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THE UNIQUE ENVIRONMENTAL FEATURES OF THE ARCTIC THAT AFFECT MILITARY CAPABILITIES

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ABSTRACT: *The study explores the question of how the Arctic's natural characteristics affect military capabilities and assets. It will show how the region-specific nature of some of the Earth's subsystems (e.g., ionosphere or hydrosphere) impacts communications, warfare, and the use of submarines and drones. The study will highlight how many of the tools used in military operations, such as batteries and communications equipment, are significantly affected by the extreme Arctic environment. It also discusses the challenges that these natural conditions pose to specific military equipment (submarines, swarm drones) and the human aspects of warfare, such as calorie and water intake, the logistics of these, and medical aspects. The paper argues that military operations in the Arctic can only be successful if comprehensive, region-specific knowledge is available.*

KEYWORDS: *arctic, polar warfare, geography, communication, drone*

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INTRODUCTION

The natural conditions of a given region are crucial components of any military operation that cannot be ignored. The more extreme the environment in which a military operation is planned, the more the natural geography of the region will influence military operations. The military presence in the Arctic is growing yearly, and the region is being addressed more and more strategically. In October 2022, the United States released its new Arctic Strategy, which is based on four pillars:

1. security: develop capabilities for the expanded arctic activity;
2. climate change and environmental protection: build resilience and advance adaptation, while mitigating emissions;
3. sustainable economic development: improve livelihoods and expand economic opportunities;
4. international cooperation and governance: sustain Arctic institutions and uphold international law.[1]

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[1] The White House 2022.

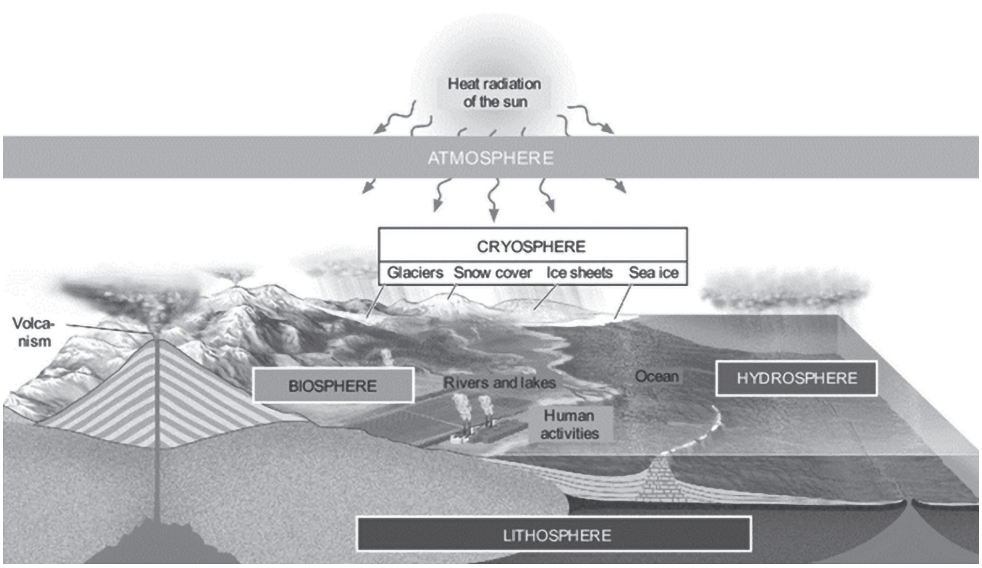

Figure 1 *The interacting subsystems of the Earth*

(Source: Razik 2014, 1.)

A key objective of the first pillar of the strategy is to better understand the operational environment in the Arctic. This includes the development of communication and navigation tools that can operate beyond the Arctic Circle, satellite coverage, weather forecasting capability, and cartographic knowledge of the region.[2] Following the new US Arctic strategy, this study shows how the environmental characteristics of the Arctic affect the application of military capabilities in the region. The layers of *Figure 1* show how the subsystems of the Earth affect military capabilities and warfare in the Arctic, for a better understanding of the study. As the US strategic vision also argued, the essay claims that military operations in the Arctic can only be successful if comprehensive, region-specific knowledge is available. This should include the characteristics of atmospheric phenomena, weather events, (sea) ice properties, ocean features, and their effects on military assets.

