sure the health crisis does not become a security crisis. And throughout, we have remained ready, vigilant and prepared to respond to any threat. Across NATO, we have seen the vital role that our armed forces have played to help save lives." – Secretary General Jens Stoltenberg, Speech at the German Institute for Global and Area Studies (GIGA), 30 Jun 2020.*

OBJECTIVES

- Leadership Capability – Competency Framework Development.
- Resilience – Individual, Team/Unit and Organization.
- Enable Increased Situational Awareness (Systems Thinking, Cognitive Diversity, Meta-Cognition).
- Cultural Relations and Trust (Emotional and Cultural Intelligence).
- Crisis Management (Agility/Flexibility, Decision Making, Adaptability).
- Command and Control (Codification).

S&T ACHIEVEMENTS

Considering how to link multi-national leadership, leader development, and technology through integrated virtual training, exploiting AI technology to facilitate greater cooperation, coordination, and collaboration amongst NATO Nations.

SYNERGIES AND COMPLEMENTARITIES

Significant elements of NATO RTG-286, specifically the Leadership "Capability Framework", will be relevant. RTG-286 has developed a conceptual framework indicating those leadership capabilities most applicable in "VUCA" environments; while the

framework has yet to be validated (the aim of a follow-on RTG), specific chapters provide literature reviews relating to key leadership capabilities.

EXPLOITATION AND IMPACT

The Specialist Team will produce a short, detailed report highlighting future leadership capabilities, and recommendations for future leader development. The Specialist Team will meet virtually over 12 months, but with easing restrictions, plan to conduct face to face meetings when authorized; it will provide a completed deliverable within the year.

CONCLUSIONS

The HFM-337 team will integrate RTG-286 conclusions and recommendations regarding leader development, based on their competency framework, where possible. Recommendations will also be made regarding the integration of technologies, such as AI, for NATO's crisis management program, including information management, education, logistics, supply chain and regional Situational Awareness.

Figure 29: Mobilized troops seen in front of NATO flag. (NATO North Atlantic Treaty Organization /flickr.com.)

CMRE RESPONSE TO COVID-19

CMRE's contribution was to adapt knowledge of tracking and predicting the movement of targets (such as ships, submarines, and aircrafts) to tracking and forecasting the number of people in a population infected with COVID-19.

Dr. Domenico Gaglione, ITA; Dr. Paolo Braca, ITA; Mr. Leonardo Millefiori, ITA; Dr. Nicola Forti, ITA; Mr. Giovanni Soldi, ITA; Ms. Enrica D'Afflisio, ITA; Mr. Samuele Capobianco, ITA; NATO STO Centre for Maritime Research and Experimentation (CMRE)

BACKGROUND

Since the beginning of 2020, the outbreak of a new strain of Coronavirus has caused hundreds of thousands of deaths and has stressed the world's most advanced healthcare systems. In order to slow down the spread of the disease, known as COVID-19, and reduce the pressure on hospitals and intensive care units, many governments have taken drastic and unprecedented measures, such as the forced closure of businesses and industries and enforced drastic social distancing regulations, including local and national lockdowns. To effectively address such pandemics in a systematic and informed manner in the future, it is of fundamental importance to develop mathematical models and algorithms to predict the evolution of the spread of the disease to support policy and decision making at the governmental level.

OBJECTIVES

There is a strong literature base describing the application of Bayesian sequential and adaptive dynamic estimation to surveillance (tracking and prediction) of objects such as missiles and ships. CMRE's Data Knowledge and Operational Effectiveness (DKOE) team applied its knowledge of Adaptive Bayesian Learning to a number of epidemiological models in order to forecast the evolution of the spread of the virus from daily publicly available infection/recovery information provided by authorities.

ACHIEVEMENTS AND IMPACT

CMRE's DKOE team, in collaboration with researchers at the University of Connecticut (UConn), developed a modelling approach to forecast the evolution of the Covid-19 epidemic. This new method helps decision makers anticipate possible future resurgences of the virus. The collaboration between DKOE and UConn contributed to the work of the Connecticut Academy of Science and Engineering (CASE) Council, which advised the Governor of Connecticut on adopting appropriate precautionary measures in spring 2020 as well as on a strategy to re-open the state after lockdown.

CONCLUSIONS

DKOE's contribution was to adapt their knowledge of tracking and predicting the movement of targets (such as ships, submarines, and aircrafts) to tracking and forecasting the number of people in a population infected with COVID-19. The researchers applied a technique called Adaptive Bayesian Learning to a number of epidemiological models, which allowed key parameters, such as the infection rate, to be modelled as time-varying instead of stationary. This research is now being exploited for early detection of subsequent "waves" of the virus. Additionally, leveraging DKOE's expertise in the analysis of maritime traffic patterns-of-life, researchers are assessing the impact of national and local lockdowns on global maritime mobility.

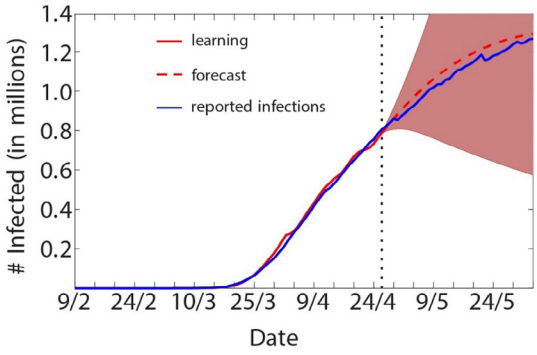

Figure 30: Reported and modelled Covid-19 infections in the US. Estimated infections during the learning phase of the model are shown as a solid red line. The forecast infections are shown as a dashed line. The vertical dashed line is 26 April 2020, the beginning the forecast. The reported number of infections are shown as a solid blue line. The red area represents the 90% confidence interval of the forecast.

THE FUTURE IMPACTS OF COVID-19 ON THE ALLIANCE (SAS-169)

SAS-169 explored potential strategic and operational military impacts of COVID-19 in the context of possible short-term (1 – 6 years) futures of the COVID-19 environment, and in so doing provided national and NATO planners, and decision makers with high level recommendations to address these potential impacts.

Gen (Rtd) Sverre Diesen, NOR, Norwegian Defence Research Establishment (FFI).

BACKGROUND AND MILITARY RELEVANCE

NATO forces must accomplish a delicate balancing act: continuing essential missions, preparing for new missions, supporting national civil efforts to deal with COVID-19, all while keeping forces healthy enough that those missions are not adversely affected. Besides operational impacts, this creates significant challenges for military leaders in the areas of training, recruiting, procurement, communications and many other areas where the impacts will vary based on the future environment.

OBJECTIVES

SAS-169 examined possible short-term (1 – 6 years) futures for the post-COVID-19 environment and analyzed the potential military strategic and operational impacts of these futures, in order to provide national and NATO planners and decision makers with high level recommendations to address the impacts.

> *The enduring COVID-19 pandemic continues to be a generational test of Allies' resilience, challenging national authorities and societies in unprecedented ways. The World Health Organization (WHO) Director-General noted "This is the sixth time a global health emergency has been declared..., but it is easily the most severe."*

S&T ACHIEVEMENTS

SAS-169 developed two analytical frameworks: A Futures Framework and A Military Impact Framework and used the two frameworks to determine possible futures and direct collection and analysis of the existing works. The team produced a short report detailing high level recommendations to address the military impacts of potential short-term futures of the post COVID-19 environment.

Figure 31: French President Emmanuel Macron visits French soldiers supporting the COVID-19 Response. (Creator: MATHIEU CUGNOT, Credit: POOL/AFP via Getty Image.)

SYNERGIES AND COMPLEMENTARITIES

Participants from six NATO and Partner Nations and four NATO bodies provided inputs into the work. In addition to open source and available national data, efforts from different NATO bodies (ACT, ACO, Civil Emergency Planning Committee (CEPC), NATO International Military Staff and International Staff) and NATO Centers of Excellence were leveraged during the analysis.

EXPLOITATION AND IMPACT

The short report describes the multiple near-term futures and potential military impacts, signalling the key impacts and making high level recommendations to NATO and national planners and decision makers on how to address those impacts. The team also makes available the detailed frameworks and data collected for future analysis.

CONCLUSIONS

The COVID-19 pandemic could affect the Alliance in many ways depending on the potential path of the pandemic. NATO and the member nations should implement a number of measures to prevent, pre empt or mitigate its adverse effects; medical, financial, operational, logistic and others.

NATO STO Programme of Work

ADVICE TO LEADERSHIP

CLIMATE-DRIVEN ENVIRONMENTAL CHANGE AND SECURITY: LEADING NATO INTO THE FUTURE OF MARITIME DEFENCE (CMRE)

For over 60 years CMRE has leveraged its considerable expertise and capabilities to understand and forecast the maritime environment. CMRE is now well positioned to advance research in maritime climate change and its implications for the defence sector.

Dr. Sandro Carniel, ITA, NATO STO Centre for Maritime Research and Experimentation (CMRE).

BACKGROUND

NATO has recognized how the effects of climate change have the potential to significantly impact Alliance planning and operations. In his speech on 28 September 2020, Secretary General Jens Stoltenberg stated, "There is no doubt that climate change affects our security. So it is essential that NATO monitors and tracks what is happening much more closely. And that we fully integrate climate change into our military planning and exercises."

Climate projections indicate that the warming trend will continue and this will greatly affect NATO planning and operations, especially in the maritime domain. Two examples of climate change impact are the Arctic ocean, where air and sea surface temperatures are changing the overall circulation of the water masses leading to the disappearance of sea ice in the summer months in the next decade, and the Mediterranean, where sea temperatures have been increasing at a much faster rate compared to the rest of the Earth's oceans. Such changes have the potential to significantly exacerbate future climate security, defence and geopolitical challenges.

