
Technical Evaluation Report

Systems Concepts and Integration (SCI) Panel SCI-329 Research Specialists' Meeting on

'Capabilities for Sensing, Search, and Surveillance in the Arctic'

Nuuk, Greenland, Kingdom of Denmark, 19-21 June 2023

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OVERVIEW

The SCI-329 Research Specialists' Meeting on 'Capabilities for Sensing, Search, and Surveillance in the Arctic' took place in Nuuk, Greenland, Kingdom of Denmark, on 19-21 June 2023. The meeting had 50 registered participants from 11 nations and 3 NATO bodies. There were 5 keynote addresses, a presentation on STO and CSO, and 23 regular presentations of papers. Even though the location is difficult to reach, being in the Far North was very important to set the tone and give first-hand experience of the Arctic to participants that had not yet had the privilege of being there, making certain issues very clear.

The two first days were spent with keynote addresses and paper presentations, with a very comprehensive assortment of stakeholders: military commands, government policymaking bodies, research institutions (university and research centres), commercial companies, and consortia that are conducting joint collaboration efforts, such as exercises, joint projects, pooling of resources and exchange of knowledge.

During the last day, besides participating in the official celebrations of the National Day of Greenland, the participants went aboard a Danish warship that is patrolling Greenland, to get a better understanding of the difficulties felt by the military in the Far North, and to network, not only with the other participants in the specialist meeting, but also with the participants in the NATO Innovation Challenge, this year under the theme "Monitoring the Arctic from Space to Seabed". The NATO Innovation Challenges are promoted by NATO Allied Command Transformation (ACT), and this year it was co-organized with NATO Communications and Information Agency (NCIA) and the Open Seas Technology Innovation Hub (supported by the US Department of Energy) and hosted by the Joint Arctic Command of Denmark.

DETAILED DESCRIPTION

The meeting started with welcoming remarks by the Specialist Meeting Chairman, Dr Ernst KROGAGER, from the Defence Research Center, Danish Ministry of Defence Acquisition and Logistics Organisation (DALO), Denmark.

Welcoming remarks were also made by Steen SØNDERGAARD, Director of Defence Research Center, DALO, Denmark, Brigadier General Poul PRIMDAHL, Acting Commander Joint Arctic Command (JACO), Denmark, and John-Mikal STØRDAL, Director, NATO Science & Technology Organization (STO), Collaboration Support Office (CSO).

OPENING SESSION

Brigadier General Poul J. PRIMDAHL, Acting Commander of Joint Arctic Command, Denmark gave the first keynote address on *An Introduction to the Joint Arctic Command*, that set the tone for the challenges that the military faces in this area. His presentation stressed the necessity of using technology (satellite and airborne images, unmanned systems, *etc.*) to monitor such a huge and hostile area.

Brigadier General Didier POLOMÉ, ACT Digital Transformation Champion and Special Advisor, NATO Allied Command Transformation (ACT), gave the second keynote address, on *NATO Digital Transformation*. The cyber domain cuts across all operational domains, and digital transformation is unavoidable. Warfighting will have to use digital transformation even in “classical” scenarios to shorten OODA loops and response times. The discussion centred on the fact that Digital Transformation and AI research is being led by private companies, and not the military. The military is therefore reliant on the commercial sector, but it is a relatively small and financially unimportant client.

The Director of the Collaboration Support Office (CSO), John-Mikal STØRDAL, gave a presentation on the mission, organization, and activities of CSO. Besides the impressive statistics of accomplishments so far, the presentation included examples of very successful activities of this vast network of researchers that pool their resources to improve the overall capabilities of NATO nations. The activities of CSO were compared to a “potluck meal”, with the added benefit that the result is better than the sum of the parts, and even small nations can contribute and receive more than they could ever accomplish by themselves.

SESSION 1 - S&T STRATEGY AND INTERNATIONAL EFFORTS

The meeting proceeded with the first paper session, dedicated to “*S&T Strategy and International Efforts*”.