THE IMPACT OF IONOSPHERIC CHANGES ON ARCTIC POSITIONING AND COMMUNICATION

Ensuring continuous communication in the region is essential for both civilian and military purposes. Stable connectivity, data transmission, and positioning are vital for maritime navigation, search and rescue operations, and the deployment of military equipment. However, maintaining these is becoming increasingly challenging as we move towards the pole.

The ionosphere is a layered part of the atmosphere ranging in altitude from 60 to about 1000km, and its polar characteristics make communication very difficult in the region. It plays a significant role in high frequency (HF 3–30 MHz) communications and in the

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[2] The White House 2022, 9.

degradation of satellite radio system performance in the very high (VHF 30–300 MHz), ultra-high (UHF 300–3000 MHz), and even higher frequency bands.[3]

The total electron content (TEC) is a significant parameter of the ionosphere, representing the electron density between the transmitter and the receiver of a radio signal. The more electrons are in the path of the radio wave, the more the radio signal is affected.[4] The detection of temporal variation in TEC has not only scientific significance but also practical implications. The ionospheric time delay error of a radio signal is directly proportional to its TEC value. From a military point of view, this phenomenon is important because of its significance in the Global Navigation Satellite System (GNSS) high precision positioning, navigation and timing (PNT) service, radio communications, and other space activities.[5]

Above the poles, the ionosphere has a high level of electron precipitation, which is involved in the formation of the aurora borealis and aurora australis. This, however, interferes with and degrades the effectiveness of HF radios, which are generally used by the military for long-range communications in the absence of satellites.[6] In addition, the areas of the ionosphere particularly affected by scintillation[7] are the regions between the sub-polar and polar latitudes and the equatorial belt. This phenomenon interferes with satellite communications and global positioning navigation systems, and reduces radar performance and radio astronomical observations, leading to severe degradation of data quality.[8]

It is important to highlight that the ionosphere is also influenced by other layers of the Earth. The interactions of the lithosphere (the Earth's crust and upper mantle), the atmosphere, and the ionosphere (LAI) are important for the biosphere of the planet for living organisms. Changes in one sphere of the LAI can affect changes in the other two. The lithosphere-atmosphere-ionosphere coupling is a phenomenon that has been studied for several decades, whereby seismic phenomena are closely linked to higher levels of the Earth's atmosphere through a coupling mechanism. This correlation involves multidimensional physical processes involving chemical, thermal, acoustic, and electromagnetic phenomena.[9] The coupling is related to the pre-earthquake anomalies, seismic reactions, tsunamis, volcanic eruptions, and explosions that occur together.[10] For the military, this means a spillover effect: if there is a change in one sphere, there might be a consequence in another, and considering the ever-changing environment of the Arctic, it is even more important in this region.

Satellites are one of the most effective ways of ensuring military and civilian communication in the Arctic because they allow information to flow and create contingency even in extreme environments without infrastructure. However, at present, areas beyond the 72nd parallel north and south are not well covered and the infrastructure coverage is insufficient, which is a further challenge in addition to the natural characteristics of the region.[11] Nevertheless, satellite remains the only viable solution for activities requiring a high bandwidth.

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[3] Dabas 2000, 35.

[4] Space Weather Prediction Center [no year].

[5] Hui Xi et al. 2020, 540.

[6] Mills 2021.

[7] Ionospheric scintillation is a rapid fluctuation in the phase and/or amplitude of a radio frequency signal. See more: Globalpartners.com [no year].

[8] Dabas 2000, 41.

[9] Sasmal et al. 2021.

[10] Calais et al. 1998, 191–202; Fitzgerald 1997, 829–834; Chen et al. 2022.

