

ICE-PPR Navigation/Intelligence, Surveillance, and Reconnaissance

Workshop Report

29 April – 1 May 2025

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Over the upcoming months, NAV/ISR participants are encouraged to take part in Working Groups (WG) and Sub-Working Groups (SWG) organized by SAWG Nav/ISR. In these groups, informal discussions on CAPs are intended to explore shared challenges, capabilities, and opportunities related to project areas highlighted during the virtual workshop. The goal is to clarify what’s possible, what needs to be done, and establish a realistic timeline – ultimately shaping a clear, actionable concept that will receive the approval of country XOs and could evolve into an Exploratory Activity (EA), or, at a minimum, support coordination through less formal avenues. 67

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Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
AI	Artificial Intelligence
AIS	Automatic Identification System
AltNav	Alternative Navigation
AUV	Autonomous Underwater Vehicles
BOEM	Bureau of Ocean Energy Management
CAP	Collaborative Activity Proposal
CRREL	Cold Regions Research and Engineering Laboratory
CUI	Critical Undersea Infrastructure
DARPA	Defense Advanced Research Projects Agency
DOD	United States Department of Defense
e-LORAN	Enhanced Long Range Navigation
EA	Exploratory Activities
EW	Electronic Warfare
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HF	High Frequency
ICE-PPR	International Cooperative Engagement Program for Polar Research
IEW	Integrated Electronic Warfare
INDOPACOM	U.S. Indo-Pacific Command
ISR	Intelligence, Surveillance, and Reconnaissance



LEO	Low-Earth Orbit
MagNav	Magnetic Anomaly-aided Navigation
METOC	Meteorological and Oceanographic
ML	Machine Learning
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAV/ISR	Navigation, Intelligence, Surveillance, and Reconnaissance
NISAR	NASA-Indian Space Research Organisation (ISRO) Synthetic Aperture Radar
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NORTHCOM	United States Northern Command
ONR	Office of Naval Research
OTHR	Over-the-Horizon Radar
PA	Project Arrangements
PNT	Position, Navigation, and Timing
RF	Radio Frequency
RFI	Radio Frequency Interference
SAR	Synthetic Aperture Radar
SAWG	Situational Awareness Working Group
SERPA (CRPA)	Controlled Reception Pattern Antennas
SIGINT	Signals Intelligence



STL	Satellite Time and Location
SWaP	Size, Weight, and Power
TSC	Ted Stevens Center for Arctic Security Studies
UAS	Unpiloted Aerial Systems
UAV	Unmanned Aerial Vehicle
USAF	U.S. Air Force
USCG	United States Coast Guard
USEUCOM	US European Command
USSAWG	U.S. Situational Awareness Working Group
USV	Unmanned Surface Vehicle
UX/UI	User Experience/User Interface
VHS	Video Home System



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Executive Summary

General

The Navigation, Intelligence, Surveillance, and Reconnaissance (Nav/ISR) Workshop held 29 April – 1 May 2025 on behalf of International Cooperative Engagement Program for Polar Research (ICE-PPR) convened scientists, research administrators, and military practitioners to advance collaboration in Arctic Nav/ISR research. This workshop was co-hosted by the Ted Stevens Center (TSC) for Arctic Security Studies, the Cold Regions Research and Engineering Laboratory (CRREL), and the Office of Naval Research (ONR) on behalf of the ICE-PPR Situational Awareness Working Group (SAWG).

Activity Overview

The three-day, international, virtual ICE-PPR Nav/ISR Workshop was held in lieu of an in-person workshop at CRREL to explore research and collaborative opportunities in polar navigation and ISR research. Day 1 of the workshop explored novel solutions to positioning, navigation, and timing challenges at high latitudes and disruptions posed by adversaries. Day 2 of the workshop looked at ISR capability gaps and research opportunities for Arctic ISR across the warfighting domains. On Day 3, the Polar Ways Collaborative Activity Proposal (CAP) was presented as a case study for the development of collaborative research and cross-working group collaboration. Presentations and participant reactions, questions, reflections, and responses were noted to compile this report.

Key Findings

Based on the interaction and feedback of workshop participants, several topic areas emerged as potential further exploration. Several areas offer potential for cross-working group collaboration.

- Arctic PNT solutions involve Global Positioning System (GPS) resilience, multi-sensor fusion, and Alternative Navigation (AltNav)
- Arctic Space ISR fusion, sharing, and interoperability
- Maritime Domain Awareness, decision support, and route optimization (Polar Ways)
- Arctic Meteorology (potential Cross-Working Group collaboration)

Path Forward/Recommendations

The following recommendations including potential collaborators can be found in the conclusion of this report with additional details on how to mature research collaboration found in Appendix 4.

Positioning, Navigation, and Timing

Promising research opportunities in positioning, navigation, and timing were explored.

Recommendation 1.1: Further explore GPS antennae hardening solutions, signal discrimination, and jamming/spoofing detection.

Recommendation 1.2: Explore map-matching for small UAVs based on visual, thermal, and other sensors with the aim of a near-term Exploratory Activity.

Recommendation 1.3: Explore the use of AI to interpret and apply remote sensing data for navigation solutions.

Recommendation 1.4: Assess interest across the Nav/ISR SWG in exploring collaboration opportunities in AltNav.

Space-based ISR

Space-based ISR capabilities held a high level of interest for practitioners and researchers alike.

Recommendation 2.1: Explore opportunities for improved sharing and interoperability among ISR stakeholders in the land domain.

Recommendation 2.2: Explore opportunities for improved sharing and interoperability among ISR stakeholders in the maritime domain.

Recommendation 2.3: Explore opportunities for improved sharing and interoperability among ISR stakeholders in the air domain.

Recommendation 2.4: Initiate further discussion of AI as a tool for intel fusion with space-based ISR producers and researchers.

Cross Working Group Collaboration

Two Cross-Working Group collaboration opportunities emerged from this workshop.

Recommendation 3.1: SAWG leadership including both SWG XOs should engage with the Polar Ways CAP.

Recommendation 3.2: SAWG/ONR leadership should draft a METOC CAP for consideration by the remaining Working Groups to determine interest in collaboration on Arctic meteorological modeling and forecasting.

Indigenous Knowledge

Indigenous Knowledge should be included in further exploration of all Nav/ISR research topics.

Conclusions from Day 1

Day 1 closed with attendees highlighting their primary takeaways. A few major areas of agreement emerged, noted below in no specific order:

- There is an emerging need to develop integrated solutions that take advantage of multiple technologies, to ensure redundancy in technology and capabilities therefore reducing risk of effective sabotage by adversaries.
- Sometimes low-tech solutions are more attractive, as harder for adversaries to interrupt.
- As we look to augment capabilities in the short-term, there must be an effort to consider what already exists: this will reduce costs and improve execution timelines in the short-term.
- General consensus of the participants was split: participants either believed GPS capabilities will be lost almost immediately in conflict, OR technology is powerful enough that while it may get messed with, it is impossible to lose GPS capability entirely.
- Modernizing Long Range Navigation (Loran) infrastructure is an exciting possibility.

Conclusions from Day 2

Participants highlighted the key takeaways and conclusions from Day 2:

- The DOD should expand its use of commercial tools to improve how it trains and operates to give troops better awareness of their surroundings and help them adapt quickly in challenging environments.
- Train military personnel for Arctic-specific challenges.
- Strengthen collaboration between the military, industry, and local communities to guide long-term innovation and ensure real-world needs are met.
- Investment is needed in tools that can reliably work in freezing temperatures.
- Information gathered from ISR tools should be built into the planning of logistics missions to help field teams make faster, safer, and more informed decisions.

Conclusions from Day 3

Day 3 concluded with participants highlighting areas of progress and identifying areas that were recognized as needing continued work:

- New ISR technologies, like drones with longer flight times and onboard AI, are being tested for Arctic missions.

- Efforts are underway to connect military and commercial satellites to deliver real-time data directly to field teams.
- Promising sensor technologies are progressing but still need to be fully tested and approved for Arctic use.
- Harsh weather, low sunlight, and limited infrastructure still make ISR operations in the Arctic difficult.
- There's a need for more training, faster tools, and simple field kits to help teams use ISR data on the ground.

Introduction

Purpose

The purpose of this workshop is to identify collaborative research opportunities in PNT and ISR related fields by examining domain awareness gaps and sharing ongoing research among Arctic Allies. The cross-cutting nature of this workshop offers mutual benefit to participants who are approaching Arctic research from different perspectives and expands the ICE-PPR Situational Awareness Working Group.

Objectives

The following outcomes will result in findings and recommendations that inform operational commands, support policy and investment decisions, and guide future stakeholder research efforts.

- Explore current Arctic PNT limitations, vulnerabilities, and risk with insights from the recent war in Ukraine as well as Polar region-specific considerations.
- Identify PNT resilience solutions and alternatives to space-based PNT that warrant further investigation or investment.
- Identify domain awareness gaps and challenges including U.S. and Allied nation perceptions and analysis.
- Discuss ISR advancements and research opportunities in the 2026-2030 timeframe.
- Advance Cross-Working group initiatives with in-person discussions (for June).
- Develop a prioritized list of Nav/ISR research needs and collaboration opportunities for the U.S. DoD and ICE-PPR SAWG (for June).

This workshop is under the auspices of the International Cooperative Engagement Program for Polar Research (ICE-PPR). Since its inception ICE-PPR has successfully fostered and developed international collaboration within several topic areas vital to Arctic security.



ICE-PPR Overview

ICE-PPR is a multilateral agreement between the defense departments and related government agencies of seven allied high-latitude stakeholder nations: The United States, Canada, Denmark, Norway, Sweden, Finland, and New Zealand. ICE-PPR partner nations share emerging scientific and technological knowledge and assets, and plan and execute experiments to advance safety and security at high latitudes. The ICE-PPR Memorandum of Understanding (MOU) which was recently renewed in 2020 has a duration of 25 years, so that substantive and lasting collaborations can be developed and executed. The US component of ICE-PPR is led by the Office of Naval Research (ONR). ICE-PPR is organized into several topical working groups including Environmental, Human Performance, Energy, Platforms and Situational Awareness. This workshop's NAV/ISR focus falls under Situational Awareness. The Situational Awareness Working Group (SAWG) is led by Randy "Church" Kee, Maj Gen (Ret) USAF who serves as both the Principal for the US component (USSAWG) and International Chair.

Contents of the ICE-PPR NAV/ISR Workshop Report

This report will: 1) detail the structure of the workshop, speaker presentations, and breakout groups and 2) compile the key insights, highlighting identified gaps and outlining questions and next steps for future SAWG constituent research. The appendices contain the agenda, participant lists, and recommendations for future work based on the outcomes of this workshop.

Structure of the Workshop

The structure of the workshop was intended to facilitate participant interaction and generate collaborative research ideas beginning with registration and ending with a final survey. The workshop began with one keynote science update followed by six panel presentations, a presentation on cross-Working Group collaboration, and included daily breakout sessions for both structured and spontaneous discussion. Twenty-nine of 30 planned speakers made presentations.

Before, during, and after the event organizers used several methods and opportunities to glean participant input. First, a registration survey allowed participants to identify their research interests and ongoing projects which helped organizers know the audience and identify additional panelists. The design of the workshop incorporated the use of Slido with an Arctic Trivia contest to engage participants followed by topical questions to record participants' responses. The balance of the workshop was designed for free and open discourse and dialogue between presenters, moderators, and workshop participants as note takers documented the event.

Each panel had an assigned moderator and notetaker, and included planned time for Q&A. The panel themes and speakers were initiated by workshop planners then rehearsed, adapted, and conducted by individual moderators.

Breakout opportunities included spontaneous breakouts and structured breakouts. Spontaneous breakout rooms were always made available for two or more participants to exit the plenary and hold a private conversation; these rooms were little used. Following each day's panel presentations, a structured breakout session was planned to gather participants' reaction to the panels and identify potential areas of research collaboration. The organization of the Day 1 breakout used a technique called "Max Mix" to establish diverse groups answering the same question about PNT with the intent to compare group responses and identify common threads among the groups. The only effort to select these otherwise random "Max Mix" groups was to ensure multi-national participation and uniformed servicemember participation in each group. On Day 2, a "Fair Style" approach to the breakout time was planned to allow participants to choose from the many ISR related topics presented during the panels and visit with experts on each of those topics. Participants could enter and leave as many breakout rooms as they liked. In addition to breakout notes, organizers could discern the relative interest in each topic by the size of the population of each breakout room.

Day 1 and Day 2, structured breakout time was shortened and modified to account for panel presentations that ran over. The agenda was further modified on Day 3 to continue to collect breakout reactions, responses, and ideas again. In the original plan and the adjusted plan, the virtual workshop responses were intended to guide the development of an in-person follow-on event when circumstances allowed.

Dr. Phil McGillivray Science Update

Dr. Phil McGillivray, the science liaison for the US Coast Guard, provided an overview of changing sea ice, military bases in the Arctic, and key Arctic security developments to include GPS, space weather events, the physical environment, critical undersea infrastructure, quantum communications and sensors, satellites, communications, and machine learning/artificial intelligence.

After discussing sea ice retreat and potential accessibility of the transarctic route, Dr. McGillivray provided overviews of military bases in the North American and European Arctic. Increased accessibility will have an impact on these Arctic bases. Such concerns led the United Nations to set up a working group for global maritime security in November 2024. This group will also address gray zone tactics that are increasingly affecting the Arctic. All the Arctic nations are addressing shortfalls in Arctic security.

Dr. McGillivray's Arctic updates for Russia, Canada, Denmark/Greenland, Sweden, Finland, Norway, and Iceland:

- **Russia** brought their new icebreaker, Yakutia, online, and have ten new icebreakers planned by 2030. While falling short of planned goals, the Russians have increased Liquefied Natural Gas transports by 8.6% over 2023. Overall, both oil and gas tanker traffic is on the rise in the Russian Arctic. In April 2025, Russia introduced its first combat icebreaker, the Ivan Papinin, and Putin was on hand to witness the launching of Russia's first submarine hypersonic missile with a range of 560NM.
- **Canada** signed a November 2024 agreement with Norway on North Atlantic security to include coast guard cooperation. Canada appointed ambassadors to Alaska and Greenland and committed \$24 billion to update NORAD radars and construct additional submarines. Canada also published an Arctic Foreign Policy Plan in Dec 2024 and reestablished a Canadian Arctic Ambassador position. In addition, Canada is building up military capabilities by purchasing two MQ-9B Predator aircraft for Arctic surveillance and will construct seven new icebreakers.
- **Denmark and Greenland** are concerned about critical undersea infrastructure and have hired a private contractor to conduct security operations until they complete construction of two of their own ships by 2026. Denmark in fact detained a Chinese ship in November for suspected cable cutting. Denmark is working to increase local security training in Greenland to enhance local Greenlandic security capabilities and has committed \$2 billion for Arctic security technology to include drones and satellites. An area of concern is increased rain and glacial runoff due to warming temperatures and Denmark is investing in research to improve iceberg navigation.
- **Sweden** is investing in new patrol vessels, has set up new Arctic and Antarctic research programs at two universities, and plans to build a new research icebreaker. Odin, the Swedish icebreaker, is in the process of mapping the transarctic cable route from Finland to Japan. The Swedish Hugin Autonomous Underwater Vehicle (AUV) has an upward looking multibeam that could be used for mapping below sea ice.
- **Finland** is committed to construct a new icebreaker for the Baltic. The Finnish security minister, while acknowledging the importance of the threat to communications cables, stated that uninsured Russian "shadow" oil tankers are of greater concern. Finland has discussed cooperation with the US in icebreaker operations and have started construction on two new patrol vessels.
- **Norway** is replacing vessels with new ones that will provide long range helicopter capabilities and is working on a "Ocean of Artificial Intelligence (AI)" project to bring together industry, environment and critical undersea infrastructure security.