The third keynote address was made by videoconference by Ian D.D. LIVERMORE (CAN), Canadian Forces Intelligence Command, Canada, on *Perspectives on Arctic Defence and Security*. A classified briefing is available on demand (contact Ian.livermore@forces.gc.ca), but the presentation given was NATO Unclassified. There is great concern with Russia’s change in posture (suspending participation in various Arctic organizations, getting closer to China, *etc.*), and great care must be taken to avoid escalation, but that is better discussed in other fora. Questions were raised about the research community’s liaison with Canadian Rangers (reservists, mostly local) that is useful, but has serious limitations due to inadequate communications and training. Other questions addressed the reliability and importance of satellite SAR images, that are very effective in open water, but less so when ice and snow are present. Infrared sensors, on the other hand, have better performance under those conditions.

Joseph BELL (USA), from the Office of Naval Research (ONR), presented the *International Cooperative Engagement Program for Polar Research (ICE-PPR)* (pronounced Ice-Paper), which is a multi-lateral MoU with a 25- year duration, to promote collaboration amongst 7 of the Arctic nations (6 from NATO, plus Sweden). Various initiatives were presented, including joint research projects, conferences, trials, and technology demonstrations. The points of contact for the ICE-PPR working groups were given. Some questions concerned why other nations are not members.

Camilla MOHRDIECK (DEU) and Martin Ulme (DEU) presented a paper named *Safety and Security for the Arctic Operational Space: Lessons Learned on Multiple Sensor Surveillance*, describing the PASSAGES (Protection and Advances Surveillance System for the Arctic: Green, Efficient, Secure) project developed by Airbus (DEU), Dalhousie University (CAN), ExactEarch Ltd. (CAN), and the Fraunhofer Institute (DEU). The project was centred on the North-West passage opening up for commercial shipping. The safety and security risks are basically the same as in 2016, except for the fact that now there is a much more realistic prospect of conflict. It was emphasized that more satellite coverage is necessary to acquire situational awareness of the northwest passage.

The monitoring should concentrate on the chokepoints, but it was noted that for certain classes of polar-reinforced ships, transits have no restrictions during the summer.

Pierre LAMONTAGNE (CAN), from Defence Research and Development Canada (DRDC), presented a paper named *Demonstration of a Hybrid Space Architecture in the Arctic Region during Arctic Edge 2022 Exercise*. It is a condensed version of the full report that is available to authorized partners. This exercise resulted from the Micro-Satellite Military Utility (MSMU) MoU amongst 9 nations with interests in the Arctic, and the resulting Hybrid Space Architecture (HSA). The exercise used around 255 available sensor systems. To conduct the exercise, the Global Unification Environment (GLUE) software was used to coordinate and greatly simplify mission planning operations. The exercise had a number of military objectives on named Areas of Interest (NAI) (Airbases, Ice Camps, Harbors etc), that were almost all met, showing the success of the adopted approach.

SESSION 2 - AIRBORNE AND SPACE-BASED CAPABILITIES

The second session, after lunch was on “**Airborne and Space-Based Capabilities**”.

Prof. Andreas REIGBER (DEU), German Aerospace Centre (DLR), Germany gave a keynote address on *Airborne SAR Research: Preparing Future Satellite Missions*. He gave a brief history of Synthetic Aperture Radars, and why they are so important. He then proceeded to present the recent F-SAR developed at DLR., that uses 4 different frequency bands simultaneously. An interesting aspect is that it is capable of multi-band circular imaging, reaching “super-resolution” accuracy, that amongst other things can produce very good 3D images revealing features beneath the ice surface. They are continuing work to produce better systems shortly.