[11] Boniface et al. 2020, 39.

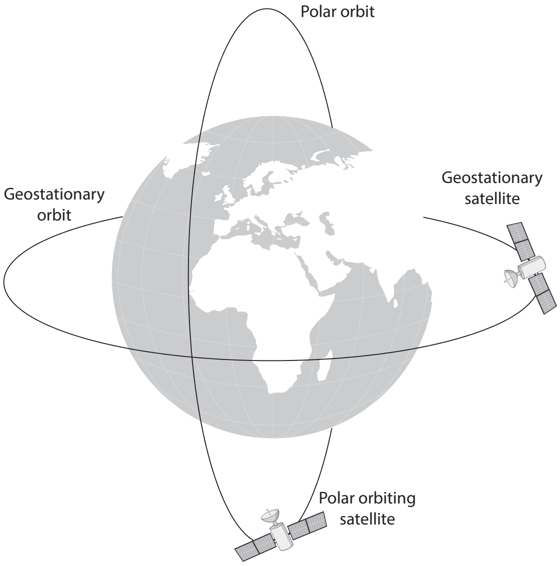

Figure 2 *Satellite trajectories*

(Source: Hardik 2022.)

The satellite link uses satellites in geostationary orbit (GEO),[12] which cover part of the Arctic. However, due to the curvature of the Earth, they do not cover the higher Arctic latitudes. There have already been examples of armies and other governmental users employing older GEO satellites that have drifted north or south of their original equatorial orbits to provide capacity in the Arctic.[13]

Several states and companies are working to increase satellite coverage of the Arctic. OneWeb and SpaceX Starlink already have satellites in the polar orbit. The Arctic Satellite Broadband Mission (ASBM) program is a joint project among the UK satellite provider Inmarsat, the Norwegian Ministry of Defence, and the US Air Force, which put two satellites into high elliptical orbit in 2024, aboard SpaceX's Falcon-9 rocket to provide polar coverage.[14]

An alternative to satellite communication is to use HF radio, but HF radio is sensitive to changes in the ionosphere. This is why HF communication in the Arctic is the least reliable, as the ionospheric variability is the most dynamic in the Arctic. Currently, only Iridium Next can provide full Arctic communications.[15] However, this system can only handle low-bandwidth services such as calls, monitoring, and tracking applications.[16]

Thus, the lithosphere-atmosphere-ionosphere coupling and other Arctic phenomena (e.g., the difference between Arctic day and night or ionospheric storms) can affect navigation, communication, and other devices that use them (e.g., targeting systems) and rely on trans-ionospheric communication. These environmental changes may therefore affect satellite communications during military operations.

According to the US Coast Guard's 2019 Arctic Strategic Outlook, high-latitude communications suffer from significant gaps due to geomagnetic interference, poor land-based infrastructure, and low satellite coverage. For this reason, one of the main objectives of the strategy is to improve the Coast Guard's communication capabilities in the region.[17] The US Coast Guard and Lockheed Martin were already working on developing an Arctic communications capability in 2014. According to Paul Scearce, Lockheed Martin's Director of Military Space Programs, conventional military systems cannot provide reliable

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[12] Hardik 2022.

[13] Rainbow 2022.

[14] Rainbow 2022.

[15] Boniface et al. 2020, 40.

[16] Rainbow 2022.

[17] United States Coast Guard 2019, 29.

communications in the Arctic Ocean, and current (Lockheed) systems do not work beyond 65 degrees north latitude.[18]

In a European context, the European Union's efforts to develop Arctic communications are worth highlighting. The Gallileo Ionospheric Prediction Service, funded by the European Commission, has been monitoring ionospheric changes and providing information to GNSS users on expected events in the ionosphere since 2019.[19]