- **Iceland** is deploying patrol vessels with Scheibel cam-copters, a capable, unmanned aircraft system that can hover in space.

Dr. McGillivray also highlighted Arctic developments for key non-Arctic nations:

- **China** is working to construct new, more capable icebreakers as well as attempting to send a crewed submersible to the bottom of the Arctic seabed. In addition, China is developing and claiming technologies that could affect their Arctic operations. These include a new submarine radar with improved detection capabilities, a high resolution spy satellite imaging system, a Chinese version of the MQ-9 Predator, and a “wall of drones” called “Bullet Curtain” to deter enemy attacks. In addition, they have a new spy ship to track satellites and incoming missiles.
- **France** has constructed a 12-person floating lab to overwinter in the Arctic while transiting from north of Russia to Greenland.
- **South Korea** is adding another larger icebreaker to complement its current one and allow for annual operations in the Arctic and Antarctic.
- **Japan** is constructing a new icebreaker. Both the Japanese and South Korean icebreakers will allow expansion of operations in the Arctic and Antarctic.
- **Britain** is funding a project called the Greenland Atlantic Ice sheet (GRAIL) to assess ice melt and iceberg calving to try to ascertain if we are close to a tipping point for the Atlantic Meridian Overturning Circulation.
- **Germany** is working on developing autonomous underwater vehicles and unmanned aircraft to monitor the Greenland Iceland submarine gap at a fraction of the cost of using ships and aircraft to do this.

Dr. McGillivray concluded his country specific analysis with the U.S.:

- The USCG has purchased the AIVIQ, renamed STORIS to augment its icebreakers. Bollinger shipyard has been given additional funding for cost overruns and continues construction of the USCG Polar Security Cutter, which will be a heavy icebreaker. The Coast Guard is also acquiring a Blue Bottle ASV with towed hydrophone to detect hostile AUVs. The USCG new force design include standup of a new robotics and autonomous systems group. The USCG now has an upgraded V-BAT UAS able to conduct SAR, satellite comms for Beyond Visual Line of Sight (BVLOS) flights with new swarming software and a 13 hour flight time. The USCG is seeking a new medium class “Arctic Security Cutter” and April negotiations with Finland could yield the first ship within 3 years.

- Defense Advanced Research Projects Agency (DARPA) has put out a request for proposals for the Ice Control for Cold Environments Project.
- Personnel cuts at NOAA resulted in a reduction in radiosonde releases which reduces the accuracy of upper atmospheric winds for Air Force and Space Force missile launch trajectories by 5-10%. NOAA has requested a manganese crust mapping cruise by Coast Guard Cutter Healy to be completed in 2025.
- The port of Nome is currently seeking contractors for the upgrade to a military capable deep water port.
- The president's executive order "Maritime Action Plan" calls for DOD/DHS/CG Arctic security plan within 90 days.
- In April, Commander INDOPACOM recommended to Congress that Adak Naval Base be reopened. A cost estimate study will be undertaken.
- Ongoing testing of the ARGUS ONE tethered surveillance drone and other persistent wide area surveillance technology platforms could yield mechanisms to provide wide area, maritime surveillance for the Arctic.

Dr. McGillivray concluded by discussing specific Arctic developments in key areas:

- **GPS:** The magnetic North Pole is still shifting toward Siberia rapidly but at a slower rate and this means GPS satellites and satellite based radio navigation still needs to be updated regularly. There has been a major advance in GPS technology with an optimal atomic clock. Communications issues still need to be worked out, but it would provide more accurate GPS data.
- **Space Weather:** There have been a number of space weather events in the last few months and they have the potential to affect communications. An event in May 2024 was the strongest in 32 years and affected power and communications as far south as Mexico. A space weather event in April 2025 cause the Automatic Dependent Surveillance-Broadcast (ADS-B) signal airports use to track air traffic to drop out. In March 2025 a successful launch of several rockets provided the opportunity for better information as we aren't getting three-dimensional information on space weather events. NASA recognizes and is trying to address the problem of better Ultraviolet radiation advance notice to prepare not only the Arctic but those further south that could be impacted. The Chinese have established the Chinese Meridian Project (CMP) to monitor space weather with sensors located in low to middle latitudes up to the polar regions. The UK has a new space weather prediction model employing AI and historical data which provides greatly increased accuracy of prediction.

- Physical Environment:** An excellent study of sea ice ridging using three decades of imagery is yielding more nuanced understanding of ridging and its potential impacts. Also, a new international bathymetric chart of the Arctic Ocean was released in Dec 2024. It utilized NASA's airborne lidar, especially near Greenland. Recently, the National Snow and Ice Data Center partnered with the University of Bergen to use a UAS to map Greenland's glacial melt.
- Critical Undersea Infrastructure (CUI):** Increased use of autonomous underwater vehicles for military purposes is helping promote innovation. The Germans are developing a metal hydride fuel cell to provide longer range for AUVs. This will help in continuing efforts to combat undersea cable breaks. In February, US Marines trained with the Finns for critical undersea infrastructure protection. Also in February, 13 NATO countries joined an antisubmarine warfare network and some of the technologies involved could assist with critical undersea infrastructure protection. This includes a new experimental and autonomous UK ship as well as a Portuguese unmanned aircraft carrier. The EU and NATO are building new ships to aid with cable repairs and NATO has set up a task force for unmanned systems to protect critical undersea infrastructure. This will continue to be a problem as demonstrated by China's Feb 2025 severing of submarine comms cable off Taiwan's coast. DARPA is funding a program to develop advanced propulsion systems for submarines and AUVs. In March 2025, China announced a 4000-meter sheathed fiber optic communication cable cutting system integrated with AUVs and manned submersibles. While they state its use as cable repair, it could also be used for nefarious ends. The US company Anduril released information in March 2025 on their new SeaSentry AUV which can detect hostile AUVs underwater. Another recent development that could aid in CUI protection is the SubUAS Naviator. This is the first integrated commercial underwater and airborne drone system. The Monterey Bay Aquarium Research Institute has partnered with Saab, licensing its long range AUV. They also patented the Neobicon Connector which repowers from a wave energy buoy. Dolphin Labs has developed a subsurface wave energy buoy capable of harvesting and transferring energy to AUVs. This allows these AUVs to work under ice providing permanent and persistent cable inspections and is a real breakthrough technology. The US Navy is continuing to work with the Defense Innovation Unit to develop a new class of AUVs.
- Quantum Communications and Sensors:** The US is moving ahead on quantum communications and quantum sensors. The US Senate introduced the National Quantum Initiative Reauthorization Act to fund research in this area and is awaiting approval. DARPA has announced a program from robust quantum sensors for deployment on maritime assets. A new breakthrough method of laser cooling should



allow for development of smaller, less energy demanding and more widely available quantum sensors and companies are moving forward with this. China has announced that it is able to communicate underwater, from underwater to aircraft and to their satellites.

- **Satellites:** Sentinel, a new consortium, will use satellites to provide sea ice data with a resolution of 5 meters. The system will also have Automatic Identification System (AIS) sensing capacities and will provide good Arctic coverage. A joint US/India NASA-India Synthetic Aperture Radar (NISAR) launch in June will lead to high resolution data to include sea ice data. NASA's Terra, Aqua and Aura satellites have been defunded, and their imagery data will soon be unavailable.
- **Communications:** Advances in Starlink connectivity with iPhone and other commercial systems can provide communications during disasters. Alphabet has spun off a company to use optical communications in locations without Starlink or as an alternative. Spire has demonstrated optical communication between satellites with the smallest ever system. So, the trend is towards cheaper and smaller satellites. Meanwhile, China has been working diligently to create an all-optical communications network and this type of technology is something the US military could benefit from.
- **Machine Learning/Artificial Intelligence:** The USAF is developing AI software for recognition and tracking of maritime targets. This is the Maritime Automated Ingestion for Scene-Aware Identification (MAINSAIL). The USCG is also working on this technology in conjunction with the National Geospatial Intelligence Agency to detect object missed by radar and AIS. Another USCG AI initiative, the Wide Area Maritime Object Recognition project, will evaluate commercial hyperspectral sensors for maritime domain awareness. This will be used for 2025 testing and 2026 deployment with the V-BAT UAS.

Perspectives of Subject Matter Experts

Panel 1: Contested GPS – Plenary Presentation and Q&A

Moderator: Mr. Matt Schell, Ted Stevens Center

Purpose

The Panel examined high latitude challenges and radio-frequency interference to Global Positioning System (GPS) to establish a baseline understanding and to define the problem for Day 1. This panel represented a call to action for the workshop participants.

Background

The United States and her Allies have long held a technological advantage over adversaries based, in part, on the world's first Global Navigation Satellite System (GNSS). Our GPS enables navigation, targeting and a host of related military capabilities. In the Arctic the advantages of GPS are not assured. Natural and manmade interference with GPS signals in the region threaten to erode our edge. This includes unique high latitude challenges that degrade reliability when operating in the Arctic coupled with increased Russian interference through jamming and spoofing as part of their hybrid tactics.

Speakers

Dr. Arthur Scholz, MITRE

Dr. Scholz addressed the limitations of GPS in the high latitudes arising from the nature of the system itself and the particular geophysical conditions posed by the Arctic.

There are 2 primary drivers of degraded GPS performance at high latitudes. The first is a geometric factor, called dilution of precision. As a result of the orbital patterns of GPS satellites, there are not enough satellites overhead. The second is called scintillation and is related to disturbances in the ionosphere.

Dilution of Precision: The GPS constellation is inclined at 55 degrees. Thus, at the higher latitudes, there are fewer satellites at higher elevations in the sky. With the satellites being low on the horizon, it will negatively impact precision based solely on the geometry of triangulation. GPS does work fairly well, a good amount of time, but it still fails intermittently with periods where the navigation solution wasn't as high quality as one would normally expect.

Scintillation: Space weather has a significant impact on the performance of GPS worldwide, but these patterns of interference are more common at both equatorial and polar zones with more consistent, long-term disruptions in the tropics and shorter, more severe disruptions at the poles. In both areas, GPS signals are scattered by structures in the ionosphere which increases the user ranging error by as much as two times. We are also approaching the solar maximum so there is likely to be significantly more activity in the ionosphere now than there was in the past five years.

Solutions/workarounds: The USCG Cutter Healy was tasked with servicing the Nansen and Amundsen Basins Observational System (NABOS) buoys in the Arctic Ocean in 2023 (Figure A), a

task normally completed by the Russians. The crew had moderate success in augmenting GPS with other, foreign constellations of GNSS systems such as the EU's Galileo, the Russian GLONASS system, and Chinese BeiDou system as well as an augmentation system from Japan that was occasionally visible. Setting aside questions as to whether one *should* be using those foreign systems in a US DoD environment, the performance proved to be fairly good. In addition to servicing the buoys, they recorded GPS signals in the Arctic to look at ionospheric disturbances.



Figure A. USCGC Healy servicing NABOS

Lt Col Andy Alfiero, American Airlines/MEANG

Mr. Andy Alfiero, Deputy for National Safety for American Airlines and an Air Force Weapons Officer with the Maine National Guard, addressed the active measures to spoof and jam GPS signals being undertaken by Russia and the effects that activity has on civil aviation.

Implications For Civil Aviation There has been an increase in the Russian use of RFI/GPS jamming/spoofing since about mid-2023 across the entire length of the Russian frontier from the Eastern Mediterranean northward through the Baltic region and into the Arctic. While this is likely intended to disrupt military airlift, intelligence, and other operations, it has had a severe effect on civil aviation. There are several factors that make civil aviation especially vulnerable. First, the GPS equipment itself is not as resilient as that of the military. Secondly, many of the pilots flying for the air carriers in the region lack military training and experience in reacting to these threats. Finally, many of the subsystems onboard modern passenger aircraft such as enhanced radar, auto throttles and terrain collision avoidance systems rely on GPS for proper functioning. The cumulative result of the interference and spoofing of these various systems has been a marked increase in the workload and cognitive overhead for pilots operating in these regions.

The industry response has been to create an ad-hoc GPS/RFI working group to come up with solutions to challenges faced by pilots operating in this new environment. The goal is to answer the questions: How are we to operate in this new world? Train to it, evaluate it, and be prepared to operate with less resilient equipment? This is an evolving working threat and will take time to build mitigations to be able to fly in these areas and keep the pilot workload down. Until such time as these measures can be developed, they recommend the use of secondary and tertiary standard operating procedures that would reduce pilot workload.

Mr. Patrick Drain, USEUCOM J5

Mr. Drain, An Arctic Security Planner with US European Command J5, provided an overview of Russia's Electronic Warfare Activities with GPS jamming and spoofing as part of its hybrid warfare tactics.

Electronic Warfare (EW): Russia uses electronic warfare, including radio frequency interference and spoofing in conjunction with other methods such as cyber-attacks (phishing and intelligence operations) as a comprehensive way of approaching its operations. These efforts are concentrated along the Russian border especially in the Baltic and Eastern Mediterranean and have been seen to do this in the Arctic (Figure B). These activities are intended to disrupt intelligence gathering and military air transportation. In 2017 Russia set up an electronic warfare unit with a GPS Jammer in the mountains facing Kirkenez, and that caused major disruptions and almost caused a plane crash in that area. Other observed impacts to infrastructure logistics and navigation airports in Finland, they were forced to revert to installing outdated technology that relies on radio signals to augment their GPS capabilities for landing aircraft. In the Baltics at the Tartu airport in Estonia flights had to be suspended for a month due to increased safety concerns over the loss of GPS. There have been multiple occasions of commercial maritime vessels being disoriented, losing course and being forced to stay in port, which delays shipment of goods.

The conflict in Ukraine shows how Russia uses EW. Initially, these integrated electronic warfare (IEW) activities were not common, but their frequency and efficacy has improved over time. It significantly hinders successful strikes by Ukrainian forces, and it highlights potential impact for other regions such as in the Arctic. Russia's use of radio frequency, interference and other electronic warfare tactics in the Arctic could increase if we were to see things slow down and come to a halt potentially in Ukraine.

Cooperation with China: The Russians have also increased their cooperation with China in the region. There have been joint patrols of both air and surface vessels. This cooperation has allowed Russia to circumvent sanctions, and it has allowed China to get greater access to the Arctic. Looking ahead to protect ourselves from these activities, the United States and its Allies can do several things to address the threat. This includes enhancing domain awareness and investing in capabilities that enhance domain awareness, such as ground-based sensors and advanced satellite communication systems and developing more resilient navigation systems. Finland's use of older radio equipment is a good example, as it demonstrates that extant systems are robust and can help augment when GPS is not working. Enhancing cybersecurity also plays a part since cyber-attacks could be used in conjunction with EW. Finally, collaboration with Allies in exercises and through information sharing can address the growing threat.