Rémi BAQUÉ (FRA), from ONERA, presented *Airborne Experiment over South Greenland for Ice Sheet Multi-frequency SAR Imagery*. It reported how ONERA, GEUS (from Denmark), and BEA managed to find part of an aircraft engine that fell from a commercial airliner over Greenland. After a lot of improvements and thanks to the stubborn persistence of the research team, the part was finally found, and recovered for analysis. Another presentation, given in the 4th Session presented GUES’s perspective on this mission, together with their other capabilities.

Vincent ROY (CAN), from Defence Research and Development Canada (DRDC), presented *The Canadian Armed Forces Joint Arctic Experiment (JAE): Using Aerial and Satellite Imagery for Arctic Surveillance*. He gave an overview of DRDC and explained the objective of JAE. In the reported experiment, a scenario where a satellite falls to earth and must be found in the Arctic, using hyperspectral cameras was simulated. Several experiments were conducted, detecting various contacts in the snow and ice. The JAE also demonstrated that it is possible to perform near-shore bathymetry under water (up to 8-10m) for charting navigation channels. The same techniques were used with commercial satellite images, with promising results, especially for change detection.

Pekka LAURILA (FIN), from ICEYE presented *Microsatellite ISR for Maritime Operations Support in the Arctic*. The company, founded by Pekka Laurila and fellow students less than 10 years ago, operates the first and largest constellation of Micro-Satellites with SAR capability. An overview of the capabilities of such systems was presented, with particular attention to high revisit rates (approx. 55 time a day) and change detection. The company envisions that soon they will be able to perform “tactical coverage” as an alternative to aircraft surveillance. A practical example of observation of the conference location (Nuuk) done just the night before the conference was presented. An example from the war in Ukraine was also presented.

Henning HEISELBERG (DNK), from the Technical University of Denmark (DTU), Denmark, presented *Dark Ships in the Arctic – an Overview*. He started by presenting the work done by the DTU Space unit. The training datasets are calibrated with known AIS tracks, and DTU currently has a very large database of calibrated images. Using Doppler shifts they can determine position, direction and speed of dark ships, and several examples of identification of dark ships and their activities were presented. DTU has involved many MSc students in research

projects in this area. There were various questions regarding resolution and sensing capabilities both from satellites and from underwater fibre-optic cables used as acoustic sensors.

Kristian SØRENSEN (DNK), from the Technical University of Denmark (DTU), Denmark, presented *On-board AI: Lightweight SAR Ship Detection*. This work tries to solve the problem of limited bandwidth to download images from satellites by doing the signal and AI processing aboard the satellite, and downloading data only when necessary, and preferably processed data. The different approaches to this problem were presented, together with a discussion on the results obtained.

Tonje ARNESEN (NOR), from the Norwegian Defence Research Establishment (FFI), Norway, presented *Observation of the Arctic Region with Various Space Based Capabilities*. One of the problems is the inability of classical geostationary communication satellites to provide service in the Far North. The space command is “as civilian as possible - as military as required”, and has launched ever more capable satellites, using cutting edge technology, enabling detection for both safety and security applications, together with communications. The Norwegian *Arctic Surveillance Program*, joining together 4 different organizations, was presented. Questions addressed various techniques that are being used in this project.

SESSION 3 - SITUATIONAL AWARENESS AND ENVIRONMENTAL MONITORING

The third session of the meeting was on “Situational Awareness and Environmental Monitoring”.

Sigmund DEHLI (NOR), from Kongsberg Satellite Services, Norway, presented *Space-based Maritime Surveillance – Need for joint Development seen from the Industry*. The capabilities and infrastructure for operating low orbit satellite systems were presented. The Svalbard station, for example, can use 14 passes a day for downloading data on practically all polar-orbiting satellites. Several examples were given of products delivered, some with high military value. The MicroSar, soon to be operational, will provide 300 kms swaths with 3m resolution, with SAR and AIS.