In addition, the European Defence Fund has launched a €157 million research program on the propagation of electromagnetic signals in 2023. The objective is to develop and test an efficient electromagnetic wave propagation model capable of assessing and predicting the propagation conditions of electromagnetic signals, in order to contribute to the development of a tactical decision support tool. The reason for the program is that military activity has recently increased significantly, particularly in Northern and Eastern Europe and the Arctic, where specific environmental parameters prevail.[20]

However, it is important to stress that it is not only high technology that can solve the communication challenges of the Arctic environment. Major General Brian Eifler, commander of the 11th Airborne Division, reactivated in 2022, said that line-of-sight communications suites are very important to his units, even if they are more limited in their capabilities. "What we found in the Arctic, as some of our Arctic neighbors know, the older the equipment is, the better it works. The more technology you have, the more challenges you have".[21]

THE IMPACT OF THE ARCTIC CRYOSPHERE AND HYDROSPHERE ON MILITARY OPERATIONS

The vast majority of the operational environments in the Arctic are maritime by nature, so the availability of submarines and ships is a key consideration in the region. The large amount of sea ice is a unique feature of the region, which significantly determines the use of surface and sub-surface assets. Firstly, this ice cover makes it difficult for anti-submarine warfare vessels to navigate and deploy towed sensor systems, submersible sonars, and sounding buoys (the same is true for their deployment by air). Secondly, sea ice also renders optical and infrared sensors ineffective, reflecting or scattering laser beams. The constantly moving sea ice creates an ambient noise that masks submarine sounds, while uneven ice cover scatters acoustic waves, further complicating acoustic propagation predictions.[22]

Under-ice submarine warfare requires special submarine and maritime skills. For communication and surface operations (e.g., missile strikes), the submarine must break through the ice in certain situations. However, this is so complex and demanding for the vessel that the submarine commander's primary task is to avoid it completely. To avoid breaking through the ice, FLAP (Fractures, Leads, and Polynyas) analysis is available, which predicts where an ice-free open water area, suitable for surfacing, will develop in the ice-cov-

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[18] LaGrone 2014.
[19] Boniface et al. 2020, 45.
[20] European Commission 2023.
[21] Trevithick 2023.
[22] Pedersen 2019, 110.

ered sea. The FLAP analysis uses satellite imagery and forecasting software to predict days in advance where open water will form.[23]

However, one should also take into account the possibility that no ice-free water is formed. An average submarine can break through one-meter-thick ice, while a reinforced one little less than three meters. In case the submarine has to break through thick ice, it uses the "static loading" method. This involves compressed air pushing water out of the ballast tanks to increase the submarine's buoyancy until the upward force cracks the ice. In this case, the breakthrough is a very slow process.[24]

Another challenge in terms of combat procedure is the "in-ice tactical problem". In essence, in an engagement between submarines, the natural conditions of the region give an advantage to the submarine hiding in the sea ice and waiting in place, while the submarine searching and moving is at a significant disadvantage. The submarine's ability to hide and the distance among its points of contact will thus become smaller and smaller.[25]

The interest in Arctic acoustics and sound propagation has a long history. It began in the early years of the Cold War with the development of nuclear-powered submarines that could operate under the ice for extended periods. While the research on this topic lost some of its importance with the end of the Cold War, in our present days, it gained significance once again.

In the sea, the speed of sound is a function of temperature, salinity, and pressure. In the central Arctic Ocean, the relationship of these variables is such that the speed of sound generally increases from the surface to the seabed as can be seen in *Figure 3*.