CMRE has a long history of working with the Nations in the strategic planning of maritime security. In the 1980s, CMRE researchers supported NATO navies in collecting the ocean climatology data required to assess sonar performance in naval choke points and strategic regions, such as the Greenland-Iceland-United Kingdom (GIUK) gap and Nordic seas. Over the following decade, in addition to focusing on new maritime domains such as the Mediterranean sea and littoral zones, CMRE scientists pioneered research on how global warming was changing the physical characteristics of the ocean and affecting the hydrosphere. As a consequence, in the last decade CMRE returned to high latitudes to conduct research with autonomous marine systems and networks to demonstrate how northern maritime environments exhibit extreme global climatic changes. For over 60 years, CMRE has leveraged its considerable expertise and capabilities to understand and forecast the maritime environment, and is now well positioned to advance research in maritime climate change and its implications for the defence sector.

OBJECTIVES

Many strategic underwater domains are still poorly known or subject to rapid environmental change, requiring a continuous effort and new methods to collect environmental information. Building on recent research on Big Data, Artificial Intelligence and Autonomy, thanks to funding support through NATO ACT, the Centre continues to address these challenges by using "disruptive technology" capable of gathering, processing, fusing and exploiting environmental knowledge and delivering standards and prototypes that can ensure Information Superiority for NATO through the Intelligence Preparation of the Battlespace (IPB).

ACHIEVEMENTS

Over the past decades, data have shown changes in ocean properties in many regions, leading to significant impact on water mass mixing and circulation. For example, results from the Nordic Recognized Environmental Picture (NREP17 and NREP18) sea trials conducted by CMRE showed great changes in water mass characteristics in the GIUK gap and the western Barents Sea, that are causing significant changes in the underwater sound channel and acoustic convergence zone, with associated implications for acoustic propagation that are still to be fully understood.

In response to a growing influx of environmental maritime data and to prepare for future security challenges for the Alliance, in collaboration with ACT and the Nations, CMRE produced the *Arctic Science and Technology Strategy 2021 – 2030.* The aim of the strategy is to identify aspects of environmental transformations already happening in the Arctic in anticipation of their impact on Anti-Submarine Warfare (ASW).

EXPLOITATION AND IMPACT

By exploiting its established expertise across many Emerging and Disruptive Technologies (EDTs), CMRE is well positioned to further increase its value to NATO in maritime environmental science. CMRE programmes are aimed at better identifying and defining threat assessments, informed by a deep understanding of environmental and military science and the monitoring of environmental changes.

In addition, CMRE can provide analysis of climate scenarios from the perspective of NATO defence in the maritime domain such as expected future changes in naval sensor performance, possible future impact of sea level rise and extreme weather on naval infrastructure and littoral operations.

This is achieved by leveraging existing datasets, continuously updated and validated through AI and statistical analysis as well as state-of-the-art numerical models, which are maintained in collaboration with the Nations.

SYNERGIES AND COMPLEMENTARITIES

CMRE has the ability to provide environmental expertise and defence capabilities to NATO Nations through the creation of international partnerships hosted at the Centre. Collaborative opportunities, such as the visiting researcher programme, bring the world's leading scientists and engineers to CMRE to engage in an exchange of knowledge in maritime environmental science. Drawing on this dynamic learning environment and through at-sea research and experimentation on the ice-capable NATO Research Vessel ALLIANCE, CMRE is uniquely placed as NATO's hub for the exchange of information and expertise in maritime environmental science.

CONCLUSIONS

The projected effects of global warming will not only dramatically change the physical and biochemical properties of the maritime environment, but also bring geopolitical, climate security and defence challenges.

The Centre has a significant track record in providing environmental expertise and capabilities to the Nations, creating international partnerships and supporting NATO environmental research, including the operation of an Arctic capable research vessel. CMRE is positioned to extend its capacity, expertise and capabilities to be the central body for NATO research in maritime environmental change.

Figure 32: NATO Research Vessel Alliance sails through sea ice in the Greenland Sea in 2018.

DATA FARMING SERVICES FOR ANALYSIS AND SIMULATION-BASED DECISION SUPPORT (MSG-155)

Data Farming is a simulation-based methodology that supports military decision making throughout the development, analysis, and refinement of courses of action to reduce uncertainty resulting in more informed and robust decisions. Data Farming is now more accessible and usable by NATO through MSG-155 "Data Farming Services (DFS) for Analysis and Simulation-Based Decision Support" efforts.

Dr. Gary Horne, USA , Blue Canopy Group, USA and LtCol Stephan Seichter, DEU, Bundeswehr Office for Defence Planning.

BACKGROUND AND MILITARY RELEVANCE

Growing data by performing many simulation runs allows for a huge variety of alternatives to be explored. Paradoxically, this method can be used to sort out through the immense amount of information generated to improve commanders' and staffs' situational awareness.

Data Farming allows NATO military decision makers in the domains of defence planning, operations, training and capability development to reduce uncertainty resulting in more informed and robust decisions. DFS allows federated decision support in military operations by technically supporting NATO's Federated Mission Networking (FMN) Specifications.

OBJECTIVES

The overall objective of MSG-155 was to extend Data Farming capability and accessibility through developing DFS for improved decision making in military operations.

S&T ACHIEVEMENTS

The MSG-155 work was structured to produce means to improved decision support through the integration of DFS developed by the task group. These services are flexible, scalable and interchangeable and allow interoperability and operation in federated environments, which leads to resilience. The DFS are designed to make Data Farming available and usable to a wide area of NATO users and applications for more efficient and better decision making.

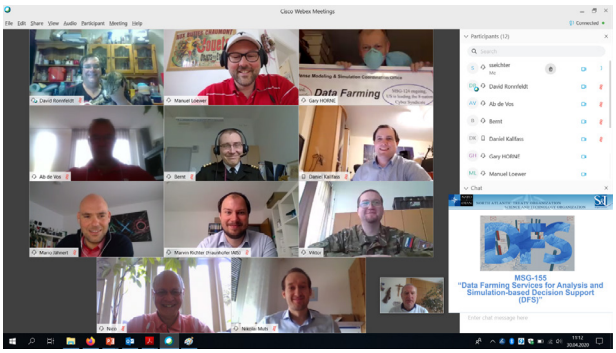

Figure 33: Data Farming Services at the CWIX 2020 eVIP day June 23rd, 2020.
Source: HQ SACT, Article "CWIX – Improving Interoperability for 22 Nations Across 10 Times Zones", June 25th, 2020, https://www.act.nato.int/articles/cwix-improving-interoperability-for-22-nations-across-10-times-zones, accessed November 14th, 2020.

> *"The kind of decision support provided by Data Farming Services to military commanders will be essential in tomorrow's high-tech conflicts."*

SYNERGIES AND COMPLEMENTARITIES

The DFS developed in MSG-155 have valuable connections with the work of MSG-164 involving Modelling and Simulation as a Service and that of MSG-117 with the objective to investigate what aspects of cyber defence can be supported with Modelling and Simulation. In addition, DFS can be used to explore questions in other areas important to NATO such as operations planning and wargaming.

EXPLOITATION AND IMPACT

This task group extended core Data Farming capability and included demonstration and testing of Data Farming use cases significantly relevant for NATO involving Future Ground Combat Operations and Cyber Defence Operations. The Coalition Warrior Interoperability eXercise (CWIX) was used as a testing platform to ensure DFS to be interoperable and technically compliant with relevant NATO M&S Standards, C2 and planning tools. These use cases were integrated within the DFS efforts providing examples to contribute to the development of the DFS and showing the impact of DFS in warfare areas important to NATO.

CONCLUSIONS

Data Farming had been codified and applied in previous task groups. This task group extends Data Farming capability and accessibility through Data Farming Services for improved decision making.

DATA KNOWLEDGE AND OPERATIONAL EFFECTIVENESS (DKOE) (CMRE)

The DKOE programme utilizes artificial intelligence, machine learning and information fusion techniques, while addressing the big data challenges of volume, velocity, variety and veracity.

Dr. Anne-Laure Jousselme, CAN, and Dr. Paolo Braca, ITA, NATO STO Centre for Maritime Research and Experimentation (CMRE).

BACKGROUND

Developing a full maritime picture, to include diverse and evolving threats, can be challenging. The quality and processing of relevant data is essential in early detection and intervention of suspicious and potentially malicious activities. In addition to big data analysis, DKOE integrates a wide range of additional data such as environmental and underwater data, in order to build a more complete maritime picture.

OBJECTIVES

The objective of the DKOE programme is to provide enhanced capability for information processing techniques to enable Maritime Information Superiority. DKOE develops research products, which can be integrated into testbed environments able to interoperate with networked systems – including military Command and Control (C2) systems.

S&T ACHIEVEMENTS

Work continued in 2020 on developing vessel prediction into a more advanced capability by utilizing deep learning in order to improve the forecasting of vessel trajectories in complex traffic environments.

The DKOE-pioneered belief propagation multi-sensor, multi-target tracking framework has been extended to process not only target measurements but also target classification information to improve tracking performance.

Research activities on maritime anomaly detection are focused on the capability to reveal dark route deviations, even in the presence of Automatic Identification System (AIS) spoofing.

Finally, the programme has continued development on the reasoning for transparent and explainable solutions for threat assessment of critical underwater infrastructure. This project considers partially reliable and conflicting sources as well as the combination of sensor information and human intelligence in threat assessment reasoning.

EXPLOITATION AND IMPACT

DKOE does research in a wide variety of fields including statistical signal processing, machine learning, information and data fusion, artificial intelligence, reasoning under uncertainty, knowledge engineering, and semantic knowledge representation and reasoning. This knowledge is used to develop solutions to a broad range of problems in Maritime Situational Awareness (MSA).

SYNERGIES AND COMPLEMENTARITIES

DKOE researchers have furthered the development of an ontology for describing experimental evaluations that is interpretable by both operators and machines. Based on a formal logic, it allows semantically enriching and validating information from different sources and bridges the gap between different types of uncertainty.

Additionally, DKOE achieved a significant improvement in the recognition of ship classes using the Sentinel 2 Multi-Spectral Instrument (MSI). This work is part of the exploitation of satellite sensors.

DKOE is developing a sequential filtering methodology through implementing Kalman filters, which may help computational efficiency and robustness in noisy environments.

CONCLUSIONS

The DKOE programme utilizes 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 MSA through improved cognition processes of perception, comprehension and projection.