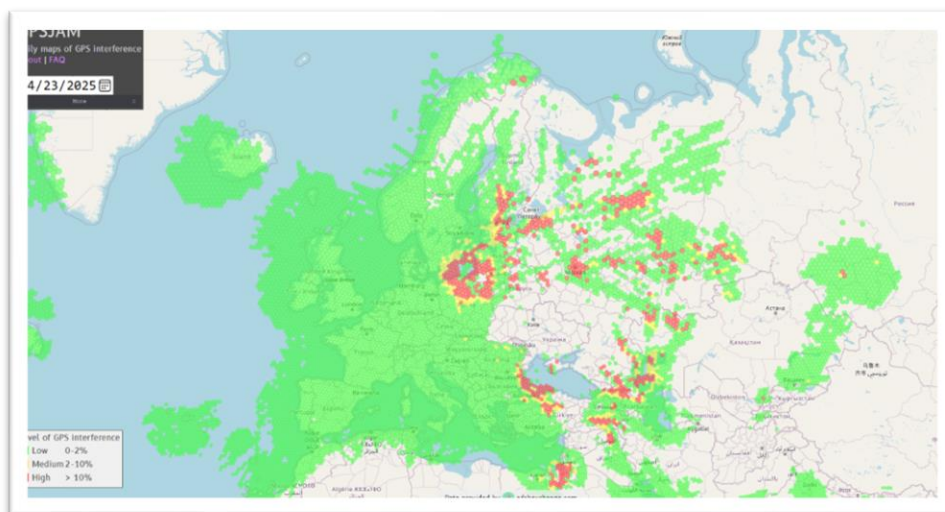


Figure B. Map of GPS Interference over Europe

Analysis and Conclusions

Panel 1 highlighted the challenges for GPS capabilities in the Arctic. Participants agreed on the following conclusions:

- The geophysical environment of the Arctic presents challenges to GPS through dilution of precision and scintillation.
- Along the Russia/NATO frontier in the Baltic and Scandinavian Arctic, this is exacerbated by Russian IEW spoofing and jamming efforts.

- These activities were already on the rise prior to the onset of the Ukrainian conflict in 2022, but since that time, the Russians have increased both the severity and sophistication of these efforts as a result of lessons learned in that conflict.
- There appears to be no end in sight for this situation and both civil and military aviation and maritime activities will continue to be affected.
- The result is going to be an increase in pilot workload and a reliance on multiple navigational systems.

Panel 2: GPS Alternatives – Plenary Presentation and Q&A

Moderator: LCDR Barry McShane, Office of Naval Research

Purpose

The second panel of the ICE-PPR NAV/ISR SAW Workshop focused on exploring GPS alternatives and resilient positioning, navigation, and timing (PNT) solutions in response to increasing threats such as GPS jamming, spoofing, and signal denial in contested and challenging environments. With maritime and aviation sectors relying heavily on GNSS, the panel aimed to highlight near-term solutions for enhancing operational security and reliability.

Background

Global Navigation Satellite Systems (GNSS) are foundational to both civilian and military operations. However, their vulnerability to cyber and electronic warfare—especially in strategic regions like the Arctic—has prompted renewed focus on resilient alternatives and backup systems. This session brought together experts from government, industry, and the military to address technological and operational pathways to mitigate GPS disruptions.

Speakers

Mr. Mark Anderson, Naval Air Systems Command

The first speaker of the panel was Mr. Mark Anderson, the GPS Platform Integration Manager for Naval Air Systems Command. Throughout his presentation, Mr. Anderson emphasized the vulnerability of GPS to jamming and spoofing, particularly in civil aviation, where protections like encrypted GPS and Controlled Reception Pattern Antennas (CRPA, or “SERPA”) are not yet widely certified. He detailed how SERPA antennas use spatial nulling to block jamming signals and provide limited spoofing resistance by filtering low-altitude threats. In the context of communications, spatial nulling refers to the technique of canceling out interference signals by creating a directional null in the antenna's radiation pattern. This means the antenna is designed to suppress incoming signals from a specific direction, effectively blocking or minimizing the interference from that

source. Despite the effectiveness of these military-grade antennas, he noted major obstacles in integrating them into civil aircraft due to certification, size, and system integration challenges. Mr. Anderson also highlighted the robust inertial and hybrid navigation systems found in newer aircraft, which help maintain functionality even during GPS disruptions. Finally, he called for better situational awareness tools in cockpits to help pilots identify and respond to GPS anomalies.

Mr. Bridge Littleton, Hellen Systems

Next, Bridge Littleton, Co-Founder and President of Hellen Systems, discussed enhanced LORAN (eLORAN) as a robust terrestrial alternative to GPS. A modernized version of the Cold War-era LORAN-C, eLORAN transmits powerful low-frequency signals that are largely immune to common GPS vulnerabilities such as jamming, spoofing, and solar interference. Mr. Littleton described both fixed and portable configurations, including rapidly deployable systems using aerostats or containerized transmitters. He further shared results from extensive testing with the U.S. Air Force, demonstrating eLORAN's ability to deliver accurate timing and navigation through thick concrete bunkers and even underwater—an advantage especially relevant in the Arctic and contested environments. With encrypted signal structure and data channels that can transmit both corrections and commands, eLORAN offers not only redundancy, but also expanded communication capabilities for mission-critical operations.

Mr. Rob Gillette, NAL Research Corporation

Closing the panel was Mr. Rob Gillette, Director of Assured PNT Solutions at NAL Research. Gillette focused his discussion on Iridium STL (Satellite Time and Location), a commercial space-based PNT solution that uses Low Earth Orbit (LEO) satellites. Unlike GPS, STL requires only a single satellite in view, and leverages Doppler shift and pseudo-range calculations, making it highly resilient and ideal for environments with obstructed views or strong jamming. Doppler shift measurements in GNSS provide a means to estimate the relative velocity between a receiver and a satellite, which can be used to calculate pseudorange. Pseudorange is essentially the "apparent" distance between the receiver and the satellite, influenced by various factors like clock errors and atmospheric effects, and it's often used in conjunction with Doppler shift measurements for precise positioning. Mr. Gillette described how Iridium's strong signal (up to 30 dB stronger than GPS) and unpredictable satellite paths additionally enhance resistance to jamming, spoofing, and cyberattack. He cited operational testing in Ukraine, Israel, and the Arctic—locations where GPS reliability is frequently compromised. According to Mr. Gillette, NAL Research has deployed over 8,000 STL-based modules across handheld, aviation, and maritime platforms, including with Air Mobility Command and commercial vessels. Devices like the Hawkeye 7500 integrate seamlessly with pilot applications like ForeFlight, while maritime variants can supply GPS-independent position data to electronic chart systems or serve anti-piracy safe-room operations.



Analysis and Conclusions

Panel 2 highlighted the urgent need for resilient alternatives to GPS in light of growing threats such as jamming, spoofing, and environmental vulnerabilities—especially in critical regions like the Arctic. Through diverse technological approaches from both industry and government, the session showcased how tested, deployable solutions already exist and can play a key role in securing Positioning, Navigation, and Timing (PNT) for military and civilian operations alike. Some key takeaways from the discussion include:

- GPS is increasingly vulnerable to disruption in contested and remote environments.
- Military-grade CRPA (SERPA) antennas offer a promising GPS alternative that can mitigate jamming, but face certification hurdles in civilian aviation.
- Enhanced LORAN (eLORAN) is a robust, terrestrial backup system with deep signal penetration and global deployment potential.
- Iridium STL, a satellite-based PNT alternative, can be highly resilient in denied environments.
- The technologies discussed by this panel have been tested and proven in real-world scenarios, including bunkers, Arctic regions, and conflict zones.
- The Arctic region presents both a challenge and an opportunity to demonstrate PNT resilience due to its strategic importance and harsh conditions.
- Integration, certification, and awareness tools are critical next steps for widespread adoption of GPS alternatives.

Panel 3: Future PNT - Plenary Presentation and Q&A

Moderator: Dr. Kelsey Frazier, Ted Stevens Center

Purpose

This panel presented research in various stages of development, offering alternatives to GPS. Based on the assumption that our adversaries will continue to try to deny existing GNSS-based PNT capability, there is value in the US and its Allies exploring long-term PNT solutions including solutions that are not dependent on satellites. There is particular value if these alternative technologies work equally well to satellite-based technologies in the Arctic.

Background

Several promising ideas are under investigation that do not rely on satellites. Celestial navigation as well as electro-optical, gravimetric, or magnetic map matching represent examples with potential for precise PNT based on detailed understanding of geophysical attributes surrounding Earth. Odometry, bathymetry, and terrestrial radionavigation including the use of signals of

opportunity offer additional alternatives to determine precise position. These are Arctic-relevant technologies that would eliminate GPS vulnerabilities to space weather and coverage limitations at high latitudes.

Speakers

Dr. Thorsten Markus, NASA - Celestial Navigation

The first speaker was Dr. Thorsten Markus of NASA Headquarters, speaking primarily on celestial navigation. Dr. Markus emphasized NASA's regular engagement with the Arctic in space. He highlighted current research that NASA is performing, which considers the impact of clouds and aerosols on Arctic sea ice. NASA also works with CRREL to deploy ice buoys with the purpose of measuring ice melt. Dr. Markus explained how NASA navigates satellites using GNSS, orbit prediction via satellite laser ranging (SLR), and systems that measure distance from Earth through relative position to stars, as well as accelerometers and magnetometers. He also shared that NASA recently invested in a 36-foot drone that can fly for up to 10 days in the Arctic, measuring snow depth. The initial mission was a success and showcased improved UAS technology which enables long distance Arctic flights.

Lieutenant Colonel Zachary "Drag" Franklin, 509th Operations Support Squadron (OSS)

The second speaker was Lieutenant Colonel Zachary "Drag" Franklin, 509th OSS, speaking on the role of celestial navigation in military operations, specifically in the context of platforms and bombers. LtCol Franklin discussed the need for accurate navigation systems that can operate without GPS, as bombs and missiles will rely on navigation solutions from their launch platform when GPS fails. Thus, if a plane does not have a dependable navigation system that can operate without GPS, the cost is paid in time, money, weapon accuracy and lives.

LtCol Franklin noted that most aircraft are equipped with a celestial Inertial Navigation System platform for redundancy, but because it uses optical tracking, clouds can severely inhibit the navigation augmentation. He also noted that radar can be used for location sensing while over land, but that capability is lost if the aircraft is flying above water. Recognizing this weakness, LtCol Franklin emphasized interest in ariel mapping capabilities that allow better navigation over water, like lidar that senses off of ocean floors, and more general improvements in geo-references. He acknowledged that the constantly changing polar sea ice is a significant challenge to this end.

Mr. Jouni Rantakokko of the Swedish Defence Research Agency, FOI

The third speaker was Mr. Jouni Rantakokko of the Swedish Defence Research Agency, FOI, speaking about PNT in the High North. First, Mr. Rantakokko identified major challenges facing PNT in the Arctic. These challenges included low-elevation angles to satellites for GPS functionality; the snow, ice and dark in the winter, as well as a lack of man-made landmarks for map-matching;

prevalence of forests adding further challenges to map-matching; a lack of RF signals-of-opportunity (SoOP), like 5g towers for signal transmission; as well as ionospheric disturbances and strong atmospheric disturbances that affect the magnetic field that many of these technologies utilize.

Mr. Rantakokko then explored possibilities that existed to address these challenges. He agreed with previous speakers that a multi-system fusion approach was required to ensure navigation system redundancy if GPS failed, but that there were many possible ways to achieve this through geophysical or radio-based techniques. He identified inertial sensors combined with a timing device as the core of the operation and noted multiple potential alternative navigation systems that could feed into the central system. These alternatives included a velocity-aiding (odometry) system, as well as acoustic, geophysical (map-matching), or radio-based systems. Mr. Rantakokko also noted that a robust network of GNSS inputs could help achieve system redundancy, by taking advantage of antenna arrays, civil GNSS signals, GPS M-code and Galileo Public Regulated Service (PRS) (military side), and jamming and spoofing detection systems. Mr. Rantakokko acknowledged that while more work needs to be done on detecting jamming and spoofing, it's much improved in recent years.

Dr. Ryan Cassel, MITRE

The fourth speaker was Dr. Ryan Cassel of MITRE, focused on Alternative PNT. Dr. Cassel began by outlining the complementary passive PNT ecosystem. It includes sensors and technologies like clocks, optical terminals and receivers/transceivers, inertial sensors, radar, sonar, magnetometer, and more. These technologies support PNT techniques including time holdover, time synchronization, feature matching, and bathymetry. Echoing previous speakers, Dr. Cassel noted that many techniques have very strong potential, but glaring weaknesses like poor night vision or vulnerability to man-made interference. His conclusion matched others on this panel: there is a need to look into duplication for capability augmentation, so that multiple techniques can cover up the limitations of each other.

To that end, Dr. Cassel said that MITRE has built a Global Navigation satellite Staten Test Architecture (GNSSTA) which can plug in information from GNSS signals, PNT sensors, pluggable data sources and algorithms, and can interchange real sensors for sensors models. He noted that the ONT capabilities and expertise at MITRE are broad, so ended with a request for specific problems and questions from operators. Dr. Cassel indicated that this would help those at MITRE know what questions would be most useful to engage with and ideally answer.

Dr. Kelly Backus, MITRE – Quantum PNT

The fifth speaker was Dr. Kelly Backes, who focuses on Quantum PNT at MITRE. Dr. Backes spoke of quantum sensors as having great potential to support alt-PNT as well as complementary PNT. Her



quantum research is focused on creating sensors that exploit quantum phenomena to measure physical quantities. The quantum sensing ecosystem includes a growing superconductor work program that touches on magnetic fields and photonics; experimental research and development around electric fields and magnetic fields; and additionally, time and frequency, gravity, and inertial acceleration.

Dr. Backes emphasized three emerging areas of quantum sensor research. The first is inertial navigation, which considers using inertial navigation system to estimate a platform's position, orientation and speed. The second area is magnetic anomaly-aided navigation (MagNav), which uses position fixing via matching local measured magnetic fields to a magnetic map of the region. The third area is gravitational anomaly-aided navigation (GravNav).

Analysis and Conclusions

A few clear takeaways emerged from the panel speakers and subsequent discussion of long-term PNT solutions.

- New technological developments have the potential to make US navigational systems and capabilities much more accurate, spoof-proof and competitive. Examples of these technologies include UAS that can fly long distances in the north equipped with visual and thermal sensors, as well as new satellite laser ranging stations, lidar arial mapping of ocean floors, upgraded versions of radio-based techniques, and quantum sensors.
- Operators have identified and are now requesting functional improvements like redundant information sources and GPS alternatives to improve navigational resilience in combat, and technologies that ensure missile accuracy within feet of a target.
- Gaps in current technologies include the loss of radar functionality over water, PNT that can adapt to the constantly changing snow and ice coverage in the Arctic, the ability for PNT technology to “see” in the dark.
- The overarching question remains: what are the best ways to duplicate and integrate navigation capabilities?
- All speakers acknowledged that affordability is a challenge and options for cost reduction are needed.

Panel 4: Land and Sea (in the Arctic and Maritime) - Plenary Presentation and Q&A

Moderator: Dr. Christine Duprow, TSC

Purpose

Panel 4 examined Arctic land and maritime ISR capabilities from various perspectives. Land domain operator and intelligence consumer perspectives established a demand signal for ISR challenges and gaps in the Arctic. A survey of maritime domain ISR capabilities helped to frame Day 2 discussions.

Background

Situational awareness on land and sea is fundamental to understanding the operating environment. ISR coverage and capabilities that are well refined in the mid-latitudes have gaps and limitations in the Arctic.