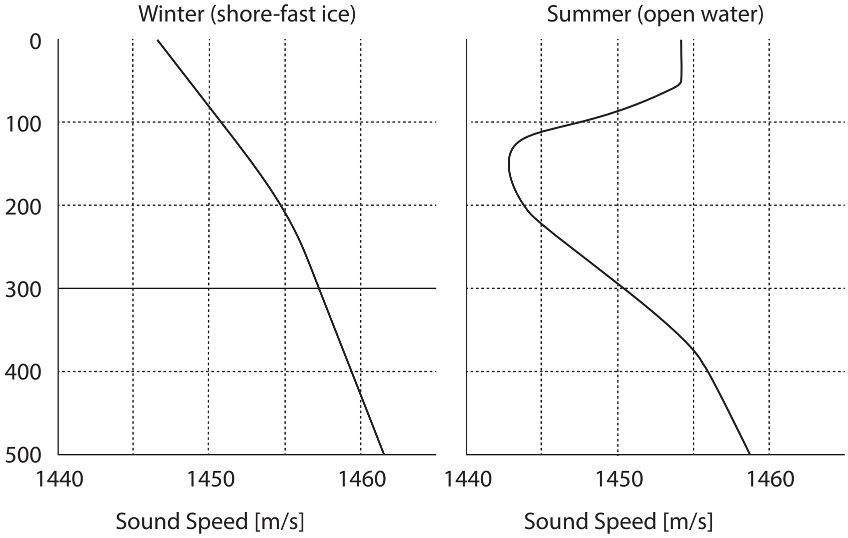

Figure 3 *Typical sound velocity profiles in the Arctic, showing the surface channel under the ice in winter and the shallow sound channel at 150m in summer.*

(Source: Cook et al. 2020, 106.)

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[23] Hambling 2018.

[24] Hambling 2018.

[25] Lyon 1992.

Speed profiles with such characteristics are only found in Arctic waters. This means that sound propagates particularly well in Arctic waters.[26] A surface detonation of 0.9 kg of TNT was detected within a radius of 1,100km. This has a clear military value in enabling detection and communication at long range in the region. Additionally, this area is perfectly suited for testing new sensors.[27] So, while ice hides underwater devices from detection above the surface, the water beneath the ice sheet has properties that greatly facilitate underwater detection and communication.

In addition to natural conditions, the biosphere should also be mentioned as a factor influencing military operations. Most wireless underwater communication modems are based on sound waves. Currently, the only communication method that allows medium- and long-range communication in seawater is based on an acoustic solution. However, it has the disadvantages of low bandwidth, slow data transmission due to the propagation of sound, and is highly unreliable in shallow water. The icy environment is a further challenge as signals are scattered every time they bounce off the ice, increasing the loss.[28]

The region is characterized by shallow water over a large area, which, like ice, poses a challenge to acoustic communication in the Arctic Ocean. Given these challenges, optical channels might be a good alternative to acoustic communication over short distances. It has the advantage of faster data transmission and allows for higher bandwidth as the speed of light propagation in water is 2.25–108 m/s. However, it should be stressed that it is only suitable for short distances. LED optical communication in coastal waters is generally reliable up to a few meters, while in deep water and under ice, data transmission has been enhanced up to 100 meters. This method of communication, considering the bandwidth and the speed of data transmission, is mainly relevant for the communication between underwater drones and drone swarms.[29]

The deployment of underwater drones in the Arctic is a key issue because the shallow waters of the Arctic archipelago are very dangerous for submarines. The large number of surface ice and islands is a limiting factor for submarines[30] but is less challenging for unmanned devices, both because of their improved maneuverability and not putting human lives at risk. Furthermore, the use of these assets is easier to deny, therefore, they are more freely deployable in the region below the level of open armed conflicts. Thus, the communication capability of underwater drones and drone swarming could be crucial issues in the future in the Arctic. *Figure 4* shows a possible concept for drone swarming under water.

Optical communication channels are significantly affected by the optical properties of water. These properties vary depending on the geographical location, the depth of the water, and the particles dissolved in the water. The main absorbers of light in the ocean are water, phytoplanktons, colored dissolved organic matter, and non-algal particles or debris. The amount of these light-absorbing constituents (especially phytoplanktons), and with it their effects, vary both seasonally and with depth.[31] This is significant because their light-absorbing properties cause communication systems to perform differently depending on water depth.

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[26] Cook et al. 106.

[27] Kutschale 1969, 246.

[28] Freitag et al. 2012, 1.

[29] Hoeher et al. 2021, 2632–2633.