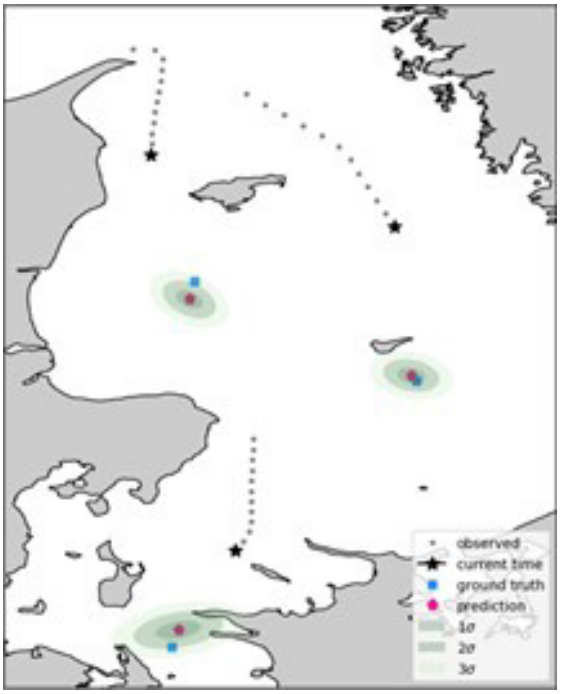

Figure 34: Vessel trajectory prediction with related uncertainty after 3 hours.

ENVIRONMENTAL KNOWLEDGE AND OPERATIONAL EFFECTIVENESS (EKOE) (CMRE)

The CMRE EKOE programme is improving the Alliance's ability to operate in the maritime domain through greater understanding of the operating environment and maintaining superiority in maritime environmental awareness—a critical capability in underwater warfare that underpins the ability of NATO forces to detect adversarial assets quickly and effectively.

Dr. Alberto Alvarez, ESP, NATO STO Centre for Maritime Research and Experimentation (CMRE).

BACKGROUND

NATO is in an era of great power competition that is re-shaping the modern geopolitical maritime security landscape. The deployment of ultra-long-range anti-access / area denial regions, or A2/AD bubbles, are of particular interest in the new geostrategic framework.

OBJECTIVES

The CMRE EKOE programme assesses disruptive and emerging technologies for their applicability to the surveillance of A2/AD environments. The ultimate goal of EKOE is to develop a distributed autonomous sensing network complemented by advanced ocean modelling and satellite remote sensing to demonstrate comprehensive surveillance over wide time and spatial scales.

S&T ACHIEVEMENTS

In 2020, autonomous networks and smart sensing research initiatives examined new sensing technologies, improved methods for underwater glider navigation and integrated acoustic sensing technology in autonomous platforms. EKOE researchers developed algorithms to support on-board communication range estimates for network nodes.

Figure 35: CMRE and Italian Navy crews recover a CMRE oceanographic mooring on-board NRV ALLIANCE during the MREP20 sea trial.

This year, EKOE researchers constructed a high quality historical oceanographic data set for the Arctic region from 1980 – 2020, by merging three data sets: the Unified Database for Arctic and Subarctic Hydrography; the Ice-Tethered Profiler Program; and the World Ocean Database 2018. The Arctic data set is updated periodically with new data for further studies and planning.

EXPLOITATION AND IMPACT

EKOE has developed advanced analytics to support naval decision making based on novel data assimilation techniques for ocean prediction. These techniques allow EKOE researchers to extract information from acoustic transmission data to improve model forecasts as well as to incorporate as many small-scale processes as allowed by computational limitations. A prototype of an advanced analytics Shared Environmental Information System was developed to collect, keep, exchange, curate and classify the information received from the sensors.

SYNERGIES AND COMPLEMENTARITIES

The Mediterranean Recognized Environmental Picture (MREP20), a novel field experiment, was conducted off Malta from 24 October – 11 November 2020, to quantitatively assess the capability of present numerical/observational technology to predict the variability of the underwater sound channels associated with strong frontal dynamics. Moreover, 3D effects on underwater acoustic propagation were investigated. An oceanographic observing network composed of gliders, moorings, drifters, conductivity-temperature-depth profilers and satellite remote sensing was deployed in the region. A second network was implemented for acoustic validation purposes. The network monitored the signal received from a moored source, at a set of locations around the front. Ship measurements were complemented by acoustic gliders and moorings. External collaborators were DRDC (CAN), DGA (FRA), SHOM (FRA), OGS (ITA), UNIBO (ITA), WHOI (USA) and HLS (USA).

The Drifter Demonstration and Research (DDR20) sea trial was performed from 06 – 10 October 2020 in the eastern Ligurian Sea to demonstrate the effectiveness of freely-drifting instruments and floats to characterize the littoral marine environment with high spatial and temporal resolution. In addition to CMRE, the following international partners were involved: ISMAR/CNR (ITA), LAMMA/CNR (ITA), OGS (ITA), SIO/UCSD (USA) and DARPA (USA)

CONCLUSIONS

CMRE's EKOE programme helps NATO forces maintain superiority in maritime environmental awareness, a critical capability in underwater warfare that underpins the ability of NATO forces to detect adversarial assets quickly and effectively.

ENVIRONMENTAL LIMITATIONS OF FIELDED EO-TDAS (SET-234)

An Electro-Optical Tactical Decision Aid (EO-TDA) predicts windows of opportunity or denial for military operations, based on predicted weather conditions. Thereby, the EO-TDA integrates the effect of the environment in short-term mission planning and the assessment of the probability of mission accomplishment.

Prof. Dr. A.M. J. (Lex) Van Eijk, NLD, Netherlands Organisation for Applied Scientific Research, Defence, Safety and Security (TNO DSS).

BACKGROUND AND MILITARY RELEVANCE

A TDA helps the warfighter to create superior situational awareness, deliver weapons on target, and survive the mission. It supports the commander in mission effectiveness by exploiting the environmental advantage. The TDA can, for example, identify time periods when the opponent's sensor has a shorter detection range than your own. Existing EO-TDAs differ widely in appearance and products, as they are designed to respond to specific mission planner requests for different contexts of operation. Nevertheless, they share the elements of the target task chain (geophysical environment, target, propagation, sensor, decision process).

OBJECTIVES

SET-234 studied the relation between the environment and the performance of EO-TDAs, with the aim to characterize the variability in performance, and to provide advice on mitigating adverse weather effects or alternatively, on exploiting environmental effects to gain a tactical advantage in theatre.

> *EO-TDAs assist the mission planner in optimizing the deployment of electro-optical sensors in the anticipated operational theatre.*

S&T ACHIEVEMENTS

The Team assessed the objective through model studies and experimentation. A field trial at White Sands Missile Range (New Mexico, USA) generated a comprehensive set of test data in a warm, desert-like environment. In this trial (supported by STO), military targets were used, such as T-72 tanks and ZIL-131 trucks. The Team also created a working group on CUBI, a simple L-shaped proxy for a target, to study its behaviour under a great variety of climatic conditions, including severe winter conditions. Specific attention was given to the disregard of clutter in the Detection, Classification and Identification (DRI) algorithms.

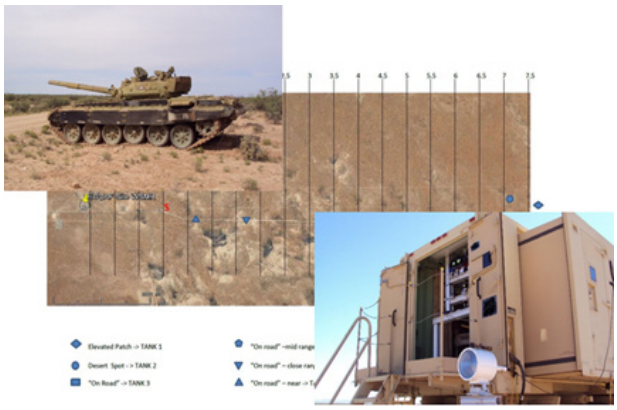

Figure 36: Impression of SET-234 field trial.

SYNERGIES AND COMPLEMENTARITIES

The eight Nations participating in SET-234 brought together a great diversity in EO-TDAs with respect to the type of mission supported, the maturity, the scientific completeness and the focus areas of ongoing improvements. The fruitful exchanges within the Team allowed each nation to improve National Capabilities, while gaining an improved understanding of alternative approaches.

EXPLOITATION AND IMPACT

SET-234 assessed the state-of-the-art in EO-TDA development and identified shortcomings in our present understanding of the relation between the environment and the EO-TDA products, which allows assessment of the robustness of current EO-TDAs. The Final Report provides guidance to Alliance members for the development of National Capabilities.

CONCLUSIONS

EO-TDAs provide a measure for in-theatre task accomplishment of friendly and hostile electro optical sensors by assessing the complete target task chain. Current EO-TDAs, however, are not robust against all environmental scenarios that may be encountered in the operational theatre.

EXPLORATORY VISUAL ANALYTICS (IST-141)

The ever-increasing accessibility of large volumes of complex multi-dimensional data provides unprecedented opportunities in defence applications, but conventional approaches are inadequate to exploit this data. Visual Analytics provides an effective means to exploit these data for acute situation awareness and thus to support informed decision making and information superiority.

Dr. Margaret Varga, GBR, University of Oxford.

BACKGROUND AND MILITARY RELEVANCE

The exploitation of all relevant information from multiple sources is a key factor for NATO's information superiority.

Visual analytics provides decision makers with better and more effective ways to understand and analyze these ever-expanding data sets, thus enabling timely and informed actions. Visualization and analytics research and development are essential in addressing the objectives of the 2015 NATO S&T Priorities Targets of Emphasis in Information Analysis and Decision Support (IA&DS):

- IA&DS-1 on Decision Support.
- IA&DS-2 on Big Data and Long Data Processing and analysis.

OBJECTIVES

The group investigated and fostered research collaborations in knowledge extraction and data analysis for timely situation awareness and effective decision making. The objectives were thus to research, develop and apply exploratory visual analytics to:

1. Exploit and make sense of large and complex data, (i.e., Big Data);
2. Help make tacit knowledge explicit;
3. Provide acute situational awareness; and
4. Support the construction and communication of informed decisions in cyber, maritime, and social media domains as well as the use of batch simulation.