Andreas STOKHOLM (DNK), from the Technical University of Denmark (DTU), Denmark, presented *Automatic Sea Ice Charting with Sentinel-1 SAR*, developed in conjunction with ESA, Phi-Lab, Plar view, NERSC, Denmark’s Meteorology Service, and the Norwegian Computer Center. Ice charts, using Egg Code (SIGRID-3) were explained, and several examples of automatic production of these charts were given. The AutoICE AI4Arctic v3 challenge competition (available at ESA’s website AI4EO) was also presented, with comments on the results.

Tim JENSEN (DNK) from Technical University of Denmark (DTU), Denmark, presented *Airborne Quantum Gravity Surveys and its Applications*. He started by showing the importance of precise measurement of gravity. The changes being introduced now with the second quantum revolution and their impact on gravity measurements were described.

SESSION 4 - SENSOR SYSTEMS AND APPLICATIONS

The fourth session of the meeting was on “Sensor Systems and Applications”

Prof. Marco MARTORELLA (ITA/GBR), University of Birmingham, United Kingdom, and CNIT's National Radar and Surveillance Systems Laboratory, Italy, gave a keynote address on *Multidimensional Radar Imaging*. He presented the basic theory behind these types of radars, with various practical examples.

Penelope HOW (GBR/DNK), from the Geological Survey of Denmark and Greenland (GEUS), presented *Search and Recovery of Aircraft Parts in Ice Sheet Crevasse Field Using Airborne and In-situ Geophysical Sensors*, developed with partners from NASA Goddard Institute for Space Studies, New York, NY, USA, Greenland

Guidance, the Netherlands, Polar Research Equipment, School of Engineering at Dartmouth College, United States, Department of Geoscience, Aarhus University, Denmark, and ONERA, France. She presented the work done by GEUS, namely the POMICE project to establish weather and geophysical monitoring stations on Greenland's ice sheet was described. The data from those stations are publicly available. She then presented the activities done by GEUS on the Ice Field and described the remarkable recovery of aircraft parts lost in the Ice Field, mentioned in ONERA's presentation in session 2.

Kristian A. SØRENSEN (DNK), from the Technical University of Denmark (DTU), Denmark presented *Detect On-ground Radars in SAR Images*. The way active radars interfere with space-based SAR was described, and it was shown how these interferences can be used to detect and characterize ground and ship-borne radars. Several practical examples were given.

Sandro CARNIEL (ITA) from NATO STO Centre for Maritime Research and Experimentation (CMRE) presented *CMRE S&T Strategy and Research Projects in a Thawing Arctic Ocean: Preparing for Future NATO Challenges*. The activities and organization of CMRE were presented, with an overview of several research projects concerning the Arctic. The plans and strategy of CMRE concerning the Arctic was presented. This strategy includes close cooperation with many national and international organizations. There is a new activity on climate changes, concerning the Arctic in particular, funded directly by the office of the chief scientist.

Kristian SØRENSEN (DNK), substituting Peder HEISELBERG, from the Technical University of Denmark (DTU), Denmark, presented *Ship Identification*. Different approaches to identify ships from Satellite images and other sensors were overviewed.

Ingebjørg KÅSEN (NOR), from the Norwegian Defence Research Establishment (FFI), Norway, presented *Ship Detection in the Arctic using Machine Learning*. The work presented was on processing Sentinel-2 images, with all the challenges that this brings, even using all the multiband sensors available. Very good results were obtained with precision over 99% and recall over 98%.

Karl ZINGLERSEN, from the Institute of Natural Resources, Greenland presented *Acoustic Sensors for Science in Greenland*. An overview of the importance of fishing to Greenland was presented, and the resources that the Institute of Natural Resources has were presented.

Ernst KROGAGER, the chairman of this meeting presented *Multidimensional Synthetic Aperture Radar for Arctic Surveillance*. Besides reviewing multidimensional radar techniques with illustrative examples, he presented the results of current research.

SESSION 5 - AUTONOMOUS SOLUTIONS, MACHINE LEARNING AND DISINFORMATION

The fifth and final session of the meeting was on "Autonomous Solutions, Machine Learning and Disinformation".