[30] Col. Leblanc 2021.

[31] Hoeher et al. 2635.

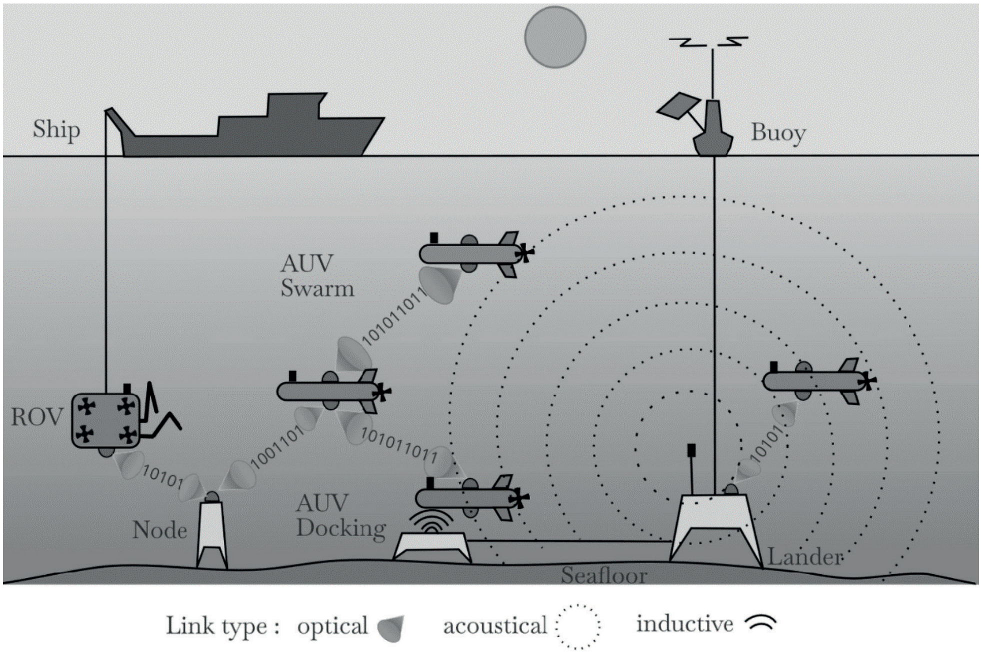

Figure 4 *Concept of communication for underwater drone swarming*

(Source: Hoeher et al. 2021, 2632.)

Thus, phytoplanktons and other organisms with similar properties that affect optical communication are also of military relevance. In the context of phytoplanktons, it should be stressed that their abundance in the Arctic varies not only seasonally but also annually due to the retreat of the ice. Between 1998 and 2018, their proportion increased by 57% in the Arctic Ocean.[32]

The current trend therefore suggests that climate change is indirectly hindering the use of underwater drones in the Arctic. However, several studies have concluded that the number of phytoplanktons in the Arctic Ocean will decline in the long term. Based on the nitrate content of the water, one study claims with 90% certainty that the chlorophyll content[33] of the Arctic Ocean will decrease in the future.[34] Another study from 2020 predicts that as the ice retreats, the number of phytoplanktons will initially increase due to improved light availability, but it will be followed by a decline in productivity due to nutrient depletion.[35]

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[32] Hansen 2020.

[33] In general, the amount of phytoplanktons is determined by the chlorophyll in the water, which is the pigment of phytoplanktons used for exploiting sunlight.

[34] Noh et al. 2023, 9.

[35] Seifert et al. 2020.