S&T ACHIEVEMENTS

IST-141 started in April 2016 and has successfully demonstrated the effectiveness of innovative approaches to enabling dynamic and interactive analysis for the exploration and understanding of complex data for situation awareness and informed decision making. The group also worked on technology transferability so that existing tools/approaches can be adapted to different applications and domains. Human factors are also incorporated in the group's research and development process to ensure the production of tools that are both useful and usable. The group organized, chaired, presented and/or published their collaborative work in NATO, national/international conferences, workshops, symposia and specialists' meetings. The group raised awareness of their cyber domain work by delivering lectures in the IST-143 and IST-170 lecture series in eight countries during 2016 - 2019. The group organized the IST-HFM-154 Cyber Symbology Specialists' meeting and the IST-178 Big Data challenges: situation awareness and decision support workshop in collaboration with IST, HFM, SAS, NCIA and CMRE. The group has 32 publications.

> *Detect the expected and discover the unexpected.*

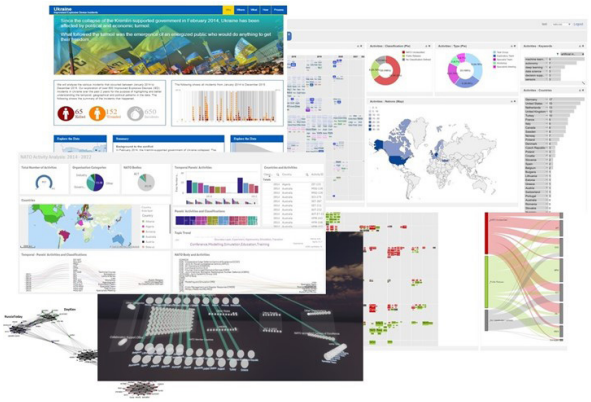

Figure 37: Exploratory visual analytics.

SYNERGIES AND COMPLEMENTARITIES

To facilitate the exploitation of exploratory visual analytics technologies, IST-141 members worked widely outside the group in collaborations with RTGs from IST, SAS, HFM and NCIA.

EXPLOITATION AND IMPACT

IST-141 demonstrated the benefits of exploratory visual analytics across a very wide range of domains relevant to all NATO Nations and Partner Nations.

CONCLUSIONS

Collaboration across nine nations and CMRE with military users and access to real data and tools are important elements to meet the goal of bringing operational benefits. Furthermore, collaboration with other RTGs in the IST, HFM and SAS Panels enable the broadening of the understanding and exploitation of exploratory visual analytics.

INTEGRATION OF WOMEN INTO GROUND COMBAT UNITS (SAS-120)

SAS-120 conducted interdisciplinary analysis of the social, cultural, and psychological factors impacting gender integration with particular focus on the integration of women into ground combat units. The analysis builds upon evidence-based research and is coupled with historical experience, lessons learned, and strategies that are rolling out across military organizations today.

Dr. Karen D. Davis, CAN, Defence Research and Development Canada (DRDC).

BACKGROUND AND MILITARY RELEVANCE

Women serve in ground combat units in many NATO and partner countries, and integration efforts continue. Recent years have also witnessed momentum to reinforce integration efforts to support operational and equality objectives, including UN Security Council Resolution 1325 (2000), which calls for increased participation of women in security forces. Leveraging the experiences of NATO and Partner Nations makes important contribution to these strategic and operational objectives.

> *Clearly, physical standards are essential and will garner substantial attention in the foreseeable future; the real and perceived impacts of physical standards are also likely to have significant impact on integration.*

Figure 38: Women serve in ground combat units in many NATO and partner nations

OBJECTIVES

SAS-120 aimed to identify the influence of social, cultural, and psychological factors of gender integration, strategies for integrating women into ground combat units, and approaches for monitoring and assessment of integration.

S&T ACHIEVEMENTS

SAS-120 highlighted persistent critical influences on integration. The analysis identified best practices for setting the conditions, early monitoring, and long-term monitoring to facilitate careers for women and optimize the dynamics of integration among women and men. SAS-120 also developed a categorized and annotated research bibliography summarizing literature which considers the participation of women in combat roles. The team organized a symposium, SAS-137, to share research and best practices, and identify research gaps.

SYNERGIES AND COMPLEMENTARITIES

In addition to capturing the experiences of the four nations on the team, SAS-120 engaged contributions from six additional nations through their symposium and leveraged the complementary efforts of the NATO STO's Human Factors and Medicine Panel.

EXPLOITATION AND IMPACT

This work contributes to the continued integration of women in combat which has particular interest for NATO and Partner Nations. Public interest is also evidenced by the media, academic inquiry, and interest groups.

CONCLUSIONS

The analysis highlights the importance of meaningful engagement with military members to contribute to culture change, short-term monitoring to facilitate feedback loops, and longer-term monitoring to support leadership response to integration challenges. Sustained effort should include qualitative analysis of multi-perspective data (e.g., attitudes, beliefs), quantitative measures of outputs (e.g., promotions, assignments), and follow through to ensure that all have the opportunity and resources to develop the competencies critical to successful integration. Finally, the analysis suggests that strategy should not be limited to existing standards and security challenges but provide opportunities for emerging practices and social inclusions to contribute to operational effectiveness.

MISSION-ORIENTED RESEARCH FOR AI AND BIG DATA FOR MILITARY DECISION MAKING (IST-173)

The multi-domain IST-173 Specialist Team (ST) developed a first instantiation of an S&T roadmap for Artificial Intelligence (AI) and Big Data for Military Decision Making to address NATO challenges. The roadmap provides an overview of the current STO Collaborative Programme of Work (CPoW) in this area and identifies key areas where new research is needed. This "living" STO co-creation captures the current state in a Wiki manner.

Dr. Ana Barros, NLD, Netherlands Organisation for Applied Scientific Research (TNO) and Mrs. Francine Desharnais, CAN, Defence Research and Development Canada (DRDC).

BACKGROUND AND MILITARY RELEVANCE

The strategic and military importance of AI was stressed by the political NATO leadership, and NATO STO responded by identifying AI and Big Data for Military Decision Making (AIBDMDM) as a theme. This activity was key in developing a military-relevant S&T roadmap for this theme.

OBJECTIVES

IST-173 aimed to assess a Mission-Oriented Approach (MOA) to develop an S&T roadmap, draft the first version of an AIBDMDM roadmap, and foster the development of an enduring Community of Interest in this area.

S&T ACHIEVEMENTS

IST-173 proved in practice the power of the MOA approach to stimulate open dialogue, self-forming research collaborations, and STO cross-panel activities. This approach was instrumental in the joint development of a first NATO S&T roadmap for two Main Capability Areas: Inform, and Command, Control and Communication. These roadmaps were integrated in an accessible online Wiki framework on the STO's Science Connect platform, which promotes visibility and facilitates ongoing development. This platform also provides easy access to the Community of Interest who participated in the roadmap process.

Figure 39: Towards "Centaur" capabilities: Leveraging AI and Data Science to enable NATO to fight and operate with machine speed and power while maintaining meaningful human control.

SYNERGIES AND COMPLEMENTARITIES

The team was composed of participants from more than nine nations, including scientists from different panels and groups, as well as military stakeholders and representatives from NATO bodies, academia, and industry. This generated a broad and diverse Community of Interest for the theme.

EXPLOITATION AND IMPACT

Lessons learned from the application of the MOA will provide guidance for future S&T roadmap development. IST-173 identified the need for a NATO data infrastructure that enables the exploration and development of data, tools and capabilities that can take advantage of AI and/or Big data, as well as the necessary policy to share and store data. These gaps, and several others identified in the roadmap, are already being pursued through approved STO activities.

CONCLUSIONS

IST-173 revealed that a multi-domain mission-oriented research approach is a powerful methodology for theme exploration and exploitation. The living roadmap and Community of Interest will enable STO to frame a harmonized cross-panel response to AIBDMDM challenges and opportunities.

> *IST-173 has revealed the potential of the multi-domain mission-oriented research approach to create a community of interest and identify the research needed to ensure that the Alliance has AI and Big Data supremacy for decision support.*

NATO GUIDE TO DATA COLLECTION AND MANAGEMENT (DC&M) FOR ANALYSIS SUPPORT TO OPERATIONS (SAS-111)

The digitalization of the battlefield implies a proliferation of real-time data (i.e., blue force tracker, RFID) that will increase the volume, velocity, and variety of data available for analysis. This massive increase in collected data offers a tremendous opportunity for NATO analysts to provide more timely and extensive advice to commanders. SAS-111's timely work helps data policy makers and commanders understand what it takes to transform military HQs into data-driven enterprises.

Ms. Jackie Eaton, GBR, NATO Joint Analysis Lessons Learned Centre and Ms. Katrin Peeper, DEU, Bundeswehr Planning Office.

BACKGROUND AND MILITARY RELEVANCE

Success in military operations relies on the ability of military commanders to make sense of data faster and more effectively than adversaries. However, the amount of data being generated every day is growing exponentially in the civilian and military worlds and there is already too much to handle. Military HQs that embrace the power of Big Data and Artificial Intelligence to inform their decision making will be at an advantage in any future conflict. A prerequisite for harnessing the power of Big Data and AI is effective DC&M. DC&M is the process of planning, coordinating, and controlling an organization's data resources. Effective DC&M enables analysts to take advantage of sophisticated tools to provide timely information to commanders. Ineffective DC&M can cost lives.

OBJECTIVES

SAS-111 sought to identify current data issues impacting NATO operations and recommend how NATO deployed HQs could enhance their DC&M capability.

S&T ACHIEVEMENTS

SAS-111 produced a Guide to DC&M for Analysis Support to Operations which included real-life use cases to demonstrate current data issues, and recommendations for how military HQs could enhance their DC&M capability through better data planning and processes, data specialists in the staff, training, and tools.

SYNERGIES AND COMPLEMENTARITIES

The work has strong synergies with the military functions: Information and Knowledge Management, Operational Assessment, Intelligence Analysis, Information Environment Assessment, Lessons Learned and Historical Analysis. It relates to Federated Mission Networking and NATO Enterprise IT solutions. It connects with several STO Information Systems Technology Panel research groups.