Speakers

[Major Matt Hefner CRREL](#)

The first speaker of the panel was MAJ Hefner, the senior advisor for Arctic Ops at CRREL and lead for the terrestrial platform group. MAJ Hefner relayed his experiences after recently leading an Arctic patrol. The winter Arctic exercises include Operation Nanook Nunavut, an annual exercise in Northern Yukon. The team spent 13 nights in the field and patrol between bases (Figures C). Activities included leveraging various vehicles but primarily used Cat V and snowmobiles (Figure D). The team also tested various new and existing technologies throughout the exercise. Furthermore, the same team will do an exercise in Norway/Sweden/Finland in 2026 and 2027 will return to Nunavut. Team findings included capability gaps in communications, intelligence, surveillance and reconnaissance. More specifically there were struggles to gathering and report useable ISR during the mission. FM radios could be relied upon, but only short distances, alternatively high frequency (HF) was successful but cumbersome to construct, and encountered frequent interruptions throughout use. Batteries were an option and functioned well, but recharge was an issue. Best performance included MPU5 or similar type radios, leveraging satellite networks charged by generator. Lastly, MPU5s, Samsung Galaxy Phones, and Starlink satellite services was the most viable option to mesh networks and facilitate communications.

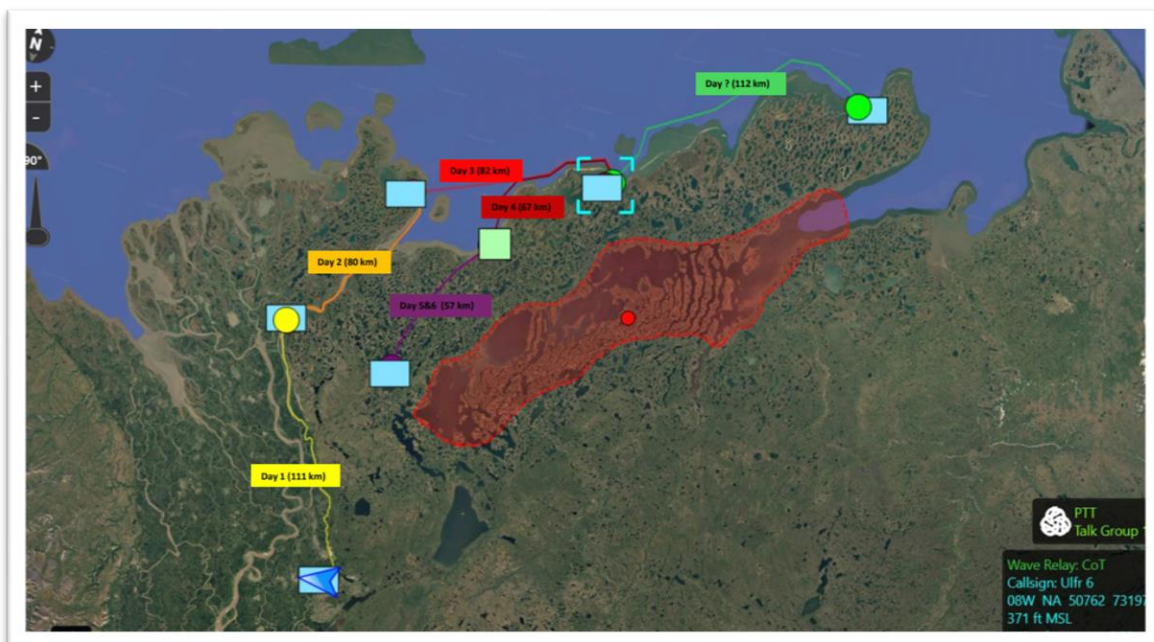


Figure C. Map of Arctic Patrol Route



Figure D. Arctic Patrol Team Member on Snowmobile with various Communications Devices

Intelligence was also well utilized through a primary human resource. The Canadian Rangers were an invaluable resource throughout the exercise. SIGINT was provided by HQ; however it was intermittent due to the communications dependent system. One more type of surveillance capability are drones, however in Arctic conditions they were ineffective. Drones struggle with range, including constant icing and battery drain. Resupplying the troops during the exercise was also an issue. The team was very visible and exposed on the terrain. MAJ Hefner highlighted snowmachines and vehicles are easy to track due to trails created by both humans and vehicles. Capability gaps continue in the Arctic, the US needs specialized units, integration and joint operations, and the correct equipment to include snowmobiles. Thermal mitigation, de-icing capabilities, hybridized energy sources track vehicles, and better clothing for cold weather conditions. Lastly, the issue of Arctic field medicine is still unsolved, and critical to mission success or failure.

LTC John Limauro, 11 ABN DIV G2 Joint Base Elmendorf

LTC Limauro discussed his intelligence experience as part of the 11th Airborne. The 11th ABN has 10k soldiers assigned who are tasked with defeating any adversary in extreme cold weather, mountainous, and high latitude environment through large-scale combat operations. The unit is assigned to INDOPACOM, with their training ground primarily in northern Alaska in the winter and warmer areas in the summer. The organization is equipped with snowmobiles, new CATV vehicle, skis, snowshoes, sleds for moving larger objects heaters etc. While in training status the organization has encountered a hostile operating environment including major temperature swings (80 degrees plus) and high winds. The 11th ABN has experienced similar limitations and challenges as other units. Drones were 'generally worthless' due to icing and battery life – the largest drone could not take off at any point during the exercise. LTC Limauro experiences support the narrative- new energy sources for drones are needed. One highlight mentioned was the positive research results achieved with propane as a fuel source. Similar challenges are as follows: lithium-ion battery charging, snow drift movement major factor for ground recon. Teams have used Star shield/Starlink and it was generally effective. During exercises, the unit also encountered liabilities with clothing, field medicine, lack of communications, and receiving timely reliable intelligence.

Dr. Christoffer Nuth, Norwegian Defense Research Establishment

The Norwegian Organization primarily provides support for customers in the defense community. Dr. Nuth provided important historical introduction surrounding maritime surveillance. For example, navigational radars were first introduced in 1940s, during the 2000s the capability for GPS availability to be turned off. During the 2002's AIS was created integrating both GPS and VHS. A critical research discovery during the 2010s aboard the International Space Station found VHS signals could be seen from space. Another key development during 2010's was the Norwegian nanosatellites, the satellites operated by the Norwegian Space Agency aim to improve maritime safety and efficiency by tracking vessels and integrating the AIS data into a national maritime

tracking system. The Norwegian Maritime Area of Interest covers an area the size of entire mainland Europe. Dr. Nuth described the benefits of satellites as the most useful for surveillance due to the high coverage, overall low fidelity. They can produce 6-8 images per day for a signal spot for both northern and southern areas of Norway. He continued to discuss the sensor fusion, detection, and identification while integrating AI to improve both speed and accuracy of vessel identification. The system also reports on maritime pattern of life, which is based in ecological sciences. The system identifies repeatable behaviors for vessels creating a background and situational image for the environment. The goal is to allow the system to identify anomalies and behavior classification for vessels. One example provided was vessel adrift, or vessels trolling over an undersea cable.

CAPT Steve White, Marine Exchange of Alaska

Mr. White described the background for the purposed of the Marine Exchange of Alaska. Their many lines of effort include, monitoring marine safety sites, AIS receiving and transmission. The Marine Exchange shares data between government, commercial, and Alaskan communities and mariners. They monitor overall sea vessel traffic, which is increasing. Current data of marine traffic along the Bering Strait was 242 vessels in 2010 with an increase to 665 in 2024. Mr. White informed the group; the Bering Strait represents one of the few strategic chokepoints in the world for sea lines of communication and commerce. He went on to explain the behavior and vessel traffic within the U.S. and Russian sides are different. On the Russia side: far more tanker traffic; spoofing is an ongoing concern. When compared with the US side: traffic is primarily barge/cargo destined for communities. Mr. White continued to elaborate, the Arctic shipping season is changing, more ice-free waters equal more vessel traffic. The Marine Exchange has received higher level of requests from communities to keep comms going during the winter to facilitate travel over ice. Mr. White finalized the conversation sharing a map of marine safety sites and terrestrial sites (Figure E).

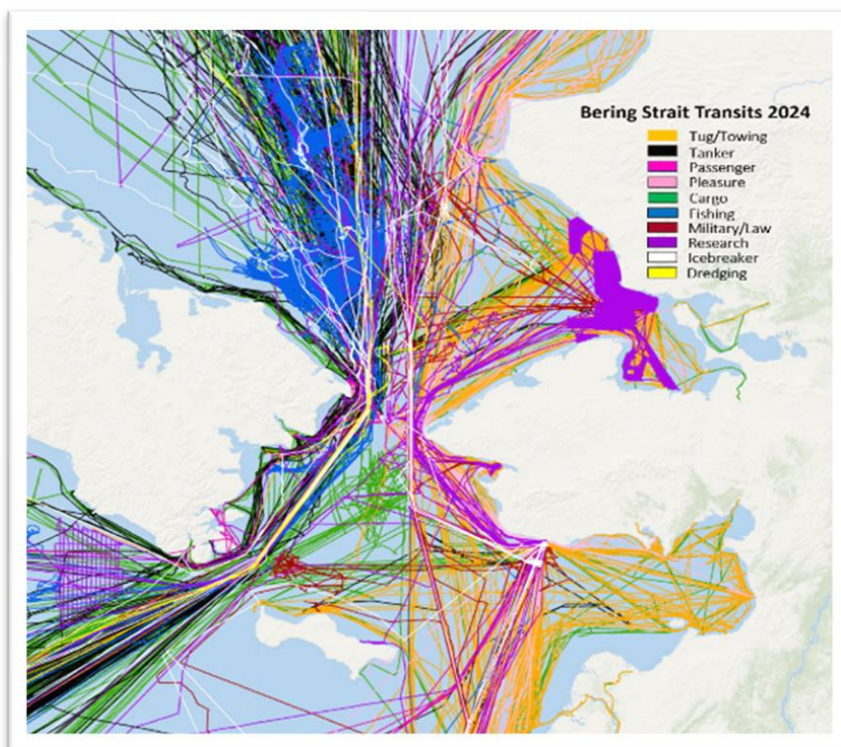


Figure E. Map of Bering Strait Transits in 2024

Analysis and Conclusions

A few clear takeaways emerged from the panel speakers and subsequent discussion of the future of maritime and land domain Arctic research.

- New science and research in the maritime space is continuing to progress and provide information and tools to all users in the space. This included communities and operators. Some examples include expanded satellite capabilities, and integration of AI to increase the speed and access to data.
- Operators have identified a need for functional improvements and equipment to continue to perform and reduce liabilities while operating in the Arctic environment.
- Current areas for improvement, some of which are being addressed included logistics, fuel sources, battery life, drone operability in the cold weather operating environment, de-icing capabilities, hybridized energy sources track vehicles, and better clothing for cold weather conditions.

Panel 5: Space-Based ISR in the Arctic – Plenary Presentation and Q&A

Moderator: Dr. Kathryn Bryk Friedman, Ted Stevens Center

Purpose

This panel explored how space-based ISR capabilities are evolving to address operational demands in the Arctic. As the region grows in geopolitical importance and remains challenging due to its remoteness, harsh weather, and limited infrastructure, speakers examined a range of space-based ISR tools that are being adapted or developed for the unique conditions of the high north.

Background

ISR in the Arctic faces persistent limitations: sparse ground-based infrastructure, auroral interference with RF signals, low sun angles that complicate optical imaging, and a lack of timely, integrated data for tactical use. This panel convened military, government, and industry experts to highlight how commercial and defense-sector innovation is closing those gaps. Together, the speakers emphasized integrating multi-source data, leveraging commercial capabilities, improving resilience to environmental disruption, and accelerating real-time ISR delivery to operators in theater.

Speakers

Alex Duchane – U.S. Space Force, Air Force Research Laboratory (AFRL)

Mr. Duchane, representing the U.S. Space Force and Air Force Research Laboratory, outlined key efforts to advance space-based ISR technologies with a focus on Arctic applications. His work centers on developing next-generation infrared sensors for missile warning, emphasizing innovations in detector materials, readout electronics, and achieving cost-effective performance. A major priority is integrating AI/ML for onboard data processing, designed to function within the strict size, weight, and power (SWaP) limitations of space platforms.

Mr. Duchane highlighted the growing importance of incorporating commercial data sources to enhance ISR coverage, particularly in contested and hard-to-reach regions like the Arctic. However, several technical challenges remain. These include designing intelligent onboard systems that operate under limited power and computational resources, successfully transitioning new sensor technologies from laboratory research through balloon-based tests to space-ready systems, and ensuring reliable performance in extreme space weather conditions such as auroral interference and low-angle sunlight.

Current projects include the Hybrid Architecture Demonstrations (HAD), which test integration and cross-tasking across commercial and government satellite networks, and the development of a unified global ISR data environment. This system is intended to allow real-time tasking, data ingestion, and delivery of actionable information directly to warfighters during live exercises.

Greg Gillinger – Senior VP, Integrity ISR

Mr. Gillinger, a veteran of both the U.S. Air Force and the National Reconnaissance Office, discussed the rapid growth and operational relevance of commercially available ISR tools. Drawing on insights from the conflict in Ukraine, he illustrated how the integration of satellite and drone-based ISR now enables near-real-time decision-making on the battlefield. He noted that this model is especially relevant to the Arctic, where vast distances and minimal infrastructure create operational challenges similar to those faced in Eastern Europe.

Gillinger also highlighted the growing strategic threat posed by Chinese and Russian ISR capabilities. He pointed to China's Yaogan satellite constellation, which conducts coordinated signals intelligence (SIGINT) and electro-optical (EO) surveillance, and noted Russia's continued deployment of experienced Arctic intelligence units. A key concern he raised was the insufficient attention U.S. forces give to their own electromagnetic emissions.

To address these issues, he recommended pushing unclassified ISR tools to the tactical edge and training operators to directly task ISR assets. He also advocated for the incorporation of commercial ISR technologies into Department of Defense exercises such as the Joint Pacific Multinational Readiness Center. Finally, he stressed the need to enhance operational security and improve emission control awareness among U.S. forces operating in the Arctic.

Derek Fleck – Director, Business Development, AIREON

Mr. Fleck introduced AIREON's global space-based aircraft tracking system, which leverages Automatic Dependent Surveillance–Broadcast sensors mounted on 68 Iridium satellites in polar orbit. This infrastructure allows AIREON to maintain continuous surveillance across all airspace, including remote and underserved regions such as the Arctic. The system currently tracks up to 200,000 flights per day, providing real-time, certified surveillance data to aviation stakeholders worldwide. He illustrated the system's capabilities with a case in which AIREON detected a spoofing incident: an aircraft appeared to be operating in Kaliningrad, but was ultimately geolocated via radio frequency signals in Poland. This example underscored the platform's value in detecting anomalies, particularly in areas where traditional radar coverage is limited or nonexistent.

Mr. Fleck emphasized several opportunities for integrating AIREON's capabilities into ISR frameworks. These include using AIREON's cooperative surveillance data as a reliable baseline for ISR data fusion, supporting airspace deconfliction and situational awareness, and enabling multi-domain ISR operations through enhanced collaboration between commercial and government entities.

Dr. Daniel Eleuterio – Program Officer, Office of Naval Research (ONR)

Dr. Eleuterio provided an overview of the ONR's Arctic-focused research portfolio, which aims to enhance intelligence, surveillance, and reconnaissance (ISR), navigation, and sensor resilience in regions affected by space weather. Recognizing the limited terrestrial infrastructure in the Arctic, ONR supports the development of modeling tools and operational platforms designed to predict and mitigate radio frequency degradation caused by auroral activity and ionospheric interference.