THE ROLE OF ARCTIC TEMPERATURES IN MILITARY CAPABILITIES

The role of hydrosphere temperature in military capabilities

Water temperature is also a factor to be taken into account in military operations. This is well illustrated by the impact of cold water on battery life. Following a training exercise in Alaska in 2019, US Navy bombardiers highlighted that it is necessary to train in this region because most of the unmanned devices and communication systems routinely deployed are either commercially available or military equipment designed for other theatres of war. As an example, it was mentioned that lithium-ion batteries have a shorter lifetime in cold water. Routine operations from shore with MK 18 MOD 1 Swordfish or MOD 2 Knifefish UUVs in natural conditions in California would be impossible in Alaska.[36]

Impact of Arctic temperatures on land capabilities

Like at sea, temperatures on land vary considerably depending on the season, time of day, and location. They also depend on the distance from the sea, altitude, and the amount of snow. Northern Alaska, Canada, and Siberia tend to be the coldest polar regions with the lowest temperatures between −54 and −46 °C. At destinations like Svalbard, Greenland, and Franz Josef Land, the summer weather in the Arctic Circle is quite moderate: the temperatures are about 0 °C (32 °F). In general, the monthly average temperature in the Arctic Circle is below 10 °C (50 °F) throughout the year, even in the summer.[37]

Arctic warfare requires specific equipment. Commander of the 11th Airborne Division Major General Brian Eifler says the Army's standard equipment is not suitable for Arctic operations. Artillery, for example, faces significant limitations in the region in several ways. In terms of the challenges posed by the temperature, the major general pointed out that operating hydraulics in the Arctic climate is also a concern. The M-777 howitzer has several hydraulic components and therefore its deployment below freezing temperatures is challenging. In addition, the tablets needed to coordinate artillery or other long-range strikes do not work in such climates. The main problem with high-tech electronic devices is that most of them are "off the shelf" devices that are not designed for such climatic conditions.[38] In addition, it is often necessary to dig down more than a meter into the snow to hit solid ground when setting up artillery.[39]

The 320 8X8 Stryker APCs are no longer in use with the 11th Airborne Division because they have failed frequently in the Arctic environment.[40] In their place, the US Army has started to procure CATVs (Cold Weather All-Terrain Vehicles). The target is 163 vehicles.[41]

Similar to the problem in the water, another challenge is that lithium-ion batteries cannot usually be charged in cold temperatures[42] and they also discharge very quickly, which has

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[36] Capt. Rojas 2019.

[37] Poseidon Expeditions [no year].

[38] Freedberg Jr. 2023.

[39] Trevithick 2023.

[40] Beynon 2022.

[41] Trevithick 2023.

[42] Saft [no year].

further negative effects on communications and vehicles. To solve the battery problem, the US military is working with Tesla, Panasonic, and LG, among others.[43]

In addition to the use of military assets, it is important to highlight the human aspect. A significant difference from a more general operational environment is the different daily calorie requirements. According to the NATO AMedP-1.11 doctrine, the energy consumption of military personnel should be about 3,600 kcal/day (15.1 MJ/d) for "normal" operations (e.g., urban policing and peacekeeping, firefighting, or tasks such as construction) and 4,900 kcal/day (20.5 MJ/d) for combat operations, i.e., tasks involving sustained infantry or special forces operations.[44] The document makes specific proposals for operations in cold climates. Among other things, it suggests that different, white packaging and higher calorie content are required. The minimum calorie intake set is 4,600 kcal/day but the document highlights that recent research shows that cold climate operations result in energy requirements over 6,000 kcal and therefore, efforts should be made to ensure that daily calorie intake exceeds the minimum requirements.[45]

In addition to adequate calorie intake, less is said about adequate hydration. Contrary to popular belief, liquid intake is still important in the Arctic climate. There are several reasons for this:

- cold-induced diuresis.
  This phenomenon occurs when people become chilled during either cold water or cold air exposure. It is an osmotic diuresis and can increase urine water loss 2-fold above basal conditions.
- increased respiratory water loss from breathing cold, dry air.
  The magnitude of water loss is dependent on both the ventilatory volume and water vapor in ambient air.
- wearing bulky, cold-weather clothing can contribute to water loss.
  Military physical training activities can generate substantial metabolic heat that must be dissipated to prevent excessive elevations in body temperature.
- added metabolic cost of movement on cold terrain.
  The addition of bulky clothing reduces mechanical efficiency and can increase the energy cost of a specific activity by an additional 10% to 20%. The metabolic cost of movement in soft snow can be 2.5 to 4.1 times greater than performing the same activity on a blacktop surface.[46]