> *Commanders must have effective DC&M to achieve decision superiority in modern conflict.*

EXPLOITATION AND IMPACT

The guide is a major reference in the development of the new NATO Data Policy. It also includes annexes on data collection and management which may be appended to existing NATO or national handbooks. Other elements from the guide will inform NATO and national military HQs as they grapple with the complexity of becoming data-centric organizations.

CONCLUSIONS

The Big Data problem in NATO military HQs comes mainly from the need to handle variety in datasets that are inherently incomplete and inaccessible, rather than from dealing with extreme velocity or volumes of data. Furthermore, staffs lack the mindset and capability to do DC&M effectively. The SAS-111 guide helps military organizations transform their HQs into data-driven enterprises.

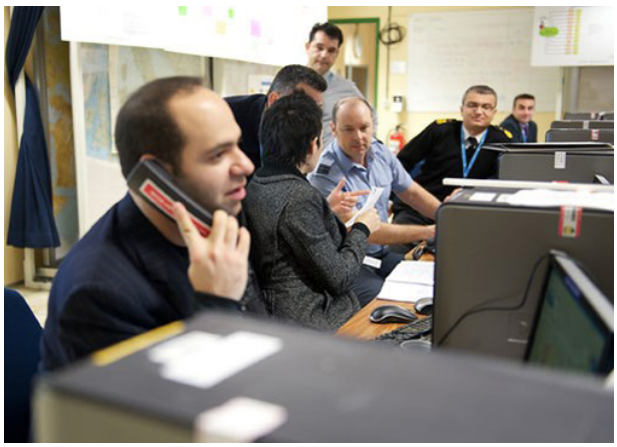

Figure 40: Effective use of data is essential for NATO staffs.

PLATFORM-LEVEL EW ARCHITECTURES TO PROTECT JOINT/ COALITION AIR OPERATIONS (SCI-260)

SCI-260 has developed an open architecture integrated Defensive Aids System (DAS) standard which provides enhanced survivability by enabling multi-spectral threat detection, integration, and intelligent effector optimization and coordination. Efficiency, cost effectiveness, and interoperability are also improved, increasing reuse and reducing reliance on bespoke interfaces. Nations across the Alliance are beginning to specify and use the standard within their procurement and development activities, which is essential for adoption and exploitation.

Dr. Nicholas Law, GBR, Defence Science and Technology Laboratory (Dstl).

BACKGROUND AND MILITARY RELEVANCE

Defensive Aids Systems (DAS) / Aircraft Survivability Equipment (ASE) contribute to survivability by providing self-protection capabilities to the warfighter, the platform, and the mission. Currently it takes too long and costs too much to upgrade and maintain these systems throughout their lifecycle. Furthermore, DAS/ ASE systems traditionally employ proprietary closed communication links between sub-systems. This restricts information sharing to the wider system that could be used to enable enhanced survivability capabilities such as: improved situational awareness; advanced decision making; and optimized countermeasure response.

SCIENTIFIC OBJECTIVES

The objectives of SCI-260 were to: a) Analyze the problem; b) Survey existing approaches; c) Define associated architecture requirements; d) Develop open architecture concepts; e) Define corresponding NATO open interfaces; and f) Make conclusions and recommendations regarding the potential development of a NATO DAS (NDAS) open architecture Standardization Agreement (STANAG).

S&T ACHIEVEMENTS

SCI-260 exceeded its original objective by delivering a draft NDAS STANAG 4781 including a detailed Allied Engineering Publication (AEP-104) in December 2018. The SCI-260 team then transitioned to become a permanent Custodian Support Team (CST) under the NAFAG, Aerospace Capability Group 3, Sub-Group 2 (NAFAG ACG3 SG/2). The ratification draft STANAG was submitted by the CST in July 2020 and entered ratification on 5 November 2020. Governments and project teams across NATO are beginning to specify and use the standard within their procurement and development activities, which is essential for adoption.

SYNERGIES AND COMPLEMENTARITIES

SCI-260 has developed the NDAS Architecture in partnership with the NAFAG ACG3 SG/2, initiating

> *"We must share ideas amongst the Alliance, and build solutions that are interoperable."*

Figure 41: NATO Defensive Aids Systems logo.

NATO Industrial Advisory Group (NIAG) Study Groups 185 and 211. These NIAG studies have provided additional industry expertise and advice with 13 nations and more than 20 companies participating overall.

EXPLOITATION AND IMPACT

The NDAS open architecture will improve interoperability across coalition forces and enable faster, more effective survivability upgrades throughout the DAS/ASE systems' lifecycle. The standard also promotes technological exploitation and wider/faster market opportunities for industry.

CONCLUSIONS

NATO SCI-260 has delivered the NDAS Architecture standard that supports enhanced survivability by enabling multi-spectral threat detection, integration, and intelligent effector optimization and coordination. Efficiency, cost effectiveness and interoperability are also improved, increasing reuse and reducing reliance on bespoke interfaces.

RECRUITMENT AND RETENTION OF EARLY CAREER CIVILIAN SCIENTISTS FOR DEFENCE S&T (SAS-148)

SAS-148 provides a synthesis of the challenges and best practices in the recruitment and retention of early career civilian scientists in defence Science and Technology (S&T) to help NATO and Partner Nations to improve their recruitment and retention strategies.

Ms. Lynne Genik, CAN, Defence Research and Development Canada (DRDC).

BACKGROUND AND MILITARY RELEVANCE

Many national S&T organizations have an aging workforce and are facing challenges recruiting and retaining young, top, diverse civilian scientists. There are many contributing factors to the current state of affairs. During the past decade, governments were faced with increasing budget pressures that resulted in a reduction and/or lack of sustained hiring in S&T workforces. At the same time, there was an increase in innovation outside of the defence public sector making the marketplace more competitive for attracting top, young talent. Furthermore, the younger generation may be less attracted by the same incentives and less likely to stay with the same organization throughout their careers, thus making it more difficult to both recruit and retain scientists using the existing compensation mechanisms and working conditions. It is vital that NATO and partner S&T organizations appropriately rejuvenate their civilian scientific workforces to continue researching new defence S&T areas, providing military decision makers with the best S&T advice possible.

> *NATO and partner S&T organizations must rejuvenate their civilian scientific workforces to continue researching and exploring new defence S&T areas, providing military decision makers with the best S&T advice possible.*

OBJECTIVES

SAS-148 aimed to exchange best practices and identify effective and sustainable recruitment and retention activities strategies for top, early career, diverse civilian scientists.

S&T ACHIEVEMENTS

The SAS-148 report provides a synthesis of the challenges and best practices gathered from seven nations and NATO organizations. Common challenges across organizations were identified, such as lengthy hiring times and competition from the private sector. Some best practices identified included the need to develop relationships with universities and employ students to attract them following graduation, marketing of the organization to target audiences, offering new scientists developmental opportunities, and regular monitoring of the workforce. Leadership was identified as having a critical role to play with key management competencies to empower a positive and diverse workplace culture.

SYNERGIES AND COMPLEMENTARITIES

SAS-148 leveraged the inputs from the defence S&T organizations of six participating nations, as well as the NATO Communications and Information Agency (NCIA). The team also leveraged the research from numerous other STO activities.

EXPLOITATION AND IMPACT

The best practices and insights in this report will be used by Alliance S&T Organizations to improve recruitment and retention strategies for early career civilian scientists.

CONCLUSIONS

Alliance S&T organizations can learn from the challenges and best practices presented in this document to improve their recruitment and retention strategies and sustain their S&T workforces.

Figure 42: Young scientists at the Walter Reed Army Institute for Research Emerging Infectious Disease Branch. (Photo by Shawn Fury.)

SPACE AS A FORCE ENABLER (SCI-345)

SCI-345 brought together operators, planners, space thinkers, and the S&T community to exchange information to determine and prioritize NATO near-, mid-, and far-term S&T needs and requirements. This activity utilized the results of SCI-318 with the intent to have SCI-345 develop the first space-focused Technology Roadmap for NATO to inform its S&T stakeholders.

Dr. Megan Fillinich, USA, L3Harris Technologies.

BACKGROUND AND MILITARY RELEVANCE

In 2018, NATO acknowledged that space is a highly dynamic and rapidly evolving area, which is essential to coherent Alliance deterrence and defence. In 2019, NATO defence ministers recognized space as a new operational domain – alongside air, land, sea and cyberspace. These recent decisions reflect many years of reflection and deliberation regarding the role and growing importance of space to the Alliance. As space has become cheaper and more readily accessible, there has also been a corresponding growth in the number of actors in space and the security environment. NATO continues to grow increasingly more reliant on space as a key enabler for its missions to include collective defence, crisis response, disaster relief, and counterterrorism.

OBJECTIVES

SCI-345 was primarily focused on improving the relevance, coherence, and collaboration of the NATO space domain related science and technology efforts within the STO. The objective of SCI-345 was to develop a high level Technology Roadmap that would serve as a plan forward for NATO Space S&T activities to be conducted in coordination with the operational community.

S&T ACHIEVEMENTS

The output of SCI-345 will serve NATO as a roadmap for development and promotion of all topics related to space activities, to include: operational overview of required data products; operational overview of S&T capability gaps and S&T requirements; identification and promotion of common standards; and production of a collaborative product to better coordinate Space activities as an Emerging and Disruptive Technology.

SYNERGIES AND COMPLEMENTARITIES

Related research has been conducted in the scope of multiple STO activities to include the HFM, SCI, AVT and SET Panels and this highlights the cross-panel nature of the space domain. This RWS was supported by studies and operational data available from the contributing nations' operational satellite systems as well as other similar previously conducted activities. SCI-345 was significant in that it brought together members of the acquisition, operational, legal, and policy space communities.

EXPLOITATION AND IMPACT

The results produced within SCI-345 will be discussed with operational representatives from the various participating nations and organizations. This Research Workshop (RWS) considers this dialogue as a critical element of its work. This RWS aligns within the current S&T Strategy Lines of Effort: 1) Stay at the Forefront of S&T; 4) Enhance Alliance Decision Making; and 5) Focus on Alliance Needs to Boost Impact.