Martins VEICHERTS (DNK), from the Danish Acquisition and Logistics Organization, presented *Ship Detection from SAR and RF (formally Space-Based Sensor Data Fusion: SAR, AIS and NRD for Maritime Surveillance in the Arctic Region)*, done in conjunction with the Technical University of Denmark (DTU) and FFI, Norway. The satellites used, and their sensors were presented. One of the satellites used monitors X-band (9-11GHz) radars, which are mandatory for ships above 300T. These systems allow a very comprehensive surveillance of maritime traffic.

Filip RENSCH-JACOBSEN (DNK), from Terma Group A/S, Denmark, presented *What difference does Machine Learning Models do for the Future of Situational Awareness?*. The basic idea is to identify patterns of life and

normal behaviours to construct digital twins, and then look for abnormalities in those patterns. Examples of behaviours and characteristics were given.

Aniello RUSSO (ITA), from NATO STO Centre for Maritime Research and Experimentation (CMRE), presented *Heterogeneous, Hybrid Networks for Pervasive, Persistent and Autonomous Maritime Situational Awareness*. The concept of networks of heterogeneous assets, including unmanned system, cooperating with each other to achieve better situational awareness was presented. The acoustic conditions in the Arctic regions, specifically under ice, were discussed.

Neil VERRALL (GBR), from DSTL, United Kingdom, presented *Considerations for Arctic Operations: The Strategic & Regional Information Environment*. Basic concepts of hybrid warfare were presented, and the present and future threats in this area were discussed, and examples given (e.g. available at Euvsdisinfo.eu/disinformation-causes).

CLOSING SESSION

A final panel discussion was chaired by the RSM chairman, Dr. Ernst KROGAGER, with panelists T. N. ARNESEN, Dr H. HEISELBERG, Dr P. HOW, Prof. M. MARTORELLA, and Prof. A. REIGBER, that raised a lot of interest amongst the participants. The discussion ranged on various subjects. One was how to involve end-users (military), commercial companies, and academia in joint development projects without violating legal and ethical rules, but still making it worthwhile for companies. There was a lot of concern that the military are not leading digital transformation and are lagging behind in crucial areas such as machine learning, handling *Big Data*, and even satellite coverage with small, SAR-enabled system.

Prof. Victor Lobo, Technical Evaluation Report author, summarized the good work done during this meeting, thanking the participants for their excellent contributions, and encouraging them to continue cooperating and improving NATO's understanding and capabilities in the Arctic.

The presentation part of the specialist meeting ended with the host, Steen SØNDERGAARD, Director of Defence Research Center, DALO, Denmark, thanking the participants and giving awards to those involved in the organization of this event.

The presentations are available at www.sto.nato.int/publications, under STO-MP-SCI-329.

Visit and short cruise on a Danish Greenland Patrol Warship, Networking, and Participation in the Celebration of Greenland's National Day.

The last day of the meeting was an opportunity to experience the operational, physical, and social environment of Greenland. The participants had a guided tour by a Greenlander of Inuit ascent, that explained the Greenland way of life, in particular of those with Inuit ascent, the transformations that have been taking place, and the concerns that it raises. The participants attended the official celebration of Greenland's national day.

They then boarded the HDMS Vædderen, a Danish Navy Warship that patrols Greenland's waters. The crew gave briefings on various aspects of the ship, its missions, and operational environment. The participants in the NATO Innovation Challenge, this year under the theme "Monitoring the Arctic from Space to Seabed" also participated in this visit and cruise. The NATO Innovation Challenges are promoted by NATO Allied Command Transformation (ACT), and this year the event was co-organized with NATO Communications and Information Agency (NCIA) and the Open Seas Technology Innovation Hub (supported by the US Department of Energy) and hosted by the Joint Arctic Command of Denmark. The short cruise was an excellent opportunity to network not only with the other participants of the Specialist Meeting, but also with Danish military serving in the Far North and the various teams and juries of NATO Innovation Challenge.