Among the current efforts is the development of predictive signal propagation models to improve the reliability forecasting of ISR systems. ONR is also testing persistent unmanned aerial vehicle (UAV) platforms capable of loitering for multiple days, with the goal of supporting long-duration Arctic patrols. Additionally, research is underway into the legal and logistical considerations necessary for conducting trans-Arctic UAV missions. The overarching goal of these initiatives is to bridge ISR capability gaps between space-based assets and airborne platforms by advancing environmental modeling and integrating long-endurance ISR systems into Arctic operations.

Lt Col Matthew Sala –109th Airlift Wing, NY Air National Guard

Lieutenant Colonel Sala, a veteran LC-130 pilot with 27 years of experience operating in polar regions, offered a ground-level perspective on the role of ISR in Arctic logistics. He currently oversees the certification of ski landing zones, a process that combines data from U.S. and Canadian satellites with traditional manual assessment methods. Despite technological advancements, he described existing ISR products as overly basic and too slow to support the

demands of rapid or contested logistics environments. His team continues to rely heavily on physical inspections to evaluate ice thickness and snow integrity, an approach that is both inefficient and potentially hazardous. To address these challenges, Lt Col Sala called for the development of ISR-integrated tools for site selection, as well as modular field kits designed to streamline ski landing zone operations and reduce risk.

Key emerging needs identified include the automation of ski landing zone scouting and certification through advanced ISR capabilities; the deployment of integrated Arctic logistics support kits that utilize fused sensor data; and greater collaboration with Nordic partners and ISR researchers to enhance operational effectiveness in the region.

Analysis and Conclusions

A number of shared insights and challenges emerged across Panel #5 presentations and discussions:

- The Arctic's infrastructure limitations make commercial, space-based ISR an indispensable complement to national assets.
- Fusing data from satellites, UAVs, and terrestrial sensors improves situational awareness and ensures resilience in contested or weather-impacted zones.
- Space weather, aurora interference, low angles of sunlight, and sparse infrastructure continue to degrade ISR effectiveness and must be modeled and mitigated.
- There is a growing demand for ISR products that are faster, modular, and directly usable in the field.
- Onboard AI, autonomous loitering platforms, and real-time data feeds are reshaping how ISR is delivered, processed, and acted upon in the Arctic.
- Several panelists emphasized the importance of cost-effective systems and the need to better train personnel in ISR tasking, emissions control, and data interpretation.

Panel 6: ISR Research (5-15 yrs) - Plenary Presentation and Q&A

Moderator: Ms. Kristi Swain, Ted Stevens Center

Purpose

This panel provided a survey of ongoing research across all domains to expose workshop participants to foundational science, applied technology, and use cases relevant to defense. Understanding that technology and related challenges and threats are evolving at a rapid pace, this

panel looks 5-15 years into the future, examining research in the context of recent and emerging challenges.

Background

Stronger together, universities, research organization, and industry partners across the Arctic Allied nations have access to opportunities for collaboration. Cost sharing is a win-win proposition that begins with connections and recognition of common interests. For example, the UAF Geophysical Institute houses numerous research programs valuable to Arctic ISR, and the robust research staff at Bureau of Ocean Energy Management (BOEM) are deep in maritime research. The 15th Operational Weather Squadron is the lead unit responsible for environmental characterization, impacts and effects in the Arctic Circle and for providing 24/7 premier terrestrial and atmospheric environmental intelligence, Space Inventor is a leader in micro-satellites, and PixElement performs advanced photogrammetry and mapping that offers high resolution 3D terrain models.

Speakers

Dr. Bob McCoy, UAF Geophysical Institute

The first speaker was Dr. Bob McCoy of the UAF Geophysical Institute. The Geophysical Institute was established primarily in response to the desire to better understand the Aurora which emerged after World War II. The Geophysical Institute owns Poker Flat Research Range in Fairbanks, AK and is developing a partnership with the Pacific Spaceport Complex in Kodiak, AK. The Institute owns and operates the High-Frequency Active Auroral Research Program (HAARP), downlinks 40% of NASA's polar operating data, and has the ability to measure permafrost across the Arctic by utilizing synthetic aperture radar data. Additionally, the Institute hosts the largest land-based rocket launch range in the world and is discussing the potential for a test range in the Aleutian Islands. In the DoD framework specifically, the Institute plays many roles including analysis of seismic activity, infrasound, space weather and meteorological sites for the office of the Deputy Assistant Secretary of Defense for Threat Reduction and Arms Control. The Institute also has a large UAS program with work that includes using drones for rural cargo delivery and acting as the 'opposing forces' doing counter-drone work for the Air Force.

Mr. Givvy Kochanowski, Bureau of Ocean Energy Management

The second speaker was Mr. Givvy Kochanowski of BOEM. Mr. Kochanowski emphasized just how big BOEM's area of responsibility is around Alaska, spanning 16 planning areas in the federal waters of Alaska. These vast areas of responsibility are considered through three primary lenses: resource evaluation, environmental awareness, and leasing and plans for use. A current major focus is on dual-use capability consideration in the planning processes for use.

Resource evaluation at BOEM includes resource analysis and economic analysis. BOEM estimates what energy is available in Alaska through consideration of mineral and other geological resources. BOEM then applies those energy and mineral estimates to economic modeling to give monetary value to the available resources. Mr. Kochanowski noted that northwestern Alaska is particularly rich in marine minerals, while there is high potential for carbon storage around Kodiak Island, and near the Bering and Chukchi Seas. BOEM relies heavily on scientific research to understand the minerals and energy that it regulates. This research is used not only by BOEM, but also by a broad range of defense entities.

Mr. Kochanowski explained that environmental awareness developed by BOEM provides decisionmakers with the scientific understanding necessary to ensure offshore research development is done safely and responsibly. BOEM's approach in Alaska blend traditional knowledge with western science to provide the best insight and information possible to stakeholders. Mr. Kochanowski also discussed that BOEM plays a role in leasing and plans comes primarily at the planning stage, helping define how operators can move forward after a lease is acquired.

Mr. Kochanowski noted that BOEM is active with the Arctic Council, specifically the working group on Protection of the Arctic Marine Environment and the working group on the Conservation of Arctic Flora and Fauna. He indicated that BOEM is also looking at getting involved with the Sustainable Development Working Group. Other close partners of BOEM include DoD Combatant Commands, the Alaska Federation of Natives, the Denali Commission, coastal communities, federal agencies, industry players and Alaska Native corporations. BOEM is currently developing a roadmap for operations in Alaska and the Arctic which should be released later this year.

Lt Col Elizabeth Ramoso, USAF

Lieutenant Colonel Elizabeth Ramoso of the USAF spoke after Mr. Kochanowski, with a focus on domain awareness. She emphasized that historical data is quickly outdated due to the rapidly changing operational environment of the Arctic. Lt Col Ramoso noted that trying to forecast weather with few stations while the ground is actively changing underneath air force operators is near impossible and creates significant challenges to completing missions. The tools used in the lower 48 and in other regions of the world are not designed for the Arctic and functionality often does not translate.

Lt Col Ramoso highlighted the need for enhanced domain awareness, given the above considerations. She also noted that some of the work to this end has already started. The Army is developing cold weather training plans and equipment, the Air Force is increasing its Arctic exercises and deployments, and the Navy and Coast Guard are also making investments targeted at northern operations.

Mr. Martin Olesen, Space Inventor

Mr. Martin Olesen works at Space Inventor, a Danish satellite company specializing in small satellites for monitoring and communication in space with a focus on defense and security. Current satellite-specific missions of Space Inventor include the Bifrost satellite, the first Danish military satellite, for monitoring the waters around Greenland; and the WINDCUBE mission, dedicated to examining how thermospheric winds impact Earth's ionosphere. Space Inventor also works in cooperation with NATO countries through development of space-based solutions for defense and security including monitoring specific parts of NATO's operational areas. Mr. Olesen emphasized that Space Inventor is looking forward to doing more, bigger and more complex work in the future, and is very excited about the Arctic as a place for collaboration.

Dr. Ben Vander Jagt, PixElement

Dr. Ben Vander Jagt spoke to his work at PixElement. He described a small business technology transfer that is being worked on in conjunction with Byrd Polar and Climate Research Center called 3D Tactical Mapping for Polar Environments (3D TMPE). Dr. Vander Jagt described the primary goal of 3D TMPE as to enhance Air Force tactical mapping capabilities in polar regions. In more detail, this means addressing the challenges of airborne and space-born mapping in GPS-denied and low-texture polar environments by targeting novel photogrammetric workflows, building upon PixElement and ArcticDEM (Terrain Aided Visual Navigation in snow and ice covered environments) technologies.

Dr. Vander Jagt stated that 3D basemaps that have high temporal and spatial accuracy are necessary for the Air Force to win in the Arctic, in the face of accelerating strategic competition between the US, Russia and China. Therefore, comprehensive geospatial datasets, including time-evolving terrain maps are critical for navigation in a rapidly changing environment. PixElement aims to address this through improved 3D tactical mapping in snow and ice covered environments with technologies that overcome blowing snow, reflective surfaces, and changing illumination conditions while generating high fidelity 3D maps. This will improve snow depth estimation and landing zone determination. Additionally, ArcticDem technology uses visual cues to determine UAS positions in GPS-bereft areas. Dr. Vander Jagt emphasized that PixElement would love to hear from DoD stakeholders to collaborate and integrate expertise.

Analysis and Conclusions

A few clear takeaways emerged from the panel speakers and subsequent discussion of the future of ISR research.

- New science and research are identifying ways to provide more nuanced information to DoD partners, including through expanded satellite capabilities, improved weather and terrain measurement tools, and more detailed maps.

- Operators have identified a need for functional improvements like more current and quickly updated operational environment data, and technology specifically made to perform in the Arctic operational environment.
- Current areas for improvement, some of which are being addressed, include 3D mapping of polar regions, use of satellites and radar to fill information gaps, and Arctic-strength equipment.

Polar Ways Project Overview

Purpose

The purpose of this session was to provide the SAWG and workshop participants an update on the Polar Ways project and to examine Polar Ways as a case study for the development of an ICE-PPR Collaborative Activity Proposal (CAP).

Background

The Polar Ways project is an ICE-PPR cross-Working Group collaboration that is emerging from the Platforms and Environmental Working Group to explore a route selection tool for polar maritime traffic. The Polar Ways project envisions the synthesis of various sensing and forecasting capabilities to achieve route optimization and decision support.

Speakers

The project was presented by Mr. John Woods of the Office of Naval Research and Dr. Blair Sweigart from Pacific Northwest National Laboratory from respective vantages.

Polar Ways Project Overview

The goal of this project is to develop an integrated navigation aid for polar maritime operations, akin to the “Waze app” for the Arctic. The decision support tool would merge ice modeling, oceanographic data, remote sensing, and route planning to create optimized navigation support for vessels operating in polar and ice-covered waters. The innovation is to combine previously siloed data and technologies into a unified software solution, ideally as a downloadable application or black-box devices. Key capabilities:

- Automated sea ice identification and classification
- Ice thickness predictions and drift forecasting
- Ocean current data integration
- Route optimization using polar classification, vessel capabilities, environmental data
- Tactical navigation and decision support tools for vessel masters

The concept originated from workshops including one at the U.S. Naval Academy driven by operational need and technological opportunity. With end users in mind, the idea developed to support vessel masters by reducing risk and improving efficiency. The concept grew as a decision aid, not a replacement, for skilled operators.

Integration of various technologies is a challenge. While many technologies exist, true value lies in software engineering to unify them into a coherent, usable interface.

Mr. Woods and Dr. Sweigart described the breadth of stakeholder involvement. The environmental community is represented by meteorologists, oceanographers, and ice modelers. Platform focused researchers included remote sensing experts with work in satellite and shipboard sensors. Human-centered design was taken into consideration with UX/UI experts to ensure usability by vessel operators. The project gained strong multi-national engagement from New Zealand, U.S., Canada. Participation was encouraged from academia, government, and industry—focused not on profit but on capability development.

The project timeline and status illustrate the scope and scale of a CAP. Initial workshops were held in 2023. Currently, the team is conducting Research and Coordination as planned for year 1. The next phases, Prototyping (years 2–4) and Testing & Evaluation (years 5–7). The project’s goal is a working prototype in the hands of operators within five to seven years which was described as aggressive for an international effort.

Polar Ways as a Case Study

Mr. Woods went on to describe Polar Ways in ICE-PPR terminology to explain how a common research topic advances from Exploratory Activity (EA) to a Collaborative Activity Proposal (CAP) and may lead to a Project Arrangement (PAs). This process of systematically growing an international PA will be applied to concepts generated by this workshop (the process is described in greater detail in Appendix 5). Polar Ways provides an example.

Exploratory Activities (EA) begin within the ICE-PPR sub-Working Groups when representatives from two or more nations decide that a common research interest is worthy of further discussion. EAs may continue with Working Group level approval and may last from several months to a year. The Polar Ways project advanced beyond these preliminary meetings in 2024.

CAP (Collaborative Activity Proposal) formalizes exploratory multinational collaboration within ICE-PPR. Initially, each nation can nominate Point of Contacts (POCs). Nations participate based on interest and national procedures. Polar Ways is ONR-funded and Navy-sponsored with key support from US Coast Guard Research and Development Center. Other examples of CAPS include iceberg modeling, ship-to-shore experiments, battery technology for polar operations.

A Project Arrangement (PA) is a legally binding, treaty-level agreement to co-develop capabilities or technologies. An example of co-development is a trilateral battery development PA (U.S., Canada, Norway) where each country builds a physical component. All three components are necessary to achieve return on investment. In contrast, CAPs are voluntary and non-binding; PAs require formal commitment and financial/legal responsibility. In summary, the typical progression is workshop → EA → CAP → Research Task → PA.

In discussion of Polar Ways, Dr. McGillivray emphasized the significance of the upcoming launch of the NISAR satellite in June, highlighting its expected impact on Arctic Ocean and sea ice data collection. He noted that Robert McCoy mentioned the University of Alaska Fairbanks will serve as the data repository for NISAR. Both McCoy and Thurston Marcus pointed out the immense volume of data the satellite will generate—described as "transformational" by the Jet Propulsion Laboratory team lead in an April 17th American Geophysical Union/EO article. Dr. McGillivray stressed that the data volume will necessitate the use of machine learning and AI tools for processing and analysis, a topic also being addressed by Walt Meyer and Ludovic. Due to the international relevance of the Arctic data, he underscored the global importance of developing AI/ML capabilities to manage and interpret the NISAR output effectively.

Additionally, it was noted that NISAR is a left-looking/facing satellite, which will result in a data coverage gap north of approximately 77.5°N latitude. As a result, there will be a continued need for complementary satellite missions to provide sea ice data for the high Arctic regions beyond NISAR's observational range.

Summary and Conclusions

- Polar Ways goal is to synthesize ice classification, cryospheric forecasts, oceanographic data, and informed route optimization in a decision support tool for maritime operators.
- Polar Ways has advanced from initial workshop ideation in 2023 to Research and Coordination (year 1) in 2025.
- The typical progression of a research topic is workshop → EA → CAP → Research Task → PA.