CONCLUSIONS

The roadmap produced by SCI-345 will provide a prioritized list of space S&T activities for the nations to consider and pursue.

Figure 43: Space assets are critical enablers of all other warfighting domains, as well as key commercial and civil capabilities.

NATO STO Programme of Work

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

EXCELLENCE IN NATO SCIENCE AND TECHNOLOGY

Every year, the NATO Science & Technology Board (STB) recognizes outstanding achievements in the international collaboration on Science & Technology (S&T) within the NATO framework. In order to motivate individuals and teams alike to continue providing exceptional contributions to the benefit of the STO community and the Alliance writ large, the STB presents to types of awards: the Von Kármán Medal and the STO Excellence Awards.

Figure 44: Von Kármán Medal.

VON KÁRMÁN MEDAL

The Von Kármán Medal is awarded to highly accomplished individuals with a life-time dedication to international S&T collaboration in NATO. Through exemplary service, recipients repeatedly delivered significant contributions to STO activities over a long period of time. They combine an internationally recognized career in S&T with leadership and vision to advance the S&T collaboration among the Allied nations. Typically, the STB awards only one Von Kármán Medal per year.

2020 VON KÁRMÁN MEDAL RECIPIENT – MICHAEL HUGGINS (USA)

In spring 2020, the STB awarded the 2020 Von Kármán Medal to Michael Huggins (USA). During an extensive and dedicated career, Mr. Michael Huggins has successfully made impactful contributions to the development of novel advanced liquid rocket engine cycles as well as developing higher performing and environmentally friendly energetics while further directing technology to dispose of aging munitions and propellants in a “green” manner. Mr. Huggins has led S&T research at a high level within the US Air Force and is recognized internationally as a senior leader in defence S&T. He has made outstanding impacts to the STO mission through three primary contributions: 1) His leadership in establishing and exponentially growing the Research and Development activities and knowledge for space operations; 2) His excellence in the realms of propulsion for aircraft, access to and in space as well as tactical missile operations; 3) His remarkable and continued leadership, culminating in an unprecedented three terms as Chairman of the AVT Panel.

STO EXCELLENCE AWARDS

The STO Excellence Awards recognize exceptional accomplishments in recent STO activities, conducted and completed during the last four years. Recipients delivered high quality original work of considerable military relevance and benefit, while achieving a significant degree of international collaboration. The STO Excellence Awards can be granted to teams and to individuals. The STB typically presents several such awards every year.

The 2020 STO Excellence Awards were granted to the following two teams and two individuals:

- Advances in Artificial Intelligence and Information Fusion for Maritime Situational Awareness [CMRE]
- Urban Combat Advanced Training Technology – Live Simulation Standards (UCATT-LSS) [MSG-140]
- Stan Cole (AVT Panel, USA)
- Dr. Michael Eismann (SET Panel, USA)

ADVANCES IN ARTIFICIAL INTELLIGENCE AND INFORMATION FUSION FOR MARITIME SITUATIONAL AWARENESS [CMRE]

CMRE led a team that received a NATO STO Scientific Achievement Team Award for the project Maritime Artificial Intelligence and Information Fusion (MAI2F). Led by CMRE's Data Knowledge and Operational Effectiveness (DKOE) group, the project resulted in a suite of improved products for multi-target tracking, anomaly detection, multi-source automated reasoning, and ship track and destination prediction.

Led by Dr. Anne-Laure Jousselme, CAN, Dr. Paolo Braca, ITA, and Mr. Leonardo Millefiori, ITA.

BACKGROUND

In April, an international team led by CMRE received a NATO Science and Technology Organization (STO) Scientific Achievement (SAA) Team Award for the project Maritime Artificial Intelligence and Information Fusion (MAI2F). The project was led by CMRE's Data Knowledge and Operational Effectiveness (DKOE) group. The STO Scientific Achievement Award recognizes exceptional accomplishments within STO's collaborative and in-house research activities that have high impact on NATO and the Nations' scientific and operational communities.

Maritime Situational Awareness (MSA) is defined by NATO as "an enabling capability which seeks to deliver the required Information Superiority in the maritime environment, to achieve a common understanding of the maritime situation, in order to increase effectiveness in the planning and conduct of operations". MSA strives to enable an informed decision-making process that improves maritime operational effectiveness (e.g., detect potential threats and take appropriate action to mitigate their impact), but challenges remain in the effective processing of available data.

One of the greatest challenges is the sheer volume of data and information available in the era of Big Data that can overwhelm analysts and operators. Moreover, information sources are heterogeneous, reports may conflict with each other, and data flows may be intermittent, corrupted, and possibly irrelevant to the tasks at hand.

OBJECTIVES

Inspired by human cognitive abilities to automate routine tasks, the objective of the MAI2F project was to address MSA issues by developing and advancing techniques to support the cognitive processes of the operators; perception, comprehension, and projection.

RESULTS

The MAI2F team demonstrated that focusing on human cognitive processes was a successful strategy, allowing vast amounts of information and data to be analyzed for operators, merging of heterogeneous data sources, and resolving conflicting, intermittent and potentially corrupted or irrelevant information. The result was a suite of improved products for multi-target tracking, anomaly detection, multi-source automated reasoning, ship track and destination prediction, achieved by exploiting original expert knowledge acquisition methods. The operational benefits of the MAI2F techniques developed through this project were confirmed by NATO's Maritime Command (MARCOM) during the Maritime Pattern-Of-Life Information Service (MPOLIS) operation and through exercises such as the International Maritime Exercise (IMX) 2019. NATO MARCOM assessed some of the team's MAI2F techniques as essential to conduct operations and requested them to be included in the next NATO Maritime Command and Control Information System (TRITON). Additionally, the scientific quality of the MAI2F team's work has been validated by more than 100 peer-reviewed publications, including one in the prestigious Proceedings of the IEEE. The MAI2F initiative was made possible through collaborations within STO as well as academic, industry and national defence organizations.

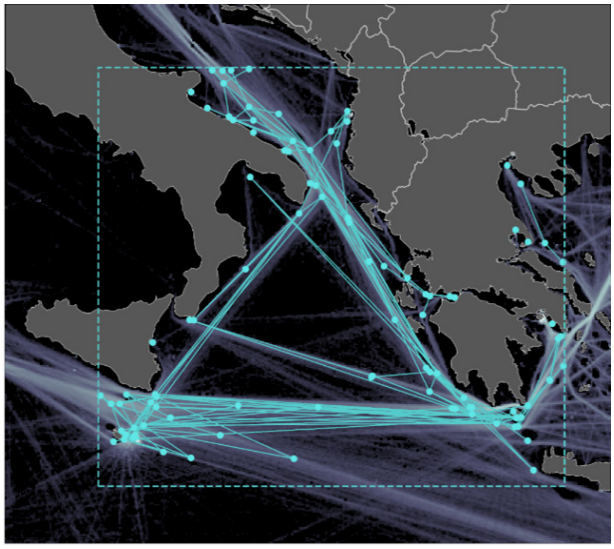

Figure 45: Maritime traffic graph.

G. Soldi, D. Gaglione, N. Forti, A. Di Simone, F. Daffina, G. Bottini, D. Quattrociocchi, L.Millefiori, P. Braca, S. Carniel, P. Willett, A. Iodice, D. Riccio, A. Farina, "Space-based Global Maritime Surveillance. Part II: Artificial Intelligence and Data Fusion Techniques," IEEE Aerospace and Electronic Systems Magazine (under review).

URBAN COMBAT ADVANCED TRAINING TECHNOLOGY – LIVE SIMULATION STANDARDS (UCATT-LSS) [MSG-140]

In the early 2000s, NATO studies showed and predicted that urban areas would continue to increase in number and size and would likely become the focal point for unrest and conflict. To ensure NATO forces were prepared to operate effectively in an environment that was considered to be the most complex and physically straining, it was advised that coalition force readiness should be increased by developing a common set of training requirements and increased interoperability for instrumented urban operation training. Since that time, UCATT has worked hard and without pause to develop and promote live simulation interoperability standards. The recent shifting of focus from expeditionary missions to securing coalition territorial integrity and deterrence has led to the adage of "training is the new operations." That fact has increased the value of UCATT standards for alliance force readiness and is testimony to the great value of UCATT as an enabler of NATO operations. Over time, UCATT has become the focal point for live simulation interoperability and standardization. On any given day of the year, UCATT is demonstrably enabling large multi-national exercises that clearly show what the combined efforts of the group has achieved and promises to achieve in the future. UCATT is continuously working on a set of standardized live Simulation interfaces, like the UCATT laser engagement standard, that has placed military users and acquisition organizations in a better position to define requirements for new projects, show industry where to invest, open tendering opportunities, and bring interoperable training to a new level. UCATT has delivered and continues to deliver.

Led by Mr. Armin Thinnes, DEU.

Figure 46: MSG-140 - German infantry soldier wearing tactical engagement simulation equipment.

STAN COLE (AVT PANEL, USA)

Mr. Stanley Cole has actively conducted excellent collaborative research on behalf of the United States of America over the last three decades. As a Panel Member-at-Large in NATO's Science and Technology Organizations (STO) Applied Vehicle Technology (AVT) Panel, he has taken on many leadership roles. Since joining STO's AVT Panel, he has acted as Panel Mentor, Chair, Technical Team Member, Programme Committee Member, and Chair for numerous NATO activities. In this way, he has significantly contributed to NATO's S&T capabilities in the field of aeroelasticity.

MICHAEL EISMANN (SET PANEL, USA)

In his nearly 10 years as Coordinator of the Optics Technology Focus Group of the Sensors and Electronics Technology Panel, Dr. Michael Eismann has brought a great deal of intensity and enthusiasm to the position. As a Panel Mentor for a large number of Task Groups, Symposia, and other Panel activities he has been instrumental in the success of SET Panel's research programme. Dr. Eismann's unparalleled and indefatigable diplomacy has lifted up all of the members of the Panel to active and productive participation in the critical research of the Alliance.