EVALUATION, CONCLUSIONS, AND RECOMMENDATIONS

The specialist meeting consistently had **very high quality presentations**, and overall the Specialist Meeting was **excellent** and offered **outstanding value** to the participants, to NATO, and the nations involved. This was explicitly mentioned by various participants, and even those that have been working on Sensing, Search, and Surveillance in the Arctic for a long time found about new developments and initiatives that are extremely important for their work.

As would be expected for an event in the Kingdom of Denmark, Denmark had the greatest number of participants, followed closely by Canada and Norway. All Arctic NATO and NATO-friendly nations participated, either with delegates in the meeting or with joint work that was presented on their behalf by partners, including Finland that recently joined NATO and participated with a government employee and with a private company. It is also worth noting that there were participants from other nations that, with or without direct participation in Arctic operations, recognize the importance of the Arctic for NATO and for the world. Such is the case of the United Kingdom (that has a lot of activity concerning this region), France, The Netherlands, Italy, and Portugal.

As mentioned in the Executive Summary, the 7 main outcomes of this meeting are:

- 1) The Arctic is **changing fast**, with serious implications for the world in general, and defence of NATO nations in particular. Care must be taken not to escalate tensions, but effective monitoring is crucial to avoid serious consequences, enable freedom of use, and ensure a safe use of new trade routes.
- 2) Efforts have to be **multi-national, and collaboration** amongst all stakeholders is a must.
- 3) Arctic sensing will have to rely mainly on **Space-based systems**.
- 4) **Machine learning** is having a profound impact on the usability of these systems, and good data is necessary for the learning process.
- 5) Advances in **signal processing** techniques are crucial to help machine learning algorithms obtain useful and relevant information with the necessary speed.
- 6) Besides satellite sensors, **aerial, ground, and seaborne sensors** of various types must be used to complement, or in case of necessity act as substitutes.
- 7) There are research **institutions and companies ready** to take up these challenges, and meetings such as this one are important to promote awareness and networking amongst stakeholders.

The main recommendations are:

- 1) The proceedings of this Specialist Meeting should be made widely available.
- 2) The executive summary, or some information about this Specialist Meeting should be sent to decision makers that must be aware of NATO challenges in the Arctic.
- 3) It is convenient to hold meetings such as this one on a regular basis, to keep all stakeholders in touch with each other.
- 4) NATO decision makers should be aware of:
 - a. The unique importance of **Space-based assets** for the Arctic
 - b. The importance of **Machine Learning** and **Signal Processing** for Arctic surveillance.
 - c. The potential **benefits and threats that opening the Arctic to shipping brings**.
 - d. The importance of **continuing research and operations** in the Arctic.

In summary, it was a fantastic meeting, promoting the awareness and networking that is needed to face the surmounting challenges that, as citizens of the world and members of the NATO Alliance we all face.

The promoters and organizers of this specialist meeting, from the Danish MoD and CSO, deserve recognition for the excellent work done.

Annex A – Closing Remarks.

At the closing session, the author of the Technical Evaluation Report summarized the meeting as follows:

The “SCI-329 Research Specialists’ Meeting on ‘Capabilities for Sensing, Search, and Surveillance in the Arctic’ was, beyond any doubt, an outstanding success and can be very useful for NATO and for all our nations. Even though this location is difficult to reach, organizing it in Nuuk in the Far North, was very important to give firsthand experience of the Arctic to participants that had not yet had the privilege of being here, making certain issues very clear. We have to thank our hosts that made this possible. The meeting had 50 registered participants from 11 nations and 3 NATO bodies. There were 5 keynote addresses, and 23 regular presentations of papers.