Breakout Group Summaries

As part of the workshop, participants engaged in breakout sessions focused on specific operational domains, including meteorology, maritime, land, space, and special operations. These discussions allowed attendees to pose questions, exchange ideas, and explore opportunities for future collaboration. The following synthesis presents key insights and takeaways that emerged from these sessions.

Meteorology

Participants emphasized the need for Arctic practitioners to advocate more actively for sustained investment in research and development. It was widely acknowledged that while such efforts are often technically demanding and financially burdensome, they are essential for bridging persistent gaps between geospatial support capabilities and military operational needs. Several participants noted that the Arctic has long been treated as a peripheral or "forgotten" domain within broader defense and policy frameworks, needing more practitioners to be vocal supporters and state the need for Arctic R&D, and urged that it be elevated as a strategic priority moving forward. The Arctic is the fight every operator hopes they never have to fight, which means it gets pushed down the priority list. The Arctic needs to be a higher priority than it is.

Maritime Domain

The session on the maritime domain highlighted the complex and evolving nature of dual-use activities, which present significant challenges for governance and security. For example, China's deployment of long-range AUV for scientific research—ostensibly for mineral mapping in the central Arctic Ocean—was cited as a case in point. Such technologies could easily be repurposed for surveillance and reconnaissance, particularly in resource-rich areas such as those containing manganese. Participants discussed the current institutional landscape, noting that while BOEM supports the U.S. Department of State on research initiatives and maintains coordination with agencies such as the Federal Bureau of Investigation and the USCG, there remains a critical deficiency in domain awareness across these bodies. Although Canada is in the process of acquiring MQ-9 unmanned aerial capabilities that could enhance regional situational awareness, these systems are not expected to become operational until 2028.

Land Domain

Operating in the Arctic land domain presents a distinct set of challenges, particularly due to extreme environmental conditions. For instance, participants reported that the durability of screens and the performance of lithium-ion batteries are significantly compromised in sub-zero temperatures. This has important implications for current portable land navigation systems, which, participants agreed, must be redesigned to be cold-resilient, resistant to PNT jamming, and capable of operating without compromising the user's location. Moreover, it was argued that infrastructure on land should not be developed in isolation but rather optimized to support broader situational awareness across maritime and aerial domains.

Space Domain

The discussion on space-based capabilities underscored a number of potential areas for collaboration between government, commercial, and tactical stakeholders. Bridging the gap between commercial space capabilities and end-users in the field was seen as essential,

particularly through improved operator education and full lifecycle engagement in the requirements development process. Participants called for a deeper operational understanding of space-based tools, which would enable more precise and actionable operational requirements. Technical collaboration on automation, cueing, and data fusion was identified as a promising avenue, particularly for integrating government and commercial assets. Enhancing interoperability, especially in joint and combined operations, was viewed as a priority. In addition, participants recommended investing in the development and testing of space-based data fusion tools that could be directly leveraged by operators on the ground during future Arctic exercises. Finally, there was strong consensus on the need to establish recurring forums or engagements to maintain momentum and facilitate ongoing coordination in this domain.

Special Operations

The session on special operations drew attention to the unique logistical and communications challenges associated with Arctic environments, particularly over long distances. Nonetheless, special operations forces were recognized as having the potential to provide significant operational reach while maintaining a relatively small footprint, a key consideration in the Arctic, where many remote communities are both economically and logistically fragile. Participants also pointed to the value of fostering stronger connections with private industry, particularly in the development of technologies and capabilities tailored to the Arctic's distinct demands. Intelligence collection gaps were cited as a priority area for future collaboration, especially with regard to improving information-sharing mechanisms and expanding the use of commercial imagery for situational awareness.

Overarching Themes and Workshop Findings

Key Takeaways

Based on the interaction and feedback of workshop participants, several topic areas emerged as potential further exploration.

- Arctic PNT solutions
 - GPS resilience options available, platform specific
 - Multi-sensor fusion may involve old or new backups
 - Alternative Navigation (AltNav) solutions may be used alone or in combination
- Arctic Space ISR
 - ISR fusion, sharing, and interoperability need improvement in the Arctic
 - Need improved coordination between Arctic ISR producers and consumers.

- AI to increase speed and access to data; AI for intel fusion
- Cross-Working Group collaboration opportunities
 - Maritime Domain Awareness, decision support, and route optimization (Polar Ways)
 - Meteorological and Oceanographic (METOC) considerations intersect the Human Performance, Environmental, Situational Awareness, and Platforms working groups as well as the land, sea, air, and space domains. None of the Working Groups are independently pursuing collaboration to improve meteorological forecasting.
- Consider the integration of Indigenous knowledge in Nav/ISR solutions – applied throughout each recommended activity.

Path Forward/Recommendations

The following recommendations are provided to ICE-PPR leadership for action through the SAWG Sub-Working Groups and/or collaboration between Working Groups. Advancing any facet of these recommended actions will depend on both a science advisor with a stake in the research field and administrative leadership. Sub-Working Group leaders are encouraged to identify a science advisor for topics that emerge as Engagement Activities (EAs) and develop subsequent meetings in partnership with the researcher. Additional details on how to mature the following recommendation may be found in Appendix 4.

Positioning, Navigation, and Timing

Promising research in positioning, navigation, and timing solutions involved several methods. First, a near term remedy to harden navigation systems against spoofing and jamming is to use a multiantenna array with software designed to discriminate between legitimate GNSS signals and false signals. Another approach to extending the lifespan of GNSS systems is to backup GNSS with proven navigation technologies such as enhanced Loran or inertial navigation (i.e. multi-sensor fusion). A third approach looks beyond current applications to the promise of known technologies to wider navigation purposes. Research opportunities include odometry, map matching (e.g. gravimeter, magnetometer, thermal, visual, lidar, radar, or sonar), terrestrial and space-based signals of opportunity, and acoustic navigation.

Recommendation 1.1: Further explore GPS antennae hardening solutions, signal discrimination, and jamming/spoofing detection to determine common understanding and application across the ICE-PPR community.

Recommendation 1.2: Explore map-matching for small UAVs based on visual, thermal, and other sensors with the aim of a near-term Exploratory Activity. Invite Swedish Defence Research Agency (Jouni Rantakokko), MITRE (Kevin Martin), et. al. to participate in an

Exploratory Activity Working Group. to discuss PNT for low flying small UAVs using visual and thermal sensors. Invite collaboration with Platforms WG.

Recommendation 1.3: Explore the use of AI to interpret and apply remote sensing data for navigation solutions.

Recommendation 1.4: Assess interest across the Nav/ISR SWG in exploring collaboration opportunities in AltNav with odometry, map matching (e.g. gravimeter, magnetometer, thermal, visual, lidar, radar, or sonar), terrestrial and space-based signals of opportunity, and acoustic navigation

Space-based ISR

Space-based ISR capabilities held a high level of interest for practitioners and researchers alike. The sessions on Day 2 were organized around military domains, but the applicability of space-based capabilities intersected several domains and ICE-PPR WGs. A predominant theme was the need for improved understanding and access to ISR data by Arctic operators. Another important aspect is that new overhead capabilities will produce data in quantities that overwhelm human capacity to interpret it.

Recommendation 2.1: Explore opportunities for improved sharing and interoperability among ISR stakeholders in the land domain to further define where gaps are present and where partner nation interest exists. Include land domain stakeholders SOCNORTH, 11th Division, NATO CWO-COE, US Army DEVCOM, PixElement, MITRE, etc.

Recommendation 2.2: Explore opportunities for improved sharing and interoperability among ISR stakeholders in the maritime domain to further define where gaps are present and where partner nation interest exists. Invite maritime domain stakeholders including Alaska Marine Exchange, USGC, POLARCTIC, etc.

Recommendation 2.3: Explore opportunities for improved sharing and interoperability among ISR stakeholders in the air domain to identify gaps and assess partner nation interest. To further explore air domain ISR gaps, seek input from AFRL, 109th Air Wing, Aerion, and Integrity ISR.

Recommendation 2.4: Initiate further discussion of AI as a tool for intel fusion with space-based ISR producers and researchers from US and multinational stakeholders such as AFRL, Space Inventor, C-Core, Integrity ISR, UAF, etc. Consider data sources that may appear valuable yet aren't well utilized.

Cross Working Group Collaboration

Two Cross-Working Group collaboration opportunities emerged from this workshop. First, with the presentation of Polar Ways, it sparked interest in SAWG involvement as ISR capabilities are involved in the concept of route optimization. Second, a breakout room discussion on meteorology raised a similar opportunity – ISR capabilities might be leveraged to overcome Arctic meteorological forecasting challenges not only in the cryosphere but also in the atmosphere.

Recommendation 3.1: SAWG leadership including both SWG XOs should engage with the Polar Ways initiative to determine potential for contribution to the Polar Ways CAP based on the growing network of SAWG researchers.

Recommendation 3.2: SAWG/ONR leadership should draft a METOC EA for consideration by the remaining Working Groups to determine interest in collaboration on Arctic meteorological modeling and forecasting. Leveraging the existing US METOC Arctic Summit, this could include the presentation of ongoing research topics to partner nation principals in each WG.

Indigenous Knowledge

Workshop participants pointed out that Indigenous knowledge was not represented or considered in the panel presentations. Going forward, exploration of all Nav/ISR research topics should consider incorporating Indigenous knowledge. The unique way of life and depth of knowledge of Arctic Indigenous cultures can inform fundamental research needs such as data collection and can contribute to security and defense solutions in a harsh and unfamiliar environment. Co-creation of knowledge is not limited by research subject area or purpose.

Appendices

Appendix 1 - Agenda

Day 1 – Tuesday, 29 April 2025: Framing ICE-PPR SAWG PNT Efforts		
Time (AKDT)		Topic
0630 – 0700	1030 – 1100	Zoom link open for tech check and troubleshooting
0700 – 0715 Time (EDT)	1100 – 1115	- Welcome/Opening Remarks - Setting the Stage - Group Connection
		Science Update Presentation and Q&A Dr. Phil McGillivray
0715 – 0750	1115 – 1150	Panel 1: Contested GPS - Plenary Presentation and Q&A - Moderator: Mr. Matt Schell, Ted Stevens Center - Dr. Arthur Scholz, MITRE - Mr. Andy Alfiero, American Airlines Safety - Mr. Patrick Drain, USEUCOM J5
0750 – 0825	1150 – 1225	
0825 – 0835	1225 – 1235	Break/Return to Plenary
0835 – 0910	1235 – 1310	Panel 2: GPS Alternatives- Plenary Presentation and Q&A - Moderator: LCDR Barry McShane, Ted Stevens Center - Mr. Mark Anderson, NAWC - Mr. Bridge Littleton, Hellen Systems - Mr. Rob Gillette, NAL Research Corporation
0910 – 0915	1325 – 1315	
		Break/Return to Plenary
0915 – 1005	1315 – 1405	Panel 3: Future PNT - Plenary Presentation and Q&A - Moderator: Dr. Kelsey Frazier, Ted Stevens Center - Dr. Thorston Markus, NASA HQ - Lt Col Zachary Franklin, 509th OSS - Mr. Jouni Rantakokko, Swedish Defence Research Agency, FOI - Dr. Ryan Cassel, MITRE - Dr. Kelly Backes, MITRE
1005 – 1015	1405 – 1415	
		- Instructions for Max Mix breakout rooms - Break/Return to Plenary



		Breakout Discussions – Max Mix
1050 – 1100	1450 – 1500	Day 1 Summary/Day 2 Preview • Closing Remarks • Group Checkout

1015 – 1050 1415 – 1450

Day 2 – Wednesday, 30 April 2025: Arctic ISR

Time (AKDT)	Time (EDT)	Topic
0630 – 0700	1030 – 1100	
		Zoom link open for tech check and troubleshooting
0700 – 0710	1100 – 1110	• Welcome Back/ Provide Day 1 Summary • Setting the Stage for Day 2 • Group Connection
0710 – 0810	1110 – 1110	Panel 4: Land and Sea (in the Arctic and Maritime) – Plenary Presentation and Q&A • Moderator: Dr. Christine Duprow, Ted Stevens Center • MAJ Matt Hefner, JTF Ulfer • LTC John Limauro, 11 ABN DIV G2 • Mr. Rob Smith, SOCNORTH • Dr. Christoffer Nuth, Norwegian Defense Research Establishment • CAPT Steve White, Marine Exchange of Alaska • Ms. Leslie Canavera, PolArctic
0810 – 0815	1210 – 1215	
0815 – 0915	1215 – 1315	Break/Return to Plenary
		Panel 5: Air and Space - Plenary Presentation and Q&A • Moderator: Dr. Kate Friedman, Ted Stevens Center • Dr. Wellesley Pereira, Space Force • Mr. Alex Duchane, AFRL • Mr. Greg Gillinger, Integrity ISR • Mr. Derek Fleck, Aerion • Dr. Dan Eleuterio, ONR 32 • Lt Col Matthew Sala, 109th Airlift Wing
0915 – 0920	1315 – 1320	
		Break/Return to Plenary



		Panel 6: ISR Research (5-15 yrs) - Plenary Presentation and Q&A
0920 – 1020	1320 – 1420	• Moderator: Ms. Kristi Swain, Ted Stevens Center • Dr. Bob McCoy, UAF Geophysical Institute
		• Mr. Givay Kochanowski, Bureau of Ocean Energy Management • Lt Col, Elizabeth Ramoso, USAF • Mr. Martin Olesen, Space Inventor • Dr. Ben Vander Jagt, PixElement
1020 – 1030	1420 – 1430	Breakout Discussions – Fair Style
1030 – 1050	1430 – 1450	Day 2 Summary/Day 3 Preview
1050 – 1100	1450 – 1500	• Closing Remarks • Group Checkout

Day 3 – Thursday, 1 May 2025: Polar Nav/Ways and Way Forward

Time (AKDT)	Time (EDT)	Topic
0630 – 0700	1030 – 1100	Zoom link open for tech check and troubleshooting
0700 – 0710	1100 – 1110	• Welcome Back/ Provide Day 2 Summary • Setting the Stage – Day 3 Agenda
0710 – 0750	1110 – 1150	• Group Connection
		Polar Nav/Ways- Plenary Presentation and Q&A
		• Mr. Church Kee, Ted Stevens Center • Mr. John Woods, International Engagement, Office of Naval Research Global
0750 – 0755	1150 – 1155	
0755 – 0850	1155 – 1250	Workshop Breakouts
		• Mr. Blair Sweigart, USCG
		Break/Return to Plenary

		Day 3 Summary/Way Forward • Define Next Steps/Actions • Closing Remarks • Group Checkout
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0850 – 0900 1250 – 1300



Appendix 2 - SLIDO Responses

What resilience or redundancy solutions should be the highest priority for research investment?