ANNEXES

COLLABORATIVE PROGRAMME OF WORK

The following six Panels and one Group address the total spectrum of this collaborative effort:

AVT	Applied Vehicle Technology Panel
HFM	Human Factors and Medicine Panel
IST	Information Systems Technology Panel
SAS	System Analysis and Studies Panel
SCI	Systems Concepts and Integration Panel
SET	Sensors and Electronics Technology Panel
NMSG	NATO Modelling and Simulation Group

These Panels and the Group are the powerhouse of the collaborative model and are made up of a network of approximately 6,000 national representatives, including recognized world class scientists, engineers, and information specialists. In addition to providing critical international S&T management and scientific oversight, they also provide coordination and cooperation opportunities with military users and other NATO bodies.

The scientific effort is carried out by Technical Teams, created inside one or across several of the Panels and Group, on specific research topics and have a defined duration (usually, from one to three years). These Technical Teams can take a variety of forms, to include, e.g., Task Groups, Workshops, Symposia, Specialist's Meetings, Lecture Series, and Technical Courses. All together, these activities represent the CPoW. In all cases, these activities result in the publication of highly valued scientific literature. The results of the research can also be found in some scientific peer reviewed journals.

With 294 activities conducted in 2020, the Collaborative Programme of Work (CPoW) has increased its efforts by more than 100% since 2011.

In the years 2016 – 2020 the average yearly number of activities had already reached a steady 270, and this called for the optimization of the structure and processes of the Collaboration Support Office (CSO).

Figure 48: NATO STO CPoW brochure.

It is expected that from mid-2021 a new CSO structure and the associated Battle Rhythm will derive from the proper assessment and implementation of lessons learned as well as from recommendations provided by the NATO Defence Manpower Audit Authority – NDMAA.

This will allow strengthening coordination efforts in organizing cross domain activities as well as addressing strategic S&T topics such as Emerging and Disruptive Technologies – EDTs. Already in 2020, 47% of the CPoW activities were related to at least one EDT.

In 2021, it is expected to see further improvements in terms of CPoW quality and relevancy to the strategic targets set by the Nations, the present COVID-19 crisis permitting. So far, while the duration of some activities has been extended, the majority of activities have been able to work virtually to progress their research activities.

All necessary information on the status of the CPoW can be found in the CPoW brochure at: www.sto.nato.int.

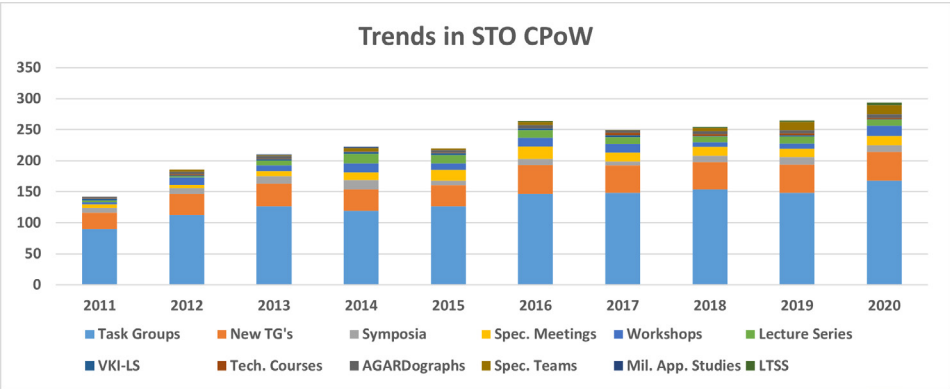

Figure 47: Trends in the NATO STO CPoW.

COLLABORATION SUPPORT OFFICE

The Collaboration Support Office (CSO) provides executive and administrative support to the STO Collaborative Programme of Work (CPoW), which materializes the collaborative business model whereby NATO and Partner Nations contribute their national resources to define, conduct and promote cooperative research and information exchange. The support provided by the CSO includes supporting the business of the six STO Panels and the NATO Modelling and Simulation Group, facilitating all collaborative activities, maintaining an active network of scientists, budget planning, managing activity reports publication, as well as a strong S&T findings dissemination support service through an Outreach and Information and Knowledge Management dedicated staff, its website, the "Science Connect" SharePoint tool, and the CPoW database. All of these tasks performed by the CSO contribute to the high quality and associated recognition of the STO CPoW.

CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

ABOUT NATO STO CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION

Directed by Dr Catherine Warner, the NATO STO Centre for Maritime Research and Experimentation (CMRE) is a world-class scientific research and experimentation facility focused on the maritime domain. The Centre delivers innovative and field-tested science and technology solutions to address defence and security needs of the Alliance.

Building on over 60 years of knowledge and experience, CMRE supports NATO's technological advantage in the maritime domain by strengthening the science and technology network, accelerating the development of critical capabilities within the Alliance and building science and technology capacity through partnerships. The Centre provides an outstanding at-sea research environment where internationally recognized scientists and engineers from all NATO Nations collaborate and deliver results more effectively than would be possible by individual nations.

RESEARCH VESSELS

Two NATO-owned research vessels enable CMRE experimentation ranging from concept development to prototype demonstration in an operational environment. Both ships, flagged and crewed by the Italian Navy, have modern facilities and are complementary, providing a flexible capability from the near shore to the deep ocean to the Arctic.

NATO Research Vessel (NRV) ALLIANCE One of the world's quietest ships, the NRV ALLIANCE is an ice-capable, global class vessel designed to minimize noise radiating from the ship into the water. The ALLIANCE is an excellent platform for sonar testing and other types of research where a quiet platform is essential. The 93-metre, 3180-ton, open ocean research vessel offers 400 square metres of laboratory space and state-of-the-art navigation and communication equipment.

S&T organization

Centre for Maritime Research & Experimentation

Coastal Research Vessel (CRV) LEONARDO Launched in 2002, the CRV LEONARDO is the smallest research vessel in the world that is fitted with dynamic positioning and substantial deck handling equipment. The CRV Leonardo is a 300-ton coastal vessel suitable for inshore operations, in particular research experiments with Autonomous Underwater Vehicles and port protection.

Interested in chartering a vessel? Please email smo@cmre.nato.int.

PROGRAMME OF WORK

CMRE conducts cutting-edge maritime scientific research and experimentation, ranging from concept development to prototype demonstration at sea. Today, the Centre's scope encompasses technological trends focused on Collaborative Autonomy, Big Data Analytics and Decision Support Tools, and Artificial Intelligence and Deep Learning. CMRE's main scientific programmes are funded by NATO Allied Command Transformation (ACT) and are designed to address future defence requirements of the Alliance in the maritime domain.

Autonomy for Anti-Submarine Warfare: Improving the Alliance's ability to counter submarine threats through networks of securely communicating autonomous systems.

Environmental Knowledge and Operational Effectiveness: Improving the Alliance's ability to operate in the maritime domain through greater understanding of the operating environment.

Data Knowledge and Operational Effectiveness: Using data science techniques to improve maritime situational awareness and information exchange between NATO Nations.

Autonomous Naval Mine Countermeasures: Strengthening NATO's ability to counter naval mines through networks of securely communicating autonomous systems.

Maritime Unmanned Systems Enablers: Providing capabilities for the development of unmanned system of systems with a high level of interoperability, security and persistence.

The main ACT-funded programmes are supplemented by projects funded by the European Commission and the Nations.

THE OFFICE OF THE CHIEF SCIENTIST

The Office of the Chief Scientist (OCS) is the STO's executive body closest to the political and military leaders at NATO HQ. Composed of three sections (Strategy and Policy; Coordination and Outreach; Advice), the OCS supports the Chief Scientist in two essential functions: as the Chairperson of the Science and Technology Board (STB), and as the senior scientific advisor to NATO leadership. Beyond providing the executive support to the STB and its chartered responsibilities, the OCS acts as a focal point for the STO Programmes of Work (PoWs) and its users represented at NATO HQ. To that end, the OCS works with the S&T results generated through the STO PoWs and promotes their use in the political and military context. Engaging the committees and staffs at NATO HQ and beyond, the OCS coordinates and generates an overview of NATO S&T programmes across the Alliance to highlight the most relevant and recent S&T results that are available to inform NATO decision making.

Furthermore, the OCS staff support the Chief Scientist in delivering analyses and assessments of significant S&T trends and developments and their potential impact on Alliance objectives, and delivering assessments of the potential security impact of emerging technologies.

During 2020, the COVID 19 pandemic has strongly affected the way we work at STO. The use of IT tools to support virtual collaboration and virtual meetings characterized almost entirely the year.

The two annual STB meetings (Spring and Fall) were conducted virtually. Nevertheless, an effective decision-making capability was supported through virtual means.

Furthermore, the lessons learned from this experience are leading OCS to think and implement new procedures for conducting discussions and making decisions in the future STB business.

Responding to the increasing focus of NATO leadership on innovation in general, the Chief Scientist continued to orient the work of the STO to enhance the impact of S&T for the Nations and NATO, with particular focus on EDTs. Under his guidance, OCS has also reinforced strategic communication about that impact.

In his capacity as a member of the Innovation Board, the Chief Scientist continued his work in advising senior leaders on addressing EDTs, promoting innovation, and maintaining the technological and knowledge advantage of the Alliance. As the emphasis on EDTs increasingly framed the forward looking discussions of decision makers, the OCS redirected the preparation of a broad technology trends analysis to tailor its upcoming report to the new demand signal and to deliver a systematic assessment of those EDTs (including maturity, current developments, potential applications, and military impact).

Due to the growing recognition of the importance and challenge of maintaining a technology edge for the Alliance, there is an increasing demand for the evidence-based advice and scientific insights that the STO can bring to NATO HQ. The Chief Scientist and his staff are dedicated to meeting that demand.

In the latter context, some issues have been particularly addressed. For example, significant activities have been conducted to advise the NATO leadership on how NATO may be able to support nuclear verification efforts.