The program was very eclectic, marked by very high quality presentations from the military, from universities and research centres, and from companies and business that are doing remarkable work for the benefit of all of us. Theodore von Kármán, the precursor of NATO STO, would be proud of the remarkable group of people that attended this meeting, that aligned the needs of the military and strategic policy makers with the capabilities of scientists that push the boundaries of knowledge, the engineers that transform that knowledge to products, and the industry that puts those products, with reliability, in the hands of those that really need them.

Thus, the meeting had an excellent balance between presentations on:

Military, strategic, and policy issues regarding the Arctic.

- 1) Exercises and trials conducted in the Arctic.
- 2) Existing infrastructures, organizations, and Memos of Understanding, that can be used for monitoring and research.
- 3) Overviews of technical areas particularly relevant for the Arctic.
- 4) Research papers, reporting on cutting edge progress in a wide variety of scientific subjects.
- 5) Company presentations, with use cases, and demonstrations of remarkable capabilities.

The Meeting started with presentations on the Military, strategic, and policy issues regarding the Arctic. General Primdahl set the tone for the whole meeting by explaining the military and strategic challenges of the Arctic. It became clear that sensing from space, with all the technology possible, will be a crucial element, but it also became clear that the Arctic will always be a very challenging operational environment, and that all available Science and Technology developments are crucial to overcome those challenges. General Polomé then discussed the Digital Transformation that NATO is going through, and how ACT is preparing to face these challenges.

We also had presentations on the strategy and plans of different nations and NATO bodies towards the Arctic, together with several partnerships and multi-national initiatives that are in place to increase our knowledge and capabilities in the Arctic, such as ICE-PPR. It became very clear that our nations need each other, and that efforts in the Arctic, for many reasons, have to be done in healthy collaboration amongst friendly nations. That collaboration was reported in presentations about large scale joint exercises such as Arctic Edge, and various very successful projects involving different nations, such as PASSAGE or the finding of fallen aircraft parts.

We had a series of presentations on Space-based and airborne sensing capabilities by research centers, universities, and companies. These included overviews of existing technologies and assets, case studies of successful developments that do push the envelope of what is possible, and research efforts to improve performance in various areas.

The third session of the meeting was on Situational Awareness and Environmental Monitoring, overviewing several efforts to map the changing scenarios of sea ice and characterize the ice sheets. The fourth session concentrated on different Sensor Systems and Applications, including classical acoustic and fiberoptic cable sensors, accelerometers, and others. The final session was on Autonomous Solutions, Machine Learning, and Disinformation that consolidated and reinforced what we had been made aware of in previous sessions, and raised

the problem of information and cognitive warfare, that has always existed but is growing to be a recognized operational domain and cuts across all the others. We ended the day with a fruitful panel discussion of all the subjects of this meeting.

Finally, from these two days of extraordinary presentations and intense networking, I would emphasize the following 7 outcomes:

- 1) The Arctic is changing fast, with serious implications for the world in general, and defense of NATO nations in particular. Care must be taken not to escalate tensions, but effective monitoring is crucial to avoid serious consequences, enable freedom of use, and ensure a safe use of new trade routes.
- 2) Efforts have to be multi-national, and collaboration amongst all stakeholders is a must.
- 3) Arctic sensing will have to rely mainly on Space-based systems.
- 4) Machine learning is having a profound impact on the usability of these systems, and good data is necessary for that learning process.
- 5) Advances in signal processing techniques are crucial to help machine learning algorithms obtain useful and relevant information with the necessary speed.
- 6) Besides satellite sensors, aerial, ground, and seaborne sensors of various types must be used to complement, or in case of necessity act as substitutes.
- 7) There are research institutions and companies ready to take up these challenges, and meetings such as this one are important to promote awareness and networking amongst stakeholders.

In summary, this was a fantastic meeting, promoting the awareness and networking that is needed to face the surmounting challenges that, as citizens of the world and members of the NATO Alliance we all face. Thank you and congratulations to you all.