Quantum Technologies

- Quantum inertia
- Quantum sensing coupled with quantum encryption
- Quantum technologies for positioning and AI-based map reading

Navigation Techniques

- Magnetic mapping and map matching (MagNav, Electro-Optical/Infrared-based odometry)
- Anti-jam PNT at the tactical level
- Integrated PNT solutions distinguishing between sources

Alternative PNT Solutions

- Ground-based navigational aids, Distance measuring equipment, eLORAN
- GPS alternatives
- Multifunction PNT receivers with embedded zero trust performance algorithms

Hardware Resiliency

- Hardened GPS Multi-Mode Receivers and Global Landing Units to deny spoofing
- Low-cost, 3-D printed sensor parts

Satellite and Communication Integration

- Satellite Communication integration
- Use of Starlink constellation for alternate timing sources
- Diversified networks integrating quantum and low Earth orbit technologies

Arctic and Remote Area Solutions

- Over-the-horizon radar (OTHR) for Arctic surveillance
- Autonomous assets for response in remote areas

- Enhancing communications in the Arctic

Logistical and Energy Solutions

- Logistical redundancy and knowledge continuity
- Reliable energy and power sources
- Small, mobile/deployable networks

What non-space based PNT solution holds the most promise for defense applications and what research must be done to advance that technology?

eLORAN

- Modernizing Loran infrastructure and receiver technology to provide a robust terrestrial backup to GPS. Research should focus on improving accuracy, coverage, and interoperability with other PNT systems.
- eLORAN portable site locations.
- eLoran (fixed and transportable sites). Need to shrink footprint and develop mobile options to improve survivability.
- eLoran systems, integrate into existing networks and field test capability and potential implementation within service capabilities.
- E-loran sounds smart. But a wide variety of options is probably most resilient and merging them to one system.
- E-loran... fixed and mobile solution with integration as a back-up to current & emerging systems.
- eLORAN should be considered as briefed today for both quick response and strategic placement locations for GPS RFI and Contested, Degraded, and Operationally-Limited (CDO) environments.
- ELORAN As it can go underwater... and muimetrics, ditto.
- eLoran, integration of the technology to operator platforms and equipment.

Ground-Based Radio Navigation

- Exploring new terrestrial radio navigation systems that can offer localized PNT services, especially in urban canyons and other GPS-challenged environments.



Quantum-Based Solutions

- Long-term is the development of quantum-based inertial sensors, medium-term is the development of methods to use quantum-based magnetometers for anomaly field matching. Shorter-term is the collection of thermal sensor data for testing of map-matching algorithms.
- Quantum techniques, MagNav.
- Quantum sensing coupled with mapping of fields em gravity etc.
- GravNav/MagNav...affordable, low SWAP, military grade sensors.

Signals of Opportunity

- Onboard AI to use all available signals of opportunity (GPS, eLoran, vision-based, etc.) and make the best estimate of current position.
- Signals of opportunity.
- Signals of Opportunity.
- Integrate current capabilities.

Over-the-Horizon Radar (OTHR)

- Same answer - OTHR. Let's work with Canada on their P=OTHR initiative.
- Anti-jam PNT available at the tactical level.

What are some areas we need to further explore and/or collaborate on moving forward?

Air Domain

- Different Planning Cycles: ICEPPR can help synchronize planning cycles.
- Sensor/C2 Fusion: Bridging the gap in the air domain with real-time full motion video and integrating space sensors.
- Inter-Agency Collaboration: Enhancing collaboration among agencies conducting airborne campaigns in the Arctic.
- Sensor Integration: Expanding air domain awareness by integrating multiple sensors and developing models to recognize deviations and anomalies.

Land Domain

- **Battery Technology:** Recharging lithium batteries and hardening screen crystals for end-user devices in extreme cold.
- **Cold Resilient Navigation:** Developing portable land navigation systems capable of contending with PNT jamming in cold environments.
- **Weather Forecasting:** Improving weather forecasting in Alaska and the Arctic by identifying and utilizing better data sources.
- **Dual Use Facilities:** Supporting the maritime and air domains through land-based facilities.
- **Force Projection:** Creating air defense bubbles to deter strategic competitors.
- **Communication Improvement:** Enhancing lines of communication across the joint force to operate effectively in the Arctic environment, improving resource allocation and unity of effort.

Maritime Domain

- **Hypersonic Testing:** Conducting hypersonic testing for advanced maritime capabilities.
- **Undersea Monitoring:** Implementing persistent undersea monitoring for enhanced maritime domain awareness.



Appendix 3 - Participants

Full Name	Group / Organization	Primary Role	Specific area of expertise in the ICE-PPR Community
Lt Col Andy “ALF” Alfiero	MeANG / American Airlines	Other	Arctic Subject-Matter Expert / Safety / USAF Weapons Officer / Warfighter
Mr. Paul Adlakha	C-CORE	Senior Leadership	Satellite Monitoring
Captain Rebecca Albert	Coast Guard Task Force - Arctic	Command and Control (Operations)	Not Specified
Mr. Douglas Allen	MIT Lincoln Laboratory	R&D	Maritime Awareness and OTHR
Dr. Niels Andersen	DTU Space	Senior Leadership	Not Specified
Mr. Mark Anderson	USN/FAA/NAWC/American Airlines	Analysis	GPS Disruption, GPS Protection, Alternate PNT
Colonel Michael Anderson	AFWERX	Other	ISR
Mr. Isaac Armijo	Joint Navigation Warfare Center / J33	Other	NAVWAR
Mr. Frederic Arpin	DRDC ORC	R&D	RF Sensing
Ms. Heather Atkinson	AFRL	R&D	Not Specified
Dr. Kelly Backes	MITRE	R&D	Quantum Sensing
Ryan Baldrige	SOCNORTH	Senior Leadership	USNORTHCOM
Mr. Joshua Barnes	National Research Council	Project / Program Management	Arctic Mobility
Col Brett Batick	174th Attack Wing	End User (Warfighter)	Remotely Piloted Operations

Mr. Anthony Bausas	U.S. Fleet Forces Command	R&D	Communications
TR Beasley	10th Special Forces Group	Project / Program Management	Arctic Regional Expertise Culture Director (Academic)
Dr. Ivan Beckman	CRREL	R&D	Not Specified
Mr. Benjamin Bell	SOCNORTH	Not Specified	SOF Operations in the Arctic
Jon Benvenuto	USCG	Project / Program Management	Not Specified
Mr. Benjamin Berman	USCG Research and Development Center	R&D	Assured PNT
Mr. James (Dan) Blackman	USCG / CG-684	Project / Program Management	Program Management
Dr. Aaron Blevins	NSWC PCD	R&D	Autonomy, Remote Sensing, Under-Ice UUVs
Dr. Dan Breton	ERDC-CRREL	R&D	Sensor Performance
1st Lt Andrew Brown	15 OWS	Analysis	Not Specified
Mr. William Byrne	ICE-PPR	Project / Program Management	Platforms Working Group
Mrs. Leslie Canavera	PolArctic	R&D	AI Sea Ice Forecasting
Major David Casas	608th Air Operations Center	Command and Control (Operations)	Bomber & Information Operations
Mr. Ronald Caton	AFRL/CJ	Other	AFRL Space Security & Int'l Partnerships Mission Area Lead
Dr. Douglas Causey	U Alaska Anchorage	R&D	Arctic Environmental Security
Mr. Daniel Chatelain	AFGSC/A5B Bomber Requirements	End User (Warfighter)	I am the PNT Lead for Air Force Global Strike Command HQ.
Dr. Jonathan Chavanne	NAVSEA Team Ships S&T Directorate	Command and Control (Operations)	Surface Ship Arctic Operations
Mr. Sean Collins	DTRA	Analysis	Arctic Policy



Dr. Eamon Conway	KRI at Northeastern University LLC	R&D	ISR, ML/AI, Remote Sensing.
Dr. Jose de Arimateia da Cruz	US Army War College	Analysis	Gray Zone
Dr. Mohammed Dabboor	Science and Technology Branch, Environment and Climate Change Canada	R&D	Satellite Remote Sensing using Synthetic Aperture Radar (SAR)
Dr. Elias Deeb	USACE ERDC-CRREL	R&D	ISR
Jason Derr	United States Military Academy	R&D	Not Specified
Dr. Michele Devlin	US Army War College	Senior Leadership	Education of Senior Leaders on Arctic/Antarctica
Dr Jessica Dibelka	ONR	Other	Marine Platforms Sub-WG lead
Mr. Kevin Dodd	Special Operations Command North (SOCNORTH)	Analysis	Arctic Intelligence Analysis
Dr. Adrian Doran	US Army ERDC-CRREL	R&D	Sensors, environment, platforms
Dr. Thomas Douglas	U.S. Army Cold Regions Lab	Project / Program Management	Snow, ice, and permafrost science
Mr. Patrick Drain	USEUCOM J5 (Booz Allen Hamilton)	Project / Program Management	European Arctic Security
Mr. Alexander Duchane	AFRL/RVSU	R&D	Missile Warning/ISR
Dr. Christine Duprow	TSC	Other	Moderator
Dr. Daniel Eleuterio	ONR 32	R&D	Ocean, Atmosphere, Cryosphere and Ionosphere impacts on ISR
Ms. Makayla Enchill	Defense Threat Reduction Agency	Project / Program Management	Not Specified



Dr. Deniz Erdogan	KRI at Northeastern University	Senior Leadership	ISR
SES / Dr. Gregory Estevez	Defense Counterintelligence and Security Agency	Senior Leadership	Intelligence, Surveillance, Reconnaissance
Mr. Scott Fields	USCG RDC	R&D	Not Specified
Mr. Derek Fleck	Aireon	Other	Air Domain Awareness
Mr. Theodoros Fotiadis	Swedish Armed Forces	R&D	Situational Awareness
Dr. Kelsey Frazier	TSC	Senior Leadership	Sea Ice Modeling
Dr. Lauren Freeman	NUWC Newport	Project / Program Management	Ocean Atmosphere SWG Lead, Ship to Shore Experiment Chief Scientist
CDR Tucker Freismuth	US National Ice Center	Senior Leadership	Not Specified
Dr. Bruce Fritz	Office of Naval Research (ONR)	Project / Program Management	Space Weather
Mr. Roger Fuller	USCG Office of C5I Capabilities	Command and Control (Operations)	Navigation
Dr. Humberto Garcia	Idaho National Laboratory	R&D	resilient and intelligent networks for control, ISR, and targeting
Ms. Sally Garrett	New Zealand Defence Force	Senior Leadership	Polar defence researcher
Robert Gillette	NAL Research Corporation	Senior Leadership	APNT for GPS Denied / Degraded environments
Mr. Greg Gillinger	Integrity ISR	Analysis	Space-based ISR
Dr. Andrew Glen	Sandia National Laboratories	R&D	Arctic Observations; Field Sites; National Security; Balloon observations

CDR Rachael Gosnell	GCMC	Analysis	Arctic security
Ms. Amna Greaves	MIT Lincoln Laboratory	R&D	AI/ML
CDR Paul Guinn	ICEPPR	Project / Program Management	HPWG
MSG Ben Hahn	SOCNORTH	Analysis	DoD Intelligence and Analysis
TSgt Lance Harrison	1WXG / 15OWS	Other	Weather
Dr. Carl Hart	U.S. Army ERDC-CRREL	R&D	Technology
Ms. Gudbjorg Rikey Hauksdottir	Arctic Initiative	Other	Arctic security and geopolitics
Mr. Richard Holmquist	HawkEye 360	Other	Satellite Remote Sensing - BD/Sales
Dr. Thomas Hughes	Mount Allison University	Not Specified	Defence policy and threat perception
Ms. Kate Ives	DCSA	Other	National Security
Dr. Jarom Jackson	NSWC PCD	R&D	Underwater electro-optics, through-ice comms
Dr. Robert Jensen	DEVCOM - Army Research Laboratory	R&D	Arctic formulations of chemical agent resistance coatings (CARC)
Major Spencer Jordan	174 ATKW	Command and Control (Operations)	MQ-9 UAS
Dr. Michael Kobold	NSWC-PCD / Navy	Analysis	PNT, sediment, & aComms
Mr. Forgiveness Kochanowski	Bureau of Ocean Energy Management	Senior Leadership	Arctic and Situational Awareness, Energy and National Security and Strategy
Mr. Risto Korhonen	Finnish Defence Research Agency (FDRA)	R&D	RF-sensors
Jo Kurucar	MIT Lincoln Laboratory	R&D	Technology Development
Mr. Paul Kutia	USACE/ERDC/CRREL	R&D	STategic outlook



Dr. Tom Lauknes	NORCE NORWEGIAN RESEARCH CENTRE AS	R&D	Remote Sensing: Satellite, Airborne, UAS, Radar, SAR
Ms. Sandra LeGrand	ERDC	R&D	Weather effects on military functions, METOC
Dr. Franz Lichtner	CRREL	R&D	Not Specified
LTC John Limauro	11th Airborne Division, US Army Pacific	Senior Leadership	ISR warfighter
Mr. Jeff Lipscomb	Arctic Regions Test Center	Other	Effects of the environment on materiel - Testing
Mr. Bridge Littleton	Hellen Systems	Project / Program Management	PNT
Col Diana Loucks	United States Military Academy	R&D	Polar Aeronomy & GPS
Ms. Marisol Maddox	Dartmouth	Academic	policy, science diplomacy
Mr. Youssef Mani	Canadian Coast Guard / Assistant Commissioner, Arctic	Senior Leadership	Not Specified
Ms. Laura Maple	NAVSEA	Project / Program Management	EW
Mr. Andy Margules	ERDC-CRREL	R&D	ERDC LNO to N&NC
Dr. Thorsten Markus	NASA HQ	Project / Program Management	sea ice observations and modeling
Ms. Michele Maxson	ERDC-CRREL-SPB	R&D	electromagnetics
Mr. Nicholas McCarthy	HawkEye360	R&D	Space-based RF collection and geolocation
SFC Joseph McCarty	SOCNORTH	Analysis	Not Specified
Dr. Bob McCoy	Geophysical Institute, University of Alaska Fairbanks	R&D	Not Specified
Ms Sue McLennan	Canadian Coast Guard	Other	Not Specified
LCDR Barry McShane	US Navy ONR ICE PPR	Not Specified	Not Specified



Mr. Dallas Meggitt	Sound & Sea Systems, LLC	Senior Leadership	Surveillance and data fusion
Ms. Karin Messenger	USCG	R&D	identifying research opportunities to address CG endusers S&T gaps.
Ms. Michelle Michaels	USACE CRREL// DoD SERDP-ESTCP	Project / Program Management	Not Specified
1st Lt Iain Miller	Alaska Air National Guard	End User (Warfighter)	Not Specified
Mr. Jason Minett	NAVSEA	Project / Program Management	Icebreakers
Lt Col Giancarlo Moats	Air Force Materiel Command	Command and Control (Operations)	Multi-Domain Ops
Ms. Sofia Montalvo	Naval Ice Center	Senior Leadership	Sea ice products and services for the USG
Wesley Moses	U.S. Naval Research Laboratory	Project / Program Management	Remote Sensing
Dr Mark Myers	USARC	R&D	Remote Sensing
Dr. Myoung-Jong Noh	The Ohio State University	Other	air and space borne photogrammetry
Dr. Adriana Avila Zuniga Nordfjeld	Swedish Defence University	Other	Not Specified
Dr. Christopher Nuth	Norwegian Defense Research Establishment	R&D	Remote Sensing, Geophysics, Sensors, Data analytics
Mr. Hans Olson	UMass Lowell - Applied Research Corporation	Other	Cyber
Mrs. Katelyn Olsson	15 OWS	Other	Not Specified
Archibald Owen	Draper	Project / Program Management	PNT