LIST OF ACRONYMS AND ABBREVIATIONS

LIST OF ACRONYMS

A2/AD	Anti Access/Area Denial
AC/326	Sub Group A (Energetic Materials Team)
ACO	Allied Command Operations
ACT	Allied Command Operations
AEP	Allied Engineering Publication
AFP	Agence France Presse
AFRL	Air Force Research Laboratory
AFSC	Alliance Future Surveillance and Control
AI	Artificial Intelligence
AIBDMDM	AI and Big Data for Military Decision Making
AIS	Automatic Identification System
ANMCM	Autonomous Naval Mine Countermeasures
ASE	Aircraft Survivability Equipment
ASW	AntiSubmarine Warfare
ATR	Automatic Target Recognition
AVS	Acoustic Vector Sensor
AVT	Applied Vehicle Technology Panel
AWACS	Airborne Warning and Control System
BARLAMARE	Bio-Acoustic Research to Learn About the Marine Environment
CAN	Canada
CBR	Chemical, Biological and Radiological
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosives
CC SBAMD	Competence Centre Surface Based Air Missile Defence
CCD	Capability Concept Demonstrator
CC SDSMA	Competence Centre Surface Based Air Missile Defence
CDT	Cooperative Demonstration of Technology
CEDEA	Centro de Experimentación de El Arenosillo
CEPC	Civil Emergency Planning Committee
CHE	Switzerland [Confoederatio Helvetica]
CIA	Central Intelligence Agency
CIMIC	Civil-Military Co-operation
CMRE	Centre for Maritime Research and Experimentation
CMTF	Crisis Management Task Force
CNAD	Conference of the National Armament Directors
CNR	National Research Council [ITA]
COB	Crisis Oversight Board
COE	Centres of Excellence
COMEDS	Committee of the Chiefs of Military Medical Services
COVID-19	Coronavirus Disease 2019
CPoW	Collaborative Programme of Work
CRV	Coastal Research Vessel
CSO	Collaboration Support Office
CST	Custodian Support Team
CWIX	Coalition Warrior Interoperability eXercise
DANS	Distributed Autonomous Networked Systems
DARPA	Defense Advanced Research Projects Agency
DAS	Defensive Aids Systems
DC&M	Data Collection and Management
DDPS	Federal Department of Defence, Civil Protection and Sport [CHE]
DEU	Germany [Deutschland]
DF-17	Dongfeng-17 [Chinese solid-fuelled road-mobile medium-range ballistic missile]
DFS	Data Farming Services
DGA	Directorate General of Armaments [FRA]
DKOE	Data Knowledge and Operational Effectiveness
Dr	Doctor
DRDC	Defence Research and Development Canada
DRI	Detection, Classification and Identification
EDT	Emerging and Disruptive Technologies
EKOE	Environmental Knowledge and Operational Effectiveness

ELROB	The European Land Robot Trial
EnRicH	European Robotics Hackathon
EO-TDA	Electro-Optical Tactical Decision Aid
EPWG	Environmental Protection Working Group
ERL	European Robotics League
ERNCIP	European Reference Network for Critical Infrastructure Protection
ESC	Economics and Security Committee
ESP	Spain [España]
ET	Exploratory Team
EU	European Union
EW	Electronic warfare
FFI	Norwegian Defence Research Establishment
FMN	Federated Mission Networking
FOM	Federation Object Model
FRA	France
GBR	United Kingdom of Great Britain and Northern Ireland
Gen	General
GIGA	German Institute for Global and Area Studies
GIONA	Education for the Future of the Sea project
GIUK	Greenland-Iceland-United Kingdom
GLOBSEC	LOBSEC Bratislava Forum on Security, European Affairs, Energy, Economy, and Strategic Communications
GS	General staff
HFM	Human Factors and Medicine Panel
HLS	Heat, Light and Sound Research, Inc
HQ	Headquarters
HS	Hellenic Ship
HTLC	High Level Technical Concepts
IA&DS	Information Analysis and Decision Support
IABMD	Integrated Air and Ballistic Missile Defence
IED	Improvised Explosive Device
IEEE	Institute of Electrical and Electronics Engineers
IMX	International Maritime Exercise
INRS	National Institute of Scientific Research [CAN]
IOP	Interoperability Profile
IPB	Intelligence Preparation of the Battlespace
IPS	Ice Protection Systems
ISMAR	Marine Sciences Research Institute [ITA]
ISR	Intelligence, Surveillance and Reconnaissance (ISR)
IST	Information Systems Technology Panel
IT	Information Technology
JAPCC	Joint Air Power Competence Centre
JAUS	Joint Architecture for Unmanned System
JCBRN Def COE	Joint Chemical, Biological, Radiological and Nuclear Defence Centre of Excellence
JIIM	Joint, Interagency, Intergovernmental, and Multi-National
JMTDS	Joint Mission Training by Distributed Simulation
JWC	[NATO] Joint Warfare Centre
KKR	Kohlberg Kravis Roberts
LAMMA Consortium	Environmental Modelling and Monitoring Laboratory for Sustainable Development [ITA]
LCAS	Littoral Continuous Active Sonar
LCG LE	NATO Land Capability Group Land Engagement
Lt. Col	Lieutenant Colonel
LTSS	Long-Term Scientific Study
LVC	Live-Virtual-Constructive
MAI2F	Maritime Artificial Intelligence and Information Fusion
MARCOM	[NATO] Maritime Command
MCM	Mine Countermeasures
MilMeD COE	Centre of Excellence for Military Medicine
MNE	Multi-National Exercise
MOA	Mission-Oriented Approach
MPOLIS	Maritime Pattern-Of-Life Information Service
MREP20	Recognized Environmental Picture Mediterranean 2020
Mr.	Mister
Ms.	Miss or Mrs

MSA	Maritime Situational Awareness
MSG	[NATO] Modelling and Simulation Group
MSI	Multi-Spectral Instrument
MSIAC	Munitions Safety Information Analysis Center
MSTC	Maritime Science and Technology Experts Committee
MUS	Maritime Unmanned Systems
MUSCLE	Minehunting UUV for Shallow Water Covert Littoral Expeditions
MUSE	Maritime Unmanned Systems Enablers
MUTC	Muscatatuck Urban Training Complex
NAC	North Atlantic Council
NAFAG ACG3 SG/2	NATO Industrial Advisory Group (NIAG) Study Groups
NATO	North Atlantic Treaty Organization
NCIA	NATO Communications and Information Agency
NCTR	Non Cooperative Target Recognition
NDAS	NATO Defensive Aids Systems
NDMAA	NATO Defence Manpower Audit Authority
NIAG	NATO Industrial Advisory Group
NLD	Netherlands
NLR	Netherlands Aerospace Centre
NMSG	NATO Modelling and Simulation Group
NN	Neural Networks
NOR	Norway
NRC	National Research Council Canada
NRV	NATO Research Vessel
NSPA	NATO Support and Procurement Agency
OCU	Operator Control Units
OCS	Office of the Chief Scientist
OEX	Ocean Explorer C [Unmanned Underwater Vehicle]
OGS	National Institute of Oceanography and Experimental Geophysics [ITA]
ONERA	Office National d 'Etudes et de Recherches Aérospatiales
ONR	Office of Naval Research [USA]
PASSEX	Passaging Exercise
PBM	Panel Business Meeting
Prof.	Professor
PRT	Portugal
PSYOPS	Psychological Operations
RFID	Radio-Frequency Identification
ROS	Robot Operating System
RSM	Research Specialists' Meeting
RST	Research Specialist Team
RTG	Research Task Group
RWS	Research Workshop
SAA	Scientific Achievement Award
SACT	Supreme Allied Commander Transformation
SAS	System Analysis and Studies Panel
SBAMD	Surface Based Air and Missile Defence
SCI	Systems Concepts and Integration Panel
SET	Sensors and Electronics Technology Panel
SHOM	Service hydrographique et océanographique de la Marine [FRA]
SIO	Scripps Institution of Oceanography
SPC	AFSC Project Office and the Steering Committee
ST	Specialist Team
STANAG	[NATO] Standardization Agreement
STB	Science and Technology Board
STEM	Science, Technology, Engineering and Mathematics
STO	Science and Technology Organiation
TDA	Tactical Decision Aid (EO-TDAS Electro-Optical Tactical Decision Aid
TG	Task Group
TNO	Netherlands Organisation for Applied Scientific Research
TNO DSS	Netherlands Organisation for Applied Scientific Research. Defence, Safety and Security
ToE	Team of Experts
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UCATT-LSS	Urban Combat Advanced Training Technology – Live Simulation Standards
UCSD	University of California San Diego

UGS	Unmanned Ground Systems
UGV	Unmanned Ground Vehicles
UN	United Nations
UNIBO	University of Bologna
US	United States [of America]
USA	United States of America
UUV	Unmanned Underwater Vehicles
UXO	Unexploded Ordnance
VUCA	Volatile, Uncertain, Complex, and Ambiguous
WHO	World Health Organization
WHOI	Woods Hole Oceanographic Institution

LIST OF LINKS/CONTACT DETAILS

OFFICE OF THE CHIEF SCIENTIST (OCS)

Twitter: @NATO_STO_OCS

LinkedIn: NATO STO OCS Office of the Chief Scientist

YouTube: NATO STO OCS Office of the Chief Scientist

Website: https://www.nato.int/sto

Address: NATO STO-OCS, NATO HQ-Blvd. Léopold III, B - 1110 Brussels- Belgium

Email: mbx.sto@hq.nato.int

COLLABORATION SUPPORT OFFICE (CSO)

LinkedIn: NATO Science and Technology Organization (CSO)

Facebook: NATO Science and Technology Organization CSO

YouTube: NATO Science & Technology Organization

Website: www.sto.nato.int

Address: NATO STO -CSO, BP 25, 92201 Neuilly sur Seine – France

Email: mailbox@cso.nato.int

CENTRE FOR MARITIME RESEARCH AND EXPERIMENTATION (CMRE)

Twitter: @sto_cmre

Facebook: NATOSTOCMRE

Linkedin: NATO STO-CMRE

Website: https://www.cmre.nato.int

Address: NATO STO-CMRE, Viale San Bartolomeo, 400 19126 La Spezia (SP) - Italy

Email: pao@cmre.nato.int


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ground
prediction
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2σ
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