A study on soldiers' fluid intake, jointly published by the Borden Institute, the Walter Reed Army Medical Center, and the US Army Medical Department Center & School, highlights that voluntary water intake of soldiers during field maneuvers in cold weather report daily fluid intakes ranging from 2 to 4 L/d, but water needs can go up to 4 to 6 L/d when energy expenditures are high. However, the study also highlights that the recommended daily hydration for soldiers is 7.6 L/d.[47]

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[43] Trevithick 2023.

[44] NATO Standardization Office 2019, 2–3.

[45] NATO Standardization Office 2019, 2–3.

[46] Montain – Ely 2010, 27–29.

[47] Montain – Ely 2010, 30.

Considering the logistical difficulties and infrastructural challenges in the region, the issue of drinking water supply for soldiers is also important. The Joint Pacific Multinational Readiness Center (JPMRC) hosted its first Arctic Regional Combat Training Center (CTC) rotation in March 2022 at Fort Greely, Alaska, and exposed a critical capability gap regarding bulk water storage and distribution in extreme cold weather (ECW). Experience has shown that the US Army's water storage units (Camel and Hippo) are not suitable for storing water in sub-zero temperatures and freeze quickly. Residual water in distribution pipes quickly freezes, causing ball valves to freeze and plastic handles to break. Several solutions to the problem have been proposed after processing the experience. One is to keep water storage units in a heated tent. This solved the problem of water freezing but in exchange, reduced the mobility of the unit because it took 90 minutes to set up the tent and more than five hours to dismantle it because the heated tent melted the snow and then it froze again after the heating was turned off, freezing the water storage unit, too. Another solution proposed is to transport and store water in the form of ice instead of keeping it above freezing level, similar to what Norway does. Depending on its size, it could also be part of soldiers' personal equipment, stored in a canteen.[48]

In addition to the daily supplies of soldiers, medical care is another aspect that is even more difficult in specific climatic conditions. Caring for the wounded and providing first aid are not only more difficult but can also be dangerous. Usually, doctors access parts of the wounded person's body by cutting off clothing if necessary. This is not feasible in the Arctic, where undressing even a perfectly healthy person can lead to severe frostbite and hypothermia.[49] For this reason, medical care is also a human aspect significantly affected by the Arctic environment and must be taken into account when planning operations.

CONCLUSION

The study analyzed how the Arctic's natural environment – from the atmosphere to the hydrosphere – affects military operations. While further examples could be given, this paper has already made it obvious that the Arctic has unique natural features, which make military operations significantly more difficult. It could be argued that the only difference between fighting in the Arctic and fighting on the Moon is that the Arctic has air. The special characteristics of the atmosphere affect communications, and ice affects sensors and presents challenges to maritime operations that are not experienced in other regions. Due to technical limitations, procedures applicable in other climatic zones do not work in the Arctic. For Arctic operations, it is therefore essential to gain adequate environmental knowledge and continuously assess the regional impact of climate change. Besides this knowledge, it is important to have suitable tools and procedures.

Any army that has a realistic possibility of having to conduct operations in such an environment should review which of their assets are suited to the area and which capabilities are degraded by environmental factors. As the issue of water transport shows, several Arctic challenges are not a matter of finance but of creative thinking. Given the NATO enlargement and the significant changes in the global security environment, this is also advisable for countries such as Hungary that are remote from the Arctic. This does not mean that a non-Arctic country should be prepared for every possible operation. While the nature of

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[48] 2nd Lt. Bedel 2022, 17–19.

[49] Trevithick 2023.

warfare in the Arctic is largely determined by the navy and the use of drones, this is primarily the responsibility of countries in the region. The capabilities primarily required by countries further away from the region are adequate personal equipment, the establishment of stable communications, land transport, and the logistics and methods to support them.

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