Mr. Robert page	USCG	Project / Program Management	PM
MAJ Jake Parker	Arctic Aviation Command, 11th ABN Division	End User (Warfighter)	Logistics
Mr. Jared Peltier	Army Futures Command / 11th ABN DIV	R&D	Science & Technology
Dr. Wellesley Pereira	Air Force Research Lab	Senior Leadership	Space-Based Multi-Modal Sensing
Mr. Robert Pickering	USCG	Project / Program Management	C2 & Sensors
Lincoln Pitcher	US Army - ERDC - GRL	R&D	Not Specified
Dr. Jonathan Pitts	MIT Lincoln Laboratory	R&D	Sensing, Analytics, Decision Support, C2
Mr. Kelly Prim	Navy PEO IWS 6.0	Project / Program Management	Assured PNT
Lt Col Elizabeth Ramoso	15 Operational Weather Squadron	End User (Warfighter)	METOC Perspective
Mr. Jouni Rantakokko	Swedish Defence Research Agency, FOI	Project / Program Management	PNT and autonomy
Vanessa Raymond	Alaska Center for Energy and Power	Senior Leadership	Arctic energy
CMSgt William Reisner	HAF/A3S	Other	Air Force Special Reconnaissance (SR / 1Z4) Career Field Manager (CFM)
Dr. Christopher Rogers	US Coast Guard	Project / Program Management	Communications
Ms. Katrina Ruane	NORAD & USNORTHCOM	Analysis	Not Specified
Lt Col Matthew Sala	109 AW	End User (Warfighter)	USAF LC-130
Capt Rachel Sax	15th Operational Weather Squadron	Other	Not Specified

Mr. Paul Sheppard	NSF/OPP	Project / Program Management	Polar Policy
Capt Lewis Simmons	174th Attack Wing, New York ANG	End User (Warfighter)	RPA Pilot
Col Steven Slosek	109th Air Wing	Senior Leadership	Arctic Aviation Operations
Mr. Patrick Smith	U.S. National Science Foundation (US Gov), Office of Polar Programs	Project / Program Management	Satcom, general technology
Sonja Nicole Smith	NSWC PCD	Project / Program Management	Underwater Sensing-Autonomy, International Collabs
Mrs. Amber Sorg	Idaho National Laboratory	Project / Program Management	Critical Infrastructure
Dr. Leigh Stearns	University of Pennsylvania	R&D	iceberg and sea ice remote sensing
Colonel Scott Stenger	DOD Liaison to NSF Office of Polar Programs	Project / Program Management	Polar Programs Support
Dr. Carolyn Stwertka	ALCOM	End User (Warfighter)	Not Specified
Dr. Hailie Suk	CRREL	R&D	Not Specified
MSG Emerson Sullivan	11th Airborne Division, US Army	Command and Control (Operations)	ISR collection and application with a Arctic environment
LCDR Lee Suring	Navy	R&D	OA
Mr. Michael Svoleantopoulos	720 Special Tactics Group	End User (Warfighter)	Reconnassaince, Tech, Signiture Management
Ms. Tori Sweet	CRREL	R&D	Extreme cold lithium-ion batteries and Arctic oil spill response research.
Major Charles Taylor	Joint Nvigation Warfare Center	Other	Not Specified



Dr. Molly Tedesche	CRREL	R&D	Snow Physics, Snow Hydrology, Glaciology, Alaska Focused
Mr. Edwin Thiedeman	U.S. Coast Guard	Project / Program Management	GMDSS and Search and Rescue Systems
Mr. Xisen Tian	Naval Postgraduate School	R&D	Secure Communications
Mr. Jon Turban	USCG Research & Development Center	R&D	Maritime Communications
Dr. Douglas Van Bossuyt	Naval Postgraduate School	R&D	Energy security / microgrids, UxS/C-UxS
Dr. Benjamin Vander Jagt	PixElement	R&D	Not Specified
Mr. John Vehmeyer	DHS S&T	R&D	Not Specified
Mr. Martin Vogdrup Olesen	Space Inventor A/S	R&D	Space - Satellites
Mr. Cisco Webb	AFGSC/A5B	Other	Bomber Requirements
Dr. Orian Welling	CRREL	Other	Not Specified
Colonel Mark Wernersbach	109th AW	Command and Control (Operations)	DoD Polar Airlift
Captain Steve White	Marine Exchange of Alaska	Senior Leadership	MDA/Analysis/Equipment Deployment
Mr. Graylin Worcester	MDSI US INC.	Senior Leadership	Multi-Domain Situational Awareness
Prof. Christopher J Zappa	Lamont-Doherty Earth Observatory of Columbia University	Project / Program Management	Surveillance and Reconnaissance



Appendix 4 - SAWG Way Forward: From Collaborative Activity Proposal (CAP) to Exploratory Activity

The ICE-PPR NAV/ISR Workshop reaffirmed the SAWG's commitment to advancing Arctic readiness, deepening technical expertise, and increasing opportunities for operational collaboration. In anticipation of the next in-person workshop, there is a need to capitalize on the momentum generated during the virtual session.

Several project areas emerged as high-interest topics during the virtual workshop, including:

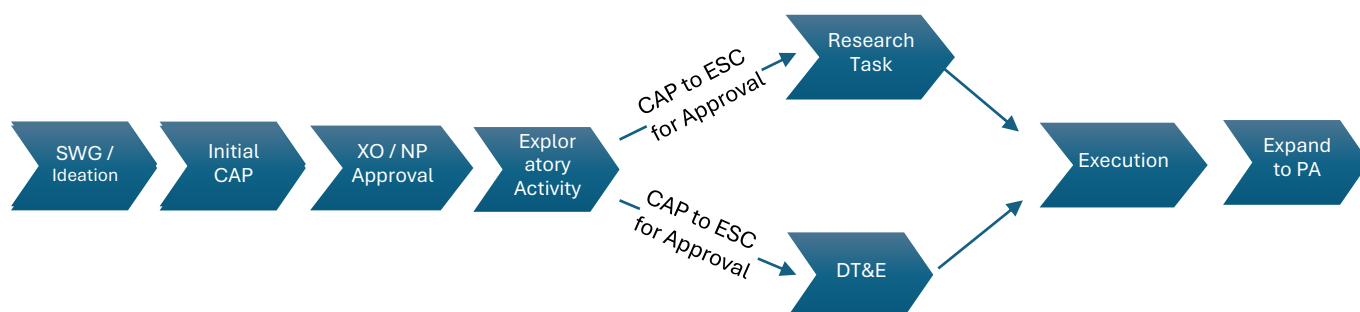
- Arctic PNT Solutions
- Arctic Space ISR
- SAWG Support to Polar Ways
- Meteorological forecasting

Pending further iteration and ESC approval of a formal CAP Workflow Process, the following outline will assist Sub-Working Group progress on high interest topics.

Over the upcoming months, NAV/ISR participants are encouraged to take part in Working Groups (WG) and Sub-Working Groups (SWG) organized by SAWG Nav/ISR. In these groups, informal discussions on CAPs are intended to explore shared challenges, capabilities, and opportunities related to project areas highlighted during the virtual workshop. The goal is to clarify what's possible, what needs to be done, and establish a realistic timeline – ultimately shaping a clear, actionable concept that will receive the approval of country XOs and could evolve into an Exploratory Activity (EA), or, at a minimum, support coordination through less formal avenues.

An ICE-PPR Maturity Model

The ICE-PPR Maturity Model provides an approach for developing project ideas from early-stage ideation/discussions to Project Arrangement (PA), which represent formal, balanced commitments/contributions among participating nations. Advancement through each stage is based on meeting defined milestones and decision points that demonstrate readiness, alignment, and mutual value.



Initial Collaborative Activity Proposal

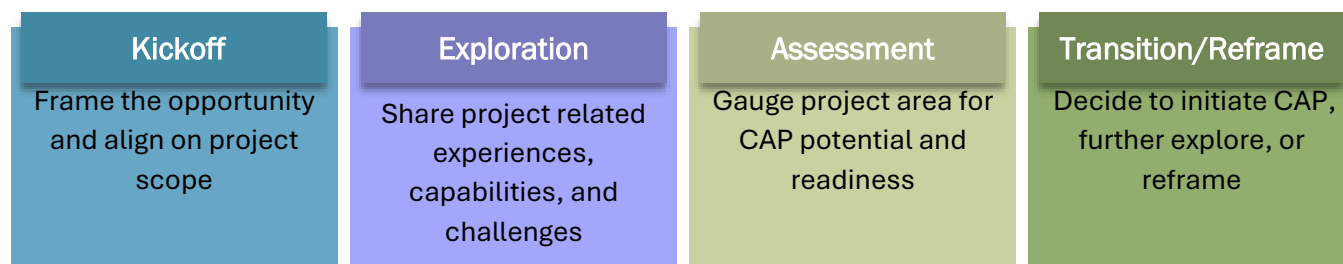
Initial discussions and ideation in ICE-PPR sub-working groups may be documented in an Initial Collaborative Activity Proposal (CAP). A designated CAP Lead drafts the proposal based on informal cross-national discussions. However, interested participants other than the CAP Lead must be identified by the national XOs and/or National Principals (NPs). The CAP includes proposed nations, resources, and funding.

The initial CAP is circulated among the national XO/NPs before it is approved by the ICE-PPR ESC.

Framework for Exploratory Activities (EAs)

The four-phase EA framework provides a path for maturing an initial CAP by turning shared project interests into actionable outcomes that support the further development of CAPs and/or advance progress in areas related to Arctic readiness.

Each phase may involve multiple discussions with international partners and subject matter experts to refine the project area, and ensure alignment with other US/international priorities, capability levels, and existing initiatives, while accounting for operational constraints.



Exploratory Activity Working Group (EAWG) Guidelines

To ensure EAs are productive and lead to meaningful outcomes, EAWGs should operate with the following principles in mind:

- **Membership Composition:** EAWGs should include members with relevant expertise, including international partners and subject matter experts (SMEs), who can provide technical insight and strategic guidance.

- Coordination and Support: A designated coordinator helps organize discussions, maintain momentum, and guide the group through the EA process toward a mature CAP and/or substantive coordination effort.
- Agile Structure: Leads have the discretion to shape the group's direction, format, and pace based on the needs of the project area and participants.
- Action Focus: While open dialogue is important, discussions should aim to build a capable team and define a clear path forward for the project area. The objective is to reach a **critical mass of engagement and alignment** that enables a smooth transition toward developing the CAP.
- Organic Evolution: As discussions develop, EAWGs may split into multiple EAs if new or distinct ideas emerge that merit separate exploration.

Participant Expectations in EAs

- Drive the Conversation: Bring forward relevant insights, operational experience, and technical knowledge to help frame the discussion and clarify the problem space.
- Test Ideas and Assumptions: Share perspectives, expertise, and lessons learned to challenge assumptions, identify gaps, and refine emerging concepts.
- Build Connections: Engage with peers across organizations and nations to strengthen relationships and uncover shared priorities and areas of mutual interest.
- Shape Next Steps: Help define what success looks like and what's needed to move forward. The goal is to reach critical mass—a clearly defined problem, strong interest, and active engagement across organizations and nations—maturing the Collaborative Activity Proposal (CAP) and attaining ESC approval.
- Capture What Matters: Contribute to documenting key takeaways, open questions, and potential directions to support continuity and follow-up.

This plan outlines milestones to guide early collaboration, shape project direction, and development of the initial Collaborative Activity Proposal (CAP). This sets the stage for determining if an approved CAP should continue as an EA, evolve into a Research Task (RT), or move to Demonstrations, Experiments & Trials (DE&T).

30-60-90 Day Exploratory Activities (EAs) Plan

Phase 1: Kickoff - Framing the Opportunity & Align on Project Scope	
Timeline: Days 0 - 30	
Primary Actions	Expected Outcomes
- Identify project areas for an initial CAP (e.g., PNT, Space ISR, METOC) - Identify a CAP Lead and a Coordinator - Establish SWG expectations and preliminary collaboration schedule (consider monthly meetings) - Identify participants (in accordance with ESC guidance) and confirm SWG roles and responsibilities - Stakeholder Outreach - Identify National Principals/Executive Officers (XOs) - Industry representatives - Academia	- EAWGs and EAs activated - Preliminary POAM established - Shared understanding of SWG project area - Initial alignment on project area goals - Defined roles/responsibilities of contributing SWG members

Phase 2: Exploration - Share Project Related Experiences, Capabilities & Challenges	
Timeline: Days 0 - 60	
Primary Actions	Expected Outcomes
- Conduct regular scheduled EA meetings (bi-monthly at a minimum) for your project areas - Validate rosters and invitations to ensure appropriate representation - Answer directional exploratory questions to gauge project area for CAP potential and readiness: - What operational experiences or challenges have been encountered in this project area? - What ideas or opportunities are emerging that are worth deeper exploration?	- Broadened understanding of community expertise and challenges - Clearly defined project area scope and direction for the initial CAP - EAWG momentum - Increased visibility of shared needs and to gauge

○ What impact could addressing this project area have on Arctic readiness or capabilities? ○ What shared interests/priorities (national and international) are reflected in this project area? ○ Who has relevant expertise, operational insight, or strategic interest in this project area? ○ What related initiatives, pilots, or frameworks are we aware of that connect to this project area?	
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- Initiate a draft of the r
- Strengthened connections across ICE-PPR nations/stakeholders with relevant

• Assess the feasibility – what can we all work on together to move the CAP forward? • Use CAP readiness questions to evaluate viability: ○ <i>What operational outcomes or capability improvements are we targeting through this CAP?</i> ○ <i>What evidence/indicators suggest that this project is mature enough to transition from EA to CAP?</i> ○ <i>What are the strategic consequences of not addressing this project area now?</i> ○ <i>How will this project area advance/align with ICE-PPR priorities?</i> ○ <i>How does this project align with the priorities of participating nations, and what commitments or contributions are needed from each to ensure maximum relevance and impact?</i> ○ <i>What roles, responsibilities, and coordination mechanisms are required to execute this CAP effectively?</i> ○ <i>What concrete deliverables or milestones can we define based on existing work or prior efforts in this project area?</i>	• CAP Lead's national XO or NP socializes the Initial CAP with partner nation XO/NPs • Evidence of project maturity and readiness for Initial CAP approval • Initial CAP submitted to ESC for approval

Share progress with the ESC/ICE-PPR leadership	
- Define problem and establish team. Clearly convey issue to be addressed/concept to be explored. Identify individuals and organizations involved and clarify their respective roles and contributions. - Contributions may differ, but there should be a shared understanding and alignment of expectations. - Don't stop the possible for the perfect—prioritize progress and clarity over precision. - Based on ESC decision, continue or reframe the CAP: - Continue the CAP: If the team is aligned and the concept is sufficiently developed, finalize the CAP, define objectives, outline high-level roadmap - Reframe the CAP: If critical elements are missing—such as data, partnerships, or clarity—identify those gaps and schedule follow-up discussions. This may require revisiting earlier phases to refine the draft CAP. - Communicate progress. Present findings, insights, and proposed next steps to ICE-PPR leadership	

Critical Considerations & Recommendations

- Clear articulation of goals and objectives for each phase
- Key Success Factors
 - Clear timelines
 - Mechanisms for stakeholder communication and feedback
 - Risk identification and mitigation strategies

Potential Risks

- Criteria for measuring success and progress
- Lack of coordination among national representatives and stakeholders

Further Recommendations

- Insufficient funding and resources
- Delays in securing points of contact (PoCs) and participation from all nations
- Ensure academics come in pre-funded and establish a rolodex of PMOs for funding
- Submit white papers and join sub-WGs to secure funding by DoD
- Focus on securing funding and establishing PoCs for CAPs and EAs
- Hold exploratory meetings to develop research tasks for each EA
- Determine the specific expertise needed for the Polar Ways initiative. **NOTE: Polar Waze was renamed as part of CAP and EA efforts**
- Consider dovetailing Iceberg and Polar Ways meetings and adjust the periodicity of meetings

